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Research Article

An Application of Analytic Hierarchy Process (AHP) for Sustainable Procurement of Construction Equipment: Multicriteria-Based Decision Framework for Malaysia

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Sustainable procurement is an emerging theme in the construction industry across the globe. However, organizations in the construction industry often encounter impediments in improving environmental performance in construction projects, especially in procurement. Besides its other facets, procurement of construction equipment is inherited to be capital-intensive and vital for managing environmental concerns associated with built environment projects. In this regard, selection criteria in such procurement processes are generally supportive of considering cost and engineering specifications as key parameters. However, sustainability apprehensions in today's Malaysian construction industry have mounted pressure on industry professionals to rethink their equipment acquisition strategies. The notion of green or sustainable procurement is still infancy for the Malaysian construction industry and facing challenges for embedding it in the current procurement practices. This research aims to address these apprehensions by considering six main criteria, namely, life cycle cost (LCC), performance (P), system capability (SC), operational convenience (OC), environmental impact (EI), and social benefits (SBs), and their 38 subcriteria towards procurement of sustainable construction equipment. A multicriteria-based equipment selection framework on the triple bottom line of sustainability in the context of the Malaysian construction industry has been developed and tested. The application of analytical hierarchy process (AHP) established the sustainable procurement index with a consistent sensitivity analysis results. As such, the proposed procurement index shall help decision-makers in the process of the acquisition of sustainable construction equipment in Malaysia.

1. Introduction

The procurement of construction equipment is a complex and multifaceted process [1]. The main objective in such a process is to arrive at the selection of the right equipment for carrying out scheduled tasks with high efficiency, productivity, and economic viability [2]. These facts are duly supported in the Malaysian construction industry wherein construction equipment selection is termed as a strategic decision and has a high economic impact on the project budget. Procurement process is characterised by supplier's commitment, purchase management, effective material delivery management, and efficient bill of quantity [3]. The advent of technological needs in construction practices demands substantial usage of mechanized equipment [4]. As a result, it is quite complex to make a competitive and best judgment during equipment acquisition [5]. In addition to judgment, there is a lack of knowledge between industry professionals and incompatibility with building components leading to higher additional costs and material handling costs [6]. A common practice which is adapted for selecting the required choice is based on comparing available equipment options with the intended tasks. Typically, such an approach is meant for taking into account a list of tangible and intangible factors such as cost, capacity, productivity, and efficiency [7]. In this way, an appropriate selection can be carried out on varying criteria, which helps the outcome of the process [8]. Earlier, Gates and Scarpa [9] have classified the selection procedure of earthmoving equipment into four criteria, which include based on the spatial relationships, soil characteristics, contract provision, and logistics. A spreadsheet-based model has been developed by Chan and Harris [10] for the selection of construction equipment. In their database, a detailed technical criterion was developed for selecting backhoes and loaders in earthmoving operations. However, this work of Chan et al. [11] focused on material handling equipment alone. Another knowledge-based approach by Haidaret al. [12] established that the equipment selection process is a function of knowledge and its subsequent optimization through genetic algorithms. It involves the screening of procured equipment from knowledge-based criteria. A decision support framework for the selection of open-pit mining equipment was also proposed in [13]. This framework was based on qualitative and quantitative factors. Goldenberg and Shapira [14] developed the analytic hierarchy process (AHP) framework, which is also based on tangible and intangible factors. The tangible factors included technical specifications, site conditions, and cost consideration. However, intangible factors are qualitative and include safety consideration, company policies regarding equipment acquisition, market conditions, and environmental constraints. This is the first-ever decision model found in the literature which has taken into account the soft consideration towards the selection of construction equipment for the building projects.

As Malaysia is planning for an increased number of construction projects to meet its infrastructure needs, it becomes crucial for the industry to understand and practice sustainable procurement procedures for reducing the negative environmental impact and hazards. Sustainable procurement is considered as a key practice of supply chains in many industrialized countries [15]. In such developing economies, sustainable procurement is considered as a key practice of supply chains [16]. Malaysia is amongst the world's emerging economies. Despite that, it has received little attention in addressing sustainability issues in the supply chain. Works on sustainable procurement have been performed in countries such as India [17], South Africa [18], China [19], Saudi Arabia [20], and Brazil [21]. Existing studies on sustainability procurement have been performed particularly in the developed countries such as UK [22], the USA [23], and Germany [24], but there is lack of studies in the Malaysian context. As a consequence of new governance, Malaysia is poised to work towards sustainability.

It is evident from the literature review presented above that the equipment selection frameworks and their respective criteria have been amply explored in various contexts with a diversified scope. Most of these studies have often considered the techno-economic aspects of equipment selection rather than environmental and social concerns in the procurement of the construction equipment. As such, the agenda of sustainability in construction projects have been ignored in the entirety. In the meantime, a new paradigm of green or sustainable construction emphasizes that all aspects of the construction process should address the triple bottom line of sustainability. It is, therefore, emphasized that the appraisal process of the equipment selection must take into account the technical, economic, environmental, and social considerations. The rest of the paper consists of several sections. Section 2 is about literature review, Section 3 provides details about material and methods, Section 4 elaborates the case study, Section 5 presents and discusses results, Section 6 provides the stability analysis of the results, and finally, Section 7 concludes the paper.

2. Literature Review Sustainable Criteria for the Selection of Construction Equipment

The concept of sustainability in the equipment selection is an innovative idea for construction projects. This concept is associated with several factors such as technical, economic, environment, and various social criteria of sustainable construction [25]. The fields of sustainable procurement and industrial sustainability have attracted researchers considerably and include topics such as sustainable supply chain management [26]. Before taking into account the concept of sustainability in the construction industry and subsequently, in the selection of construction equipment, it is pertinent to mention that such considerations have already become part and parcel of various modern-day knowledge areas. The sustainability concept has origins in the term "sustainable development" which emerged for the first-ever time in 1987 in the Brundtland Commission report of the United Nations more commonly known as the United Nations Commission on Sustainable Development (UNCSD). The UNCSD sustainability framework comprised of social, environmental, economic, and institutional criteria, which further comprised of main and subcriteria. This followed some formal consideration of the sustainability aspect in various fields. For example, Mihyeon Jeon and Amekudzi [27] have addressed sustainability in the public transportation system by defining indicators and metrics which emphasized that consensus should be developed on the economy, environment, and social well-being of society while addressing the sustainable trends in transportation. Singh et al. [25] have also emphasized that sustainability criteria are not only significant yet are very effective towards the formulation of strategy and thus suggested that these criteria are valuable in making policy in terms of environment and socio-economic and technological improvements. Their research work further emphasized that an indicator of sustainable development should be carefully selected, refined, and revisited in order to maintain its contextual effectiveness. In another study, Bradley Guy and Kibert [28] have established that sustainability criteria provide a systematic approach to measure the robustness of a system in a simple and reasonable manner.

In the construction industry, various sustainability criteria have been identified in the contemporary literature. For example, Bourdeau [29] had identified economic, social, and cultural criteria as the key elements of a sustainability framework. It is emphasized in this study that priorities of the sustainability criteria have geographical diversity, and these may, as such, vary in a different locations and different contexts. Singhet al. [30] have also identified the sustainability criteria for a decision support system for the development of the water utilities in the UK construction industry. This study identified two key factors which support the identification of the sustainability criteria. As such, this study emphasis that application of the set of criteria and its practicability under the agenda of sustainability are two main concerns. Furthermore, Akadiri and Olomolaiye [31] have proposed comprehensive guidelines for the identification of the sustainability criteria for the selection of sustainable materials. According to this study, 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 meaningful analysis [30, 32].

The above presented precise literature review illustrates that the majority of the researchers have a common opinion on the fundamental aspects of sustainability. Economic, environmental, social, and technical aspects are judged as key sustainability criteria. These findings lay a foundation as a guiding principle for making selection criteria for the procurement of sustainable construction equipment. In this context, Waris et al. [4] have developed broad-based, effective, and meaningful criteria which encapsulate the fundamental aspects of sustainability in the selection of construction equipment. Their research has identified six latent factors (herewith termed as main criteria) associated with the thirty-eight subfactors (herewith termed as subcriteria). Table 1 illustrates the six dimensions of their criteria's, which are considered significant and used for the development of a sustainability index towards the selection of sustainable construction equipment.

Table 1: Indicators of sustainable criteria for construction equipment.

Sustainable criteria	References
Life cycle costing	
Ownership cost	[33–37]
Operational cost	[38–40]
Performance	
Equipment capacity	[41–44]
Equipment reliability	[44–47]
Equipment efficiency	[47–50]
Equipment operational life	[51–53]
Equipment productivity	[54–56]
Fuel efficiency	[35, 57]
Equipment age	[58, 59]
System capability	
Implement system	[60, 61]
Traction system	[62–64]
Power train system	[65, 66]
Control and information system	[67–69]
Equipment standardization	[70, 71]
Operational governance	
Site operating condition	[72, 73]
Job and operational requirement	[74, 75]
Spare parts availability	[76, 77]
Repair and maintenance	[36, 78]
Veracity of equipment	[79, 80]
Haul road conditions	[81, 82]
Environmental impacts	
GHG emissions	[35, 83]
Fossil fuel consumptions	[84, 85]
Energy saving	[86, 87]
Noise control	[88, 89]
Vibration control	[4, 90]
Quantity of black smoke emission	[91, 92]
Oil and lube leakage control	[93]
Use of sustainable fuels	[94]
Biodegradable lubricant and hydraulic oil	[95]
Environmental statutory compliance	[93]
Social benefit	
Availability of local skilled operators	[93]
Operator health issues	[93, 96]
Safety features	[97, 98]
Operational proficiency	[99, 100]
Training for operators	[101, 102]
Relationship with dealers	[103, 104]
Operator view and comfort	[93, 105]

2.1. Framework for Sustainable Procurement. Waris et al. [4] derived sustainable criteria and subcriteria from the ranking and factor analysis of the expert opinions from the Malaysian construction industry; as such, it is important to benchmark the scope of the criteria with the standard equipment selection guidelines. In this regard, ISO-10987 [106] standard for the earthmoving machinery sustainably was considered as a point of reference for the considered sustainable criteria. This standard has set out general principles for addressing the sustainability of the earthmoving machinery and played an important role by establishing sustainable terminologies and identifying significant sustainability factors for earthmoving machinery. According to this standard, potential sustainability issues relevant to the selection of earthmoving machines include the following but not limited to

(i) Greenhouse gas/carbon emissions

(ii) Energy use

(iii) General processes during design, manufacture, machine life, and end of life

(iv) Management system for sustainability communication, training, and development

(v) Training for machine use: worksite managers, operators, and maintenance

(vi) Social aspect: health, safety, comfort, and ergonomics
(vii) Noise and vibration (operator)
(viii) Impact on the environment: noise, dust, ground disturbance, noise, and vibration (spectator)
(ix) Manufacturing and remanufacturing
(x) Dismantling and recycling
(xi) Emissions after treatment
(xii) Biofuels and oils
(xiii) Hazardous substances

A comparison of the derived sustainability criteria with the ISO-10987 : 2017 sustainability factors confirms the extent of the scope in addressing sustainability for construction equipment. As illustrated in Figure 1, the sustainable criteria can be viewed in the form of three core stages. The primary level is the foundation stone of the sustainable agenda for the procuring organization and enclosed by the second level of six main criteria, life cycle cost, performance, system capability, operational convenience, environmental impact, and social impact. The outer core or third level reflects the factors which form the subcriteria and influence the procuring decision for achieving a sustainable strategy. This sustainability framework, which is derived from the literature and compared with ISO-10987 (2017) standard, provides a balanced insight to analyse the same by using a case study for developing sustainable procurement index of construction equipment.

3. Method

3.1. Multicriteria Decision-Making (MCDM). MCDM is an operational research method that is normally used for dealing with complex decision problems. MCDM enables the assessment and multiple expert judgments and is employed to overcome the presence of imprecision and vague information in the evaluation process [107]. Multicriteria decision-making (MCDM) requires more than one set of criteria for establishing a qualitative judgment. MCDM techniques select or rank the alternatives with several decision criteria [108]. MCDM methods are well capable of managing and understanding decision problems by persuading participatory decision process. In addition to this, it also makes it possible for the decision-makers to do compromise or trade-offs between the different available options. Hence, the quality of judgment is consequently improved [109]. MCDM is classified into two broad classes, i.e., Multiobjective decision-making (MODM) and Multiattribute decision-making (MADM). In MODM, the priorities are first reduced to an optimal set rather than considering all predetermined alternatives. This can be done by introducing constraints to the objective function. In this way, a most agreeable elucidation could be pursued for the desired solution. However, MADM generally includes such attributes which are quantifiable. In such a case, this set of attributes is being used for the evaluation alternatives [108]. Various researchers have applied MCDM methods in issues pertaining to sustainable agenda as well since it greatly supports the entire decision-making process by considering the significant aspect referred as the triple bottom line of sustainability which comprises of the people, profit, and planet. MCDM has found its diverse application in the field of sustainable energy planning and environment. Løken [110] has applied MCDM for managing energy planning issues in the local environment. Other researchers such as Greening and Bernow [111] formulated energy and environment policies by applying MCDM methods. However, Pohekar and Ramachandran [112] have supported the linking of multiple scenarios with MCDM. In addition to this, Tsoutsos et al. [113] have also stated that MCDM is an appropriate methodology for dealing with sustainable energy problems. According to them, MCDM is helpful as it permits analysis and combination of a unilateral objective with many alternatives. It encompasses the evaluation criteria and corresponding weight of every alternative for a meaningful output. AHP methodology has widely been used for solving MCDM issues in different sectors such as education, industry, and engineering [114–116]. There are several MCDM techniques discussed in the literature. However, each set of techniques has diverse characteristics and application. In this study, the analytic hierarchy process (AHP) method of the MADM branch of MCDM is used to develop a sustainability assessment framework for the sustainable selection of construction equipment.

3.2. Application of Analytic Hierarchy Process. Analytic hierarchy process (AHP) is considered as the most effective and commonly used method of MCDM in various studies of the diverse field. AHP provides a convenient approach to analyse decision problems. It is a method to evaluate subjective and objective functions in multicriteria decision-making and help users to reach on an agreeable solution. Another important feature of AHP is to achieve consensus in the group decision-making process. AHP has the ability to guide the decision-makers for achieving the best and optimal judgment for their problem rather than to get "correct" answers. It offers a broad and balanced hierarchical structure for addressing decision problems on a common goal and related criteria [117]. AHP has multiple applications in diversified situations such as choice making, rank orders, prioritization, and resource allocation. AHP helps quantify the weight of the appraised criteria in the form numeric basis. The criteria weight of each element determines its relative importance with the other elements of the hierarchy. Hence, it facilitates the decision-makers to identify and prioritize significant factors [31]. Besides this, the calculation of the inconsistency index is another salient feature of AHP. It makes possible for the decision-makers to check the consistency of their judgments. A higher value of inconsistency index, i.e., greater than 0.10, should not be considered as appropriate, and reevaluation is required in such calculations [118]. One of the applications of AHP was included by Subramanian and Ramanathan [119] who have classified the AHP into five broad areas of operation research which include operation strategy, process, product design, planning and scheduling resources, and project management and managing the supply chain process as prominent decision areas. In the

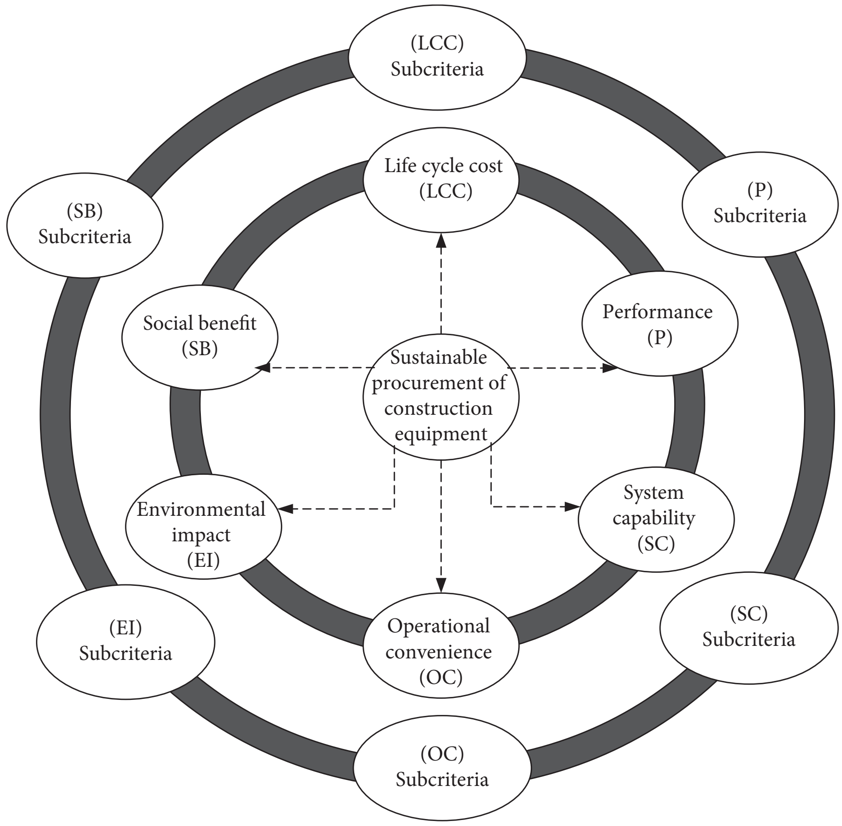

Figure 1: Framework for sustainable procurement of construction equipment.

construction industry, AHP is considered as a rational tool during project appraisals phases. It has been used in prequalification of contractors and in selecting the potential bidders. Besides this, AHP applications are also found in material and equipment selection, conflict resolution, and project team selection [120–122]. AHP has also been used in information technology (IT) to evaluate the quality of software systems [123]. Mathivathanan et al. [15] suggested application of AHP in the decision-making of farming and agricultural lands in developing countries. AHP has also been applied heavily in macro and people-oriented issues together with the supply chain management field [107]. AHP is commonly being used in sound judgment decision-making due to the linkage of linguistic data [124]. The main steps required in the formulation of AHP framework comprises of hierarchy construction, pairwise comparisons, deriving relative weights, consistency checking, and synthesizing results [118].

3.2.1. Step 1: Hierarchy Construction. The construction of the hierarchical structure is a foundation stone of AHP. It is considered as an important step of AHP, and there is no specialized approach for making a hierarchy. The construction of hierarchy is a top-down process and comprises of several levels. The elements of hierarchical levels are managed in such a way that they are on the same scale and magnitude. The elements of the same hierarchy level must be correlated with the other corresponding factors of the structure. The formation of AHP hierarchy normally starts from the higher-level goal and subdivides into lower-level decision factors. In any AHP model, the number of hierarchical levels is a function of problem intricacy and the degree of quantification for each of the element. However, a typical AHP model comprises of four levels. It starts from Level 1 as objectives or goal, its associated main criteria as Level 2, subcriteria as Level 3, and Level 4 of the hierarchy contains the choices of alternatives. Overall, the criteria, subcriteria, and alternatives options are clustered for achieving the top-notch goal or objective.

3.2.2. Step 2: Pairwise Comparison. After the hierarchy construction, the next step is to establish the relative importance of the main criteria and subcriteria by comparing them in the form of pairs. It is an important step and considered as a spine of AHP. During this process, the items in each set of the hierarchy are compared with their corresponding group members. For this, a nine-point scale, as shown in Table 2, is used to measure the relative importance of the items. The intensity of this scale ranges from one to nine. There is no "correct" or "incorrect" choice when comparing the items. Nevertheless, it is the choice of preference between two items on the number scale. When making a choice between two items, it should be noted that which preference is more important over the other item on the same level of the hierarchy. And the second key aspect is to assign a numerical value to quantify the judgment [125].

The pairwise judgments are recorded in a decision matrix. An algebraic representation of a comparison matrix is shown in the below equation:

Table 2: Numeric comparison scale.

Intensity of importance	Definition
1	Equal importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong
8	Very very strong
9	Extreme importance

$$\mathbf{A} = \begin{bmatrix} \mathbf{a}_{11} & \mathbf{a}_{12} & \cdots & \mathbf{a}_{1n} \\ \mathbf{a}_{21} & \mathbf{a}_{22} & \cdots & \mathbf{a}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \mathbf{a}_{n1} & \mathbf{a}_{n2} & \cdots & \mathbf{a}_{nn} \end{bmatrix}. \tag{1}$$

The above matrix "A" represents the judgments or relative importance of alternatives as $n \times n$ matrix, where "n" is the number of items being evaluated. The entries of matrix "A," i.e., $\mathbf{a}_{ij}$ are the relative judgments between the two alternatives i and j in such a way that the ith row corresponds to the jth column of "A." Equations show the characteristics as

$$\mathbf{a}_{ii} = 1 \Longleftrightarrow i = j, \tag{2}$$

$$\mathbf{a}_{ij} = \frac{1}{\mathbf{a}_{ij}}, \tag{3}$$

where $\mathbf{a}_{ij}$ can also be written as

$$\mathbf{a}_{ij} = \frac{w_i}{w_j}, \tag{4}$$

where w_i shows the relative weight of the alternative i.

3.2.3. Step 3: Deriving Relative Weights. This step requires the estimation of relative weights for each of the criteria and subcriteria of decision hierarchy. Researchers have developed many approaches to estimate the relative weights from the comparison matrix. However, eigenvector and logarithmic methods are commonly used for deriving relative weights. Saaty (1991), as a pioneer of AHP, has proposed the eigenvector method, which is derived from the matrix theory. In this method, the corresponding weights of decision elements are determined by comparing the normalized eigenvalue to the principal eigenvalue [125]. As per equations (2)–(4), the matrix "A" in equation (2) can be represented as

$$\begin{array}{c|ccccc} \mathrm{C} & \mathrm{A}_1 & \mathrm{A}_2 & \mathrm{A}_3 & \ldots.. & \mathrm{A}_\mathrm{n} \\ \hline \mathrm{A}_1 & w_1/w_1 & w_1/w_2 & w_1/w_3 & \ldots.. & w_1/w_n \\ \mathrm{A}_2 & w_2/w_1 & w_2/w_2 & w_2/w_3 & \ldots.. & w_2/w_n \\ & w_3/w_1 & w_3/w_2 & w_3/w_3 & \ldots.. & w_3/w_n \\ \mathrm{A}_3 & & & & & \\ ' & & & & & ' \\ \mathrm{A}_n & w_n/w_1 & w_n/w_2 & w_n/w_3 & \ldots.. & w_n/w_n \end{array}, \tag{5}$$

here, the aim is to find eigenvalues "w," where w is

$$w = (w_1, w_2, w_3, \ldots, w_n), \tag{6}$$

where "w" is the eigenvector and a column matrix.

Despite many other approaches, the geometric mean is considered as the best choice for generating the eigenvector. It is calculated by multiplying each row of the above matrix. As there is "n" number of entries, take the nth root of the multiplication. Finally, the normalized roots are obtained by deriving the total and subsequently divide them by the total outcome. He has suggested that the eigenvalues are not consistent with this approach. So, the consistency test must be carried out before finalizing the results [125].

3.2.4. Step 4: Checking the Consistency Ratio. The measure of "Consistency Ratio" (CR) is an important aspect of AHP. The optimal decision-making in pairwise comparison is mainly associated with the permissible value of consistency ratio. This step acts as a gateway to observe the consistency and inconsistency of the decision matrix. Normally, cardinal and ordinal consistency checks are considered for pairwise comparison. Ordinal consistency requires that if a is greater than b and b is greater than c, then a must be greater than c. However, cardinal consistency states that a stronger relationship is required between the factors to be evaluated. In this case, if a is two times more important than b and b is three times more important than c, then a should be six times more important than c. In order to calculate the consistency ratio, an index was formulated to measure the consistency of weights. In this regard, the acceptable range of CR should be equal to or less than 0.10. However, a revision in the pairwise comparison is compulsory, if CR is greater than this boundary value [125].

3.2.5. Step 5: Synthesizing Results. The final step starts from the summation of relative values for each set of alternatives on all hierarchy levels. These values are combined together to establish the overall score or criteria weight of each alternative. As an outcome, the normalized local priority vectors are obtained due to this additional function. Now, the final priorities are synthesized by aggregating the product of local priority vector and the relative weights of the respective alternative. The process of aggregation starts from the bottom level of the hierarchy and proceeds upwards to the highest level goal. It is pertinent to note that summation of all weights of alternatives and their corresponding importance are equal to 1.00. The following equation shows a simplified arithmetical formulation for aggregation of criteria weights at different levels of hierarchy:

$$\begin{aligned} &\text{final weight of criteria} \\ &\quad = \sum[(\text{weight of alternatives w.r.t criteria}) \\ &\quad \times (\text{importance of criteria})]. \end{aligned} \tag{7}$$

This study has adopted the AHP technique for the formulation of an integrated framework. The process flow of the proposed AHP-based decision support framework is outlined in Figure 2 and illustrates a top-down relationship between sustainable evaluation criteria and AHP.

This framework indicates that sustainable criteria provide an overall objective and relevant alternatives to develop matrixes for pairwise comparison. Now, these matrixes help determine the normalized weights of each alternative (i.e., main criteria and subcriteria). At this stage, the measurement of consistency ratio (CR) is a gateway for the further appraisal of the alternatives. Any alternative having the CR value less than 0.10 shall need reassessment with respect to each other. After calculating the consistent, normalized weights of each alternative (i.e., $CR > 0.10$), the overall weight is determined along with the combined value of achieved sustainability by the corresponding option. Lastly, based on the final sustainability score, the most suitable and sustainable equipment is selected.

4. Case Study

Case studies allow deeper insights into the real-life problem and can be supportive in determining the empirical investigation through qualitative means [126]. This approach also provides an effective way to describe theories where insufficient information is available. Various earlier studies have also considered a case study-based approach in dealing with project planning, design, construction, economic issues, and to study the political phenomenon [127]. The case study presented here is based on an intended scenario which will implement the AHP technique on the established main criteria and subcriteria for selection of sustainable construction equipment. This case study describes a situation which requires the selection of sustainable earthmoving equipment, i.e., a wheel loader for performing earthmoving operations such as hauling, digging, and demolishing. It is significantly important equipment used during the construction of roads and highways. However, they produce GHG emissions [128]. Generally, in a construction project, it is the responsibility of a contractor to utilize necessary equipment and machinery for undertaking complex activities at the site. Accordingly, during the project bidding process, contractors list down the anticipated arrangement of equipment and machinery in their technical bid. Equipment procurement for the project is often a huge capital investment by the contractor. As such, contractors are always concerned that procured equipment must have a high rate of utilization, greater efficiency along with minimum downtime, and repair cost. However, if these factors were to add up with the agenda of sustainability, the situation becomes multifaceted and complex to select the best choice among many alternatives. In such a case, the contractor's management team is responsible for deciding on the multicriteria basis. Thus, ensuring that the company's investment is being rationally spent on procuring such heavy equipment fulfills operational needs and meets the triple bottom line of sustainability.

Three alternatives of the front-wheel loader (a type of earthmoving equipment) for carrying out earthwork operations on an infrastructure project have been chosen for this case study. The brief synopsis is discussed below.

4.1. Alternative A. This model of the bucket wheel loader is designed and manufactured by "XX" Inc., and it is well capable of doing earthmoving operations with low cost. The most noteworthy aspect of this model is its ability to protect the environment. It has met the Tier 3 emission standard and complies with environmental regulatory requirements. It lowers routine maintenance while eliminating waste to the environment. The use of a load-sensing steering system results in a more efficient power system, thus reducing the reducing fuel consumption and higher production. Besides this, demand-driven cooling fans and automatic engine idle shutdown system help more efficient fuel management, which gradually reduces the level of emissions.

4.2. Alternative B. This model comprises of environment-friendly engine's, i.e., turbo-charged low emissions and high torque near idle rpm gives the low fuel consumption, and designed and manufactured by "YY" Ltd. Its electronically controlled and hydraulically driven cooling fans only operates at the desired level and economize fuel usages. Its turbo-charged engine meets all governing emission requirements according to Stage IIIA in Europe and Tier 3 in the USA. The advanced fuel injection and electronic engine control make efficient use of every drop of fuel. The smart system for internal exhaust gas recirculation reduces No_x emissions by lowering peak combustion temperatures. In addition to this, load-sensing hydraulics and steering systems contribute to lower fuel consumption. It also allows provisions for biodegradable hydraulic oil that supports environment-friendly operations.

4.3. Alternative C. This innovative model "ZZ" of the bucket wheel loader offers a wide variety of operational features that support high productivity with minimizing environmental impacts. This model complies with the latest EU regulations on emission standards. It is fitted with a muffler filter, oxidation catalyst, and exhaust temperature control system which capture air pollutants and automatically burn down at desired temperature. This system is supported by variable geometry turbocharger that encourages optimal combustion and high volume-cooled EGR (exhaust gas recirculation), which also helps reduce nitrous oxide levels. Besides this, the use of optional autoengine shutdown function helps prevent fuel wastage by stopping the engine while the wheel loader is long idling.

The three equipment choices described above are summarized in Table 3 and will be evaluated for the selection of sustainable earthmoving equipment, i.e., wheel loader. Since, the three alternatives have a different purchase price, manufacturer, and somewhat specifications too. The application of the AHP technique will help in the selection of the most sustainable wheel loader for this scenario, meeting the triple bottom line of sustainability. The subsequent sections will illustrate the process of application of AHP methodology concerning the decision-making problem of this paper case study.

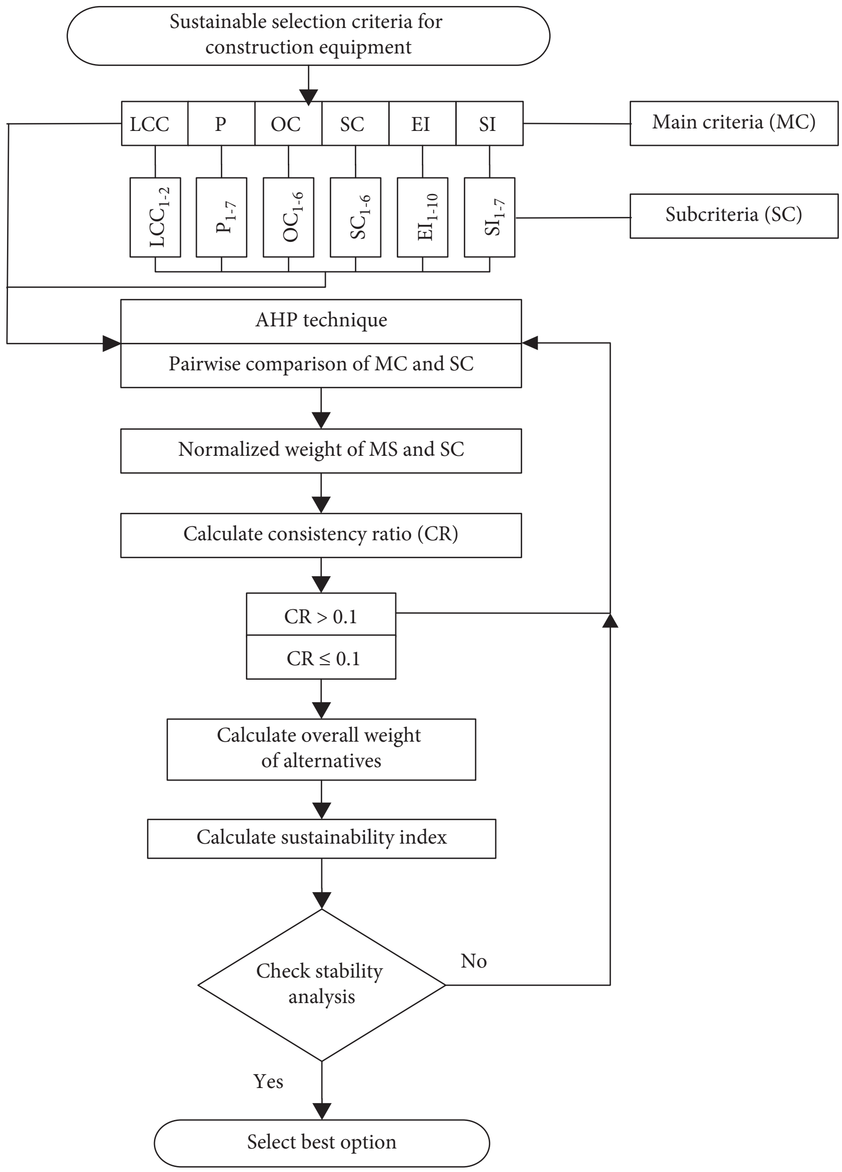

Figure 2: AHP framework for sustainable procurement of construction equipment.

4.4. Hierarchy of Decision Problem. This is the first step towards the mathematical formulation of the AHP framework. The user has to define the ultimate goal, main criteria, and subcriteria. Figure 3 shows the hierarchy of the decision problem. It is evident from Figure 3 that at the top of all levels is the goal which is the selection of sustainable construction equipment followed by the next level of main criteria and subsequently subcriteria all altogether related to the three alternatives All three alternatives shall be weighted based on each of subcriteria of the main criteria and subsequently on the basis of each main criterion to provide the alternative weight as described in the following sections of the paper.

4.5. Data Collection for Pairwise Comparison. Now the next step for developing the AHP framework is to collect data for the pairwise comparison of all alternatives on each hierarchy level. In order to achieve this aim, a questionnaire based on Saaty's scale of comparison was developed to undertake the survey. The range of this scale varies from one to nine, which is generally found very appropriate for pairwise comparison. This scale measures the superiority of each element with respect to the other elements of the hierarchy. The limitation of the Saaty scale is that it only provides a comparison of one set of criteria at a time. Guidelines on answering instruction and examples had been explicitly mentioned in the questionnaire. As regards the sample size, it may be noted that AHP is a subjective approach for addressing specific issues. Therefore, a survey under this methodology does not require a large sample size for analysing data. A higher degree of inconsistency is usually associated with large sample size. The relevant literature wherein AHP surveys had also been undertaken

Table 3: Summary of alternatives option.

Description	Alternative A	Alternative B	Alternative C
Project type	Infrastructure	Infrastructure	Infrastructure
Operation type	Hauling/digging/demolishing	Hauling/digging/demolishing	Hauling/digging/demolishing
Equipment type	Earthmoving	Earthmoving	Earthmoving
Category	Wheel loader	Wheel loader	Wheel loader
Manufacturer	XX	YY	ZZ
Model	XX 00	YY 00	ZZ 00
Mode of payment	100% buy	100% buy	100% buy

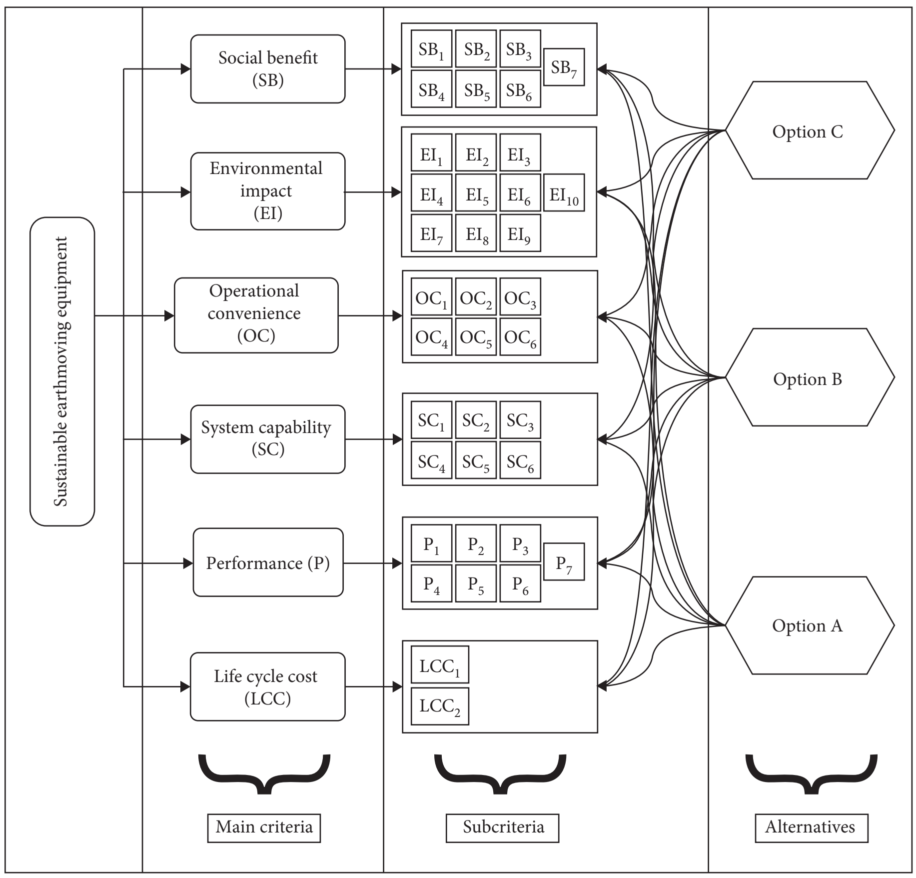

Figure 3: Hierarchy of the decision problem.

considerably comprised of small sample size since it is more appropriate and reliable for focusing on decision problem being studied. The tendency to receive arbitrary feedbacks in such case shall be low in this case, thus resulting in a high degree of consistency. Accordingly, the questionnaires were sent to the ten respondents of G7 Class A category of Malaysian contractors who all were well experienced and had sufficient knowledge of sustainable construction. These respondents of a questionnaire survey of this study were all from the private sector and had relevant qualification and satisfactory work experience as well. All the participants in the survey had more than 20 years of field experience and had a minimum of bachelor's degree. Some of these respondents had also acquired additional postgraduate qualifications. The respondent's credentials show their involvement in different infrastructure projects such as roads, highways, bridges, and dams. This information pertaining to the respondent is significant to suggest that questionnaires are filled by the experienced and senior professionals having vast experience in construction projects. Their opinions and views are quite important and reliable in order to establish the findings.

5. Results and Discussion

In this section, based on AHP steps for the case study discussed and basic model developed in Section 4 of this paper, the results pertaining to pairwise comparison of main and subcriteria and pairwise of comparison of alternative and synthesized results are presented.

Table 4: Comparison matrix and priority vector for the main criteria.

Main criteria	LCC	P	SC	OC	EI	SB	Priority vector	CR
LCC	1	**3**	**3**	**3**	**4**	**4**	0.385	
P		1	1	**2**	**2**	**3**	0.176	
SC			1	**2**	**2**	**2**	0.165	0.03
OC				1	**2**	**3**	0.128	
EI					1	1	0.077	
SB						1	0.069	

5.1. Pairwise Comparison of Main Criteria. The judgments of the respondents were listed in the comparison matrix and subsequently checked for the consistency ratio. According to Saaty and Vargas [118], the judgments were accepted if the consistency ratio (CR) is equal to or less than 0.10. Out of ten respondents, the judgments of two of them were not in the desired range of consistency as such their feedbacks were sent them back and requested for a careful examination of the judgments. After receiving consistent judgments from all the respondents, pairwise comparisons were performed, and the aggregated results were produced by using the geometric mean method. Table 4 shows the principal comparison matrix and their corresponding priority vectors with respect to the overall objective of the decision problem. The diagonal values of the matrix are equal to 1. It shows that the weight of criteria with respect to itself is always 1. The value of CR for this matrix is 0.03. As this ratio is less than 10%, the matrix is taken as consistent for further consideration and comparisons. The numerical representations of judgments displayed in bold numbers in the matrix signify that the row element is preferred to the column element. While the judgments shown in grey cells revealed that both the row and column elements are judged as equal in importance. It is important to note that numerical representation of a judgment does not necessarily mean that one element is preferred to the other by the numerical amount instead the relative priority vectors for all main criteria carry actual importance which is calculated and tabulated in the last column of the comparison matrix. It shows that life cycle cost (LC) has the highest value of priority vector, followed by the performance (P) and system capability (SC).

5.2. Pairwise Comparison of Subcriteria. Following having judgments in the form of priority vector of main criteria, the next step is to commence the pairwise comparison of subcriteria of respective main criteria. This subcriteria comparison process flow is in a similar fashion as that of performed for developing the matrix as a priority vector and consistency ratio for the main criteria in Section 5.1. Tables 5–10 show the pairwise comparison matrix for all of the 38 subcriteria with their corresponding elements (note: italic numbers show that the column elements are preferred with respect to the corresponding row elements). These matrices 3 to 8 illustrated the pairwise comparison of all subcriteria of six main criteria. The CR values of the matrices are well below 0.10 range. Hence, the judgments are considered as reliable for the final pairwise comparison of alternatives.

Table 5: Comparison matrix and priority vector for life cycle cost.

Sub criteria	LCC_1	LCC_2	Priority vector	CR
LCC_1	1	1	0.5	0.00
LCC_2		1	0.5	

5.3. Pairwise Comparison of Alternatives and Synthesizing Results. In this case study, three different types of wheel loaders were considered as possible alternatives for the decision-makers. These wheel loaders are from different manufacturers and have varying specifications. During the survey questionnaire, the respondents were explicitly informed about the manufacturer and model information. In order to maintain the confidentiality of the manufacture trademark and model, this research paper has used the letters XX, YY, and ZZ to represent these three alternatives (with a different manufacturer). The local criteria weights of the alternatives are shown in Table 11. Following all the pairwise comparison process, the normalized priority vectors, i.e., the rating of each criterion, subcriteria, and alternatives, that were synthesized to obtain global weights are also shown in Table 11. A local weight is associated with the single criteria and a derivative of a distinct judgment. However, the global weight of the subcriteria is calculated by the multiplication of its local priority vector with the corresponding local weight of the main criteria. This same approach is used for determining the global weights of alternatives. These calculations were performed using Expert Choice 11.5 version. This software package provides two synthesis modes, i.e., distributive and ideal. An Ideal synthesis mode is also known as "open system" which assigns the full weight of each covering objective to the best (highest priority) alternative for each covering objective. The other alternatives receive weights under each covering objective proportionate to their priority relative to the best alternative under each covering objective. These weights or priorities for all the alternatives are then normalized so that they sum to 1.0. On the contrary, the distributive mode is called "closed system," which distributes the weight of each covering objective to the alternatives in direct proportion to the alternative priorities under each covering objective. The global weights of the criteria are synthesized to establish the overall priorities for the selection of the sustainable alternative, as shown in Table 11.

It is evident from the results tabulated in Table 11, which are based on the AHP methodology, that out of three available alternatives, the wheel loader model "YY" has attained highest priority score of 0.368 and thus judged as

Table 6: Comparison matrix and priority vector for performance.

Sub criteria	P_1	P_2	P_3	P_4	P_5	P_6	P_7	Priority vector	CR
P_1	1	2	1	1	1	1	1	0.122	
P_2		1	**3**	**3**	1	**2**	1	0.232	
P_3			1	1	2	**2**	1	0.117	
P_4				1	2	**2**	1	0.117	0.03
P_5					1	**2**	1	0.183	
P_6						1	1	0.093	
P_7							1	0.138	

Table 7: Comparison matrix and priority vector for system capability.

Sub criteria	SC_1	SC_2	SC_3	SC_4	SC_5	SC_6	Priority vector	CR
SC_1	1	1	1	1	2	1	0.143	
SC_2		1	**2**	1	1	2	0.163	
SC_3			1	2	2	2	0.100	0.03
SC_4				1	1	1	0.178	
SC_5					1	**2**	0.231	
SC_6						1	0.185	

Table 8: Comparison matrix and priority vector for operational convenience.

Sub criteria	OC_1	OC_2	OC_3	OC_4	OC_5	OC_6	Priority vector	CR
OC_1	1	3	1	1	1	1	0.138	
OC_2		1	1	1	1	1	0.203	
OC_3			1	**2**	1	1	0.186	0.04
OC_4				1	**2**	1	0.168	
OC_5					1	1	0.146	
OC_6						1	0.159	

sustainable earthmoving equipment. This judgment of the "YY" manufacturer model of earthmoving equipment being sustainable is based on the fact that it has performed well on the majority of the sustainability criteria of this study. The "YY" manufacturer model has exceptionally performed well on operational convenience, environment, and social benefits sustainability criteria. The alternatives "ZZ" (priority score = 0.347) and "XX" (priority score = 0.286) have lower performance on the sustainability criteria compared to the "YY" model, as such ranked as second and third best alternatives, respectively.

These results are extremely significant both with respect to the methodology and on the basis of the sustainability criteria of this study. The sensitivity analyses of these results are further undertaken to determine their stability and robustness in the following section.

6. Stability Analysis

The outcome of the AHP framework is a function of hierarchical structure and weightage of the relative judgments as assigned by the decision-makers. It has been observed that a change in hierarchy and judgments may directly affect the framework outcome. Therefore, the robustness of the AHP framework was duly verified by performing the stability analysis. The stability of the ranking was checked for different projected scenarios. To this end, dynamic sensitivity analyses were undertaken by changing the priorities of the objectives and to determine how these changes affect the ranking of the alternatives. The dynamic sensitivity analyses were accomplished by increasing or decreasing the criteria weights, which would result in the change of priorities of the alternatives. In this study, seven scenarios were taken into consideration and simulated for different values of sustainability criteria.

6.1. Scenario 1. In the first simulated scenario, the weights of all the six main criteria were kept uniform in the left-hand column of the dynamic, sensitive graph, as shown in Figure 4.

It is observed that by keeping the uniform weights of the main criteria, the final ranking of the alternative remains unchanged, as shown in Figure 4, which establishes the internal consistency of the questionnaire survey and subsequent pairwise comparison undertaken using AHP methodology.

6.2. Scenario 2. In the second scenario, LCC main criteria have been assigned a weight of 50%, which alters the weights of the other criteria, as shown in Figure 5. However, as evident, the ranking of the alternative is still consistent.

Table 9: Comparison matrix and priority vector for environmental impact.

Sub criteria	EI_1	EI_2	EI_3	EI_4	EI_5	EI_6	EI_7	EI_8	EI_9	EI_{10}	Priority vector	CR
EI_1	1	*3*	*3*	*2*	*2*	*3*	*3*	1	1	*2*	0.046	
EI_2		1	1	**2**	**2**	**2**	**2**	**2**	**2**	1	0.157	
EI_3			1	**2**	**2**	**2**	**2**	**2**	**2**	1	0.157	
EI_4				1	1	1	*2*	**2**	**2**	1	0.087	
EI_5					1	1	*2*	**2**	**2**	**2**	0.096	
EI_6						1	1	**2**	**2**	**2**	0.108	0.03
EI_7							1	**5**	**5**	**2**	0.155	
EI_8								1	1	*2*	0.050	
EI_9									1	*2*	0.050	
EI_{10}										1	0.093	

Table 10: Comparison matrix and priority vector for social benefits.

Sub criteria	SB1	SB2	SB3	SB4	SB5	SB6	SB7	Priority vector	CR
SB1	1	3	5	5	1	1	1	0.062	
SB2		1	4	4	1	**2**	1	0.098	
SB3			1	**4**	**4**	**6**	1	0.354	
SB4				1	**3**	**5**	1	0.217	0.09
SB5					1	1	1	0.076	
SB6						1	1	0.062	
SB7							1	0.130	

Table 11: Overall ratings of sustainable criteria for developing sustainable procurement index.

Main criteria	Local weight (1)	Subcriteria	Local weight (2)	Global weight (3)	Local weight of alternative			Global weight of alternative		
					XX	YY	ZZ	XX	YY	ZZ
Life cycle cost (LCC)	0.385	LCC_1	0.500	0.193	0.333	0.333	0.333	0.064	0.064	0.064
		LCC_2	0.500	0.193	0.333	0.333	0.333	0.064	0.064	0.064
Performance (P)	0.176	P_1	0.122	0.021	0.168	0.349	0.484	0.004	0.007	0.010
		P_2	0.232	0.041	0.169	0.443	0.387	0.007	0.018	0.016
		P_3	0.117	0.021	0.169	0.387	0.443	0.004	0.008	0.009
		P_4	0.117	0.021	0.333	0.333	0.333	0.007	0.007	0.007
		P_5	0.183	0.032	0.169	0.443	0.387	0.005	0.014	0.012
		P_6	0.093	0.016	0.169	0.387	0.443	0.003	0.006	0.007
		P_7	0.138	0.024	0.333	0.333	0.333	0.008	0.008	0.008
System capability (SC)	0.165	SC_1	0.143	0.024	0.260	0.413	0.327	0.006	0.010	0.008
		SC_2	0.163	0.027	0.260	0.413	0.327	0.007	0.011	0.009
		SC_3	0.100	0.017	0.260	0.413	0.327	0.004	0.007	0.006
		SC_4	0.178	0.029	0.260	0.413	0.327	0.008	0.012	0.009
		SC_5	0.231	0.038	0.169	0.443	0.387	0.006	0.017	0.015
		SC_6	0.185	0.031	0.333	0.333	0.333	0.010	0.010	0.010
Operational convenience (OC)	0.128	OC_1	0.138	0.018	0.163	0.540	0.297	0.003	0.010	0.005
		OC_2	0.203	0.026	0.169	0.443	0.387	0.004	0.012	0.010
		OC_3	0.186	0.024	0.333	0.333	0.333	0.008	0.008	0.008
		OC_4	0.168	0.021	0.333	0.333	0.333	0.007	0.007	0.007
		OC_5	0.146	0.019	0.196	0.493	0.311	0.004	0.009	0.006
		OC_6	0.159	0.020	0.200	0.400	0.400	0.004	0.008	0.008

Table 11: Continued.

Main criteria	Local weight (1)	Subcriteria	Local weight (2)	Global weight (3)	Local weight of alternative			Global weight of alternative		
					XX	YY	ZZ	XX	YY	ZZ
Environmental impact (EI)	0.077	EI_1	0.046	0.004	0.250	0.500	0.250	0.001	0.002	0.001
		EI_2	0.157	0.012	0.250	0.500	0.250	0.003	0.006	0.003
		EI_3	0.157	0.012	0.250	0.500	0.250	0.003	0.006	0.003
		EI_4	0.087	0.007	0.500	0.250	0.250	0.004	0.002	0.002
		EI_5	0.096	0.007	0.500	0.250	0.250	0.004	0.002	0.002
		EI_6	0.108	0.008	0.200	0.400	0.400	0.002	0.003	0.003
		EI_7	0.155	0.012	0.333	0.333	0.333	0.004	0.004	0.004
		EI_8	0.050	0.004	0.250	0.500	0.250	0.001	0.002	0.001
		EI_9	0.050	0.004	0.333	0.333	0.333	0.001	0.001	0.001
		EI_{10}	0.093	0.007	0.333	0.333	0.333	0.002	0.002	0.002
Social benefits (SBs)	0.069	SB_1	0.062	0.004	0.333	0.333	0.333	0.001	0.001	0.001
		SB_2	0.098	0.007	0.200	0.400	0.400	0.001	0.003	0.003
		SB_3	0.354	0.024	0.163	0.297	0.540	0.004	0.007	0.013
		SB_4	0.217	0.015	0.260	0.413	0.327	0.004	0.006	0.005
		SB_5	0.076	0.005	0.333	0.333	0.333	0.002	0.002	0.002
		SB_6	0.062	0.004	0.143	0.429	0.429	0.001	0.002	0.002
		SB_7	0.130	0.009	0.192	0.634	0.174	0.002	0.006	0.002
Total	1.000									
Priority level								0.286	0.368	0.347
Alternative ranking								3	1	2

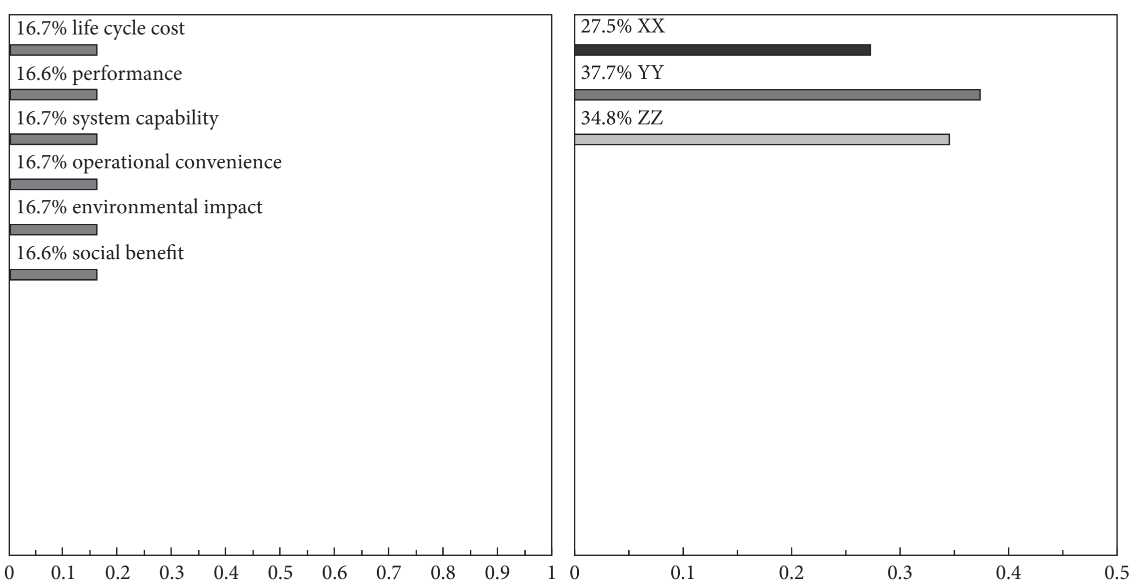

Figure 4: Dynamic sensitivity graph for AHP framework (with all criteria equal weight).

6.3. Scenario 3. In this scenario, as shown in Figure 6, the alternative ranking remains stable despite the 50% importance weightage assigned to the performance (P) criteria.

6.4. Scenario 4. In this scenario, 50% importance level is assigned to system capability (SC) criteria. The graphical representation in Figure 7 yet shows YY alternative as a sustainable option.

6.5. Scenario 5. In this case, a 50% importance level is assigned to operational convenience (OC) criteria. The graphical representation in Figure 8 shows that YY alternative still attains the highest priority score in this case as well.

6.6. Scenario 6. In Figure 9, environmental impact (EI) criteria have been assigned at 50% importance level. As depicted from the graph of Figure 9, the trend of right-hand bars is consistent with the preceding scenarios.

6.7. Scenario 7. Finally, in this scenario, social benefit (SB) has been assigned a 50% importance level, and the trend of alternatives illustrated in Figure 10 shows the consistency of the ranking of alternatives.

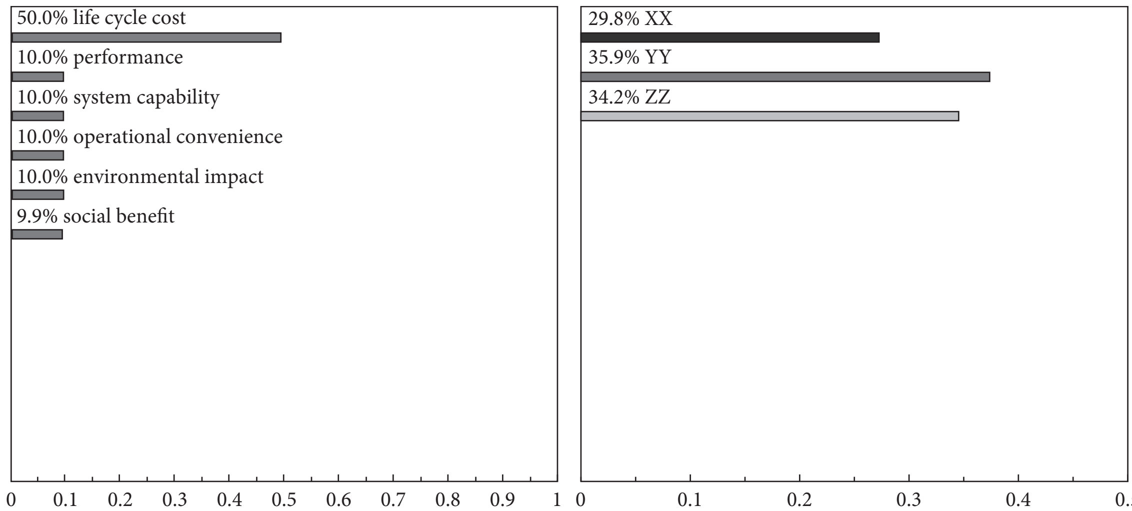

Figure 5: Dynamic sensitivity graph for AHP framework (with 50% LCC weight).

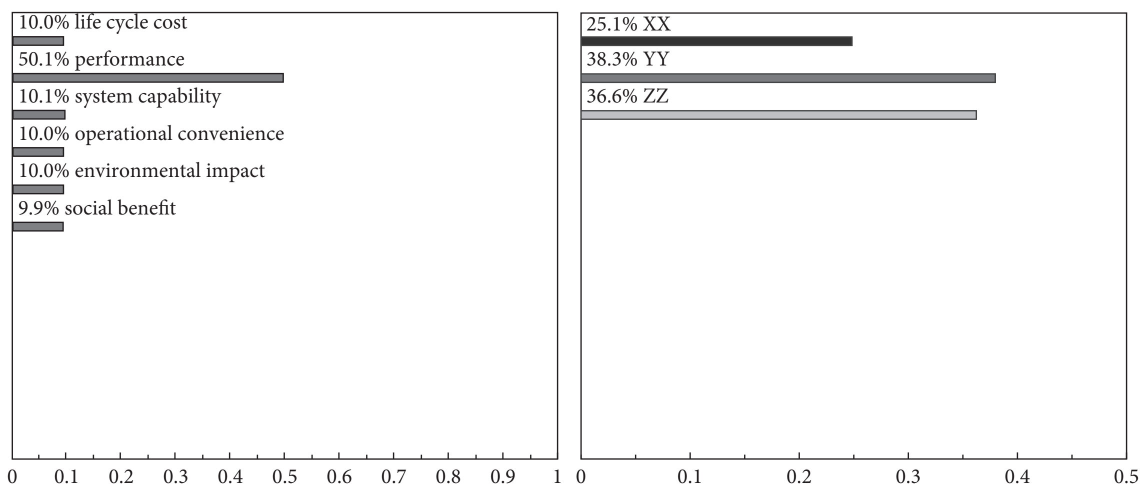

Figure 6: Dynamic sensitivity graph for AHP framework (with 50% performance weight).

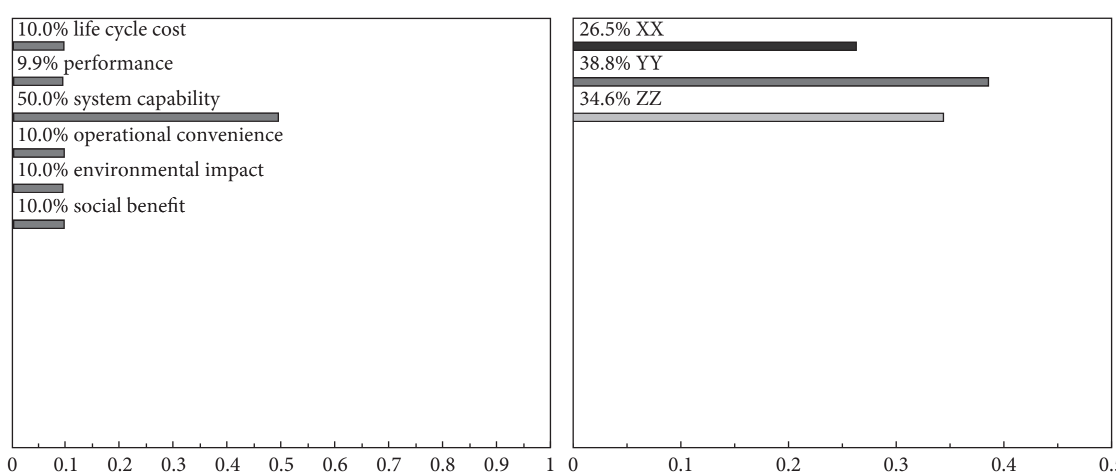

Figure 7: Dynamic sensitivity graph for AHP framework (with 50% SC weight).

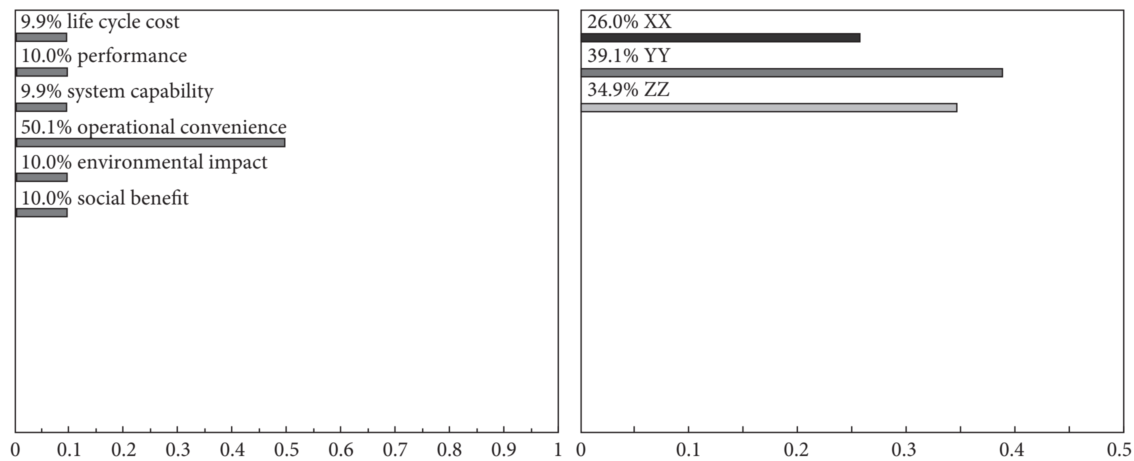

Figure 8: Dynamic sensitivity graph for AHP framework (with 50% OC weight).

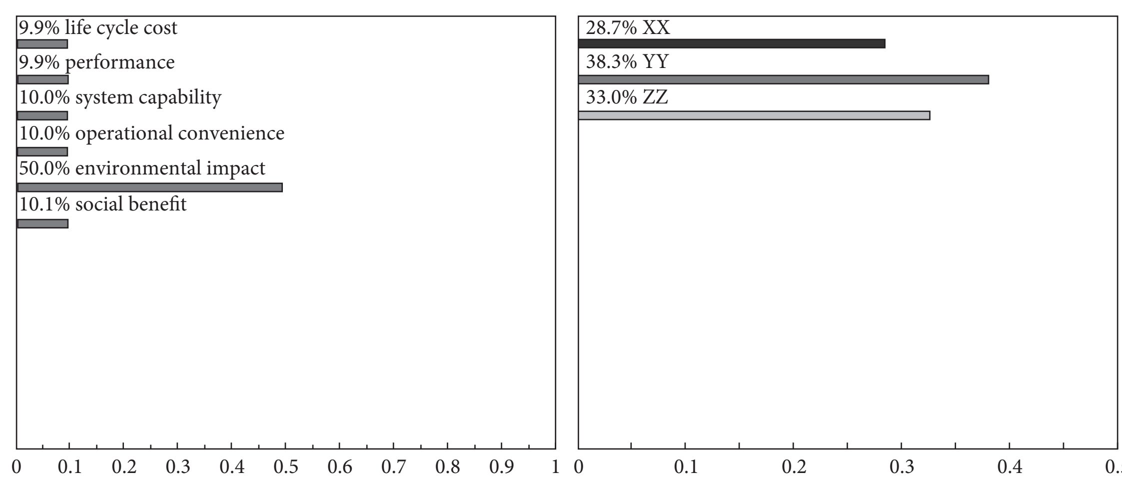

Figure 9: Dynamic sensitivity graph for AHP framework (with 50% EI weight).

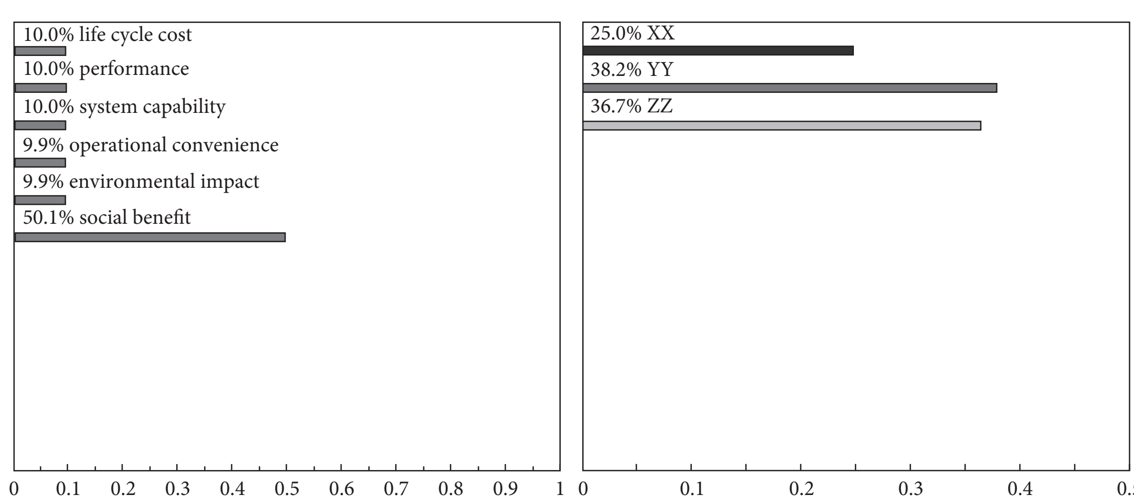

Figure 10: Dynamic sensitivity graph for AHP framework (with 50% SB weight).

It is, therefore, evident from the sensitivity analysis undertaken under all of above scenarios of this study that as the priority of one objective changes, the priorities of the alternatives decrease or increase in proportion to their original value. However, the ranking of the alternative remains unchanged in all these scenarios. The bar chart analysis also indicates that options YY and ZZ are very much close to each other as compared to the option XX. Thus, the assigned criteria weights and indexes are considered as stable. Besides this, these analyses also suggest that the alternatives YY and ZZ are evaluated as close alternatives for the selection of the sustainable wheel loader.

7. Conclusions

The concept of sustainable or green procurement is one of emerging and now largely accepted theme across the globe. However, in Malaysia, this concept was only first outlined in the 10^{th} Malaysian Plan. Since then, the government is concerned that sustainability parameters must be embedded in the national strategy for achieving Malaysia's societal and economic development. It would after all lead towards a sustainability culture in the country and ensure accelerated economic growth without compromising the environment. As such, the emphasis has been across the board at government level to integrate sustainability aspects in the procurement of products and services for future construction projects. However, subsequent to these developments, the focus of sustainability in the Malaysian construction industry is more inclined towards the material selection, structure design, and materials recycling rather than environmental concerns. As such, evidently a gap exists between the appraisal of the conventional approach of equipment selection and inclusion of sustainable concept in the decision-making during the procurement phase of a project. In order to address this gap, this study has attempted to establish a comprehensive link by proposing an AHP-based assessment framework for developing sustainable procurement index for the procurement of earthmoving equipment. This framework is based on a multilayered hierarchy and comprised of six main criteria and thirty-eight subcriteria. The AHP evaluation further measured the indicative sustainable procurement index values for the Malaysian construction industry. Among them, it is found that *life cycle cost* is an important decision factor in the selection of sustainable earthmoving equipment and has a percentage weightage 38.5%. It has also the highest value of priority vector, which represents that decision-makers have considered it significantly more important. It is followed by other main criteria, i.e., *performance* (17.6%), *system capability* (16.5%), and *operational convenience* (12.8%), have higher values of importance. The indexes weights for *environmental impact* and *social benefits* are relatively lower and acquired a priority score of 7.7% and 6.95%, respectively. The final results of the multicriteria-based AHP framework revealed that alternative "YY" is a best-evaluated option for achieving sustainable practices during the desired earthmoving operations. It offers versatile features including high efficiency with low cost of operation, maintenance, high hour machine life standards, and multiple rebuild options for continued uptime and long machine life. Besides this, it has many other benefits for the operator as it minimizes operator fatigue, resulting in a safe, productive work site and reduced GHG emissions. The sensitivity analysis further depicts that alternatives "YY" and "ZZ" are close to each other and have a stable ranking in different scenarios.

The procurement index developed in this study is considered a significant first contribution with respect to the selection of sustainable construction equipment for the Malaysian construction industry. It will help practitioners to undertake rational decisions during procurement of construction equipment. The proposed sustainability index is expected to greatly assist them to understand the decision problem by forming a hierarchy and transforming the qualitative judgments into meaningful quantitative weights for ranking the alternatives. The established framework of this study is specifically related to earthmoving equipment, which is recommended to be extended for other types of nonroad construction equipment as well.

Data Availability

The survey questionnaire used to support the finding of the study is available from the corresponding author upon request.

Conflicts of Interest

The authors would like to mention that they have no conflicts of interest associated with this research endeavor.

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References

[1] M. Jin and A. Junfang Yu, "Procurement auctions and supply chain performance," *International Journal of Production Economics*, vol. 162, pp. 192–200, 2015.

[2] K. Govindan, S. Rajendran, J. Sarkis, and P. Murugesan, "Multi criteria decision making approaches for green supplier evaluation and selection: a literature review," *Journal of Cleaner Production*, vol. 98, pp. 66–83, 2015.

[3] S. O. Ajayi and L. O. Oyedele, "Waste-efficient materials procurement for construction projects: a structural equation modelling of critical success factors," *Waste Management*, vol. 75, pp. 60–69, 2018.

[4] M. Waris, M. Shahir Liew, M. F. Khamidi, and A. Idrus, "Criteria for the selection of sustainable onsite construction

equipment," *International Journal of Sustainable Built Environment*, vol. 3, no. 1, pp. 96–110, 2014.

[5] J. E. Schaufelberger and G. C. Migliaccio, *Construction Equipment Management*, Prentice-Hall, Upper Saddle River, NJ, USA, 1999.

[6] L. Shen, Z. Zhang, and Z. Long, "Significant barriers to green procurement in real estate development," *Resources, Conservation and Recycling*, vol. 116, pp. 160–168, 2017.

[7] D. D. Gransberg, C. M. Popescu, and R. Ryan, *Construction Equipment Management for Engineers, Estimators, and Owners*, CRC Press, Boca Raton, FL, USA, 2006.

[8] H. Kerzner and H. R. Kerzner, *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*, John Wiley & Sons, Hoboken, NJ, USA, 2017.

[9] M. Gates and A. Scarpa, "Criteria for the selection of construction equipment," *Journal of the Construction Division*, vol. 106, no. 2, pp. 207–219, 1980.

[10] C. M. R. Chan and F. C. Harris, "A database/spreadsheet application for equipment selection," *Construction Management and Economics*, vol. 7, no. 3, pp. 235–247, 1989.

[11] F. T. S. Chan, R. W. L. Ip, and H. Lau, "Integration of expert system with analytic hierarchy process for the design of material handling equipment selection system," *Journal of Materials Processing Technology*, vol. 116, no. 2-3, pp. 137–145, 2001.

[12] A. Haidar, S. Naoum, R. Howes, and J. Tah, "Genetic algorithms application and testing for equipment selection," *Journal of Construction Engineering and Management*, vol. 125, no. 1, pp. 32–38, 1999.

[13] A. Bascetin, "A decision support system using analytical hierarchy process (AHP) for the optimal environmental reclamation of an open-pit mine," *Environmental Geology*, vol. 52, no. 4, pp. 663–672, 2007.

[14] M. Goldenberg and A. Shapira, "Systematic evaluation of construction equipment alternatives: case study," *Journal of Construction Engineering and Management*, vol. 133, no. 1, pp. 72–85, 2007.

[15] D. Mathivathanan, D. Kannan, and A. N. Haq, "Sustainable supply chain management practices in Indian automotive industry: a multi-stakeholder view," *Resources, Conservation and Recycling*, vol. 128, pp. 284–305, 2018.

[16] D. Delmonico, C. J. C. Jabbour, S. C. F. Pereira, A. B. L. de Sousa Jabbour, D. W. S. Renwick, and A. M. T. Thomé, "Unveiling barriers to sustainable public procurement in emerging economies: evidence from a leading sustainable supply chain initiative in Latin America," *Resources, Conservation and Recycling*, vol. 134, pp. 70–79, 2018.

[17] N. Agarchand and B. Laishram, "Sustainable infrastructure development challenges through PPP procurement process," *International Journal of Managing Projects in Business*, vol. 10, no. 3, pp. 642–662, 2017.

[18] F. Mashele and T. Chuchu, "An empirical investigation into the relationship between sustainability and supply chain compliance within the South African public and the private sector," *Journal of Business and Retail Management Research*, vol. 12, no. 2, 2018.

[19] Q. Zhu, Y. Geng, J. Sarkis, and K.-H. Lai, "Barriers to promoting eco-industrial parks development in China," *Journal of Industrial Ecology*, vol. 19, no. 3, pp. 457–467, 2015.

[20] M. M. Islam, M. W. Murad, A. J. McMurray, and T. S. Abalala, "Aspects of sustainable procurement practices by public and private organisations in Saudi Arabia: an empirical study," *International Journal of Sustainable Development & World Ecology*, vol. 24, no. 4, pp. 289–303, 2017.

[21] B. Fahimnia, J. Sarkis, and H. Davarzani, "Green supply chain management: a review and bibliometric analysis," *International Journal of Production Economics*, vol. 162, pp. 101–114, 2015.

[22] S. Brammer and H. Walker, "Sustainable procurement in the public sector: an international comparative study," *International Journal of Operations & Production Management*, vol. 31, no. 4, pp. 452–476, 2011.

[23] A. V. Roman, "Institutionalizing sustainability: a structural equation model of sustainable procurement in US public agencies," *Journal of Cleaner Production*, vol. 143, pp. 1048–1059, 2017.

[24] J. Palm and F. Backman, "Public procurement of electric vehicles as a way to support a market: examples from Sweden," *International Journal of Electric and Hybrid Vehicles*, vol. 9, no. 3, pp. 253–268, 2017.

[25] R. K. Singh, H. R. Murty, S. K. Gupta, and A. K. Dikshit, "An overview of sustainability assessment methodologies," *Ecological Indicators*, vol. 15, no. 1, pp. 281–299, 2012.

[26] R. Dubey, A. Gunasekaran, S. J. Childe, T. Papadopoulos, S. F. Wamba, and M. Song, "Towards a theory of sustainable consumption and production: constructs and measurement," *Resources, Conservation and Recycling*, vol. 106, pp. 78–89, 2016.

[27] C. Mihyeon Jeon and A. Amekudzi, "Addressing sustainability in transportation systems: definitions, indicators, and metrics," *Journal of Infrastructure Systems*, vol. 11, no. 1, pp. 31–50, 2005.

[28] G. Bradley Guy and C. J. Kibert, "Developing indicators of sustainability: US experience," *Building Research & Information*, vol. 26, no. 1, pp. 39–45, 1998.

[29] L. Bourdeau, "Sustainable development and the future of construction: a comparison of visions from various countries," *Building Research & Information*, vol. 27, no. 6, pp. 354–366, 1999.

[30] R. K. Singh, H. R. Murty, S. K. Gupta, and A. K. Dikshit, "Development of composite sustainability performance index for steel industry," *Ecological Indicators*, vol. 7, no. 3, pp. 565–588, 2007.

[31] P. O. Akadiri and P. O. Olomolaiye, "Development of sustainable assessment criteria for building materials selection," *Engineering, Construction and Architectural Management*, vol. 19, no. 6, pp. 666–687, 2012.

[32] Y. Chen, G. E. Okudan, and D. R. Riley, "Sustainable performance criteria for construction method selection in concrete buildings," *Automation in Construction*, vol. 19, no. 2, pp. 235–244, 2010.

[33] B. S. Dhillon, *Life Cycle Costing for Engineers*, CRC Press, Boca Raton, FL, USA, 2009.

[34] J. V. Farr, I. J. Faber, A. Ganguly, W. A. Martin, and S. L. Larson, "Simulation-based costing for early phase life cycle cost analysis: example application to an environmental remediation project," *The Engineering Economist*, vol. 61, no. 3, pp. 207–222, 2016.

[35] J. M. Luk, H. C. Kim, R. De Kleine, T. J. Wallington, and H. L. MacLean, "Review of the fuel saving, life cycle GHG emission, and ownership cost impacts of lightweighting vehicles with different powertrains," *Environmental Science & Technology*, vol. 51, no. 15, pp. 8215–8228, 2017.

[36] M. Bengtsson and M. Kurdve, "Machining equipment life cycle costing model with dynamic maintenance cost," *Procedia CIRP*, vol. 48, pp. 102–107, 2016.

[37] B. T. H. Lim, W. Zhang, and B. L. Oo, "Sustainable procurement in Australia: quantity surveyors' perception on life cycle costing," *International Journal of Integrated Engineering*, vol. 10, no. 2, 2018.

[38] H. Islam, M. Jollands, and S. Setunge, "Life cycle assessment and life cycle cost implication of residential buildings-a review," *Renewable and Sustainable Energy Reviews*, vol. 42, pp. 129–140, 2015.

[39] J. Auer, N. Bey, and J.-M. Schäfer, "Combined life cycle assessment and life cycle costing in the eco-care-matrix: a case study on the performance of a modernized manufacturing system for glass containers," *Journal of Cleaner Production*, vol. 141, pp. 99–109, 2017.

[40] K. S. Woon and I. M. C. Lo, "An integrated life cycle costing and human health impact analysis of municipal solid waste management options in Hong Kong using modified eco-efficiency indicator," *Resources, Conservation and Recycling*, vol. 107, pp. 104–114, 2016.

[41] J. Razmi, M. Barati, M. S. Yousefi, and J. Heydari, "A stochastic model for operating room planning under uncertainty and equipment capacity constraints," *Journal of Industrial Engineering International*, vol. 11, no. 2, pp. 269–279, 2015.

[42] L. Zhu, H. Su, S. Lu, Y. Wang, and Q. Zhang, "Coordinating and evaluating of multiple key performance indicators for manufacturing equipment: case study of distillation column," *Chinese Journal of Chemical Engineering*, vol. 22, no. 7, pp. 805–811, 2014.

[43] A. Zhilenkov and S. Chernyi, "Investigation performance of marine equipment with specialized information technology," *Procedia Engineering*, vol. 100, pp. 1247–1252, 2015.

[44] R. Domingo and S. Aguado, "Overall environmental equipment effectiveness as a metric of a lean and green manufacturing system," *Sustainability*, vol. 7, no. 7, pp. 9031–9047, 2015.

[45] R. Akhavian and A. H. Behzadan, "Construction equipment activity recognition for simulation input modeling using mobile sensors and machine learning classifiers," *Advanced Engineering Informatics*, vol. 29, no. 4, pp. 867–877, 2015.

[46] J. Park, E. Marks, Y. K. Cho, and W. Suryanto, "Performance test of wireless technologies for personnel and equipment proximity sensing in work zones," *Journal of Construction Engineering and Management*, vol. 142, no. 1, Article ID 04015049, 2015.

[47] M. Romanenko and M. Baybus, "Implementation of overall equipment efficiency methodology in the semiconductor test facility ER: equipment reliability and productivity improvement," in *Proceedings of the 2017 28th Annual SEMI Advanced Semiconductor Manufacturing Conference (ASMC)*, Saratoga Springs, NY, USA, July 2017.

[48] S.-F. Fam, S. L. Loh, M. Haslinda, H. Yanto, L. M. S. Khoo, and D. H. Y. Yong, "Overall equipment efficiency (OEE) enhancement in manufacture of electronic components & boards industry through total productive maintenance practices," *MATEC Web of Conferences*, vol. 150, Article ID 05037, 2018.

[49] B. Shah, J. Richmond, and M. Shemyakim, "Monitoring for equipment efficiency and maintenance," Google Patents, 2014.

[50] S. Kunio, *TPM for Workshop Leaders*, Routledge, Abingdon, UK, 2017.

[51] J. E. Katz, "Virtualization of legacy instrumentation control computers for improved reliability, operational life, and management," in *Methods in Molecular Biology*, pp. 309–324, Springer, Berlin, Germanya, 2017.

[52] M. Lips, "Length of operational life and its impact on life-cycle costs of a tractor in Switzerland," *Agriculture*, vol. 7, no. 8, p. 68, 2017.

[53] D. D. Gransberg and E. P. O′Connor, *Major Equipment Life-Cycle Cost Analysis*, Minnesota Department of Transportation, Research Services & Library, USA, 2015.

[54] M. K. Parthasarathy, R. Murugasan, and R. Vasan, "Modelling manpower and equipment productivity in tall residential building projects in developing countries," *Journal of the South African Institution of Civil Engineering*, vol. 60, no. 2, pp. 23–33, 2018.

[55] S. C. Ok and S. K. Sinha, "Construction equipment productivity estimation using artificial neural network model," *Construction Management and Economics*, vol. 24, no. 10, pp. 1029–1044, 2006.

[56] G. R. Chakravarthy, P. N. Keller, B. R. Wheeler, and S. V. Oss, "A methodology for measuring, reporting, navigating, and analyzing overall equipment productivity (OEP)," in *Proceedings of the IEEE/SEMI Advanced Semiconductor Manufacturing Conference ASMC*, Stresa, Italy, June 2007.

[57] J. Ally and T. Pryor, "Life cycle costing of diesel, natural gas, hybrid and hydrogen fuel cell bus systems: an Australian case study," *Energy Policy*, vol. 94, pp. 285–294, 2016.

[58] R. Waddell, "A model for equipment replacement decisions and policies," *Interfaces*, vol. 13, no. 4, pp. 1–7, 1983.

[59] Y. Peng and M. Dong, "A prognosis method using age-dependent hidden semi-Markov model for equipment health prediction," *Mechanical Systems and Signal Processing*, vol. 25, no. 1, pp. 237–252, 2011.

[60] V. Arvidsson, J. Holmström, and K. Lyytinen, "Information systems use as strategy practice: a multi-dimensional view of strategic information system implementation and use," *The Journal of Strategic Information Systems*, vol. 23, no. 1, pp. 45–61, 2014.

[61] S. Gao and S. P. Low, "The last planner system in China's construction industry—a SWOT analysis on implementation," *International Journal of Project Management*, vol. 32, no. 7, pp. 1260–1272, 2014.

[62] J. D. I. Bolivar, "Automobile traction track system and device," Google Patents, 2018.

[63] J. Feng, J. Xu, W. Liao, and Y. Liu, "Review on the traction system sensor technology of a rail transit train," *Sensors*, vol. 17, no. 6, p. 1356, 2017.

[64] V. G. Sychenko, D. O. Bosiy, and E. M. Kosarev, *Improving the Quality of Voltage in the System of Traction Power Supply of Direct Current*, Archives of Transport, Poland, 2015.

[65] B. H. DeWeese, G. Hornsby, M. Stone, and M. H. Stone, "The training process: planning for strength-power training in track and field. Part 1: theoretical aspects," *Journal of Sport and Health Science*, vol. 4, no. 4, pp. 308–317, 2015.

[66] A. Lacroix, R. W. Kressig, T. Muehlbauer et al., "Effects of a supervised versus an unsupervised combined balance and strength training program on balance and muscle power in healthy older adults: a randomized controlled trial," *Gerontology*, vol. 62, no. 3, pp. 275–288, 2016.

[67] F. Leite, Y. Cho, A. H. Behzadan et al., "Visualization, information modeling, and simulation: grand challenges in the construction industry," *Journal of Computing in Civil Engineering*, vol. 30, no. 6, Article ID 04016035, 2016.

[68] X. Wang and H.-Y. Chong, "Setting new trends of integrated Building Information Modelling (BIM) for construction

industry," *Construction Innovation*, vol. 15, no. 1, pp. 2–6, 2015.
[69] K. Zhou, T. Liu, and L. Zhou, "Industry 4.0: towards future industrial opportunities and challenges," in *Proceedings of the 2015 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD)*, Zhangjiajie, China, August 2015.
[70] A. Gulghane and P. Khandve, "Management for construction materials and control of construction waste in construction industry: a review," *International Journal of Engineering Research and Applications*, vol. 5, no. 4, pp. 59–64, 2015.
[71] L. Shen and V. W. Tam, "Implementation of environmental management in the Hong Kong construction industry," *International Journal of Project Management*, vol. 20, no. 7, pp. 535–543, 2002.
[72] S. Mohamed, "Safety climate in construction site environments," *Journal of Construction Engineering and Management*, vol. 128, no. 5, pp. 375–384, 2002.
[73] T. Yang and C.-C. Hung, "Multiple-attribute decision making methods for plant layout design problem," *Robotics and Computer-Integrated Manufacturing*, vol. 23, no. 1, pp. 126–137, 2007.
[74] J. L. Ashford, *The Management of Quality in Construction*, Routledge, Abingdon, UK, 2002.
[75] K. W. Chau, M. Anson, and J. P. Zhang, "Four-dimensional visualization of construction scheduling and site utilization," *Journal of Construction Engineering and Management*, vol. 130, no. 4, pp. 598–606, 2004.
[76] M. Prasad Nepal and M. Park, "Downtime model development for construction equipment management," *Engineering, Construction and Architectural Management*, vol. 11, no. 3, pp. 199–210, 2004.
[77] H. Martin, A. A. Syntetos, A. Parodi, Y. E. Polychronakis, and L. Pintelon, "Integrating the spare parts supply chain: an inter-disciplinary account," *Journal of Manufacturing Technology Management*, vol. 21, no. 2, pp. 226–245, 2010.
[78] K. Matzler, V. Veider, and W. Kathan, *Adapting to the Sharing Economy*, MIT, Cambridge, MA, USA, 2015.
[79] A. May, V. Mitchell, S. Bowden, and T. Thorpe, "Opportunities and challenges for location aware computing in the construction industry," in *Proceedings of the 7th International Conference on Human Computer Interaction with Mobile Devices & Services—MobileHCI '05*, Salzburg, Austria, 2005.
[80] E. Badu, D. J. Edwards, and D. Owusu-Manu, "Trade credit and supply chain delivery in the Ghanaian construction industry," *Journal of Engineering, Design and Technology*, vol. 10, no. 3, pp. 360–379, 2012.
[81] A. J. Lang, W. Michael Aust, M. Chad Bolding, K. J. McGuire, and E. B. Schilling, "Comparing sediment trap data with erosion models for evaluation of forest haul road stream crossing approaches," *Transactions of the ASABE*, vol. 60, no. 2, pp. 393–408, 2017.
[82] A. Soofastaei, "Payload variance plays a critical role in the fuel consumption of mining haul trucks," *Aust Resour Invest*, vol. 8, no. 4, p. 64, 2014.
[83] J. Hong, G. Q. Shen, Y. Feng, W. S.-T. Lau, and C. Mao, "Greenhouse gas emissions during the construction phase of a building: a case study in China," *Journal of Cleaner Production*, vol. 103, pp. 249–259, 2015.
[84] W. Haas, F. Krausmann, D. Wiedenhofer, and M. Heinz, "How circular is the global economy?: an assessment of material flows, waste production, and recycling in the European Union and the world in 2005," *Journal of Industrial Ecology*, vol. 19, no. 5, pp. 765–777, 2015.
[85] Z. Liu, D. Guan, W. Wei et al., "Reduced carbon emission estimates from fossil fuel combustion and cement production in China," *Nature*, vol. 524, no. 7565, pp. 335–338, 2015.
[86] X. Ji and B. Chen, "Assessing the energy-saving effect of urbanization in China based on stochastic impacts by regression on population, affluence and technology (STIRPAT) model," *Journal of Cleaner Production*, vol. 163, pp. S306–S314, 2017.
[87] Y. Zhang, C.-Q. He, B.-J. Tang, and Y.-M. Wei, "China's energy consumption in the building sector: a life cycle approach," *Energy and Buildings*, vol. 94, pp. 240–251, 2015.
[88] A. W. A. Hammad, A. Akbarnezhad, and D. Rey, "A multi-objective mixed integer nonlinear programming model for construction site layout planning to minimise noise pollution and transport costs," *Automation in Construction*, vol. 61, pp. 73–85, 2016.
[89] N. Kwon, M. Park, H.-S. Lee, J. Ahn, and M. Shin, "Construction noise management using active noise control techniques," *Journal of Construction Engineering and Management*, vol. 142, no. 7, Article ID 04016014, 2016.
[90] D. Efanov, G. Osadchy, D. Sedykh, D. Pristensky, and D. Barch, "Monitoring system of vibration impacts on the structure of overhead catenary of high-speed railway lines," in *Proceedings of the 2016 IEEE East-West Design & Test Symposium (EWDTS)*, Yerevan, Armenia, October 2016.
[91] S. Yusoff, R. Nordin, and H. Yusoff, "Environmental management systems (EMS) ISO 14001 implementation in construction industry: a Malaysian case study," *Issues In Social And Environmental Accounting*, vol. 9, no. 1, pp. 18–31, 2015.
[92] C. K. Saha and J. Hosain, "Impact of brick kilning industry in peri-urban Bangladesh," *International Journal of Environmental Studies*, vol. 73, no. 4, pp. 491–501, 2016.
[93] M. K. Ghorabaee, M. Amiri, E. K. Zavadskas, and J. Antucheviciene, "A new hybrid fuzzy MCDM approach for evaluation of construction equipment with sustainability considerations," *Archives of Civil and Mechanical Engineering*, vol. 18, no. 1, pp. 32–49, 2018.
[94] J. Hong, G. Q. Shen, S. Guo, F. Xue, and W. Zheng, "Energy use embodied in China′s construction industry: a multi-regional input-output analysis," *Renewable and Sustainable Energy Reviews*, vol. 53, pp. 1303–1312, 2016.
[95] S. Z. Razali, R. Yunus, S. Abdul Rashid, H. N. Lim, and B. Mohamed Jan, "Review of biodegradable synthetic-based drilling fluid: progression, performance and future prospect," *Renewable and Sustainable Energy Reviews*, vol. 90, pp. 171–186, 2018.
[96] S. S. Kamaruddin, M. F. Mohammad, and R. Mahbub, "Barriers and impact of mechanisation and automation in construction to achieve better quality products," *Procedia—Social and Behavioral Sciences*, vol. 222, pp. 111–120, 2016.
[97] S. J. Ray and J. Teizer, "Dynamic blindspots measurement for construction equipment operators," *Safety Science*, vol. 85, pp. 139–151, 2016.
[98] M. Çağdaç Arslan, B. Çatay, and E. Budak, "A decision support system for machine tool selection," *Journal of Manufacturing Technology Management*, vol. 15, no. 1, pp. 101–109, 2004.
[99] R. R. Cabahug, D. J. Edwards, and J. Nicholas, "Classifying plant operator maintenance proficiency: examining personal

variables," *Building Research & Information*, vol. 32, no. 2, pp. 119–127, 2004.

[100] Y. Fang and Y. K. Cho, "Effectiveness analysis from a cognitive perspective for a real-time safety assistance system for mobile crane lifting operations," *Journal of Construction Engineering and Management*, vol. 143, no. 4, Article ID 05016025, 2016.

[101] I. J. Shin, "Factors that affect safety of tower crane installation/dismantling in construction industry," *Safety Science*, vol. 72, pp. 379–390, 2015.

[102] H. Guo, Y. Yu, and M. Skitmore, "Visualization technology-based construction safety management: a review," *Automation in Construction*, vol. 73, pp. 135–144, 2017.

[103] D. Silka, "Development of organizing and economic measures for monitoring the cost of construction resources," *MATEC Web of Conferences*, vol. 106, Article ID 08042, 2017.

[104] J. Irwin, B. Lahneman, and A. Parmigiani, "Nested identities as cognitive drivers of strategy," *Strategic Management Journal*, vol. 39, no. 2, pp. 269–294, 2018.

[105] Caterpillar, *Caterpillar Performance Handbook*, Caterpillar, Peoria, IL, USA, 2014.

[106] International Organization for Standards, *ISO-10987 Earth-Moving Machinery—Sustainability—Terminology, Sustainability Factors and Reporting*, International Organization for Standards, Geneva: Switzerland, 2017.

[107] M. Bouzon, K. Govindan, C. M. T. Rodriguez, and L. M. S. Campos, "Identification and analysis of reverse logistics barriers using fuzzy Delphi method and AHP," *Resources, Conservation and Recycling*, vol. 108, pp. 182–197, 2016.

[108] J. Climaco, *Multicriteria Analysis*, Springer-Verlag, Berlin, Germany, 1997.

[109] M. Rogers, M. Bruen, and L. Maystre, "ELECTRE and decision support: methods and applications in engineering and infrastructure investment," *Journal-Operational Research Society*, vol. 53, no. 12, pp. 1396-1397, 2002.

[110] E. Løken, "Use of multicriteria decision analysis methods for energy planning problems," *Renewable and Sustainable Energy Reviews*, vol. 11, no. 7, pp. 1584–1595, 2007.

[111] L. A. Greening and S. Bernow, "Design of coordinated energy and environmental policies: use of multi-criteria decision-making," *Energy Policy*, vol. 32, no. 6, pp. 721–735, 2004.

[112] S. D. Pohekar and M. Ramachandran, "Application of multi-criteria decision making to sustainable energy planning–a review," *Renewable and Sustainable Energy Reviews*, vol. 8, no. 4, pp. 365–381, 2004.

[113] T. Tsoutsos, M. Drandaki, N. Frantzeskaki, E. Iosifidis, and I. Kiosses, "Sustainable energy planning by using multi-criteria analysis application in the island of Crete," *Energy Policy*, vol. 37, no. 5, pp. 1587–1600, 2009.

[114] K. Govindan, M. Kaliyan, D. Kannan, and A. N. Haq, "Barriers analysis for green supply chain management implementation in Indian industries using analytic hierarchy process," *International Journal of Production Economics*, vol. 147, pp. 555–568, 2014.

[115] T. Harputlugil, M. Prins, A. T. Gultekin, and Y. L. Topcu, "Conceptual framework for potential implementations of multi criteria decision making (mcdm) methods for design quality assessment," in *Proceedings of the Management and Innovation for a Sustainable Built Environment MISBE 2011*, Amsterdam, Netherlands, June 2011.

[116] S. Mangla, J. Madaan, and F. T. S. Chan, "Analysis of performance focused variables for multi-objective flexible decision modeling approach of product recovery systems," *Global Journal of Flexible Systems Management*, vol. 13, no. 2, pp. 77–86, 2012.

[117] A. Shapira and M. Goldenberg, "AHP-based equipment selection model for construction projects," *Journal of Construction Engineering and Management*, vol. 131, no. 12, pp. 1263–1273, 2005.

[118] T. Saaty and L. Vargas, *The Logic of Priorities*, RWS Publications, Pittsburgh, OA, USA, 1991.

[119] N. Subramanian and R. Ramanathan, "A review of applications of Analytic Hierarchy Process in operations management," *International Journal of Production Economics*, vol. 138, no. 2, pp. 215–241, 2012.

[120] M. J. Skibniewski and L. C. Chao, "Evaluation of advanced construction technology with AHP method," *Journal of Construction Engineering and Management*, vol. 118, no. 3, pp. 577–593, 1992.

[121] M. Hastak, "Advanced automation or conventional construction process?," *Automation in Construction*, vol. 7, no. 4, pp. 299–314, 1998.

[122] M. Hastak and D. W. Halpin, "Assessment of life-cycle benefit-cost of composites in construction," *Journal of Composites for Construction*, vol. 4, no. 3, pp. 103–111, 2000.

[123] W. Ossadnik and O. Lange, "AHP-based evaluation of AHP-Software," *European Journal of Operational Research*, vol. 118, no. 3, pp. 578–588, 1999.

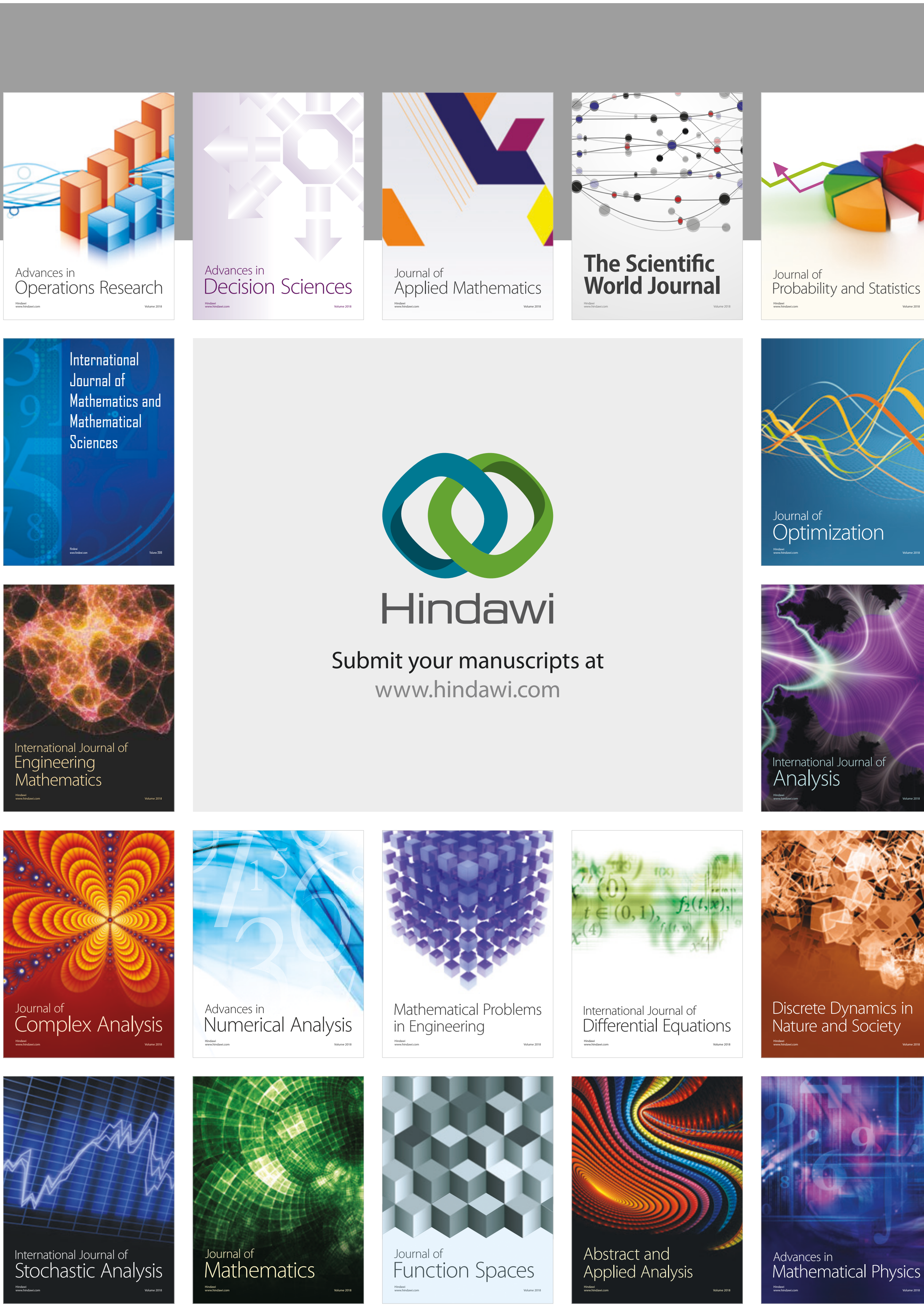
[124] A. Ishizaka and A. Labib, "Analytic hierarchy process and expert choice: benefits and limitations," *OR Insight*, vol. 22, no. 4, pp. 201–220, 2009.

[125] T. L. Saaty and L. G. Vargas, *The Logic of Priorities*, RWS Publications, Pittsburgh, PA, USA, 1991.

[126] R. K. Yin, *Case Study Research: Design and Methods*, Sage Publications, Thousand Oaks, CA, USA, 3rd edition, 2003.

[127] B. Gillham, *Case Study Research Methods*, Bloomsbury Publishing, London, UK, 2000.

[128] W. Rasdorf, P. Lewis, S. K. Marshall, I. Arocho, and H. C. Frey, "Evaluation of on-site fuel use and emissions over the duration of a commercial building project," *Journal of Infrastructure Systems*, vol. 18, no. 2, pp. 119–129, 2012.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