Fuzzy AHP based Multi-Criteria Decisions Support System for Eco-Design

[1]Chanjief Chandrakumar, [3]Asela K. Kulatunga
[1,3]Department of Production Engineering, Faculty of Engineering
University of Peradeniya
Peradeniya, Central – 90000, Sri Lanka
mtcchanjief@gmail.com , aselakk@pdn.ac.lk

[2]Senthan Mathavan
[2]School of Mechanical and Manufacturing Engineering
Loughborough University
LE11 3TU, United Kingdom
s.mathavan@ieee.org

***Abstract*- This paper presents multi-criteria decisions support system based on fuzzy AHP for eco-design of a product. The proposed DSS is based on the guidelines given by ISO 14063 standards used in the eco- design of a product. The fuzzy AHP techniques have been applied at relevant steps of product design and development stage of the standard methodology in order to evaluate different tradeoffs related to eco-design strategies. The triangular fuzzy numbers are generated based on the fuzziness of the linguistic variables of the DSS model. In addition to comparing the environmental aspects against the economic aspects, even the social aspects have been considered in this study. The proposed model has been validated with the selected designs of the local traditional brass manufacturing industry in Sri Lanka. The results reveal that the local brass manufacturers should concentrate further on the triple bottom-line of sustainability when developing their designs for eco-manufacturing. Further, this research can be extended to other stages of the standard methodology and as well as to other phases of the life cycle.**

Keywords — Multi-Criteria Decisions Support System, Eco-design, Fuzzy AHP, Triangular Fuzzy Numbers

I. Introduction

Early industries concentrated on mass-scale production and their only concern was making profit. This strategy led to affect the eco-system in later times and this resulted in increasing public awareness to eco-friendliness. Thus the consumers focus on the eco-friendliness of the products they consume despite of the sizes and costs due to several environmental issues and impacts. Thus, today, manufacturers are enforced to manufacture goods and provide services sustainably, which have benefits for the stakeholders like consumers, manufacturers, and nature in numerous ways. Consumers gain the experience and satisfaction of using eco-friendly products, which will entertain the next generations with a greener world. Meanwhile, manufacturers and service providers are correspondingly profited economically through optimizing material consumption, improving the processes, reducing waste generations, and fulfilling the social responsibility as sustainable manufacturers. Not only being socially responsible manufacturers, but also they have opportunities to advertise themselves as sustainable manufacturers to retain the competitive business market while entertaining tax benefits. If both consumers, manufacturers and service providers give priorities to be green in each aspect, then the nature retains as greener with reduced hazards and threats. Therefore, practicing to be greener is a win-win situation for all the stakeholders of sustainable products and services.

In order to yield the benefits of sustainable products/ services, governments and related authorities impose environmental rules, regulations and standards, which assess and grade the greenness of each product/ service. Even though developed countries follow such rules and regulations greatly, today, many of the developing countries too adhere to these legal liabilities due to the consumer preferences and related constraints. Nowadays, these liabilities are used as tools to rank the products/ services based on their eco-friendliness. This has led the manufacturers to green the supply chain by adapting strategies:

- Reassess and optimize the manufacturing processes continuously
- Undergo several phase shifts, optimize the resources
- Utilize the wastes and bi-products in all phases

II. Literature Review

Multi criteria decisions support systems (MCDSS) are inevitable in the process of evaluating and optimizing complex decisions in the stage of manufacturing of any product. MCDSS are not only confined to the area of manufacturing, but also utilized in several other areas of studies despite the scope. Even though decision making is inevitable in any area, it is comparatively high in complexity and requires more knowledge in order to deal with. A study [1] elaborates the issues related to decision making and the knowledge acquisition in enterprises in detail. Haritha presents a multi stage decision support system (DSS) for coordinated sustainable product and supply chain design in the PhD thesis [2]. The objective is to help in identifying the optimal sustainable product design and its supply chain configuration by considering the TBL of sustainability. However the thesis emphasizes the necessities of considering the TBL equally, the study only considers the employee working environment and related factors to assess the social aspects.

Gokhan [3] has developed an optimization model that simultaneously considers product and SC design decisions, but this research too does not focus on all the TBL aspects. A quantitative optimization model to coordinate product and logistic network design decisions is presented in another research [4]. But the research does not concentrate on the entire supply chain for optimization. Forza [5] presents a review of studies to facilitate the coordination between product, process and SC design. Similarly, another research [6] discusses the needs for coordinating product, process, and SC design related designs. Similar to the field of manufacturing, MCDSSs are used in the field of construction as well. In order to select low-cost green building materials and components a MCDSS has been proposed by Yang et al (2013) [7]. This model focuses on improving the understandability of the principles related to the impacts of low-cost green building materials and components. The previous paragraphs emphasize the requirements of having MCDSS for different industrial applications. Diverse techniques are available to solve these MCDSSs. Analytical hierarchy process (AHP) is one of the popular mathematical tools used in decision making, which derives priority scales through pairwise comparisons based on the judgments of experts. Saaty [8] provides systematic methodology to explain the process of how AHP works. AHP has been used for many applications and an overview of them is provided by Vaidya et al (2006) [9].

Today, the concept of sustainability is practiced in diverse areas including construction. In an ongoing research, Attaran et al (2013) [10] propose a method to identify consumer ranking and weights of a major building rating system's categories. They utilize AHP to evaluate their alternatives in decisions making. Another decision supports system (DSS) for selecting low-cost green building materials and components has been evaluated using AHP [11]. In this study eco-design strategies have been taken into consideration, but the linguistic parameters and uncertainties are not accurately quantified. A similar DSS is developed and AHP is applied in the selection process of lecturer at an academic institution in Indonesia [13]. In another study [12], the guided ranked AHP (GRAHP) has been introduced, where decision matrix tables are filled based on ranked data automatically. Furthermore, due to the presence of the complexities in the supply chain, the process of selecting the most appropriate measure has become very difficult and this problem is handled by Sharma and Pratap [14] by identifying the risk and determining risk optimization. Even though AHP is used for several industrial applications, it is difficult to implement for a more complex and uncertain problem, for example, expressing a comparison judgment in the form of ratios. In order to cater the uncertainty in the judgments fuzzy sets or fuzzy numbers are used. These fuzzy sets are capable of incorporating the vagueness of human thinking to a certain extent, therefore this is called as fuzzy AHP (FAHP), an extension of AHP.

Similar to AHP, fuzzy AHP is also applied in several areas including computer science and information technology [15]. Kong et al (2005) [16] use fuzzy AHP to evaluate the uncertainties and the linguistic parameters in the study to evaluate the success factors of e-commerce. Though a similar work [17] is carried out in order to evaluate the services rendered in the field of business, the proposed method in the study eliminates the requirements of additional aggregation and ranking procedures by deriving crisp weights from fuzzy comparison matrices. Also, FAHP is applied to the problems like supplier selection at the marketing department [18], performance evaluation of employees [19] and evaluation for employee selection [20] at business firms. When considering the applications of FAHP in manufacturing, a study employs the Russian theory of inventive problem-solving and the FAHP for designing a novel shape for machine tools. In this study, fuzzy AHP is used to represent the qualitative and subjective assessments in the MCDSS [21]. Further, a green supply chain management evaluation model is developed and applied to a selected publication company in Iran. The proposed model, having 5 main criteria and 21 sub-criteria, is solved using FAHP [22]. Likewise, in the filed of disaster management, especially estimating the vulnerability to natural disasters has been presented in another study also from Iran. The authors handle problems like vagueness absorption, evaluation and documentation at each stage of their DSS with AHP and its extension, FAHP [23].

Complexities in logistics systems and the large volumes of data related to international routes are handled by proposing a DSS using FAHP [24]. The proposed model can play a vital role in facilitating the international intermodal transport routes linking different countries. Therefore, it is revealed that the FAHP is also employed for several applications similar to AHP despite the complexities in the decision making.

From the literature presented in this section the following conclusions can be made:

1. Although the interests on the area of sustainable supply chain management is high, most of the researches are limited to only economical and environmental aspects. Very few of the researches discuss the importance of social aspects, which is one of the TBL of sustainability.
2. Several MCDSSs have been developed from time to time for different purposes like green material selection, supplier selection, product selection, personal selection etc. Among the available DSSs, none of them evaluates eco-design strategies.
3. Similarly, hundreds of researchers use AHP and FAHP as tools to evaluate the alternatives in the process of decision making. Very few of the DSSs related to manufacturing field use FAHP.

Therefore, this research is intended to develop/ modify an existing MCDSS by considering the TBL of sustainability. In addition to economic considerations, this study focuses on the environmental and social aspects of the product design and development (PDD) phase of any general product in the field of manufacturing, since the PDD relates with 80 per cent of decisions and costs related to the product. Alternatives in each stage of the MCDSS will be evaluated using FAHP, since the decisions in the PDD phase relates to fuzziness, which is the novelty of this research project. This thesis is organized as follows: methodology, theory of FAHP, case-studies and conclusions and future works in the chapter 3, 4 and 5 accordingly.

III. METHODOLOGY

This research project is an extension of the previous study conducted by Kulatunga et al. [25]. Their research proposes a DSS model for eco-design based on ISO 14063 guidelines, which consists 8 major stages. However the proposed model provides an adequate amount of overview on the eco-design based model, it requires extended studies to be carried out. Even though this study emphasizes the requirements of providing importance for the triple bottom-line of sustainability, the model fails to consider the social aspects. Further, authors have used AHP to evaluate their alternatives in the process of decisions making, which is not always possible to assign numbers for the linguistic variables in the model.

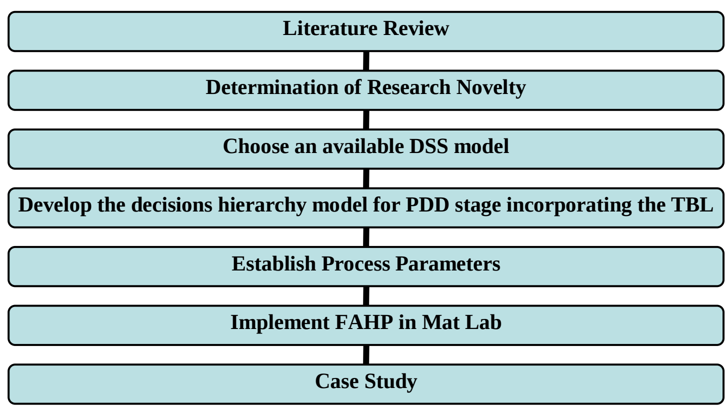

Figure 1: Framework of the Study

Therefore, this study proposes a MCDSS, which is a modification of the already proposed model [30]. This aims at the stage of eco-design strategies in detail while incorporating the triple bottom-line of sustainability. Moreover, this proposed model concentrates on the environmental and social aspects especially. Since the MCDSS involves with more complex decisions, where vagueness is highly present fuzzy AHP is applied to evaluate the alternatives in decision making. The proposed framework of the study is presented in Figure 1 and the detailed procedure of each step is presented in this section.

A. *Selection of an available MCDSS*

A DSS developed for PDD [25] is selected for the study.

B. *Extensive study on selected stage*

After choosing an available MCDSS, the stage of eco-design strategies is opted for a detail study. Accordingly, the sub-domains in this stage is modified and presented in Figure 2.

C. *Incorporation of TBL of Sustainability*

Each sub-domain is evaluated based on the TBL of sustainability. Under each criteria of TBL, several sub-criteria are incorporated and for each sub-criteria different design alternatives are evaluated using FAHP [26].

D. Selection of best design alternative

In order to select the best alternative design pair-wise comparison matrices are fed into the developed FAHP code in MATLAB. The code will return the normalized weights of each design alternative, where the design receives the highest weight is chosen as the best design which incorporates the eco-design strategies.

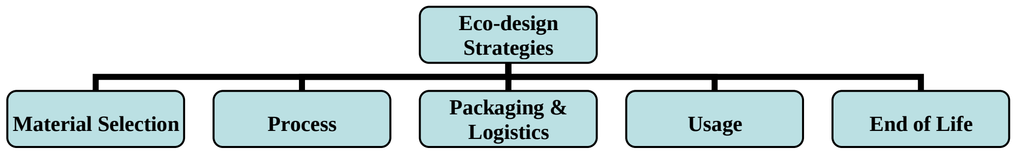

Figure 2: Eco-Design Strategies

IV. CASE STUDY: EVALAUTION OF DIFFERENT BRASS MANUFACTURING METHODS

Brass manufacturing is one of the popular industries which has been carried for several centuries. Even though the history reveals lot about this industry in Sri Lanka it is still carried out as a cottage industry in and around the Kandy district (Pilimathalawa, Nattaranpotta, Kalapuraya etc.) mostly. Today, the industry faces several issues related to its sustenance. Therefore, this case study is conducted in order to determine the variations and complexities of local brass manufacturing method when compared to the other high-tech methods. Here, we consider three different brass manufacturing methods like sand casting, die casting and investment casting. Even though TBL dimensions are reflected in this application, the scope is confined to its manufacturing phase (gate to gate) since the other four phases of the brass products are almost the same.

Table 1: Summary - Brass Manufacturing Methods

Processes/ Specification	**Alternative methods of Brass Manufacturing**		
	Sand Casting (X)	***Die Casting (Y)***	***Investment Casting (Z)***
Metal Pouring	• Molten metal is poured into the cavities from the furnace. • Metal should be melted in a separate cupola.	Forcing molten metal under high pressure	Ceramic cavity is created
Use of heavy metal equipment	Not used	2 harden tool steel dies are used (made of Zn, Cu, Al, Mg, Pb, Sn)	Not used
Secondary Operations - Requirements	High	Less	Very Less
Mold Reusability	Molds are expandable- so sand can be reused	Cold chamber machine	Wax can be reused
Size of castings	Medium to large size products – Good range	Small to large size products – Very good range	usually used for small size castings (but even 300kg size product is also possible)
Solidification	No uniformity, uneven cooling	Acceptable	Acceptable
Capital costs	Less	Very high	High
Volume of production	Less	High	Medium
Cost of processing	Cheap	Less	Very expensive
Complexity of the process	Medium	Less	High
Pattern	Made of wood, metal	Machine profiles	master pattern is made of clay, wood, wax, plastic
Solidifying method	Ramming is required (Mechanically done in Sri Lanka)	Hydraulic press	Rotational motion
Dimensional accuracy	Less	High	Very high
Labor intensive	High	Low	Low
Cooling mechanisms	Gas & steam are exit through the permeable sand or via risers	air entrapments are there- vents and parting lines are used	Water cooling, air cooling
Working environment - Cleanliness	Very poor	Good	Good
Health & Safety - Workers	Very poor	Good	Medium
H & S-Community	Very poor	Good	Good

Table 2: PCM for TBL Dimensions: Manufacturing/ Assembly Phase

TBL	Economical	Environmental	Social
Economical	(1, 1, 1)	(1, 3/2, 2)	(1, 3/2, 2)
Environmental	(1/2, 2/3, 1)	(1, 1, 1)	(1, 3/2, 2)
Social	(1/2, 2/3, 1)	(1/2, 2/3, 1)	(1, 1, 1)

Table 31: PCM for Social Dimension

	Labor intensiveness	Volume of Production	Cost of investments	Complication of process	Employees- health & safety	Community- health & safety
LI	(1, 1, 1)	(1, 3/2, 2)	(1, 3/2, 2)	(1, 1, 1)	(1, 1, 1)	(1, 1, 1)
VoP	(1/2, 2/3, 1)	(1, 1, 1)	(1, 1, 1)	(2/3, 1, 2)	(2/5, 1/2, 2/3)	(2/5, 1/2, 2/3)
CoI	(1/2, 2/3, 1)	(1, 1, 1)	(1, 1, 1)	(2/3, 1, 2)	(2/5, 1/2, 2/3)	(2/5, 1/2, 2/3)
CoP	(1, 1, 1)	(1/2, 1, 3/2)	(1/2, 1, 3/2)	(1, 1, 1)	(1/2, 2/3, 1)	(1/2, 2/3, 1)
E-H&S	(1, 1, 1)	(3/2, 2, 5/2)	(3/2, 2, 5/2)	(1, 3/2, 2)	(1, 1, 1)	(1, 1, 1)
C-H&S	(1, 1, 1)	(3/2, 2, 5/2)	(3/2, 2, 5/2)	(1, 3/2, 2)	(1, 1, 1)	(1, 1, 1)

Table 4: PCM for Labor Intensiveness

Labor intensiveness	X	Y	Z
X	(1, 1, 1)	(2/5, 1/2, 2/3)	(2/3, 1, 2)
Y	(3/2, 2, 5/2)	(1, 1, 1)	(1/2, 1, 3/2)
Z	(1/2, 1, 3/2)	(2/3, 1, 2)	(1, 1, 1)

Table 5: PCM for Volume of Production

Volume of Production	X	Y	Z
X	(1, 1, 1)	(1/2, 2/3, 1)	(1/2, 1, 3/2)
Y	(1, 3/2, 2)	(1, 1, 1)	(2, 5/2, 3)
Z	(2/3, 1, 2)	(1/3, 2/5, 1/2)	(1, 1, 1)

Table 6: PCM for Initial Investments

Initial Investments	X	Y	Z
X	(1, 1, 1)	(3/2, 2, 5/2)	(1, 3/2, 2)
Y	(2/5, 1/2, 2/3)	(1, 1, 1)	(1/2, 1, 3/2)
Z	(1/2, 2/3, 1)	(2/3, 1, 2)	(1, 1, 1)

Table 72: PCM for Complication of Process

Complication of process	X	Y	Z
X	(1, 1, 1)	(2/5, 1/2, 2/3)	(1/2, 1, 3/2)
Y	(3/2, 2, 5/2)	(1, 1, 1)	(1, 3/2, 2)
Z	(2/3, 1, 2)	(1/2, 2/3, 1)	(1, 1, 1)

Table 8: PCM for Employee – Health & Safety

Employees- health & safety	X	Y	Z
X	(1, 1, 1)	(2/7, 1/3, 2/5)	(1/3, 2/5, 1/2)
Y	(5/2, 3, 7/2)	(1, 1, 1)	(1/2, 1, 3/2)
Z	(2, 5/2, 3)	(2/3, 1, 2)	(1, 1, 1)

Table9: PCM for Community – Health & Safety

Community- health & safety	X	Y	Z
X	(1, 1, 1)	(2/7, 1/3, 2/5)	(1/3, 2/5, 1/2)
Y	(5/2, 3, 7/2)	(1, 1, 1)	(1/2, 1, 3/2)
Z	(2, 5/2, 3)	(2/3, 1, 2)	(1, 1, 1)

Similarly, comparison matrices are developed for the economical, environmental dimensions and for the corresponding criterions and sub-criterions. Initially, the matrices corresponding to the economical aspects are fed to the MATLAB code and the ranks for the three alternative methods are obtained.

Table 10: Scores of the Alternatives: Manufacturing Phase –Considering Economical Dimension Only

Design	Score	Rank
Sand Casting (X)	0.2994	**2**
Die Casting (Y)	0.4299	**1**
Investment Casting (Z)	0.2707	**3**

Thereafter, the matrices for all TBL dimensions are fed to the MATLAB code and the corresponding scores for the three alternative methods are obtained.

Table 11: Scores of the Alternatives: Manufacturing Phase – Considering all TBL Dimensions

Design	Score	Rank
Sand Casting (X)	0.2401	**3**
Die Casting (Y)	0.4065	**1**
Investment Casting (Z)	0.3535	**2**

According to the Table 10, it can be revealed that the die casting (Y) method has ranked the first among the three methods and the next is the sand casting (X) based on the economical aspects of manufacturing. The least score of 0.2707 is obtained by the investment casting (Y) method. But, when considering the TBL aspects die casting scores the highest of 0.4065 and the sand casting scores the least of 0.2401. The two tables clearly demonstrate the effect of incorporating social and environmental factors in decision making as the design choice orders are different depending on the dimensions considered. For both the analyses, die casting is chosen as the best design method. Since the sector is cottage in nature, the die casting technology will not be accessible, if not for any government or private investment. Hence, the other two are the real choices available for the manufacturers currently. Out of the two, although the analysis has shown that investment casting is the next best choice for the TBL, sand casting is practiced only, evidently for its financial advantage, as shown in Table 10. So, based on this evaluation using FAHP, the current sand casting method practiced in Sri Lanka lacks sustainability and the manufacturers must adopt investment casting instead. Therefore, it is recommended that some initiatives should be taken in order to improve the standard practices of brass manufacturing in Sri Lanka in order to maximize the benefits considering the TBL.

V. CONCLUSIONS AND FUTURE WORKS

This chapter provides the findings of the study and the summary of conclusions. Further, future research opportunities and ideas for extending the modified MCDSS model are also proposed in this section.

A. *Summary and Conclusions*

In this thesis, a Multi Criteria Decisions Support System based on the ISO 14063 guidelines for eco-design, considering the triple bottom-line of sustainability is presented. This study specifically focuses on the environmental and social aspects of the product design and development (PDD) phase of any general product in the manufacturing field. Many of environmental and social considerations are qualitative than quantitative, hence are better expressed as fuzzy variables. Even though there are many MCDSS already available, this particular model is developed using FAHP approach in order to evaluate the fuzziness of the qualitative nature of the variables.

The developed model reflects the total life-cycle from the phase of material extraction/ acquisition to end of life phase. Further, the model evaluates the environmental performance of the alternate designs in order to select the best design that has the optimum economic, environmental and social benefits.

In order to validate the solution procedure the proposed approach is applied to a problem in the local brass manufacturing industry. The study is limited to the manufacturing phase only. However, the application of the method can be easily extended to the other process segments as well. In this regard, three different types of brass manufacturing methods in the world are compared in order to position the Sri Lankan brass manufacturing industrial practices. However, for this study, actual data is collected from the local brass manufacturing industry in Sri Lanka, and data from the literature is used wherever required. The outcomes of the study indicate that the eco-design strategies play a critical role in improving the TBL performance of the entire SC. The proposed model provides considerable addition to the current sustainable supply chain management research through considering PDD decisions from sustainability perspectives and evaluating the alternatives using FAHP techniques. Therefore, it can be concluded that the study aims to fulfill the identified gaps in the literature, which lacks a FAHP based MCDSS for manufacturing, which also considers the TBL dimensions.

B. *Future Works*

The proposed model has been validated for a single process segment of brass manufacturing, and it will be extended to the other segments for an overall analysis. In next phases, new industries will be investigated using this method for their sustainability. Furthermore, the proposed model for a general product can be modified in order to apply for specific products. Authors recommend that more criterions and sub-criterions can be included in the model, therefore the results will be more precise and also more advanced techniques like analytical network process (ANP) can be utilized for more complicated systems.

REFERENCES

[1] Monika Piróg-Mazur, "The model of decision support system for manufacturing company," Artificial Intelligence Driven Solutions to Business and Engineering Problems, pp. 46-53.

[2] Haritha Metta, "A Multi-Stage Decision Support Model for Coordinated Sustainable Product and Supply Chain Design", University of Kentucky Doctoral Dissertations, USA, 2011.

[3] Gokhan, N. M., "Development of a simultaneous design for supply chain process for the optimization of the product design and supply chain configuration problem", PhD Dissertation. University of Pittsburgh, Pennsylvania, USA, 2007.

[4] Krikke, H.R., Bloemhof-Ruwaard, J.M., and Van Wassenhove, L.N., (2003), "Concurrent product and closed-loop supply chain design with an application to refrigerators", International Journal of Production Research, Vol. 41, pp. 3689–3719.

[5] Forza, C., Salvador, F., Rungtusanatham, M., "Coordinating product design, process design, and supply chain design decisions: Part B. Coordinating approaches, tradeoffs, and future research directions", Journal of Operations Management, Vol. 23, Issues 3-4, 2005, pp. 319-324.

[6] Rungtusanatham, M., and Forza, C., "Coordinating product design, process design, and supply chain design decisions. Part A. Topic motivation, performance implications, and article review process", Journal of Operations Management, Vol.23, Issue 3–4, 2005, pp. 257–265.

[7] Junli Yang, Ibuchim Cyril B. Ogunkah, "A Multi-Criteria Decision Support System for the selection of Low-Cost Green Building Materials and Components", Journal of Building Construction and Planning Research, volume 1, 2013, pp. 89-130.

[8] T.L. Saaty, "Decision making with the analytic hierarchy process," International Journal of Services Sciences, Vol. 1, No. 1, 2008, pp. 83-98.

[9] O.S. Vaidya, S. Kumar, "Analytc herarchy process: An overview of applications," Euraopean Journal of Operational Research 169, 2006, pp. 1-29.

[10] S. Attaran, B.G. Celik, "Analytic Hierarchy Process: An Application in Green Building market Research," International Journal of Management and Marketing, Vol. 3, No. 3, 2013, pp. 122-133.

[11] J.Yang, I.C.B. Ogunka, "A Multi-Criteria Decision Support System for the Selection of Low-Cost Green Building Materials and Components

[12] Adriyendi, Y. Melia, "DSS using AHP in Selection of Lecturer," International Journal of Advanced Science and Technology, Vol. 52, Mar. 2013, pp. 35-43.

[13] F. Ahmad, M.Y.M. Saman, F.S. Mohamad, Z. Mohamad, W.S.W. Awang, "Group Decision Support System Based on Enhanced AHP for Tender Evaluation," International Journal of Digital Information and Wireless Communications, Vol. 4(2), 2014, pp. 248-257

[14] Shivani Sharma and Ravindra Pratap, "A Case Study of Risks optimization Using AHP Method," International Journal of Scientifc and Research Publications, Vol. 3, Issue 10, Oct. 2013, pp. 1-6

[15] P. Srichetta, W. Thurachon, "Applying Fuzzy analytic Hierarchy Process to Evaluate and Select Prodcut of Notebook Computers," International Journal of Modeling and Optimization, Vol. 2, No. 2, Apr. 2012, pp.168-173.

[16] Feng Kong, Hongyan Liu, "Applying Fuzzy Analytic Hierarchy Process to Evaluate Success Factors of E-Commerce", International Journal of Information and Systems Sciences, volume 1, number 3-4, 2005, pp. 410-412.

[17] L. Mikhailov, P. Tsvetinov, "Evaluation of services using a fuzzy analytic hierarchic process," Applied Soft Computing, Vol 5, 2004, pp. 23-33

[18] M.B. Ayhan, "A Fuzzy AHP Approach for Supplier Selection Problem: A Case Study in a Gear motor Company," International Journal of Managing Value and Supply Chains, Vol. 4, No. 3, Sept. 2013, pp. 11-23.

[19] C.C. Sun, "A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods," Expert Systems with Applications, Vol. 37, 2010, pp. 7745-7754

[20] R.K. Ablhamid, B. Santoso , M.A. Muslim, "Decision Making and Evaluation System for employee Recruitment using Fuzzy AHP," International Refereed Journal of Engineering and Science, Vol. 2, Issue 7, July 2013, pp. 24-31

[21] Ho-Nien Hsieh, Jeng-Fung Chen, Quang Hung, "Applying TRIZ and Fuzzy AHP Based on Lean Production to Develop an Innovative Design of a New Shape for Machine Tools," Information, Vol. 6, 2015, pp. 89-110

[22] A.A.A. Rostamy, M. Shaverdi, I. Ramezani, "Green Supply Chain Management Evaluation in Publishing Industry Based on Fuzzy AHP Approach," Journal of Logistics Management 2013, 2(1), pp. 9-14.

[23] R. Aghataher, M.R. Delavar, M.H. Nami, N. Samnay, "A Fuzzy-AHP Decision Support system for Evaluation of Cities Vulnerability Against Earthquakes," World applied Sciences Journal 3, 2008, pp. 66-72

[24] H.J. Ko, "A DSS approach with Fuzzy AHP to facilitate international multimodal transportation network," International Journal of Maritime Affairs and Fisheries, Vol. 1, Issue 1, 2009, pp. 51-70.

[25] A.K. Kulatunga, N. Karunatilake, N. Weerasinghe, R.K. Ihalawatta, "Sustainable Manufacturing based Decisions Support Model for Product Design and Development Process," 12th Global Conference on Sustainable Manufacturing, Procedia CIRP 26, 2015, pp. 87-92.

[26] Fuzzy Set Theory and its Applications, H.-J. Zimmermann, Kluwer Academic Publishers, 2001, pp. 359-369.

BIOGRAPHY

Chanjief Chandrakumar is a final year Production Engineering undergraduate at the Faculty of Engineering, University of Peradeniya, Sri Lanka. He has been involved in research areas like Industrial Engineering, simulation, lean, operations research and sustainable manufacturing. He is a student member of IEOM, IEEE, ASME and IESL. He also serves as the president of IEOM society at University of Peradeniya, Sri Lanka.

Senthan Mathavan is a mechatronics engineer with ASML in the Netherlands. He is also a visiting academic and visiting fellow at Loughborough and Nottingham Trent Universities in the UK respectively. He received the BSc degree in Mechanical Engineering from the University of Peradeniya, Sri Lanka, in 2005. He then obtained the PhD degree in Mechatronics from Loughborough University in the UK, in 2009.

From 2005 to 2006, he was an assistant lecturer attached to the Mechanical Engineering Department, University of Peradeniya. He held a Rolls-Royce funded post-doctoral research position at Loughborough University from 2010 to 2011.

Asela K. Kulatunga is a senior lecturer in the Department of Production Engineering at the Faculty of Engineering, University of Peradeniya, Sri Lanka. He earned Bachelors in Production Engineering from University of Peradeniya, Sri Lanka and PhD in Mechanical/ Industrial Engineering from University of Technology, Sydney, Australia.

He has published more than 50 books/book chapters, journal and conference papers. Dr. Kulatunga has carried out various research projects with local manufacturing and service sectors. He is currently serving as a co-drafter for organizational LCA, for UNEP/SETAC Life Cycle Initiative. His research interests include lean and sustainable manufacturing, Industrial Engineering. He is the country representative for IEOM in Sri Lanka. He also holds associate membership at IEEE, ERSCP, and IESL.