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An AHP-MOLP Approach on Prioritizing Competitive Strategies Toward Sustainable Business

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Abstract

Incorporating sustainability in business processes has extended its scope from a supply chain or life cycle perspectives to highly, technical engineering designs of products and processes. Streamlining of opportunities for possible integration of sustainability and business process has shown an overwhelming increase of research interests in current literature. At the conceptual level, decision-making on areas that concern strategy or long term goals is a crucial task as it directs future status of the firm, at least in the area of sustainability. Thus, long term decisions must be critically designed to address future conditions of the firm. This paper explores how competitive dimensions influence the triple-bottom line. A hybrid approach using analytic hierarchy process (AHP) and multi-objective linear programming (MOLP) is shown in this paper to provide insights on such influences. A case study of a group of experts is shown in this work. Results show that businesses which maintain quality as their competitive advantage are likely sustainable as it impacts both economic and social performances. It is also shown that economic and social performances can be traded-off to increase environmental performance. The significance of this paper lies in presenting a range of alternative Pareto optimal solutions which are relevant in providing decision-makers a trade-off in sustainable business performance.

Key words: *Analytic Hierarchy Process, Multi-objective Linear Programming, Pareto Front, Sustainable Business*

1. INTRODUCTION

Due to the emerging policies imposed by influential developed economies and institutions on improving thesocio-environmental performance of products and services across the supply chain, the inclusion of such concepts and approaches to the mainstream of business processes has become central to discussion in both research and practice. For instance, the EU directive on Waste Electrical and Electronic Equipment (WEEE) in 2003 [1] and reviewed in 2012 [2] has inspired numerous scientific articles ranging from purely technical works that explore characterization studies, recovery schemes, material tests, etc. [3-4] to overarching policy development, implementation, evaluation and management across various spatial scales [5-7]. Other policies and initiativessuch as the Restriction on the use of Hazardous Substances (RoHS) [8-10], eco-labelling [11-12] and ISO 14000 series [13-14] have been likewise influentialin stimulating firms to develop programs that transcend beyond cost reduction, quality improvement, productivity and efficiency into involving holistic views that capturethe interests of both environment and society. This development is strongly evidencedby the increasing number of approaches and strategies toward a more sustainable enterprise which includethe 5R approach, cleaner production, corporate social responsibility, sustainability reporting, etc. A comprehensive evaluation of these approaches can be found in Lozano [15].

Various claims in literature have emerged on the impact of these approaches on firms' financial and market performance. Zailani et al. [16] empirically tested a number of relationships of green approaches on firms' performance. Results claim that environmental purchasing has positive effect on operational and social performance of firms; sustainable packaging has positive impact on social, economic and environmental performance; sustainable supply chain management improves market and financial performance. Wong et al. [17] suggest the positive impact of process-oriented environmental practices on firms' financial and environmental performance. Schoenherr [18]discusses the positive impact of ISO certifications on financial performance. Yang et al., [19] show a positive impact of supplier management on environmental performance.

However, there are also corresponding negatives effects that were singled out in previous works. For instance, Yang et al., [20]argue that although environmental practices such as life cycle assessment (LCA), design for environment (DfE), eco-design etc may support environmental and economic performance as discussed by Tseng et al., [21] and Giovanni and Vinzi [22], it would possibly entail negative effects on financial and market performance in the short run. This is supported by Gimenez et al., [23] which indicate that internal social initiatives has positive impact on social and environmental performance but may likely decrease economic performance. A more likely explanation of this negative impact on performance would be that implementation of some sustainable manufacturing strategies requires relatively high investment in the short-run and quantifying the return of investment has not been well-established in literature [24-25] because of the high degree of uncertainty caused by intangibles especially in socio-economic aspects. For instance,Thiede et al., [26] agree that efficient technologies require relatively high amount of investment. Compared to traditional cost and quality performance which are tangibles to the firm, the presence of intangibles in sustainability structure such as community well-being, product responsibility and employee career development makes firms uncertain on whether they would invest in these areas or not. Complexity arises primarily because of the difficulty in quantifying the benefits firms could obtain from this initiative brought about by longer time horizons and higher degree of uncertainty of the results.Nevertheless, the set of benefits for firms in carrying out environmental and sustainability initiatives is still a long list [27].

Another line of interesting inquiry is brought about by the works of [16, 28] and expanded by Johansson and Winroth [29]. Vachon and Klassen [28] and Zailani et al., [16] examine the positive influence of environmental collaboration in the supply chain on competitive priorities, i.e. cost, quality, delivery and flexibility. They argue that enhanced supplier-customer relations on environmental issues tend to strengthen the competitive base of each member in the supply chain on the four competitive areas. Johansson and Winroth [29], on the other hand, developed a framework that relates stakeholders' sustainability interests with the competitive priorities. This indicates that as stakeholders' interests change, a corresponding change of the priorities attached to each competitive dimension must be observed. With this, changing the priorities of stakeholders by designing relevant policies could alter the direction of businesses toward sustainability. However, the impact of a particular set of competitive priorities on sustainability, which is a reverse relation, has not been explored in literature. This paper adopts the argument that a particular set of competitive orientation yields a more sustainable business. For instance, a semiconductor business that drives on quality orientation may likely use a huge amount of virgin materials as inputs to production and will continuously use lead (Pb) in its moulding process as an established practicethat is known to have consistent high quality moulded semiconductor packages. In this particular case, increase resource consumption and the use to toxic substance would certainly be a relevant sustainability issue. Thus, there exists a particular set of priorities in competitive orientation that yields more sustainable strategy with respect to the triple-bottom line, i.e. environmental, economic and social dimensions. This is a relevant question that links competitive strategy to business sustainability in a way that discusses how a set of competitive priorities explored by a business firm impact sustainability dimensions. However, such an approach would be more effective if the trade-off in the triple bottom line is recognized. This offers decision-makers with several options in exploring sustainability performance. This paper illustrates the use of analytic hierarchy process (AHP) and multi-objective optimization (MOO) to provide a set of competitive orientation as a result of the priorities attached to each sustainability dimension as regarded by the decision-maker. The significance of this paper lies in demonstrating how structuring competitive dimensions provide trade-off in the sustainability dimensions so that a sustainable business is achieved.

2. LITERATURE REVIEW

2.1 **Competitive Strategy**

Literature is consistent on the type of four competitive priorities on which a business strategy could possibly pursue. These are cost, quality, dependability and flexibility [30-32]. Competing on cost requires a strategy that minimizes inefficiencies in business operations so that products are offered at low cost (or price). This is addressed by labor, materials, capital productivities, inventory turnover and unit costs [31]. A business strategy that establishes quality as dominant capability requires higher quality in standard product or one that offers wider features or performance characteristics compared to other competitors with similar products. Measurement could be percent defective or rejected, field failure frequency, cost of quality and mean time between failures [31]. Dependability involves a business that is able to do work as specified, delivered on time and the firm makes sure that its resources are ready to ensure that any failures are corrected immediately. It could be achieved by dealing on product mix flexibility, volume flexibility and lead time for new products [31]. Flexibility on the other hand comes in two forms: product flexibility and volume flexibility – denotes a strategy that could enable firms to introduce new products more quickly in the market or to rapidly change its capacity to address sudden demand fluctuations [30]. Measurement items could be percentage of on-time shipments, average delay and expediting response time [31]. A comprehensive discussion of these four capabilities was outlined by Ward et al., [32]. Firms must "attach definite priorities to each, and those priorities determine how that business will be positioned relative to its competitors – in terms of its competitive advantage" [30,33]. Different business firms emphasize each of the four competitive capabilities to varying degrees [30]. As long as these priorities are not explicitly considered in a consistent manner, the firm could not achieve an effective business strategy [30].

2.2 **Triple-bottom Line**

A more explicit definition of sustainable development is discussed by Ragas et al., [34] which describes sustainability as“a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and the institutional change are in harmony and increase the present, as well as the future, possibility to accommodate human needs. The relation between the society and its physical environment should be such that a natural carrying capacity is ensured for future generations.” The resulting process of change is expected to be a heterogeneous system but should maintain spatial and temporal equilibrium states [35]. This implies a development that caters to the needs and demands of the present while taking a look at how this development can be maintained or increased so that needs and demands of the future will be likewise met. The most widely-accepted approach to sustainability in general is the triple-bottom line approach [36-38] which was formerly introduced by Elkington [39]. This approach maintains that sustainability is achieved by considering simultaneously the three pillars of sustainability, i.e. environmental stewardship, economic growth, and social well-being [40]. Sustainability is viewed at the intersection of these three pillars. Intersection of any two pillars could represent sets of programs which address specific issues that may not be truly sustainable at all as presented by Rosen and Kishawy [41]. Another stream of research in triple-bottom line is on exploring interdependencies on three three dimensions. The relevance of this area lies in providing information to decision-makers involving investment decisions, resource allocation, strategic planning, etc. There are two supporting views in this area. One view suggests that there exists a trade-off in the three dimensions [42-43] which implies that improving a single dimension could possibly reduce the performance of other dimension (s). The other view provides guidance on the possible interactions of the three dimensions considering trade-offs. For instance, Yang et al.,[20] and Wagner [43] maintained that environmental performance has a positive relationship with economic performance. Salzmann et al., [44] presented a review of the frameworks supporting social and environmental performance to economic performance. Lankoski [45] also argued that higher revenues (economic sustainability) are achieved with enhanced economic and social performance.

While these two areas of sustainability and competitive strategy have been initially explored, the impact on sustainability brought about by the priorities attached to the competitive dimensions, to our knowledge, has not been explored in current literature. This integration is of relevance to decision-makers in order to assess the sustainability of the competitive strategy the firm is pursuing.

3. RESEARCH METHOD

3.1 **Analytic Hierarchy Process**

AHP is a powerful tool in multi-criteria decision-making (MCDM). AHP decomposes a decision problem into components of different levels. Decomposition is significant in decision analysis as it provides depth, comprehensive and organized decision-making process. Decision-makers elicit paired comparisons, based on their value judgments, of the elements in the same level with respect to an element in higher immediate level. Generally, the procedure of AHP can be described as follows:

1. Structuring the decision problem

In AHP, decision problems are structured hierarchically in a top-down approach [47]. The decision of the inclusion of components in decision-making is usually carried out either through a critical review of literature with regard to the facts of the decision problem or through group of experts who have sufficient knowledge and experience of the problem under consideration. Decision components and elements are usually a combination of both objective and subjective ones, with measurements in different and multiple dimensions.

2. Eliciting judgment in paired comparisons

Paired comparisons of elements in the same level with respect to an element in the immediate higher level are carried out in the AHP. The generic question in making paired comparisons is like this: “Given a parent element and given a pair of elements, how much more does a given member of the pair dominate other member of the pair with respect to a parent element?” [48]. To achieve a uni-dimensional scaling property of the comparisons, Saaty [49] established the famous Saaty fundamental 9-point scale which can be found in different works using AHP (see [50]). The result of this process is a positive reciprocal paired comparisons matrix. For instance comparing A_{11} with A_{13} has a rating of 3, then comparing QUOTE $\mathbf{A_{13}}$ QUOTE $\mathbf{A_{13}}$ with A_{11} must be 1/3. Priority vectors ($\mathbf{w}$) are obtained from the pair wise comparisons matrix ($\mathbf{A}$) by solving an eigenvalue problem in the following relation:

$$\mathbf{Aw}=\lambda_{\mathbf{maxw}} \qquad (1)$$

where $\lambda_{\mathbf{maxw}}$ is the maximum eigenvalue of the positive reciprocal square matrix (A). The approach also provides a way to measure the consistency of judgments in the pair wise comparison matrix. When decision-making in the pairwise comparisons matrix is consistent $\lambda_{\mathbf{max}}$=n; otherwise, $\lambda_{\mathbf{max}}>$n where **n** is the number of elements being compared. The

Consistency Index (CI), as a measure of degree of consistency, was calculated using the formula:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

The consistency ratio (CR) is computed as

$$CR = \frac{CI}{RI} \quad (3)$$

where RI is the mean random consistency index. See Alonso and Lamata [51] for Tables of RI. Acceptable CR values must be less than 0.1. Decision-makers were asked to repeat the paired comparisons for CR values greater than 0.1.

3. Synthesizing judgments

Saaty [47] described that synthesizing judgments in AHP is done by weighting the elements being compared in the lower level to an element in the next immediate level, referred to as the parent element, by the priority of that element and adding all parents for each element in the lower level. This is referred to as the distributive mode of the AHP. This can be represented in the form

$$w_j = \sum_{i=1}^{n} c_i x_{ij} \quad (4)$$

where w_j is the global weight of alternative **j**, $\mathbf{c_i}$ is the weight of criteria **i** with respect to the goal, and $\mathbf{x_{ij}}$ is the local weight of alternative **j** with respect to criteria **i**. Alternatively, in matrix form:

$$W^T = XC^T \quad (5)$$

where W is an $m x 1$ matrix, **X** is an mxn($j \in m$, $i \in n$) matrix of alternative weights with respect to each criterion and **C** is an $1 x n$ matrix of criteria weights. This synthesized vector of priority weights of alternatives is also termed as the global priority vector.

3.2 **Multi-objective Linear Programming (MOLP)**

MOLP is generally an extension of linear programming with two or more objective functions. The algorithm used in this study to solve MOLP problems is based from the "constraint method" developed by Cohon [52] and is used by a highly cited paper of Azapagic and Clift [53]. The algorithm is described as follows:

1. Pay-off table

a. Solve **Q** single-objective optimisation problems tofind the optimal solution for each of the **Q** objectives. Optimal solution for the $\mathbf{q}$ the objective is denoted as $x^q = x_1^q, x_2^q, \ldots, x_I^q$.

b. Compute the value of each objective at each of the Q optimal solutions:

$$F_1(x^q), F_2(x^q), \ldots, F_Q(x^q), q = 1, 2, 3, \ldots, Q$$

This gives $\mathbf{Q}$ values for each of the $\mathbf{Q}$ objectives.

c. Construct a payoff table with rows corresponding to x^1, x^2, …x^Q and the columns equal to the number of objectives.

d. Identify the largest and the smallest numbers in the **q** th column and denote them by $\mathbf{M_q}$ and $\mathbf{n_q}$, respectively.Repeat for q=1,2,...., Q.

2. Constraints

Convert a MOLP problem to itscorresponding constrained problem by making all objectives but one converted into constraints.

3. Right-hand side coefficients

The $\mathbf{M_q}$ and $\mathbf{n_q}$ represent the upper and lower boundsfor the **q** the objective: $\mathbf{n_q} \leq \varepsilon_\mathbf{q} \leq \mathbf{M_q}$. Choose the numberof different values of $\varepsilon_\mathbf{q}$ and denote it by **r.**

4. Optimisation

To generate a range of non-inferior solutions, solve the constrained problem in Step 2 for every combination of values for the $\varepsilon_\mathbf{q}$, $q = 1, 2, \ldots, h-1, h+1, \ldots Q,$ where:

$$\varepsilon_q = n_q + \left[\frac{t}{r-1}\right](M_q - n_q), t = 0, 1, 2, \ldots, (r-1) \quad (6)$$

3.3 **Proposed Method**

Generally, the methodology used in this study described as follows:

1. Perform AHP pairwise comparisons. Saaty [54] recognized the relevance of classical linear programming (LP) technique with Analytic Hierarchy Process (AHP) especially in allocating intangible resources. This approach transforms LP coefficients into relative measurements derived from AHP paired comparisons. There are three sets of AHP paired comparisons described in this. First set relates the relative priorities of competitive dimensions with each of the three dimensions in the triple-bottom line. Second set obtains the relative importance of business functions with each of the three dimensions. Lastly, relative priorities of competitive dimensions with each of the business resource functions are obtained. Using equations (1) through (4), local priority vectors, maximum eigenvalues and consistency rations are obtained.

All priority vectors are incorporated into the MOLP model.

2. Construct the multi-objective linear programming (MOLP) model. The MOLP model can be described as follows:

$$\max \lambda_1 \tag{7}$$

$$\max \lambda_2 \tag{8}$$

$$\max \lambda_3 \tag{9}$$

$$\text{s.t.} \tag{10}$$

$$\sum_{i=1}^{4} w_{1i} x_i \leq w_1$$

$$\sum_{i=1}^{4} w_{2i} x_i \leq w_2$$

$$\vdots$$

$$\sum_{i=1}^{4} w_{6i} x_i \leq w_6$$

The three objective functions correspond to the three dimensions of the triple-bottom line. The decision variables x_1, x_2, x_3 and x_4 denote the competitive dimensions i.e. cost, quality, dependability and flexibility. Six constraints are referred to as general resources in any business organization. resources can be tangible or intangible that support business goals and objectvies. In this study, these resources are directly linked to the six business functions i.e. marketing, operations, quality assurance, finance, management information system (MIS) and human resource. At the conceptual level, functional areas are resources in themselves that have finite capacities in terms of focus, direction and and scope. Thus, how these resources pay attention or respond to the competitive advantages of any organization remains an interesting question.w_1, w_2 ... w_6 are the normalized relative priorities of business functions with respect to the triple bottom line. The values w_{ji} correspond to the relative priorities of competitive dimension **i** with respect to the business function **j**.

3. Solve MOLP model using the constraint method described in section 3.2. This is done first by solving single-objective optimization problems to obtain each **q** optimal solution. Second is to compute for the value of each **Q** objective at each of **q** optimal solution. Third is to construct a payoff table with rows corresponding to the **q** optimal solutions and columns with the **Q** objectives. Fourth is to determine maximum and minimum values for each column. Fifth is to choose arbitrarily an objective function and the rest is converted to constraints. The right-hand side of these objective-constraints will be a set of values from a range of minimum to maximum for each column. Lastly, compute for the non-inferior solutions and draw the Pareto frontier.

4. RESULTS

A group of 10 experts was asked to perform paired comparisons based on the context of AHP. The composition of these experts include four department managers in large business firms, three management consultants with sufficient background in business processes and three academicians with research focus on sustainability and stategy. The hierarchical model is described in Fig. 1. The hierarchical model is composed components in four levels. The first level describes the overall sustainability of a business firm. The second level illustrates the three fundamental areas of sustainability. The third level corresponds to the six business resource functions that support each area of sustainability. The codes MR, OR, QR, FR, MR, HR stand for marketing resource, operations resource, quality assurance resource, finance resource, management information system resource and human resource, respectively. These resources have varying degrees of impact to each sustainability area. This degree of impact can be referred to as the extent of the ability a particular resource to support sustainability. The codes P, Q, D and F correspond to price, quality, delivery and flexibility.

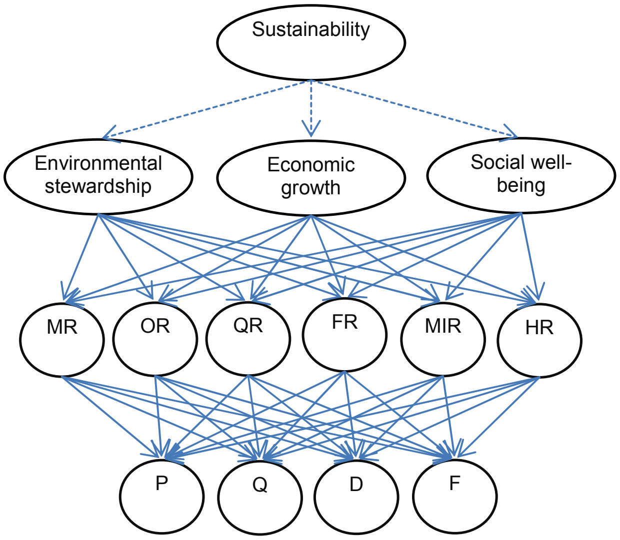

Figure 1. Hierarchical model of sustainability across business resource functions

Paired comparisons are conducted based from the hierarchical model in Fig. 1. Tables 1, 2 and 3 show these paired comparisons and the corresponding priority vectors.

Table 1. Relative contribution of competitive dimensions on environmental performance

environmental performance	price	quality	dependability	flexibility	priority vector
price	1	1/2	1/5	1/2	0.1005
quality	2	1	1/3	1	0.1819
dependability	5	3	1	3	0.5357
flexibility	2	1	1/3	1	0.1819

Table 2. Relative contribution of competitive dimensions on economic performance

economic performance	price	quality	dependability	flexibility	priority vector
price	1	2	3	2	0.4289
quality	1/2	1	2	1	0.2223
dependability	1/3	1/2	1	1/2	0.1265
flexibility	1/2	1	2	1	0.2223

Table 3. Relative contribution of competitive dimensions on social performance

social performance	price	quality	dependability	flexibility	priority vector
price	1	1/3	1/5	1/2	0.0914
quality	3	1	1/2	2	0.2619
dependability	5	2	1	3	0.4915
flexibility	2	1/2	1/3	1	0.1552

Ratio scales of comparison used in Table 1-3 are derived from Saaty's Fundamental 9-point scale [49]. The question being asked in these paired comparisons for instance is like this: “Comparing price and quality, which one influences environmental performance and by how much?” Priority vectors are computed using the eigenvector approach. This is done by normalizing column and then raising the matrix to sufficiently large powers. By doing so, the row values will converge to its Cesaro sum [49, 54]. Priority vectors show the dominance of competitive dimensions on a specific sustainability objective. For instance in Table 1, dependability influences more than the environmental performance. Ranking is as follows: dependability, flexibility, quality and price.

The next set of paired comparisons matrices is on the relative influence of competitive dimensions on a specific business resource function. Tables 4-9 show the relative vectors obtained from pairwise comparisons.

Table 4. Relative use of marketing resource

marketing	price	quality	dependability	flexibility	priority vector
price	1	1	1/2	3	0.2309
quality	1	1	1/2	3	0.2309
dependability	2	2	1	4	0.4448
flexibility	1/3	1/3	1/4	1	0.0934

Table 5. Relative use of operations resource

operations	price	quality	dependability	flexibility	priority vector
price	1	1	1/3	1/2	0.1434
quality	1	1	1/3	1/2	0.1434
dependability	3	3	1	2	0.4617
flexibility	2	2	1/2	1	0.2514

Table 6. Relative use of quality assurance resource

quality assurance	price	quality	dependability	flexibility	priority vector
price	1	1/5	1/3	1	0.1026
quality	5	1	3	5	0.5756
dependability	3	1/3	1	3	0.2192
flexibility	1	1/5	1/3	1	0.1026

Table 7. Relative use of finance resource

finance	price	quality	dependability	flexibility	priority vector
price	1	4	3	2	0.4799
quality	1/4	1	1/2	1/3	0.1026
dependability	1/3	2	1	1/2	0.1554
flexibility	1/2	3	2	1	0.2621

Table 8. Relative use of MIS resource

MIS	price	quality	dependability	flexibility	priority vector
price	1	1/2	1/3	1/3	0.1120
quality	2	1	1/2	1/2	0.1826
dependability	3	2	1	1	0.3527
flexibility	3	2	1	1	0.3527

Table 9. Relative use of HR resource

human resources	price	quality	dependability	flexibility	priority vector
price	1	1	1/2	1/3	0.1434
quality	1	1	1/2	1/3	0.1434
dependability	2	2	1	1/2	0.2514
flexibility	3	3	2	1	0.4617

The question being asked in these paired comparisons as shown in Table 4-9 for instance is like this: “Comparing price and quality, which one uses more marketing resource and by how much?” Relative vectors obtained from these paired comparisons relate to the relative use of competitive dimensions to a particular business function. For instance in Table 4, dependability uses more marketing resource compared to other competitive dimensions. The order of dominance is as follows: dependability, price, quality and flexibility.

The last set of AHP paired comparisons is on the relative importance of business functions with respect to sustainable business. In doing this, we obtain relative importance of business functions with respect to each objective and then aggregate the relative vectors by normalizing the values with the use of the results obtained by Ocampo and Clark [55]. Environmental, economic and social dimensions have relative weights 0.2, 0.4 and 0.4, respectively. The normalized priority vector is shown in Table 10. The values obtained from the normalized priority vector will be the right-hand side values in the constraints of the MOLP model. From Table 10, it is shown that operations and quality assurance functions have relatively higher impact to sustainable business.

Table 10. Relative importance of business functions to attain sustainable business

functions	environmental	economic	social	normalized vector of priorities
marketing	0.2379	0.1659	0.0761	0.1444
operations	0.4225	0.3037	0.3604	0.3501
quality assurance	0.0927	0.3037	0.1967	0.2187
finance	0.1408	0.0707	0.1149	0.1024
MIS	0.0531	0.1034	0.0553	0.0741
human resource	0.0531	0.0524	0.1967	0.1102

The relative vectors obtained from Table 1-10 provide numerical values to the MO model. For instance, priority vectors obtained in Table 1-3 are the coefficients in the objective functions. Table 4-9 show the coefficients in the left-hand of the constraints. Lastly, Table 10 shows the right-hand side values of the constraints. The multi-objective linear programming model can be described as follows:

$$\max \lambda_1 = 0.1005x_1 + 0.1819x_2 + 0.5357x_3 + 0.1819x_4 \quad (5)$$

$$\max \lambda_2 = 0.4289x_1 + 0.2223x_2 + 0.1265x_3 + 0.2223x_4 \quad (6)$$

$$\max \lambda_3 = 0.0914x_1 + 0.2619x_2 + 0.4915x_3 + 0.1552x_4 \quad (7)$$

s.t.

$$0.2309x_1 + 0.2309x_2 + 0.4448x_3 + 0.0934x_4 \le 0.1444 \quad (8)$$

$$0.1434x_1 + 0.1434x_2 + 0.4617x_3 + 0.2514x_4 \le 0.3501 \quad (9)$$

$$0.1026x_1 + 0.5756x_2 + 0.2192x_3 + 0.1026x_4 \le 0.2187 \quad (10)$$

$$0.4799x_1 + 0.1026x_2 + 0.1554x_3 + 0.2621x_4 \le 0.1024 \quad (11)$$

$$0.1120x_1 + 0.1826x_2 + 0.3527x_3 + 0.3527x_4 \le 0.0741 \quad (12)$$

$$0.1434x_1 + 0.1434x_2 + 0.2514x_3 + 0.4617x_4 \le 0.1102 \quad (13)$$

Equations (1), (2) and (3) represent the objective functions relating to environmental, economic and social performance, respectively. Equations (8) through (13) pertain to the business functions i.e. marketing, operations, quality assurance, finance, MIS and human resource. The constraint method demonstrated by Azapagic and Clift [53] is utilized to obtain a Pareto frontier which is used to show trade-off analysis. A Pareto front is a set of non-inferior or non-dominated solutions which is optimum on the basis of one objective function. No objective function can be made better off without sacrificing other objectives. In the constraint method, optimal solutions from single-objective optimization problems are obtained. Objective function values **$\Lambda_q(X^q)$** are computed from the set of optimal solutions **X^q**, q=1,2,3 obtained from single-objective optimizations. Table 11 shows the results of single-objective optimizations and Table 11 shows a payoff table with rows corresponding to **X^q** and columns equal to **$\Lambda_q(X^q)$**

Table 11. Optimal solutions from single-objective optimizations

X^q	x_1	x_2	x_3	x_4	$\Lambda_q(X^q)$
X^1	0	0	0.2101	0	0.1126
X^2	0.1457	0.3165	0	0	0.1329
X^3	0	0.3736	0.0167	0	0.1061

Table 12. Payoff table of objective function values from set of optimal solutions

X^q	$\Lambda_1(X^q)$	$\Lambda_2(X^q)$	$\Lambda_3(X^q)$
X^1	0.1126	0.0266	0.1033
X^2	0.0722	0.1329	0.0962
X^3	0.0769	0.0852	0.1061
M_q	0.1126	0.1329	0.1061
n_q	0.0722	0.0266	0.0962

The values in the diagonal of the payoff table in Table 12 represent the optimal solution values from single-objective optimizations. Note that each column pertains to the objective function value given an optimal solution set. Note further that largest values for each column coincide with the optimal solution of that objective obtained from single-objective optimizations – the values in the diagonal of the payoff table. The values of M_q and n_q are the maximum and minimum values of a specific objective function λq. It is also referred as the range of the feasible region of a particular objective function [53].

The next step is to arbitrarily select one objective function and then to transform other objective functions to constraints. The new optimization model can be described as follows:

$$\max \lambda_1 = 0.1005x_1 + 0.1819x_2 + 0.5357x_3 + 0.1819x_4 \quad (14)$$

s.t.

$$0.2309x_1 + 0.2309x_2 + 0.4448x_3 + 0.0934x_4 \le 0.1444 \quad (15)$$

$$0.1434x_1 + 0.1434x_2 + 0.4617x_3 + 0.2514x_4 \le 0.3501 \quad (16)$$

$$0.1026x_1 + 0.5756x_2 + 0.2192x_3 + 0.1026x_4 \le 0.2187 \quad (17)$$

$$0.4799x_1 + 0.1026x_2 + 0.1554x_3 + 0.2621x_4 \le 0.1024 \quad (18)$$

$$0.1120x_1 + 0.1826x_2 + 0.3527x_3 + 0.3527x_4 \le 0.0741 \quad (19)$$

$$0.1434x_1 + 0.1434x_2 + 0.2514x_3 + 0.4617x_4 \le 0.1102 \quad (20)$$

$$0.4289x_1 + 0.2223x_2 + 0.1265x_3 + 0.2223x_4 \ge e_1 \quad (21)$$

$$0.0914x_1 + 0.2619x_2 + 0.4915x_3 + 0.1552x_4 \ge e_2 \quad (22)$$

In this study, we choose economic and social dimensions to be objective-constraints. The right-hand side values of equations (21) and (22) are described as $\mathbf{n_1 \le e_1 \le M_1}$ and $\mathbf{n_2 \le e_2 \le M_2}$, respectively. We select five values in the range of $\mathbf{e_1}$ and $\mathbf{e_2}$ to represent points A, B, C, D and E. These five points represent the non-inferior solutions in the MOLP model described by equations (5) through (13). The set of non-inferior solutions is shown in Table 13 and Fig. 1.

Table 13. Non-inferior points

Non-inferior points	environmental	economic	social
A	0.1088	0.0476	0.0982
B	0.0973	0.0686	0.1002
C	0.0825	0.0896	0.1021
D	0.0813	0.091	0.1024
E	0.0791	0.094	0.1027

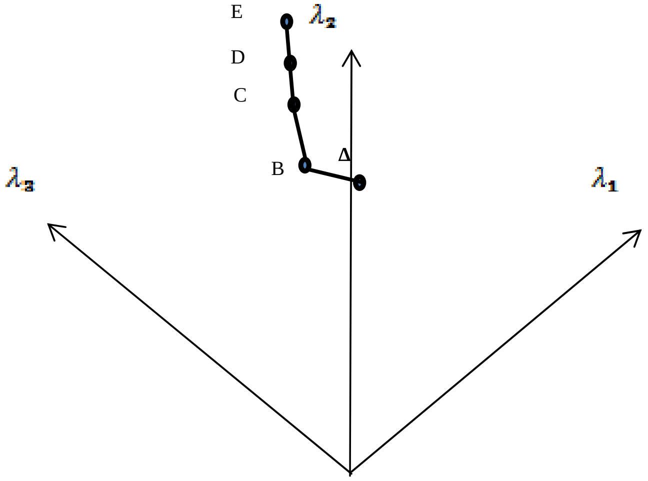

Figure 2. Non-inferior curve for multi-objective optimization

The non-inferior curve as shown in Fig. 2 is a Pareto optimal solution of the MOLP model. This curve is optimal in the sense that one objective could not be improved without worsening the other objectives. At the Pareto front, the optimal relative values of the competitive dimensions are shown in Table 14.

Table 14. Optimal relative priorities of competitive dimensions at non-inferior points

Competitive dimensions	Non-inferior points				
	A	B	C	D	E
price	0.054	0.0616	0.0497	0.0473	0.0454
quality	0	0.1151	0.2784	0.2934	0.3173
dependability	0.193	0.131	0.0502	0.0432	0.0315
flexibility	0	0	0	0	0

5. DISCUSSION

In this paper, analytic hierarchy process (AHP) is incorporated with multi-objective linear programming (MOLP) by providing coefficients in MOLP model through vector of priorities. Decision variables relating to competitive dimensions as well as resource use and the right-hand side values of the constraints are expressed in relative terms. Since competitive dimensions are intangibles which are hard to quantify, expressing it into relative terms using AHP provides us insights in quantifying allocation of these intangibles. The non-inferior curve in Fig. 2 is optimal in the Pareto sense as no objective can be made better off without worsening other objectives. Decision-makers can choose solutions from points A to E depending on which objective to give up so that they can gain another. The choice of solution point along the Pareto frontier depends on the value judgments of decision-makers. At point A, environmental performance and social performance are close to their optimum values obtained using single-objective optimization having 3.4% and 7.4%, respectively below optimum. At point B, social performance increases towards its optimum so as with economic performance. Environmental performance deviates from the optimum from point A to point B. At points C, D and E environmental performance departs gradually from the optimum while economic and social performance increases towards the optimum. At point E, environmental and economic performances have almost equal percentage away from the optimum. From A to E, social and economic performances converge towards the optimum while environmental performance diverges from the optimum. When economic and social dimensions are prioritized more, parallel with the results of Ocampo and Clark (2012a), point E is considered to be the option. Quality is essential at this solution point followed by price and dependability. By moving from point A to E, decision-makers give up environmental performance and trade it with economic and social performances. When sustainable business dimensions are considered equal, solution between points B and C is considered relevant where quality and dependability are considered vital for a business.

This information regarding tradeoff between sustainability dimensions is significant to the business firm. They can assess which competitive dimensions they are leaning to and then make a tradeoff in order to provide focus to other sustainability dimensions. This paper suggests that those businesses with quality as their competitive advantage are more likely to be sustainable as it drives economic and social performances which are considered as important aspects of sustainability [55]. However, if these businesses with quality as their advantage are willing to give up some of their economic performance with environmental performance, they must lose some of its focus to quality and increase price and dependability. The significance of incorporating AHP with multi-objective optimization lies in providing a set of alternative solutions to decision-makers and then as a consequent, they could contribute some aspects in the decision-making based from their value judgments.

6. CONCLUSION

The choice of a competitive advantage could steer up business sustainability. Businesses should not focus on a single aspect of sustainability as it does not yield Pareto optimal solution. This choice belongs to an inferior point in the feasible solution region of the MOLP model. Rather, businesses must choose a point in the Pareto front for it to be optimal. By choosing trade-offs with the triple-bottom line, relative measurements of the competitive dimensions could be generated. This paper shows that when economic and social dimensions are prioritized, firms must direct its advantage to quality, and a proportion to price and dependability. When environmental performance is significant to a firm, it must redirect its focus on dependability and quality and a proportion to price.

This paper provides a relevant groundwork of investigating the interface between corporate competitive advantages with sustainable business model. Using analytic hierarchy process and multi-objective linear programming, this study was able to show the relevance of providing trade-off analysis on the significance of sustainable business dimensions and then relate it to the set of relative competitive dimensions a firm must direct to yield the desired trade-off.

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AHP-MOLP pristup postavljanja prioriteta konkurentnih strategija prema održivom poslovanju

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Rezime

Uključiti održivost u poslovne procese je proširilo svoj raspon iz perspektive lanca nabavke ili životnog ciklusa na viši nivo, na tehničke inženjerske dizajne proizvoda i procesa. Istraživanje mogućnosti radi moguće integracije održivosti i poslovnog procesa pokazalo je izuzetan porast istraživačkih interesovanja u postojećoj literaturi. Na konceptualnom nivou, donošenje odluka u oblastima vezanim za strategiju ili dugoročne ciljeve je veoma važan zadatak s obzirom na to da određuje pravac budućeg statusa kompanije, barem u oblasti održivosti. Stoga, dugoročne odluke moraju da budu kritički dizajnirane kako bi se odnosile na buduće uslove kompanije. Ovaj rad istražuje kako konkurentna dimenzija utiče na trostruko postavljenu liniju. Hibridni pristup koji koristi analitički hijerarhijski pristup (AHP) i višeciljno linearno programiranje (MOLP) prikazan je u radu kako bi *obezbedio uvid u ove uticaje. Studija slučaja grupe eksperata je prikazana u radu. Rezultati pokazuju da su poslovanja koja održavaju kvalitet kao konkurentnu prednost najverovatnije održiva jer to utiče i na ekonomske i na društvene performanse. Takođe se pokazuje da ekonomske i društvene performanse mogu da predstavljaju ustupak za povećanje performanse zaštite životne sredine. Značaj ovog rada leži u prezentaciji raspona alternativnih Pareto optimalnih rešenja koji su relevantni kako bi onima koji donose odluke pružili ustupak u održivoj poslovnoj performansi.*

Ključne reči: *analitički hijerarhijski proces, višeciljno linearno programiranje, Pareto Front, održivo poslovanj*