JJMIE

Volume 9 Number 3, June.2015
ISSN 1995-6665
Pages 177 - 186

Jordan Journal of Mechanical and Industrial Engineering

A Sustainable Manufacturing Strategy Decision Framework in the Context of Multi-Criteria Decision-Making

Lanndon Ocampo[a *], Eppie Clark[b]

[a] Department of Mechanical Engineering, University of San Carlos, Cebu City, 6000 Cebu, Philippines
[b] Department of Industrial Engineering, De La Salle University, 2401 Taft Avenue, 1004 Manila, Philippines

Received 13 March 2014 Accepted 3 June 2015

Abstract

The present paper proposes a sustainable manufacturing strategy decision framework that integrates classical manufacturing strategy and sustainable manufacturing. Former approaches in these two fields were not inclusive; thus, an integrative decision framework is necessary. Along with this integration, the inclusion of major issues directly associated with manufacturing sustainability, such as firm size, various interests of different stakeholders and strategic responses, becomes a highlight of the proposed framework. Using an appropriate approach, the framework could provide the content of a sustainable manufacturing strategy which is helpful for manufacturing decision-makers in promoting both competitiveness and sustainability. Hypotheses are developed from the proposed framework. A review of a possible methodological approach is shown with a strong emphasis on multi-criteria decision-making. A discussion of a future work, following the decision framework, is also presented. The contribution of the present work lies in the development of a comprehensive decision framework that attempts to integrate a manufacturing strategy and a sustainable manufacturing.

Keywords: *Manufacturing Strategy, Sustainable Manufacturing, Framework, Firm Size, Stakeholders, Strategic Responses*.

1. Introduction

The work of Wickham Skinner in 1969 on Manufacturing Strategy (MS) is considered foundational in its field. Hayes and Wheelwright [1], building on Skinner, defined MS as a consistent pattern of decision-making in the manufacturing function that is directly linked to the business strategy. This link became more pronounced following Skinner's hierarchical top-down strategy framework which highlights the relationships of corporate, business and manufacturing strategies and, thus, indirectly providing the link of MS to corporate strategy. Skinner's [2] classical framework was remarkable as it, over a span of decades, became a guideline of later approaches in this field. It was agreed by domain scholars and practitioners that MS does not only support business strategy but also translates the strengths and resources of the firm into opportunities in the market [3]. This highlights both the internal and external functions of MS to the manufacturing firm.

Wheelwright [4] emphasized that MS supports business strategy only if a sequence of decisions over structural and infrastructural categories is consistent over long-term planning horizons. Structural decisions, i.e., process technology, facilities, capacity and vertical integration, enable long-term impacts to the firm and they require a huge amount of investments. Infrastructural decisions, i.e., organization, manufacturing planning and control, quality, new product introduction and human resources, on the other hand, are strategic and they require relatively less investment but they are perhaps difficult to subject changes when in place. When the policies over these decision categories are consistent, MS develops a set of manufacturing capabilities or competitiveness determined by the business strategy. This set of competitive priorities is a convergence of both corporate strategy and the position – market or technology-leader – it intends to contest with its competitors. Theories of MS have been established and tested over decades of research and application in this field. Despite the advancements in the manufacturing strategy as a field of study, issues of sustainability have inadequately been studied in the current literature. The struggle of manufacturing firms for competitiveness is insufficient to sustain the manufacturing industry from the perspectives of resource depletion, carbon emissions, human toxicities, land use and environmental degradation. The earlier advances in this field should have been coupled with strategies that address sustainability, which requires a holistic and systems approach.

Due to the increasing concerns about environmental degradation, resource consumption and social equity, the notion of sustainable development has become a focal and

* Corresponding author. e-mail: don_leafriser@yahoo.com.

integral component in the decision-making of various legislative bodies, global economies and several economic sectors. Sustainable development, as defined in the famous report of the United Nations World Commission on Environment and Development (UNWCED) in 1987, is "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [5]. A review on how this philosophy came into prominence was detailed by Linnenluecke and Griffiths [6]. One important key to sustainability is the manufacturing sector [7] due to its high volume of resource consumption, increasing annual introduction of new products that relatively require a high amount and a generation of materials, energy and wastes, increasing volume of emissions throughout product life cycles and the collective effect of manufactured products and manufacturing processes to immediate stakeholders [8]. Manufacturing industry is now held responsible for the impact of their products and processes, including waste management and recycling [9]. This gives rise to a growing subfield in sustainability, i.e., sustainable manufacturing which has significantly drawn the attention of domain scholars over the past decade or so.

Sustainable Manufacturing (SM) drives the development of products and processes that simultaneously addresses environmental stewardship, economic growth and social well-being, widely known as the triple-bottom line [10]. With on-going concerns on climate change, destruction of the natural environment, increasing consumption of non-renewable resources, among others, the desire for a sustainable development has gained more attention today than in the past. One enabling and motivating factor to engage manufacturing firms toward sustainability is the presence of stakeholders' interests. Conversely, sustainability is achieved when the interests of different stakeholders, i.e., the government, customers, suppliers, community, competitors, shareholders, employees and consumers, are satisfied [11]. Stakeholders could offer valuable inputs and resources to help firms achieve sustainability. Satisfying stakeholders' interests along with the strategic activities of a manufacturing firm demanded by the manufacturing strategy stimulates the complexity of the decision-making over various decision areas; a relevant framework must be available to provide guidance for addressing this complex condition. This has not been addressed in current literature.

Following this complexity, manufacturing firms are confronted with issues of developing MS, on one hand, and addressing SM, on the other. Recent frameworks provide limited information on how to integrate these two issues. The framework of Hallgren and Olhager [12] provides a quantitative approach for developing MS taking into account the decision categories, manufacturing objectives, market requirements and a recursive guide in improving these components in bridging the gap between the market requirements and the manufacturing objectives. However, Hallgren and Olhager's [12] approach failed to clearly address the issues associated with the sustainability of manufacturing. The conceptual frameworks of Azapagic [13], Reich-Weiser *et al.* [14] and Subic *et al.* [15] on manufacturing sustainability are disintegrated with the competitiveness agenda of the manufacturing function and were merely referenced from the TBL perspective. With emphasis on integration, the work of Johansson and Winroth [16], which explored the impact of stakeholders' concerns for the environment to the MS formulation process, provides a promising starting point of discussion. Their model incorporates the relationships among the decision categories and the competitive priorities described by the works of Wheelwright [3], Hayes and Pisano [17] and Hallgren and Olhager [12] and the stakeholders' interests described in sustainability literature. They emphasized that incorporating environmental issues alters the policy areas of all decision categories and requires an environmental performance as a competitive strategy.

Despite this attempt, the work of Johansson and Winroth [16] fails to consider a number of significant areas. First, the framework considers environmental and economic sustainability only, with no clear guidelines for the specific interests of stakeholders that address the TBL. Second, it does not consider the strategic orientation or responses of manufacturing firms to sustainability [18]. As strategic orientation varies from one firm to another, the strategy to achieve SM also varies. For instance, a compliance-oriented response would be different from market-oriented response as the former is geared towards superficially complying with the minimum requirements set forth by the stakeholders while the latter is geared on setting sustainability as means to attract more interests from the market. Third, the emerging literature in the field of sustainability identified the firm size as a relevant component in decision-making as sustainability approaches require, relatively, high investment [19-20] and a shortage of resources, such as time, manpower and money characterize small and medium enterprises [21]. Lastly, the framework does not consider various interrelationships of corporate, business and MS as these constitute a more cohesive framework. Thus, an integrative framework is required to serve as a guide for developing a SMS.

The major concern of the present paper is the holistic integration of the competitiveness perspectives of manufacturing strategy and the issues associated with sustainability. This has not been addressed in current literature to a plausible level of details. The present work attempts to link together in a single framework the demands of manufacturing strategy and sustainability, so that the resulting decisions at firm level can address these two issues. This paper aims to propose an integrated decision framework in the development of a sustainable manufacturing strategy. This framework attempts to integrate two seemingly independent theories of MS and SM. The objective of the present work is to develop the content of MS which bases itself on sustainability, incorporating significant issues associated in it such as firm size, firm's competitive strategy, and the firm's strategic responses along with the persuading role of different stakeholders' interests. The framework intends to develop quantitative models that are able to address such conditions. The contribution of the present work is two-fold: (1) the development of a sustainable manufacturing strategy (SMS) that integrates MS and SM, and (2) the development of a framework used to guide decision-makers in SMS with relevant issues such as firm size, competitive priority, strategic response and stakeholders' sustainability interests.

The remainder of the present work is provided as follows: Section 2 elaborates a literature review on firm size, interests of stakeholders and strategic responses. A holistic decision framework is presented in Section 3. Section 4 highlights the hypotheses from the proposed framework and a discussion of the possible solution approaches. Finally, Section 5 presents a conclusion and future work.

2. Relevant Issues in Sustainable Manufacturing Strategy (SMS)

This section attempts to establish the major issues associated with the sustainability of manufacturing firms. These are firm size, stakeholders' interests and strategic responses.

2.1. Firm Size

This review focuses primarily on how firms respond to sustainability issues in relation to their sizes. The arguments of Ageron *et al.* [19] and Law and Gunasekaran [21] rely on the idea that the firm size promotes differences on the responses of firms on the basis that the sustainability approaches require a relatively high amount of investment and as the firm size shrinks, time, human and financial resources are limited in SMEs [21]. This central idea is widely shared in literature [22-23].

Traditional discussion on this domain is centered on the size-innovation relationship of firms [24-25] and later evolves into size-eco-innovation issues [26-28] as the result of the continuous effort in addressing the sustainability concerns. There are opposing stances regarding the firm size and innovation. Symeonidis [24] contends that innovation increases with the firm size proportionately. However, Laforet [25] argues that the organizational innovation has relatively greater impacts on small firms as it is positively associated with small firm's profit margin, competitiveness, market leadership and the improvement of the design of products and processes. Laforet [25] also claims that smaller firms yield more cost-efficient in innovation and they are also more innovative and adaptable and have quicker response times to implement new technologies and to meet specific customer needs. This discussion on firm size-innovation relationship has been extended to challenge the link of firm size to sustainability issues such as eco-innovation [27], corporate social responsibility [29-30], small business social responsibility [22], corporate giving [31] and employment share distribution [32]. Bos-Brouwers [26] emphasized that companies with a sustainability in their orientation and innovation processes create value by introducing new products to the market and by a close cooperation with different stakeholders. Explicitly, Schrettle *et al.* [33] reported that the firm size is a crucial factor in linking sustainability drivers to strategic decisions of manufacturing firms. They found out that the firm size moderates the differences in the level of the sustainability efforts a firm undertakes. The firm size curbs the relationship between the drivers of sustainability and the sustainability efforts as large firms can engage in sufficiently a large number of sustainability programs over longer duration of time. These works establish a common argument that the firm size plays a significant role in forging the sustainability of manufacturing firms.

Various studies explored the differences between different firm sizes based on their capability to respond to sustainability issues and related domains. Bourlakis *et al.* [34] observed the relationship between firm size and sustainable performance in food supply chains in Greece. Bronchain [29] discussed the role of firm size on Corporate Social Responsibility (CSR) and pointed out that the firm size increases the capability to act on CSR initiatives. Howard and Jaffee [35] elaborated the tensions between the firm size and the sustainability goals, taking a rigorous look not just at the resources of firms as an impediment to sustainability but also at the ethical stances each firm size has on addressing sustainability issues. As a counterpart of CSR on SMEs, Lepoutre and Heene [22] provided a critical review of the impact of the firm size on Small Business Social Responsibility (SBSR). Their findings suggest that small business would likely experience more difficulties in engaging "socially responsible action" than larger counterparts. Similarly, Amato and Amato [31] examined the effects of firm size on corporate giving and found out that charitable giving rises with firm size up to a certain threshold and falls in medium-sized firms and rises up again at the upper end of large firm distribution. This implies that small and "upper end" large firms contribute to social programs on ethical stances as opposed to "brand image view" of other firm sizes. Nisim and Benjamin [36], on the other hand, discussed the public visibility as one of the key differences of firm sizes. This means that unlike large firms with high public exposure, CSR and sustainability related activities of SMEs tend to be out of sight from the public.

While previous studies established relationships between firm sizes and sustainability agenda and their differences, however, there is a significant gap in identifying the content of an MS that conforms to sustainability in relation to firm size. Such gap advances the link of firm size and sustainability by following a careful identification of strategy content. However, the current literature provides a limited help in critically evaluating the content of an MS for SMEs and large firms. This provides a possible direction to managers and policy-makers as decision support in critical and complex decision areas in manufacturing.

2.2. Stakeholders' Interests

The classical model of Skinner [2] and Wheelwright [3] on MS was mostly motivated by market requirements and behavior. As a result of buying experiences, dynamic needs, etc., the market creates a priority set of the four widely accepted competitive priorities, namely cost, quality, dependability and flexibility [1, 4, 17, 37]. This prioritization process of the market motivates the priority set of competitive priorities of a business unit which in turn directs the manufacturing function accordingly. This network of influences from the market to the business unit and to the manufacturing function and back to the business unit and market seems to function only when the market is solely the focal point of interest. However, this network could not cope with the conditions that demand simultaneous considerations of several stakeholders. The best example of these conditions is the demand of sustainability. Thus, an update of this network becomes necessary for addressing the complex interests of several stakeholders.

Recent studies have placed a great emphasis on the role of stakeholders in forging sustainability of manufacturing organizations [11, 16, 39-40]. Pham and Thomas [40] argue that traditional organizations tend to focus only on a handful, limited number of stakeholders with a special attention to shareholders, such as board of directors and investors. Griffiths and Petrick [39] contend that such an approach fails to develop stakeholder integration for firms. A widely accepted notion is that when stakeholders are managed well, they are capable of offering invaluable assistance and resources beyond simply exerting pressures on firms [41]. For instance, customers can possibly exert pressure on suppliers to establish corporate social responsibility practices either as a precondition for tendering to supply or as a complementary variable in their considerations of different suppliers [42]. On the other hand, employees can provide recommendations for advancing the firm's responsibility for the community by pointing out inputs related to the current socio-economic conditions of the local community. Suppliers play a critical role in providing insights which are associated with technology, materials and processes that could be helpful in strengthening firm's environmental efforts [43]. Harrison *et al.* [44] claim that manufacturing firms are likely to build trusting relations across several stakeholders when the firms include them in their key decision-making processes. With stronger relations with stakeholders, necessary insights for deciding how to allocate limited resources towards efforts that satisfy stakeholders could be certainly gained.

A growing body of literature claims that stakeholders play a significant role in the firm's sustainability efforts [42, 45]. Aside from exerting pressures on manufacturing firms, stakeholders could assist firms in deciding which environmental and social programs or initiatives to adopt because stakeholders have already established some forms of perspectives, experiences and resources vital in addressing sustainability issues. Creating programs that enhance close relations with employees and suppliers advances the capability of the firms in integrating the environmental aspects into key organizational processes. With the emerging issues on sustainability confronted by manufacturing firms, manufacturing organizations must proactively create value through investment in customers, suppliers, employees, processes, technology and innovation [40]. While these claims are significant, current studies are still leaning to a descriptive stance on the relationships between stakeholders and sustainability. Prescriptive approaches on how to evaluate strategies that address stakeholders along with the competitiveness agenda of MS are still lacking in current literature. These approaches are crucial in providing possible directions of manufacturing firms towards competitiveness and sustainability and at the same time serve as decision support tools for manufacturing decision-making.

2.3. Strategic Responses

The first work that attempts to group MS comprehensively was done by Sweeney [46]. The groupings were termed by Sweeney [46] as "generic manufacturing strategies" which include caretaker, marketeer, reorganizer and innovator strategies. Aside from this, Sweeney [46] also recognized transition routes from one strategy type to another strategy type. The idea was that manufacturing organizations tend to brand themselves into a particular stance on key decisions in developing MS. For instance, the environmental regulations being placed today by several institutional bodies eventually become a gauge in identifying the type of strategy manufacturing organizations engage. Some organizations become responsive to these regulations and take initiatives to further its responsibility for protecting the environment and the society. Others take a stance by merely complying with the minimum requirements being stipulated by a particular regulation. And, regretfully, some become irresponsive to these regulations.

In a similar argument, this discussion of generic manufacturing strategies was further refined by Miller and Roth [47]. Building upon this work, Frohlich and Dixon [48] supported the previous report on manufacturing taxonomies using different types of samples. However, with slight modifications, Frohlich and Dixon [48] identified three types of manufacturing strategies which are caretakers, marketeers and innovators. Aside from classifying MS types, Sweeney [46] provided this notion of transition paths or routes for firms to achieve the most positive form of strategy, which is an innovator strategy. This transition would guide firms to the manufacturing policies and competitive advantages they must place to support a particular route.

The discussion on this research domain became prominent following several works published in literature. Interestingly, there is a consistency in the types of strategic responses of manufacturing organizations as identified by the literature. With the influx of interests in sustainability, the former taxonomies were paralleled by the reactions or stances of firms toward the sustainability issues as described by the works of de Ron [49] and Heikkurinen and Bonnedahl [18]. Their works highlighted the three strategic responses that firms engage in embracing sustainability issues. These are stakeholder-oriented, market-oriented and sustainability-oriented. The proposed idea is that the concept of transition could similarly be applied to the transition of the strategic responses of manufacturing toward sustainability. This implies that firms are initially stakeholder-oriented and their policies are addressed at satisfying stakeholders' requirements. As they evolve around meeting these requirements, they transform their responses from stakeholder-orientation to market-orientation, developing strategies that extend stakeholder requirements into exploiting sustainability to create a competitive advantage. At this stage, firms view sustainability from a marketing perspective as a way to enhance market leadership in the industry. As firms enhance this, they evolve by achieving the sustainability-oriented stage wherein the goal extends from merely complying stakeholder requirements and attaining market leadership into a genuine care for the environment, the economy and the society. Despite these observations, the current literature fails to examine the impact of these strategic responses on developing a strategy that addresses sustainability and competitiveness.

3. Sustainable Manufacturing Strategy Decision Framework

Following the issues relevant to SMS, a proposed decision framework is presented in this section as shown in Figure 1. The framework consists of models that, by using appropriate methodology, are able to identify the content of SMS. The first decision model explores the impact of firm size on SMS development. This model consists of five decision components: goal, firm size, manufacturing decision categories, policy areas and policy options. The goal component comprises one single element which is the development of a SMS. Firm size has two elements: Small-Medium Enterprise (SME) and large firms. SMEs are those firms that have no more than 250 employees with annual sales of less than US$50 million [50]. Otherwise, firms are considered large firms. Manufacturing decision categories are those nine categories discussed in section 1. However, due to sustainability issues similar to those described by Johansson and Winroth [16] policy areas are revised to address these sustainability issues. Each policy area has policy options which constitute the SMS of the firm. These decision components are linked together in a decision network allowing interrelationships and interdependencies to take place. The model is expected to provide priorities of SMEs and large firms on their capability to develop SMS.

The second model explores the impact of competitive priority to SMS development. Unlike the former approach which considers only the market requirements as the main reference in attaching priorities in competitive dimensions, this model explores the integration of different stakeholders' interests as an influencing component to competitive priorities. This competitive priority set influences the kind of strategic response a firm would take in addressing sustainability. Then, the kind of strategic response a firm considers determines its SMS. The competitive priorities component consists of four elements: cost, quality, dependability and flexibility. The model is expected to provide priorities of each competitive priority in developing SMS. The significance of this model lies in its providing some guidelines on policy options when a specific competitive priority is chosen.

The third model is expected to draw some insights on the impact of strategic responses to manufacturing policy options. Developed from the previous two models, this model incorporates the hierarchical flow of strategy from a corporate strategy through strategic responses as described in the operational framework. A corporate strategy has one element which is the sustainability at a corporate level. The business strategy has two components: technology-oriented and market-oriented. MS has one element. Strategic responses have three elements: stakeholder-oriented, market-oriented and sustainability-oriented. The model is expected to provide priorities for each strategic response on the degree of its influence on developing an SMS. This model is significant as it provides guidelines to policy options for each strategic response.

Integrating the three models constitutes a quantitative unifying framework used to explore the integration of MS and SM fields in developing SMS.

4. Hypotheses and the Multi-Criteria Decision-Making Approach

Based on the proposed decision framework, the following hypotheses are set forth:

H1: Different firm sizes yield different configurations of sustainable manufacturing strategy.

H2: Manufacturing decision priority focus varies with different firm sizes.

H3: Government is the most influential stakeholder in developing a sustainable manufacturing strategy.

H4: Quality is the most important competitive priority in forging a sustainable manufacturing strategy.

H5: A technology-oriented business strategy enforces the development of a sustainable manufacturing strategy.

H6: A sustainability-oriented manufacturing strategy embodies a sustainable manufacturing strategy.

The integration of MS and SM in developing an SMS requires a decision framework that operates on manufacturing decision categories with components that share complex relationships. A Multi-Criteria Decision Analysis (MCDA) is relevant to this framework due to the following reasons: (1) the qualitative structure of the decision framework involving interests of different stakeholders, generic SM strategies, firm size, manufacturing capabilities, business and corporate strategies, (2) the complexity of decision components of the decision framework, (3) the interdependencies of the decision components, (4) uncertainty of the measurements of decision components, and (5) the inherent structure of assessment involving value judgments, assumptions and scenarios [51]. MCDA involves determining the overall preferences for several alternatives and choosing the best alternative subject to different criteria that may be tangible or intangible [52-53]. When the number of alternatives is finite, MCDA introduces Multi-Criteria Evaluation Methods (MCEM); otherwise, if it is infinite, it focuses on Multi-Criteria Design Methods (MCDM) [52]. MCEM has ELECTRE, ORESTE, PROMETHEE, Multi-Attribute Utility Theory (MAUT), AHP/ANP, regime method, convex cone approach, hierarchical interactive approach, fuzzy set theory and Bayesian analysis while MCDM has goal programming, data envelopment analysis, method of Geoffrion, Dyer and Feinberg, method of Zionts and Wallenius, reference point method, Pareto race, interactive weighted Tchebycheff procedure [52-53]. A survey of literature on MCDA applications implies that AHP/ANP and outranking methods are commonly used in industry-related applications [53].

Previous studies embarked on the use of MCDA methods in environmental or sustainability assessment. For instance, the widely-used AHP [54] is used in computing the product sustainability index [55], computing the sustainability index with time as an element [56], developing the sustainability index for a manufacturing enterprise [57], developing multi-actor multi-criteria approach in complex sustainability project evaluation [58], evaluating industrial competitiveness [59], evaluating energy sources [60], developing an AHP-based impact matrix and sustainability-cost benefit analysis [61] and developing a reverse logistics model [62]. This leaves AHP as the most prominent MCDA method in the sustainability assessment [63] especially in product and process design [54].

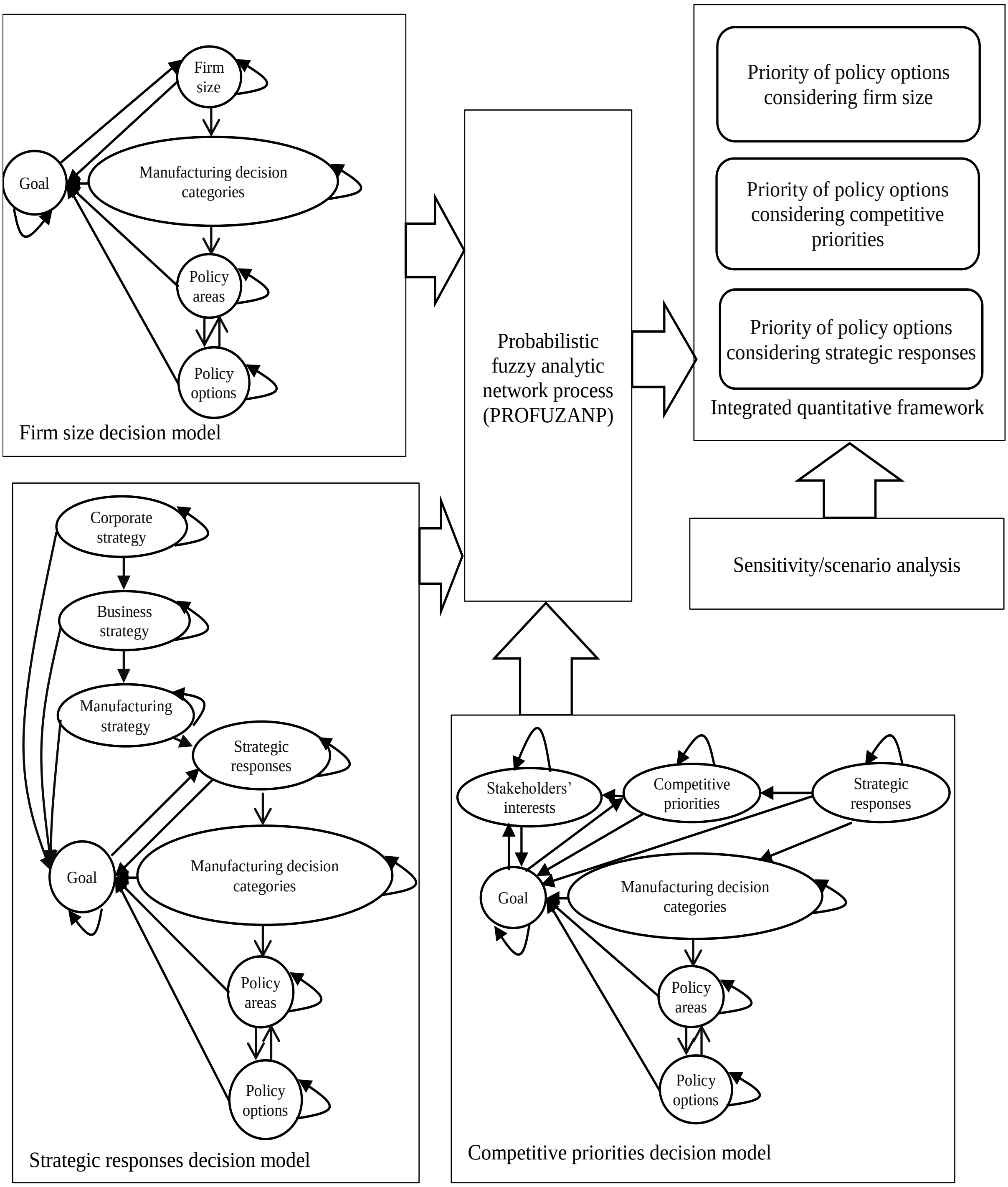

Figure 1. A sustainable manufacturing strategy decision framework

Some previous studies involving strategy selection and development used the MCDM methods. Barad and Gien [64] proposed a two-phased deployment process based on QFD and competitive priorities. Tsai and Chou [21] presented a hybrid approach combining DEMATEL, ANP and Zero-One Goal Programming (ZOGP) in the selection of management systems for phased implementation. Yu and Hu [65] proposed a fuzzy TOPSIS for evaluating the performance of manufacturing plants with productivity, production amount, production cost, inventory amount and quality cost as performance indicators for capability. Vinodh *et al.* [66] utilized fuzzy association rules mining used to evaluate the sustainability in the presence of attributes such as cost, market share performance, profitability, quality, toxicity, legislative factors, social cohesion, trade opportunities and flexibility. Vinodh and Girubha [67] proposed PROMETHEE based MCDM methodology in the selection of the best sustainable concept from the triple-bottom line wherein the sustainable concept is classified as material-oriented, product-oriented and manufacturing process-oriented. Al-Hawari *et al.* [68] applied AHP to select the best temperature measuring sensor for a certain industrial application. Dalalah *et al.* [69] explored AHP in crane selection for construction operations. Jajimoggala *et al.* [70] show the integration of AHP and TOPSIS for supplier selection problem under uncertainty. Chen *et al.* [71] explored a business strategy selection for green supply chain management using ANP. They agreed that AHP and ANP are appropriate analytical tools for addressing locations, programs or strategy selection problems. Zhou *et al.* [72] utilized mixed-integer programming and simulation models in the selection and evaluation of green production strategies. The model is able to provide trade-offs between green improvement and economic performance. With the same problem on the selection of Green Production (GP) strategies, Zhou *et al.* [73] proposed a hybrid approach of combining discrete-event simulation, multi-objective genetic algorithm to search for Pareto optimal values in the selection of GP strategies. Following these literatures, strategy development and selection fairly adopted MCDM methods particularly AHP/ANP.

For the proposed decision framework which is described in three different models, the hybrid methodological approach developed by Ocampo and Clark [74], as shown in Figure 2, especially for the conditions required to holistically address uncertainty in a group decision-making. A probabilistic fuzzy analytic network process is proposed by Ocampo and Clark [74], which is a hybrid approach that integrates Fuzzy Set Theory (FST), simulation and Analytic Network Process (ANP). The use of ANP is motivated from the complexity of the decision problems under consideration. It offers a flexible and viable approach in modelling the decision problem with various components and elements that are inherently connected in complex relationships. From a complex decision structure, ANP has the capability to measure the objective and the subjective elements of the decision problem based on a ratio-scale and then to synthesize them based on its supermatrix approach. Eventually, the ANP facilitates identification of the content of SMS which is the core problem of the present work.

A probabilistic fuzzy analytic network (PROFUZANP) approach is highly appropriate in the present work due to the following motivations:

1. the decision problem of developing SMS consists of several components with complex interrelationships
2. judgment elicitation must be done in linguistic variables to address uncertainty due to incomplete and imprecise information
3. the group of expert decision-makers could possibly be a quasi-collaborative group where the resulting group decision is also uncertain.

5. Conclusion

The present work expands the knowledge concerning: (1) the development of a sustainable manufacturing strategy and design of sustainability program based on consideration of both manufacturing strategy and sustainable manufacturing fields, and (2) the development of a framework used to guide decision-makers in sustainable manufacturing strategy development with relevant issues, such as firm size, competitive priority, strategic response and stakeholders' interests. Specifically, the interesting insights are: (1) the sustainable manufacturing strategy supports the competitive advantage of the firm, (2) the framework extends the traditionally market-perspective of strategy to a holistic approach which incorporates the interests of stakeholders to address sustainability, (3) stakeholders' interests are not independent but are allowed to interact with each other which happens in actual cases, (4) the framework explores the impact of firm size which other researchers failed to consider, (5) it also explores the impact of strategic responses of manufacturing on sustainability, (6) it also provides an opportunity to explore the relationship between the competitive strategies and decision areas, (7) the conceptual framework relates a sustainable manufacturing strategy to the best practices developed today. Several studies may be extended from this framework: (i) empirical studies using factor analysis or Structural Equation Modelling (SEM) could be conducted to test the validity of the proposed framework, (ii) development of a content sustainable manufacturing strategy using Multi-Criteria Decision Methods (MCDM) is seen as a fruitful work which creates a set of decisions on key manufacturing decision areas, (iii) optimization studies using multi-objective techniques of allocating firm's resources on the resulting manufacturing decisions, (iv) sequencing of firm's strategic decisions using artificial neural networks or meta-heuristic algorithms, and (v) identifying Key Performance Indicators (KPIs) of the sustainable manufacturing strategy.

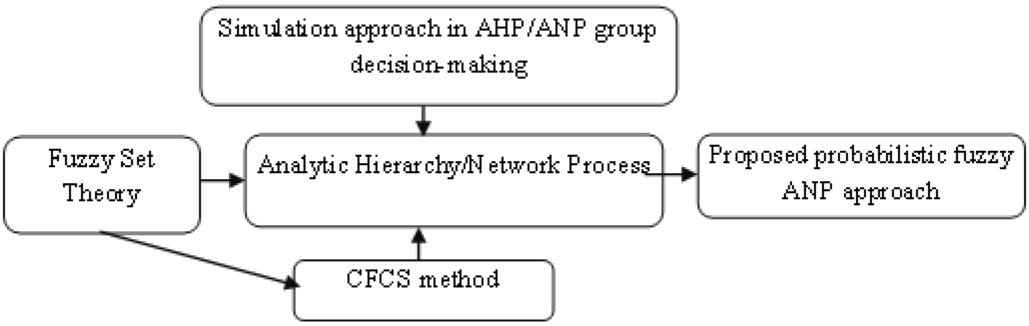

Figure 2. Proposed methodological framework (adopted from Ocampo and Clark [74])

6. Acknowledgement

The present work was part of the dissertation of L. Ocampo who expresses appreciation to the dissertation technical panel, especially to Dr. Anthony Chiu, Dr. Ma. Victoria Tibon, Dr. Michael Promentilla and Dr. Kathleen Aviso for the constructive comments on the proposed framework. The dissertation is funded by DOST Engineering Research and Development for Technology (ERDT) scholarship of the Department of Science and Technology, Republic of the Philippines. We thank the two anonymous reviewers for their insightful comments that improved the content of this work.

References

[1] Hayes RH, Wheelwright SC. Restoring our competitive edge: competing through manufacturing. John Wiley and Sons, New York; 1984.

[2] W. Skinner, "Manufacturing-missing link in corporate strategy". Harvard Business Review, Vol. 47 (1969), 136-145.

[3] S.C. Wheelwright, "Manufacturing strategy: defining the missing link". Strategic Management Journal, Vol. 5 (1984) No. 1, 1984, 77-91.

[4] S.C. Wheelwright, "Reflecting corporate strategy in manufacturing decisions". Business Horizons, Vol. 21 (1978) No. 1, 57-66.

[5] Brundtland, GH. Report of the world commission on environment and development: Our common future. Oxford, UK: Oxford University Press; 1987.

[6] M.K. Linnenluecke, A. Griffiths, "Corporate sustainability and organizational culture". Journal of World Business, Vol. 45 (2010) No. 4, 357-366.

[7] C.B. Joung, J. Carrell, P. Sarkar, S.C. Feng, "Categorization of indicators for sustainable manufacturing". Ecological Indicators, Vol. 24 (2013), 148-157.

[8] L.A. Ocampo, E.E. Clark, "Developing a framework for sustainable manufacturing strategies selection". DLSU Business & Economics Review, Vol. 23 (2014) No. 2, 115-131.

[9] A. Azab, A. Ziout, W. ElMaraghy, "Modeling and optimization for disassembly planning". Jordan Journal of Mechanical and Industrial Engineering, Vol. 5 (2011) No. 1, 1-8.

[10] Elkington, J. Cannibals with Forks: The Triple Bottom Line of 21st Century Business. Oxford: Capstone; 1997.

[11] G. Theyel, K. Hofmann, "Stakeholder relations and sustainability practices of US small and medium-sized manufacturers". Management Research Review, Vol. 35 (2012) No. 12, 1110-1133.

[12] M. Hallgren, J. Olhager, "Quantification in manufacturing strategy: a methodology and illustration". International Journal of Production Economics, Vol. 104 (2006) No. 1, 113-124.

[13] A. Azapagic, "Systems approach to corporate sustainability: a general management framework". Process Safety and Environmental Protection, Vol. 81 (2003) 5, 303-316.

[14] C. Reich-Weiser, A. Vijayaraghavan, D. Dornfeld, "Metrics for sustainable manufacturing". International Manufacturing Science and Engineering Conference, Illinois, 2008.

[15] A. Subic, B. Shabani, M. Hedayati, E. Crossin, "Capability framework for sustainable manufacturing of sports apparel and footwear". Sustainability, Vol. 4 (2012) No. 9, 2127-2145.

[16] G. Johansson, M. Winroth, "Introducing environmental concern in manufacturing strategies: implications for the decision criteria". Management Research Review, Vol. 33 (2010) No. 9, 877-899.

[17] R.H. Hayes, G.P. Pisano, "Manufacturing strategy: at the intersection of two paradigm shifts". Production and Operations Management, Vol. 5 (1996) No. 1, 25-41.

[18] P. Heikkurinen, K.J. Bonnedahl, "Corporate responsibility for sustainable development: a review and conceptual comparison of market-and-stakeholder-oriented strategies". Journal of Cleaner Production, Vol. 43 (2013), 191-198.

[19] B. Ageron, A. Gunasekaran, A. Spalanzani, "Sustainable supply chain management. An empirical study". International Journal of Production Economics, Vol. 140 (2012) No. 1, 168-182.

[20] K.M.Y. Law, A. Gunasekaran, "Sustainability development in high-tech manufacturing firms in Hongkong: motivators and readiness". International Journal of Production Research, Vol. 137 (2012) No. 1, 116-125.

[21] W.H. Tsai, W.C. Chou, "Selecting management systems for sustainable development in SMEs: A novel hybrid model based on DEMATEL, ANP, and ZOGP". Expert Systems with Applications, Vol. 36 (2009) No. 2, 1444-1458.

[22] J. Lepoutre, A. Heene, "Investigating the impact of firm size on small business social responsibility: a critical review". Journal of Business Ethics, Vol. 67 (2006) No. 3, 257-273.

[23] R. Banomyong, N. Supatn, "Developing a supply chain performance tool for SMEs in Thailand". Supply Chain Management: An International Journal, Vol. 16 (2011) No. 1, 20 – 31.

[24] Symeonidis G. Innovation, firm size and market structure: Schumpeterian hypotheses and some new themes. Economics Department Working Papers No. 161. Paris: OECD; 1996.

[25] S. Laforet, "Organizational innovation outcomes in SMEs: Effects of age, size, and sector". Journal of World Business, Vol. 48 (2013) No. 4, 490-502.

[26] H.E.J. Bos-Brouwers, "Corporate sustainability and innovation in SMEs: Evidence of themes and activities in practice". Business Strategy and the Environment, Vol. 19 (2010) No. 17, 417–435.

[27] A. Triguero, L. Moreno-Mondéjar, M.A. Davia, "Drivers of different types of eco-innovation in European SMEs". Ecological Economics, Vol. 92 (2013), 25-33

[28] J. Klewitz, E.G. Hansen, "Sustainability-oriented innovation of SMEs: a systematic review". Journal of Cleaner Production, Vol. 65 (2014), 57-75.

[29] Bronchain, P. Towards a sustainable corporate social responsibility. European Foundation for the Improvement of Living and Working Conditions, Luxembourg: Office for Official Publications of the European Communities; 2003.

[30] R. Vázquez-Carrasco, M.E. López-Pérez, "Small & medium-sized enterprises and Corporate Social Responsibility: a systematic review of the literature". Quality & Quantity, Vol. 47 (2013) No. 6, 3205-3218.

[31] L.H. Amato, C.H. Amato, "The effects of firm size and industry on corporate giving". Journal of Business Ethics, Vol. 72 (2007) No. 3, 229-241.

[32] N. Doi, M. Cowling, "The evolution of firm size and employment share distribution in Japanese and UK manufacturing: a study of small business presence". Small Business Economics, Vol. 10 (1998), 283-292.

[33] S. Schrettle, A. Hinz, M. Scherrer –Rathje, T. Friedli, "Turning sustainability into action: Explaining firms' sustainability efforts and their impact on firm performance". International Journal of Production Economics, Vol. 147 (2014), 73-84.

[34] M. Bourlakis, G. Maglaras, E. Aktas, D. Gallear, C. Fotopoulos, "Firm size and sustainable performance in food supply chains: Insights from Greek SMEs". International Journal of Production Economics, Vol. 152 (2014), 112-130.

[35] P.H. Howard, D. Jaffee, "Tensions between firm size and sustainability goals: fair trade coffee in the United States". Sustainability, Vol. 5 (2013) No. 1, 72-89.

[36] S. Nisim, O. Benjamin, "Power and size of firms as reflected in cleaning subcontractors' practices of social responsibility". Journal of Business Ethics, Vol. 83 (2008) No. 4, 673-683.

[37] C.H. Fine, A.C. Hax, "Manufacturing strategy: a methodology and an illustration". Interfaces, Vol. 15 (1985) No. 6, 28-46.

[38] P.T. Ward, D.J. Bickford, G.K. Leong, "Configurations of manufacturing strategy, business strategy, environment and structure". Journal of Management, Vol. 22 (1996) No. 4, 597-626.

[39] A. Griffiths, J.A. Petrick, "Corporate architectures for sustainability". International Journal of Operations and Production Management, Vol. 21 (2001) No. 12, 1573-1585.

[40] D.T. Pham, A.J. Thomas, "Fit manufacturing: a framework for sustainability". Journal of Manufacturing Technology Management, Vol. 23 (2012) No. 1, 103-123.

[41] N. Misani, "The convergence of corporate social responsibility practices". Management Research Review, Vol. 33 (2010) No. 7, 734-748.

[42] D. Baden, I. Harwood, D. Woodward, "The effect of buyer pressure on suppliers in SMEs to demonstrate CSR practices: an added incentive or counterproductive?". European Management Journal, Vol. 27 (2009) No. 6, 429-441.

[43] M. Cheung, M.B. Myers, J.T. Mentzer, "The value of relational learning in global buyer-supplier exchanges: a dyadic perspective and test of the pie-sharing premise". Strategic Management Journal, Vol. 32 (2011) No. 10, 1061-1082.

[44] J. Harrison, D. Bosse, R. Philips, "Managing for stakeholders, stakeholder utility functions, and competitive advantage". Strategic Management Journal, Vol. 31 (2010) No. 1, 58-74.

[45] A. Paloviita, V. Luoma-aho, "Recognizing definitive stakeholders in corporate environmental management". Management Research Review, Vol. 33 (2010) No. 4, 306-316.

[46] M.T. Sweeney, "Towards a unified theory of strategic manufacturing management". International Journal of Operations and Production Management, Vol. 11 (1991) No. 8, 6-23.

[47] J.G. Miller, A.V. Roth, "A taxonomy of manufacturing strategies". Management Science, Vol. 40 (1994) No. 3, 285-304.

[48] M.T. Frohlich, J.R. Dixon, "A taxonomy of manufacturing strategies revisited". Journal of Operations Management, Vol. 19 (2001) No. 5, 541-558.

[49] A.J. de Ron, "Sustainable production: the ultimate result of a continuous improvement". International Journal of Production Economics, Vol. 56-57 (1998), 99-110.

[50] M.E. Gonzalez, G. Quesada, C. Mora-Monge, "An international study on manufacturing competitive priorities". Journal of Management Policy and Practice, Vol. 13 (2012) No. 3, 116-128.

[51] R. Heijungs, G. Huppes, J.B. Guinee, "Life cycle assessment and sustainability analysis of products, materials and technologies: toward a scientific framework for sustainability life cycle analysis". Polymer Degradation and Stability, Vol. 95 (2010) No. 3, 422-428.

[52] K.T. Cho, "Multicriteria decision methods: an attempt to evaluate and unify". Mathematical and Computer Modeling, Vol. 37 (2003) No. 9-10, 1099-1119.

[53] M. Herva, E. Roca, "Review of combined approaches and multi-criteria analysis for corporate environmental evaluation". Journal of Cleaner Production, Vol. 39 (2013), 355-371.

[54] N. Subramanian, R. Ramanathan, "A review of applications of analytic hierarchy process in operations management". International Journal of Production Economics, Vol. 138 (2012) No. 2, 215-241.

[55] Gupta A, Vangari R, Jayal AD, Jawahir IS. Priority evaluation of product metrics for sustainable manufacturing. In: Bernard A, editor. Global Product Development, 2011, pp. 631-641.

[56] D. Krajnc, P. Glavic, "A model for integrated assessment of sustainable development". Resources, Conservation and Recycling, Vol. 43 (2005) No. 2, 189-208.

[57] I.H. Garbie, "Framework of manufacturing enterprises sustainability incorporating globalization issues". 41st International Conference on Computers and Industrial Engineering, Los Angeles, California, 2011.

[58] K. de Brucker, C. Macharis, A. Verbeke, "Multi-criteria analysis and the resolution of sustainable development dilemmas: a stakeholder management approach". European Journal of Operational Research, Vol. 224 (2013) No. 1, 122-131.

[59] S.B. Sirikrai, J.C.S. Tang, "Industrial competitiveness analysis: using the analytic hierarchy process". Journal of High Technology Management Research, Vol. 17 (2006) No. 1, 71-83.

[60] A.I. Chatzimouratidis, P.A. Pilavachi, "Technological, economic and sustainability evaluation of power plants using the analytic hierarchy process". Energy Policy, Vol. 37 (2009) No. 3, 778-787.

[61] M.S. Chiacchio, "Early impact assessment for sustainable development of enabling technologies". Total Quality Management and Excellence, Vol. 39 (2011) No. 3, 1-6.

[62] T.J. Barker, Z.B. Zabinsky, "A multicriteria decision-making model for reverse logistics using analytical hierarchy process". Omega, Vol. 39 (2011) No. 5, 558-573.

[63] S. Seuring, "A review of modeling approaches for sustainable supply chain management". Decision Support Systems, Vol. 54 (2013) No. 4, 1513-1520.

[64] M. Barad, D. Gien, "Linking improvement models to manufacturing strategies–a methodology for SMEs and other enterprises". International Journal of Production Research, Vol. 39 (2001) No. 12, 2675-2695.

[65] V.F. Yu, K. Hu, "An integrated fuzzy multi-criteria approach for the performance evaluation of multiple manufacturing plants". Computers & Industrial Engineering, Vol. 58 (2010) No. 2, 269-277.

[66] S. Vinodh, K.E. Selvan, N.H. Prakash, "Evaluation of sustainability using fuzzy association rules mining". Clean Technology and Environmental Policy, Vol. 13 (2011) No. 6, 809-819.

[67] S. Vinodh, R. Girubha, "PROMETHEE based sustainable concept selection". Applied Mathematical Modelling, Vol. 36 (2012) No. 11, 5301-5308.

[68] T. Al-Hawari, S. Al-Bo'ol, A. Momani, "Selection of temperature measuring sensors using the analytic hierarchy process". Jordan Journal of Mechanical and Industrial Engineering, Vol. 5 (2011) No. 5, 451-459.

[69] D. Dalalah, F. AL-Oqla, M. Hayajneh, "Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of cranes". Jordan Journal of Mechanical and Industrial Engineering, Vol. 4 (2010) No. 5, 567-578.

[70] S. Jajimoggala, V.V.S.K. Rao, S. Beela, "Supplier evaluation using fuzzy analytical network process and fussy TOPSIS". Jordan Journal of Mechanical and Industrial Engineering, Vol. 5 (2011) No. 6, 543-551.

[71] C.C. Chen, H.S. Shih, H.J. Shyur, K.S. Wu, "A business strategy selection of green supply chain management via an analytic network process". Computers and Mathematics with Applications, Vol. 64 (2012) No. 8, 2544-2557.

[72] M. Zhou, Y. Pan, Z. Chen, W. Yang, B. Li, "Selection and evaluation of green production strategies: analytic and simulation models". Journal of Cleaner Production, Vol. 26 (2012), 9-17.

[73] M. Zhou, Y. Pan, Z. Chen, W. Yang, "Optimizing green production strategies: an integrated approach". Computers and Industrial Engineering, Vol. 65 (2013) No. 3, 517-528.

[74] L.A. Ocampo, E.E. Clark, "A framework for capturing uncertainty of group decision-making in the context of the Analytic Hierarchy/Network Process". Advances in Industrial Engineering and Management, Vol. 3 (2014) No. 3, 7-16.