# AN ANALYTIC HIERARCHY PROCESS (AHP) APPROACH IN THE SELECTION OF SUSTAINABLE MANUFACTURING INITIATIVES: A CASE IN A SEMICONDUCTOR MANUFACTURING FIRM IN THE PHILIPPINES

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**ABSTRACT**

This paper proposes an evaluation framework of sustainable manufacturing (SM) initiatives using the hierarchical structure of sustainability indicators set adopted by the US National Institute of Standards and Technology (US NIST) in the context of the Analytic Hierarchy Process (AHP). Evaluating SM initiatives developed by manufacturing firms is crucial for resource allocation, and ensuring that investments enhance the sustainability performance of the firm. This evaluation is a challenge because of the multi-criteria nature of the problem and the presence of subjective criteria for which little or no information on their measurement systems is available. Thus, this study is appropriate due to the following reasons: (1) US NIST provides a comprehensive evaluation model of sustainability with its four-level hierarchy that provides evidence of depth and details of sustainability evaluation, and (2) AHP has the capability to handle multi-level decision-making structure with the use of expert judgments in a pairwise comparison process. A case study of a semiconductor manufacturing firm is presented to illustrate the proposed evaluation framework. Results show that firms must strengthen their financial base through programs that improve efficiency, quality and productivity before carrying out initiatives that address the environment and the immediate community. This work presents a framework that could guide decision-makers, in a way that is simple and comprehensive in their attempt to promote sustainability.

Keywords: sustainable manufacturing, evaluation, Analytic Hierarchy Process, multi-criteria decision-making

## 1. Introduction

The current global focus on sustainability compels manufacturing firms to structure their decisions on manufactured products and manufacturing processes beyond traditional profit-based approaches, and utilize a more holistic view that incorporates environmental


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concerns and social well-being. This discussion has been the focal point of research following the UN report that formally declared the need to adopt sustainable development (Brundtland, 1987). The manufacturing industry, as a key sector in the sustainability focus (Rosen and Kishawy, 2012; Joung et al., 2013), has a role in translating sustainability from a profound concept into manageable pieces worthy of attention in research (Mani et al., 2012). Furthermore, the explicit declaration of the U.S. Department of Commerce on sustainable manufacturing (SM) which promotes "the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers and are economically sound" (Joung et al., 2013) has formally linked manufacturing to the mainstream sustainability research. Interest in SM has developed in both industry and academia and has inspired leading economies (Kovac, 2012).

The evidences from these efforts include well-established approaches such as cleaner production (Engelhardt et al., 1994), industrial ecology (Frosch and Gallopoulus, 1989; Baas and Boons, 2004), 5R approach (reduce, reuse, remanufacture, recycle and recovery) (Ageron et al., 2012), green production (Lai, 1993), and design for recyclability (Despeisse et al., 2012). Approaches to SM are derived primarily from addressing sustainability in three widely accepted dimensions, i.e. environmental, economic and social, most notably known as the triple-bottom line (Elkington, 1997). As firms adopt SM initiatives, sustainability indicators are designed to measure and monitor performance of a given approach (Ragas et al., 1995). A number of indicators have been published by renowned institutions, international agencies and bodies, universities, and government and industries. A review of such indicator sets is carried out in several works, e.g. Joung et al. (2013), Singh et al. (2012), Böhringer and Jochem (2007), Mayer (2008). These indicator sets and a hybrid of these sets have been used to assess and evaluate sustainability in different domains (Chen et al., 2012, Jawahir et al., 2007, de Silva et al., 2009 and Mani et al., 2012). At present, the most critical and comprehensive framework of SM indicators has been developed by Joung et al. (2013) with results adopted by the US National Institute of Standards and Technology (US NIST). Ocampo and Clark (2015) adopted this framework in identifying input elements in developing sustainable manufacturing initiatives. The framework is a critical integration of eleven internationally-accepted sustainability indicator sets in different levels of the economy. The framework is plausible as it is hierarchically structured so that a great level of detail is achieved.

The evaluation of SM initiatives is a multi-criteria decision problem because a number of criteria must be taken into consideration when assessing the degree to which these initiatives conform to the dimensions of sustainability. The complexity increases due to the presence of subjective criteria with little or no information available on their corresponding measurement systems. One important consideration in selecting a particular method in strategy selection problems is the ability of the method to address assessment involving value judgments, assumption and scenarios (Heijungs et al., 2010) which are characteristics of MCDM methods (Herva and Roca, 2013). A survey of literature in MCDM carried out by Herva and Roca (2013) indicates that Analytic Hierarchy Process/Analytic Network Process (AHP/ANP) and outranking methods are commonly used in industry-related applications. Due to its logical and simple structure in handling comprehensive evaluation of multi-layer decision problems, AHP is used in this


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paper to select SM initiatives. In AHP, a decision problem is expressed as a hierarchy of decision components and priorities are derived from pairwise comparisons and judgments (Saaty, 1980). Numerous applications of AHP in sustainability assessment were explored in the literature (Krajnc and Glavic, 2005, Gupta et al., 2011, Garbie, 2011; Ocampo and Clark, 2015). This leaves AHP as the most prominent MCDA method in sustainability assessment (Seuring, 2013). A critical review of AHP and its applications is carried out by Vaidya and Kumar (2006) and Subramanian and Ramanathan (2012).

Although several published works on sustainability assessment have already been done, selection of SM initiatives based on a comprehensive framework is rare. This paper attempts to present a selection process of SM initiatives which has an SM evaluation framework based from US NIST and where the decomposition and prioritization process is done using AHP. This extends the work of Ocampo and Clark (2015) where the main departure of this work lies on the evaluation of SM initiatives carried out by a manufacturing firm. This area is an important focus in research as it provides better insights for managers and decision-makers at the firm level on the selection of initiatives that advance sustainability. This aids in the decision-making process of problems that comprise both tangible and intangible components with multi-dimensional scales. A case study of a multi-national semiconductor firm with a manufacturing site located in the Philippines is presented to describe the selection process.

This paper is organized as follows: Section 2 provides the general methodology of the study. Section 3 presents a case study in a semiconductor manufacturing firm. Section 4 and Section 5 present the results and discussion of the selection process using AHP and relevance of the results in sustainability research. Section 6 concludes the study with a discussion of future possible work.

## 2. Proposed Method

### 2.1 Analytic Hierarchy Process

AHP is a powerful tool in multi-criteria decision analysis (MCDA) particularly in hierarchical decision-making. AHP decomposes a decision problem hierarchically into components of different levels. Decision-makers elicit pairwise comparisons, based from their value judgments, of the elements in the same level with respect to an element in a higher immediate level using the famous Saaty fundamental 9-point scale (Saaty, 1980). Priority vectors (w) are obtained from the pairwise comparison matrix (A) by solving an eigenvalue problem in the following relation:

$$\mathrm{Aw} = \lambda_{\max}\mathrm{w} \tag{1}$$

where $\lambda_{\max}$ is the maximum eigenvalue of the positive reciprocal square matrix (A). When decision-making in the pairwise comparisons matrix is consistent $\lambda_{\max} = \mathrm{n}$; otherwise, $\lambda_{\max} > \mathrm{n}$ where n is the number of elements being compared. The Consistency Index (CI), as a measure of degree of consistency, is calculated using the formula

$$\mathrm{CI} = \frac{\lambda_{\max} - \mathrm{n}}{\mathrm{n} - 1} \tag{2}$$


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The consistency ratio (CR) is computed as

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{3}$$

where RI is the mean random consistency index. It is suggested that a $\mathrm{CR} \leq 0.10$ be obtained; otherwise, decision-makers are asked to revise the pairwise comparisons matrix. Synthesizing priorities across the hierarchy is done using the distributive mode of the AHP which can be represented in the form:

$$w_j = \sum_{i=1}^{n} c_i x_{ij} \tag{4}$$

where $w_j$ is the global weight of alternative j, $c_i$ is the weight of criteria i with respect to the goal, and $x_{ij}$ is the local weight of alternative j with respect to criteria i. This produces a global priority vector of alternatives. See Saaty (1980) for the comprehensive discussion of the AHP.

**2.2 Proposed Model**

In general, the procedure of selecting SM initiatives using AHP is as follows:

1. Adopt the hierarchical evaluation structure described by Joung et al. (2013) which later became the standard SM indicators used by US NIST. The structure and its details can be accessed through the sustainable manufacturing indicators repository (SMIR) website (SMIR, 2011). It is composed of three levels which are (from top to bottom) the SM dimension component, the criteria component and the sub-criteria component. The application of this structure and its formation into an evaluation framework comprises the general hierarchical evaluation framework adopted in this study as shown in Figure 1.


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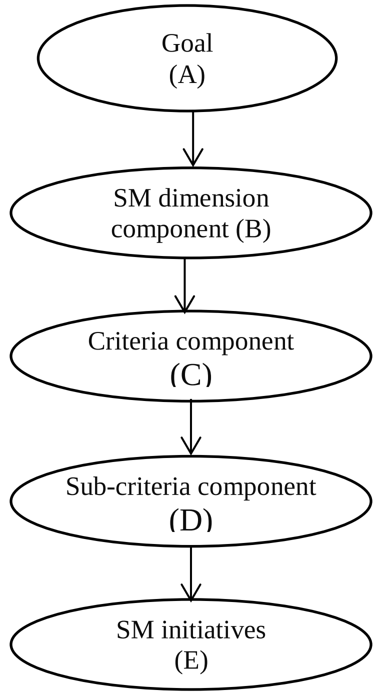


Figure 1. General hierarchical evaluation framework

2. Elicit pairwise comparisons based on the framework developed in step 1 using Saaty's fundamental scale. In eliciting pairwise comparison, generally we ask this question: "Given a parent element and given a pair of elements, how much more does a given member of the pair dominate the other member of the pair with respect to a parent element?" (Promentilla et al., 2006). This forms a positive reciprocal pairwise comparisons matrix. Local priority vectors are computed using Equation 1. Consistency is checked using Equations 2 and 3. Note that it is suggested that C.R. be less than 0.10 (Saaty, 1980).

3. After obtaining all local priority vectors, a judgment is synthesized using Equation 4 to obtain global priorities of alternatives. Note that this vector is used to rank alternatives with their degree of impact or contribution to the goal.

## 3. Case Study

An actual case study was carried out from the work published by Ocampo and Clark (2014). The case study focused on identifying SM initiatives of a semiconductor manufacturing firm in the Philippines. FC Semiconductor is a multi-national firm which is one of the prime players in the semiconductor industry (Ocampo and Clark, 2014). FC has sites strategically located around the world with manufacturing sites mostly located in developing countries such as the Philippines. As part of corporate directives, FC is committed to adopting sustainability practices in decision-making especially on critical areas in its manufacturing sites in Asia. Despite being a key manufacturing industry in technological advancement, the semiconductor industry has serious sustainability issues


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which have been brought about by the unprecedented growth of natural resource consumption as inputs to production, a large number of new chemicals introduced annually, and the health and safety concerns related to the use of these chemicals (Ocampo and Clark, 2014). FC's Cebu, Philippines manufacturing site strives to address these issues and conform to the corporate drive toward sustainability by complying with international standards such as the directive of the European Union on the Restricted use of Hazardous Substances (RoHS), and the Waste Electrical and Electronic Equipment Directive (WEE Directive), and with international certifications such as the ISO 9000, ISO 14000 and ISO 18000 series. Furthermore, the site has developed initiatives that promote sustainability, the details of which can be found in the work of Ocampo and Clark (2014).

In this paper, we evaluated SM initiatives of FC Semiconductor with their degree of relevance to sustainability using the hierarchical framework of Joung et al. (2013). Five SM initiatives were presented for evaluation: health and wellness programs (E1), competitive employee compensation and career development (E2), sound occupational health and safety program (E3), elimination of lead (Pb) in the plating process (E4) and lean six sigma programs (E5). Details of each initiative are found in the work of Ocampo and Clark (2014). Table 1, obtained from the work of Joung et al (2013), shows the decision components with their corresponding codes, and Figure 2 presents the operational framework of this case study. The coding system for this study assigned alphabetical letters to each level of the hierarchical framework and numbers were assigned to the arrangement of elements in each level. This is consistent with the coding system adopted by Ocampo and Clark (2015) except for the SM initiatives component. The goal is coded as A; SM dimensions are coded as B; criteria components are coded as C; sub-criteria components are coded as D; and lastly, SM initiatives are coded as E. For instance, employee health and safety, a sub-criterion, is coded as D25.


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Table 1
Decision components and their codes

| Decision components and elements | Code | Decision components and elements | Code | Decision components and elements | Code |
|---|---|---|---|---|---|
| Evaluation of sustainable manufacturing initiatives | A | Acidification substance | D5 | End-of-service-life product handling | D22 |
| Environmental stewardship | B1 | Effluent | D6 | Research and development | D23 |
| Economic growth | B2 | Air emissions | D7 | Community development | D24 |
| Social well-being | B3 | Solid waste emissions | D8 | Employees health and safety | D25 |
| Pollution | C1 | Waste energy emissions | D9 | Employees career development | D26 |
| Emissions | C2 | Water consumption | D10 | Employee satisfaction | D27 |
| Resource consumption | C3 | Material consumption | D11 | Health and safety impacts from manufacturing and product use | D28 |
| Natural habitat conservation | C4 | Energy/electrical consumption | D12 | Customer satisfaction from operations and products | D29 |
| Profit | C5 | Land use | D13 | Inclusion of specific rights to customer | D30 |
| Cost | C6 | Biodiversity management | D14 | Product responsibility | D31 |
| Investment | C7 | Natural habitat quality | D15 | Justice/equity | D32 |
| Employee | C8 | Habitat management | D16 | Community development programs | D33 |
| Customer | C9 | Revenue | D17 | Health and wellness program | E1 |
| Community | C10 | Profit | D18 | Competitive employee compensation and career development | E2 |
| Toxic substance | D1 | Materials acquisition | D19 | Sound occupational health and safety | E3 |
| Greenhouse gas emissions | D2 | Production | D20 | Elimination of lead in plating process | E4 |
| Ozone depletion gas emissions | D3 | Product transfer to customer | D21 | Lean six sigma programs | E5 |
| Noise | D4 | | | | |

The operational framework in Figure 2 shows how this selection process implements the inputs obtained from the US NIST SM indicators repository, from the work of Ocampo and Clark (2014) on SM initiatives in union with the AHP. A detailed form of the hierarchy is shown in Figure 3. A group of experts composed of four sustainability researchers, two manufacturing managers from the case firm, and three consultants were invited to a focus group discussion (FGD) in order to elicit judgments through pairwise comparisons. These groups of experts were selected to promote a balance between conceptual and applicable approaches for the case firm. Sustainability researchers and consultants were able to provide comprehensive knowledge on the current state of sustainability manufacturing initiatives both locally and globally. On the other hand, manufacturing managers from the case firm provided information on the firm's internal configurations that were applicable. Although these groups have different perspectives, these differences were not investigated in this work. Selection of domain experts was based on their involvement in manufacturing industries with a threshold set of at least 10 years managerial experience. This qualification ensured that they had the capacity and previous knowledge in carrying out vital manufacturing decisions. These managers have sufficient background in sustainability which includes technical knowledge in quality, environmental and social responsibility management systems. These individuals were made known to the researchers through peer referrals or respected scholars and practitioners in the field. The expert group was informed of the purpose of the group


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discussion in advance, and their role in eliciting judgments. The FGD required the group to come up with a consensus judgment for each pairwise comparison, thus the use of group aggregation approaches in the framework of the AHP was not applicable. The results of the pairwise comparisons are presented in the next section.

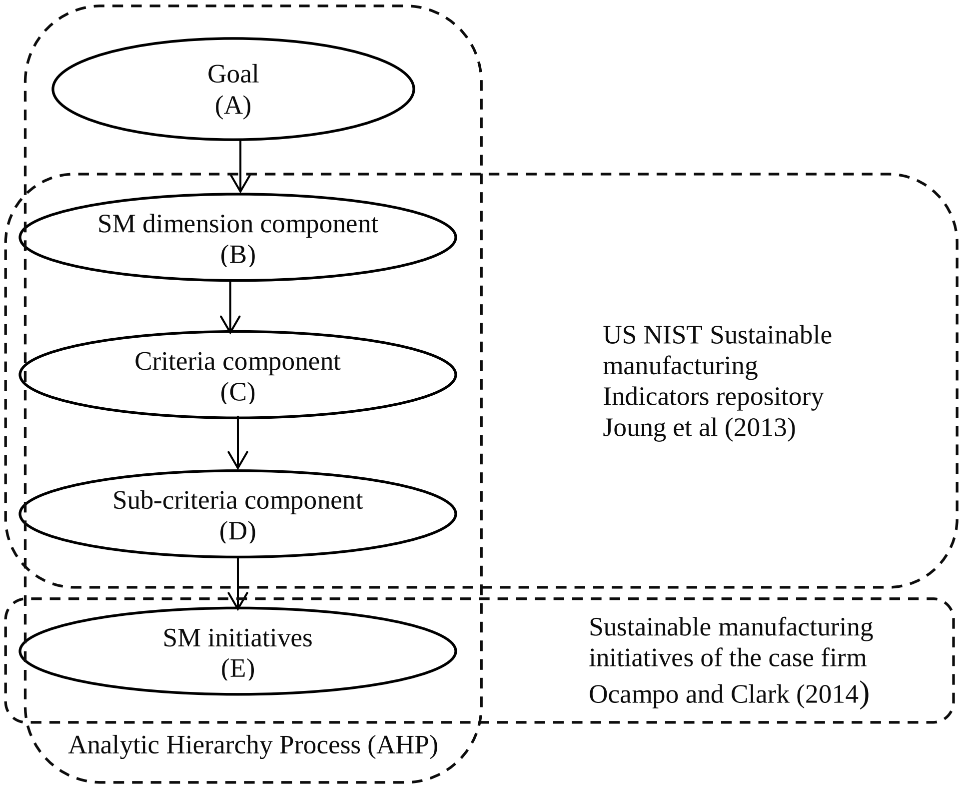


Figure 2. Operational framework of the case study


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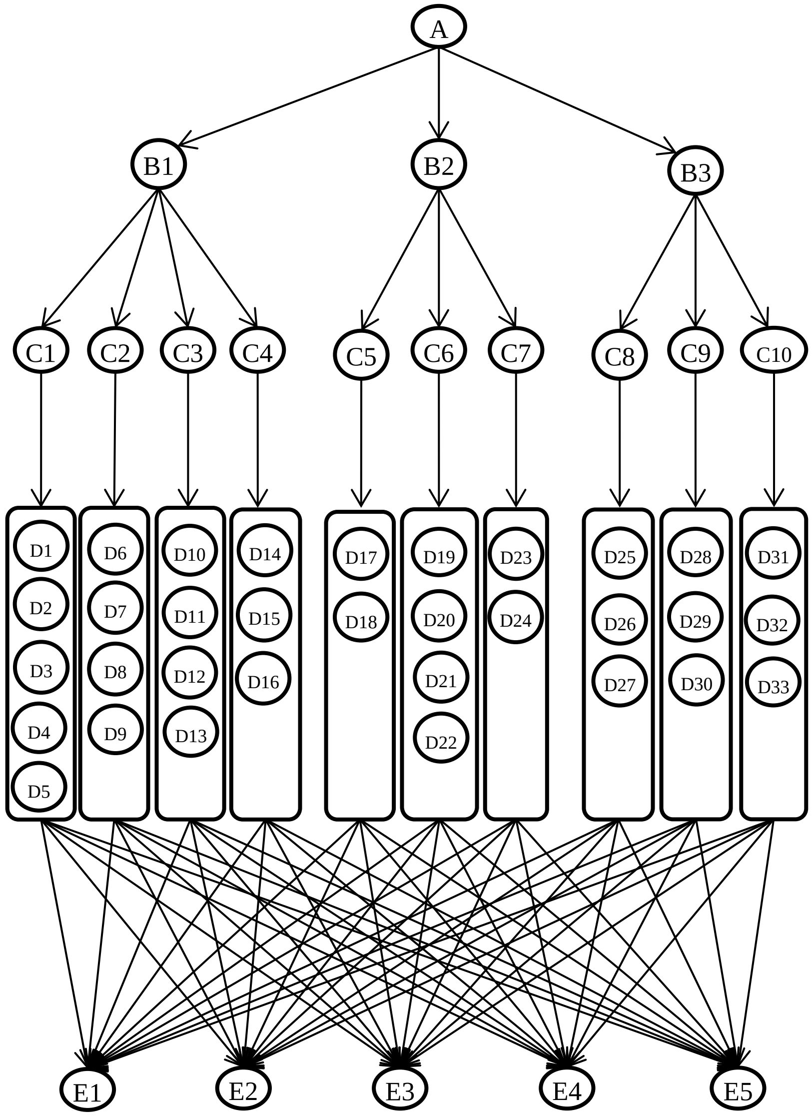


Figure 3. Decision problem of the evaluation of SM initiatives

## 4. Results and discussion

Based on Figure 3, there are four types of pairwise comparisons in this study. The first type describes pairwise comparisons of elements of the SM dimensions component with respect to the goal. The second type describes pairwise comparisons of the elements in the criteria component with respect to their parent SM dimension element. The third type refers to the pairwise comparisons of the elements in the sub-criteria component with respect to their parent criterion. Lastly, the fourth type of pairwise comparisons describes comparing pairwise the SM initiative with respect to each sub-criterion. A total of 47 pairwise comparisons were required in this study.


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We could not present all 47 pairwise comparisons in this paper due to the large amount of space that would be required to do so. Readers may request the full set of tables from the corresponding author. Nevertheless, we provide sample pairwise comparison matrices in the following discussions. A sample pairwise comparison of the first type which is comparing SM dimensions on their degree of impact to sustainability is shown in Table 2. The question being asked in Table 2 is this: "Comparing environmental stewardship (B1) and economic growth (B2), which one more dominates the goal (G) and by how much?" The resulting priority vector, the maximum eigenvalue ($\lambda_{\max}$) and the consistency ratio (C.R.) are shown in Table 2. Table 3 shows a sample of the pairwise comparisons of the second type. The question being asked in Table 3 is this: "Comparing pollution (C1) and emissions (C2), which one more dominates environmental stewardship (B1), and by how much?" Table 4 shows a sample of the pairwise comparisons of the third type. The question being asked in Table 4 is this: "Comparing toxic substance (D1) and greenhouse gas emissions (D2), which one more dominates pollution (C1), and by how much?" Finally, Table 5 shows a sample of pairwise comparisons of comparing SM initiatives with respect to each sub-criterion. The question being asked in Table 5 is this: "Comparing health and wellness programs (E1) and competitive employee compensation and career development (E2), which one more dominates employee health and safety (D25), and by how much?". The following tables present the local priority vectors of each pairwise comparisons matrix with their corresponding maximum eigenvalues and consistency ratio (C.R.). C.R. values range from 0.0 to 0.0732 which satisfy the 0.10 threshold of Saaty (1980).

Table 2
Comparing environmental stewardship (B1) and economic growth (B2), which one more dominates the goal (G) and by how much?

| A | B1 | B2 | B3 | Local priority vector |
|---|---|---|---|---|
| B1 | 1 | 1/2 | 1/2 | 0.200 |
| B2 | 2 | 1 | 1 | 0.400 |
| B3 | 2 | 1 | 1 | 0.400 |

$\lambda_{\max} = 3, \mathrm{C.R.} = 0.0$

Table 3
Comparing pollution (C1) and emissions (C2), which one more dominates environmental stewardship (B1), and by how much?

| B1 | C1 | C2 | C3 | C4 | Local priority vector |
|---|---|---|---|---|---|
| C1 | 1 | 1 | 3 | 2 | 0.351 |
| C2 | 1 | 1 | 3 | 2 | 0.351 |
| C3 | 1/3 | 1/3 | 1 | 2 | 0.161 |
| C4 | 1/2 | 1/2 | 1/2 | 1 | 0.137 |

$\lambda_{\max} = 4.155, \mathrm{C.R.} = 0.058$


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Table 4
Comparing toxic substance (D1) and greenhouse gas emissions (D2), which one more dominates pollution (C1), and by how much?

| C1 | D1 | D2 | D3 | D4 | D5 | Local priority vector |
|---|---|---|---|---|---|---|
| D1 | 1 | 1 | 3 | 5 | 3 | 0.348 |
| D2 | 1 | 1 | 3 | 5 | 3 | 0.348 |
| D3 | 1/3 | 1/3 | 1 | 2 | 1 | 0.120 |
| D4 | 1/5 | 1/5 | 1/2 | 1 | 1/2 | 0.065 |
| D5 | 1/3 | 1/3 | 1 | 2 | 1 | 0.120 |

$\lambda_{\max} = 5.005, \mathrm{C.R.} = 0.001$

Table 5
Comparing health and wellness program (E1) and competitive employee compensation and career development (E2), which one more dominates employee health and safety (D25), and by how much?

| D25 | E1 | E2 | E3 | E4 | E5 | Local priority vector |
|---|---|---|---|---|---|---|
| E1 | 1 | 4 | 1 | 2 | 6 | 0.342 |
| E2 | 1/4 | 1 | 1/4 | 1/3 | 3 | 0.084 |
| E3 | 1 | 4 | 1 | 2 | 6 | 0.342 |
| E4 | 1/2 | 3 | 1/2 | 1 | 5 | 0.182 |
| E5 | 1/6 | 1/3 | 1/6 | 1/5 | 1 | 0.050 |

$\lambda_{\max} = 5.091, \mathrm{C.R.} = 0.021$

Table 6 shows all the priority vectors of SM initiatives with respect to each sub-criterion. Such vectors are obtained from the last type of pairwise comparisons process. Table 7, on the other hand, presents the normalized priority vectors of the elements in the sub-criterion component. This normalization process follows the distributive mode of the AHP. The sum of all these weights is equal to unity.


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Table 6
Priority vectors of SM initiatives

| | D1 | D2 | D3 | D4 | D5 | D6 | D7 | D8 | D9 | D10 | D11 | D12 | D13 | D14 | D15 | D16 | D17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E1 | 0.251 | 0.170 | 0.198 | 0.201 | 0.263 | 0.151 | 0.146 | 0.125 | 0.125 | 0.112 | 0.112 | 0.125 | 0.167 | 0.143 | 0.143 | 0.143 | 0.119 |
| E2 | 0.074 | 0.084 | 0.082 | 0.067 | 0.079 | 0.070 | 0.075 | 0.125 | 0.125 | 0.112 | 0.112 | 0.125 | 0.167 | 0.143 | 0.143 | 0.143 | 0.119 |
| E3 | 0.153 | 0.116 | 0.116 | 0.512 | 0.114 | 0.108 | 0.103 | 0.125 | 0.125 | 0.112 | 0.112 | 0.224 | 0.167 | 0.143 | 0.143 | 0.143 | 0.191 |
| E4 | 0.448 | 0.566 | 0.541 | 0.090 | 0.465 | 0.607 | 0.602 | 0.500 | 0.224 | 0.480 | 0.185 | 0.125 | 0.333 | 0.429 | 0.429 | 0.429 | 0.080 |
| E5 | 0.074 | 0.064 | 0.063 | 0.130 | 0.079 | 0.064 | 0.075 | 0.125 | 0.401 | 0.185 | 0.480 | 0.401 | 0.167 | 0.143 | 0.143 | 0.143 | 0.492 |

| | D18 | D19 | D20 | D21 | D22 | D23 | D24 | D25 | D26 | D27 | D28 | D29 | D30 | D31 | D32 | D33 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E1 | 0.060 | 0.125 | 0.075 | 0.167 | 0.200 | 0.086 | 0.338 | 0.342 | 0.134 | 0.134 | 0.143 | 0.125 | 0.167 | 0.125 | 0.200 | 0.250 |
| E2 | 0.076 | 0.125 | 0.075 | 0.167 | 0.200 | 0.086 | 0.338 | 0.084 | 0.414 | 0.414 | 0.143 | 0.125 | 0.167 | 0.125 | 0.200 | 0.250 |
| E3 | 0.179 | 0.125 | 0.213 | 0.167 | 0.200 | 0.127 | 0.181 | 0.342 | 0.134 | 0.134 | 0.143 | 0.125 | 0.167 | 0.125 | 0.200 | 0.250 |
| E4 | 0.137 | 0.224 | 0.104 | 0.167 | 0.200 | 0.504 | 0.082 | 0.182 | 0.086 | 0.086 | 0.429 | 0.224 | 0.167 | 0.401 | 0.200 | 0.125 |
| E5 | 0.549 | 0.401 | 0.534 | 0.333 | 0.200 | 0.198 | 0.061 | 0.050 | 0.232 | 0.232 | 0.143 | 0.401 | 0.333 | 0.224 | 0.200 | 0.125 |


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Table 7
Normalized priority vectors of sub-criteria elements

| Sub-criterion | Normalized vector | Sub-criterion | Normalized vector |
|---|---|---|---|
| D1 | 0.024 | D18 | 0.080 |
| D2 | 0.024 | D19 | 0.053 |
| D3 | 0.008 | D20 | 0.053 |
| D4 | 0.005 | D21 | 0.027 |
| D5 | 0.008 | D22 | 0.027 |
| D6 | 0.016 | D23 | 0.027 |
| D7 | 0.032 | D24 | 0.053 |
| D8 | 0.016 | D25 | 0.060 |
| D9 | 0.005 | D26 | 0.020 |
| D10 | 0.009 | D27 | 0.020 |
| D11 | 0.003 | D28 | 0.040 |
| D12 | 0.009 | D29 | 0.080 |
| D13 | 0.009 | D30 | 0.080 |
| D14 | 0.016 | D31 | 0.033 |
| D15 | 0.008 | D32 | 0.033 |
| D16 | 0.008 | D33 | 0.033 |
| D17 | 0.080 | | |

Multiplying Tables 6 and Table 7 in matrix form, the product is the global priority vector or final weights of the SM initiatives. This process is described in Equation 4. Technically, through matrix multiplication, the contributions of a particular SM initiative for all sub-criteria are added up and the sum is thus the global weight of that initiative. Results are reflected in Table 8.

Table 8
Ranking of SM initiative

| SM initiative | Global priority vector |
|---|---|
| E5 | 0.276 |
| E4 | 0.243 |
| E3 | 0.172 |
| E1 | 0.162 |
| E2 | 0.146 |

Final ranking of SM initiatives shows that lean six sigma programs initiative ranks first followed by elimination of lead in the plating process, sound occupational health and safety, health and wellness programs and competitive employee compensation and career development. These results could provide substantial insights to decision-makers and sustainability researchers. First, the dominant priority of lean six sigma programs could be explained in two ways. Although the current discussions on sustainability are motivated toward socio-environmental well-being, one cannot deny that at the firm level, the basic premise is the existence of the firm into the future. Thus, firms create initiatives in an attempt to promote financial stability along with stiff market competition. In that sense, firms seldom promote relevant environmental and social drives if the financial base of the firm is weak. Furthermore, growing discussions in the current literature also argue that these environmental and social programs may require a relatively high investment in the short-run and quantifying the return on such investments has not been well established (Ageron et al., 2012; Law and Gunasekaran, 2012). Therefore, the requisite of a firm being economically stable must be satisfied first before moving on to other significant environmental and social initiatives. Second, central also to current research, is the exploration of positive relationships of lean manufacturing strategies on environmental programs such as cleaner production. Next, while lean manufacturing is widely known to enhance market and financial performance, it also improves environmental practices (Yang et al., 2011) because manufacturing organizations advocating lean manufacturing have the established infrastructures for identifying and eliminating wastes (Bergmiller and McCright, 2009). Lastly, sound occupational health and safety, health and wellness programs and competitive employee compensation and career development initiatives are part of firms' social responsibility to their employees and to the immediate community as well. Aside from being part of the social responsibility of firms, maintaining the health and safety of a workforce and creating programs that enhance job security and career development are fundamental to strengthening the human resource base of an organization which is essential to achieving corporate goals (Zhang and Liu, 2011).

## 5. Conclusion

Evaluating sustainable manufacturing initiatives of manufacturing firms is an essential step in assisting decision-makers in identification of priority initiatives that have a higher degree of impact on sustainability. This will eventually result in the efficient allocation of a firm's resources and faster advancement of a firm to the demands of sustainability. This kind of an evaluation is a challenge due to the number of criteria that must be considered, notwithstanding the subjectivity and difficulty of measurement on these criteria. This problem is addressed in the current literature through MCDM methods of which AHP is a popular one because of its simplicity and comprehensiveness in dealing with multi-level and multi-criteria decision problems involving intangibles. The framework which includes the number and depth of the evaluation process is also crucial in developing a comprehensive solution to the problem. Thus, this paper presents an evaluation framework of SM initiatives by using the hierarchical sustainability indicators structure of US NIST combined with the methodology of AHP. A case study is conducted in a semiconductor manufacturing firm in order to demonstrate the proposed framework. Results show that the lean six sigma programs have the largest priority followed by the elimination of lead in the plating process, sound occupational health and safety, health and wellness programs and competitive employee compensation and career development. These results are related in a way to show how firms can improve their investment allocations, relationships with customers and suppliers, and the pattern of technological


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development that the firm or the industry directs. This supports some claims which state that financial viability of the firm serves as the basis for further implementation of initiatives which may include environmental and social programs. Firms may resist these forms of investments if the financial base of the firm is weak and the competitiveness of the firm is not established or fully developed. Note that the results of this study may be representative only for large manufacturing firms, not small and medium-sized firms. Future theories and empirical studies for smaller firms must be undertaken to support this claim. Furthermore, this work assumes that the composition of the group is homogeneous, which may not be so in a general case. Investigating differences among group members could be an extension of this work. Nevertheless, this application of AHP advances our knowledge about selecting SM initiatives and has resulting implications in decision-making.

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