Combining Customer and Sustainability Requirements in Quality Function Deployment for a Composite Aircraft Structure

Sezen Ayber
Ph.D. Candidate of Industrial Engineering
Institute of Graduate Programs
Eskisehir Technical University
Eskişehir, Turkey
sezen.dulger@gmail.com.tr

Nihal Erginel
Professor of Industrial Engineering
Faculty of Engineering
Eskisehir Technical University
Eskişehir, Turkey
nerginel@eskisehir.edu.tr

Abstract

Today, companies that produce economically, taking into account the social and environmental effects of production processes, as well as meeting customer needs, are more successful. Quality Function Deployment (QFD) is a methodology that listens and analyzes customer voices then transforms them to engineering characteristics. In this study, an extended QFD is proposed by considering not only customer needs but also sustainability requirements. While defining the priorities of all requirements, Analytic Hierarchy Process (AHP) is used. The proposed approach is applied for a composite horizontal stabilizer. The horizontal stabilizer is a fixed aircraft wing section that is used to maintain the aircraft in longitudinal balance, provide stability for the aircraft and keep it flying straight. It is a composite-based aircraft component. With the increasing popularity of composite materials for aircraft construction, it is crucial to make suitable product design for customer needs and sustainability requirements. The proposed methodology is appropriate for use in product design to handle customer needs and social, economic, environmental aspects of production together. In literature, integration sustainability with QFD is few studied. New discoveries of the proposed approach are illustrated in detail using a case study of a composite horizontal stabilizer that is used in a military aircraft.

Keywords
Quality Function Deployment; Sustainable Production; Product Design; Composite Horizontal Stabilizer; Aircraft

Acknowledgments
This work was supported by Eskisehir Technical University, Scientific Research Agency as a doctoral research project with the number of 20DPR005.

1. Introduction
The 20th century witnessed rapid industrialization and technology. Significant environmental effects by producing more waste, using toxic materials and consuming valuable resources, leading to climate change, pollution, ozone layer depletion, resource depletion have come along with this rapid advance (Omer 2008; Sepúlveda et al. 2010). In the end, these risks on human health and eco-system created awareness for sustainable design and production and push manufacturing and service systems to develop them. Many countries have promulgated environmental legislations and regulations for checking the use of products, processes and wastes that may be harmful to the environment by giving lists for permissible wastes, restricting the use of toxic materials or energy consumption during use (Cui and

Forssberg 2003; Gurauskiene and Varzinskas 2006; Lee et al. 2009). These regulations forced companies to improve the environmental performance of their products and they must consider sustainability requirements to get sustainable production.
Therefore, companies require a sustainable approach to optimize engineering characteristics of products at the design stage. QFD is a structured method for converting customer needs (CNs) to engineering characteristics (ECs) via listening to the voice of customers for product development. In this research, an extended QFD model will be developed by combining CNs and sustainability requirements (SRs) that include social, economic, environmental aspects together to achieve sustainability at the design stage. QFD approach is commonly used for environmentally product design process (Madu et al. 2002; Sakao 2007; Kuo et al. 2009), integration sustainability with QFD is few studied in literature. While applying this technique, AHP is used for determining the relative importance of CNs and SRs and the proposed approach's novel discoveries are showed using a case study of a composite horizontal stabilizer of an aircraft.

The rest of this paper is organized as: the background literature for the proposed methodology is presented in second section, an extended QFD is proposed by considering not only customer requirements but also sustainability requirements in third section, data collection and the application for composite horizontal stabilizer are presented in fourth section, the results and their implications are discussed in fifth section, and the conclusion is shown in the sixth section.

2. Literature Review

Sustainability is defined as ''using resources to meet the needs of the present without compromising the ability of future generations to meet their own'' (Linton et al. 2007). Sustainable production aims to make improvements in production and service industries for a better social, environment and economic development simultaneously for long term competitiveness (Carter and Rogers 2008).

QFD is a methodology that translates customer needs into technical requirements of new products and services. Akao firstly introduced the QFD in 1972 at Mitsubishi's Kobe shipyard site, and then Toyota and its suppliers developed it for their study. It has been successfully applied in many areas such as product development, quality management, decision making, engineering and management etc. to build competitive advantages (Chan and Wu 2002).

In this section, a literature survey about QFD applications with environmental and sustainable conscious is presented. Zhang et al. (1999) presented green QFD II that combined life cycle analysis and costing into QFD matrices. Masui et al. (2003) developed QFD for environment (QFDE) for new product development process. QFDE is based on four phase methodology for design for environment (DFE). Reyes and Wright (2001) developed a four-phase QFD methodology with using eco profile strategies. Madu et al. (2002) presented an approach for environmentally conscious design with using QFD, AHP and Taguchi experimental design. Bovea and Wang (2003) developed an approach for identifying environmental improvement options by using the life cycle analysis methodology, fuzzy approach and QFD. Sakao (2007) enhanced QFDE with theory of inventive problem solving (TRIZ) into QFD. Kuo et al. (2009) developed an Eco-quality function deployment (Eco-QFD). Halog (2004) presented a method to select the optimal sustainable option for system improvement. Utne (2009) applied QFD to achieve sustainability in the Norwegian fishing fleet. Vinodh and Chintha (2011) presented an application on fuzzy QFD for enabling sustainability. Roach (2014) proposed an approach to design sustainability products with QFD. CNs are categorized as candidate sustainability needs and they are analyzed. The purpose of the analysis is to sort the Candidate Sustainability Needs into two categories: Sustainability Needs and Sustainability Constraints. In literature, one of aspects of sustainability (environmental, economic and social) combined with QFD. There are few studies about whole sustainability requirements with QFD.

Also, because of shortcomings of traditional QFD framework, while determining their relative importance, several methods are applied. AHP, fuzzy set theory and analytic network process (ANP) are the frequently used methods (Büyüközkan and Berkol, 2011). Saaty (1980) developed the AHP and ANP that provide a prioritization scale from pairwise comparison of elements. AHP integrated with QFD were used by such studies Lu et al. (1994), Koksal and Egitman (1998), Zakarian and Kusiak (1999), Partovi and Corredoira (2002), Bhattacharya et al. (2005), Çelik et al. (2009) and Rajesh and Mallinga (2013).

3. Methods

A typical QFD consists of four phases: house of quality, parts deployment, process planning and production planning and these phases are showed in Figure 1 (Shillito 1994). The house of quality (HOQ) is the first phase, which translates CNs (WHATs) into ECs (HOWs). The second phase translates ECs (WHATs) into part characteristics (HOWs). The third phase translates parts characteristics (WHATs) into process operations (HOWs). Finally, the fourth phase is production planning which translates key process operations (WHATs) into production requirements (HOWs).

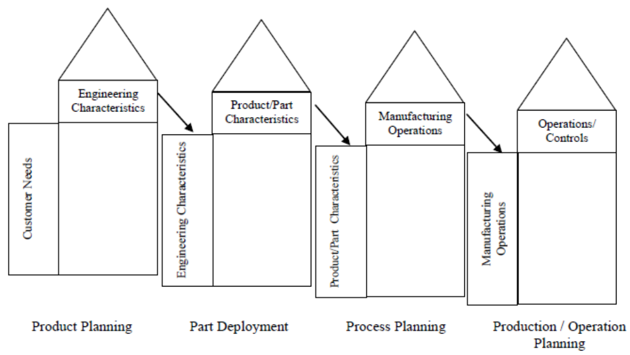


Figure 1. The four interlinked phases of QFD (Shillito 1994).

The house of quality (HOQ) is the first phase of QFD and the strategic tool to determine the ECs that satisfy the CNs. Figure 2 shows the proposed HOQ. Section A consists of two parts: CNs and SRs, Section B contains relative importance for prioritizing CNs and SRs. HOQ includes a matrix which demonstrates the relationship between each element of CNs/SRs in rows and ECs in columns at the body section (Partovi 2007). Section C contains ECs and Section D shows relationships between each element of CNs/SRs and ECs. Section E contains ECs interrelationships and Section F shows design priorities.

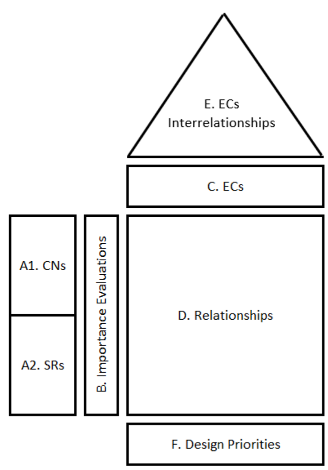


Figure 2. House of Quality (HOQ)

In this study, an extended QFD is proposed by considering not only customer requirements but also sustainability requirements. While defining the priorities of all requirements, AHP is used.
The methodology of extended QFD can be explained in following steps:

- Step 1: Defining and listing CNs: This is the voice of customers that describe customer needs and requirements for a product or service (Lin et al 2010).
- Step 2: Defining and listing SRs: Social, economic, environmental aspects are defined to achieve sustainable production.
- Step 3: Calculating relative importance of CNs and SRs: CNs and SRs must be rated because of dealing with too many needs. In this study AHP is used for rating and Table 1. shows AHP scale.

Table 1. AHP scale

Verbal answer	AHP Scale
Equally important	1
Important	2
Moderately more important	3
Intermediate	4
Strongly more important	5
Intermediate	6
Very strongly more important	7
Intermediate	8
Extremely more important	9

- Step 4: Developing a relationship matrix between CNs and ECs, SRs and ECs: In classical QFD 0 or blanks means no relation, 1-3-9 are assigned for weak to strong relationships respectively. In modern QFD, ratio scales are used (ISO 16355-1:2015). Relationship values are assigned according to the Table 2. Empty cell shows no correlation.

Table 2. 5-point scale relationship values table

Relationship - qualitative	Relationship – ratio scale
Weak	0.069
Moderate	0.135
Strong	0.267
Very Strong	0.518
Extremely Strong	1

- Step 5: Defining the ECs and constructing the correlation matrix among ECs: Symbols are commonly used to describe the strength of the interrelationships. In this study, "+" represents a positive relationship, "-" represents a negative relationship.
- Step 6: Calculating importance of each EC by multiplying the importance evaluations of all requirements (CNs and SRs) and values in the relationship matrices between CNs and ECs, SRs and ECs. Then summing of them for each EC.
- Step 7: Calculating relative importance degree of each EC by dividing the degree of importance of each EC to the sum of cumulative degree of importance and ranking ECs and suggesting actions in areas with the high importance.

4. Data Collection

The proposed approach is applied on a composite aircraft structure as a case study. The horizontal stabilizer is an aerodynamic surface and is crucial to the safety and stability of the aircraft (McLean 1990). Figure 3. shows stabilizers of an aircraft. According to aircraft accident reports, aircraft structural damage of the control surfaces like the horizontal stabilizer often leads to crashes and deaths (Wong et al. 2006; Flight 2010; Chetan 2012).
It is a composite-based aircraft component. With the increasing popularity of composite materials for aircraft construction, it is crucial to make suitable product design for customer and sustainability requirements. Composite-based components provide high strength, stiffness, fatigue, temperature and corrosion resistance characteristics also they are lighter than traditional aircraft materials so fuel consumption and emissions can be reduced.

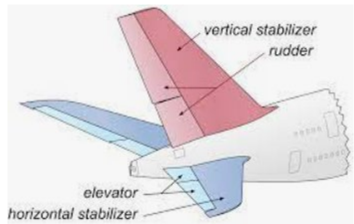


Figure 3. Horizontal stabilizer of an aircraft

Aircraft is one of the most expensive industrial systems which at the same time has the highest reliability and safety requirements with complex and expensive parts. Product design is an essential phase of an aircraft's life cycle therefore manufacturers have to decide which technical characteristics are more important in the design phase. In this study, CNs and SRs are handled together to rank ECs to obtain sustainability.
The customer needs and sustainability requirements were obtained through observation by going to Gemba, focus group studies, collecting existing information and manufacturer failure data reports. The customer in this study is the internal customer. Also, a committee of company experts conducts the evaluation and defines ECs. All these requirements can be listed as in Table 3, Figure 4. shows affinity diagram of CNs and SRs.

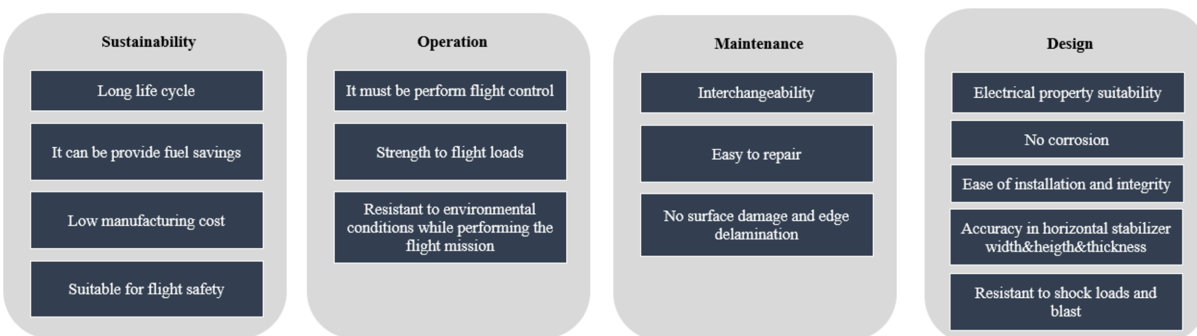


Figure 4. Affinity diagram of customer needs and sustainability requirements

Table 3. Customer, sustainability and design requirements

CN1	Ease of installation and integrity
CN2	It must be perform flight control mission
CN3	No corrosion
CN4	Resistant to environmental conditions while performing the flight mission
CN5	Strength to flight loads
CN6	Easy to repair
CN7	No surface damage and edge delamination
CN8	Electrical property suitability
CN9	Resistant to shock loads and blast
CN10	Interchangeability
CN11	Accuracy in horizontal stabilizer width&heigth&thickness
SR1	Long life cycle
SR2	It can provide fuel savings
SR3	Low manufacturing cost
SR4	Suitable for flight safety
EC1	Mechanical strength
EC2	Fatigue strength

EC3	Corrosion resistance
EC4	Weight
EC5	Dimensional stability
EC6	Thermal insulation
EC7	Electrical conductivity
EC8	Thermal expansivity
EC9	Stiffness
EC10	Moisture resistance
EC11	Aeroelasticity
EC12	Surface geometry
EC13	Wear tolerance
EC14	Abrasion resistance
EC15	Drag resistance
EC16	Projection area

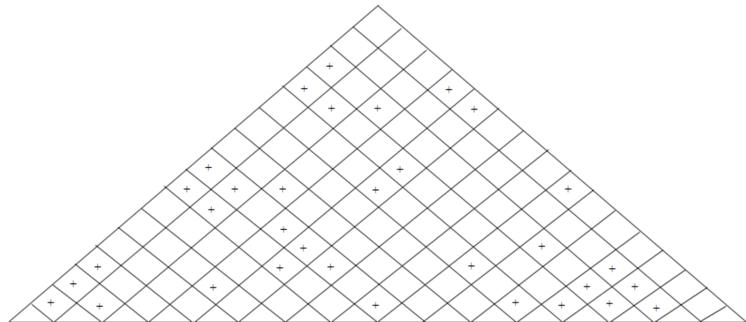
CNs and SRs are weighed according to their importance and for this purpose AHP is used. Table 4. shows the evaluations and results. The question asked is: “How much the need in the row is more important than the requirement in the column?” Consistency check for AHP application in this study is made.

Table 4. Relative importances of CNs and SRs

Req.	CN1	CN2	CN3	CN4	CN5	CN6	CN7	CN8	CN9	CN10	CN11	SR1	SR2	SR3	SR4	Relative Importance
CN1	1.0	0.2	0.3	1.0	0.2	0.3	0.3	0.3	0.3	0.3	1.0	0.3	1.0	0.2	0.3	0.020
CN2	5.0	1.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	0.325
CN3	3.0	0.1	1.0	1.0	0.3	1.0	1.0	1.0	0.3	0.3	1.0	1.0	3.0	3.0	0.3	0.036
CN4	1.0	0.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	3.0	1.0	3.0	3.0	0,3	0.042
CN5	5.0	0.1	3.0	1.0	1.0	3.0	3.0	3.0	1.0	3.0	5.0	3.0	5.0	5.0	1.0	0.085
CN6	3.0	0.1	1.0	1.0	0.3	1.0	1.0	1.0	0.3	1.0	3.0	3.0	5.0	0.2	0.3	0.041
CN7	3.0	0.1	1.0	1.0	0.3	1.0	1.0	1.0	0.3	0.3	5.0	3.0	5.0	0.3	0.3	0.041
CN8	3.0	0.1	1.0	1.0	0.3	1.0	1.0	1.0	0.2	0.2	3.0	3.0	1.0	0.2	0.3	0.033
CN9	3.0	0.1	3.0	1.0	1.0	3.0	3.0	5.0	1.0	1.0	7.0	3.0	5.0	3.0	0.3	0.076
CN10	3.0	0.1	3.0	1.0	0.3	1.0	3.0	5.0	1.0	1.0	7.0	3.0	3.0	3.0	0.1	0.065
CN11	1.0	0.1	1.0	0.3	0.2	0.3	0.2	0.3	0.1	0.1	1.0	1.0	1.0	0.2	0.1	0.016
SR1	3.0	0.1	1.0	1.0	0,3	0.3	0.3	0.3	0.3	0.3	1.0	1.0	3.0	3.0	0.2	0.031
SR2	1.0	0.1	0.3	0.3	0.2	0.2	0.2	1.0	0.2	0.3	1.0	0.3	1.0	0.3	0.1	0.015
SR3	5.0	0.1	0.3	0.3	0.2	5.0	3.0	5.0	0.3	0.3	5.0	0.3	3.0	1.0	0.2	0.054
SR4	3.0	0.1	3.0	3.0	1.0	3.0	3.0	3.0	3.0	7.0	9.0	5.0	9.0	5.0	1.0	0.118

5. Results and Discussion

Figure 5 shows HOQ of the case study. After determining importance evaluations of CNs and SRs, a relationship matrix between CNs and ECs, SRs and ECs is developed using scales in Table 2. The correlation matrix among ECs is constructed. Then importance of each EC is calculated. These values are presented for EC4 as follows; (0.325*0.267) +(0.085*0.267) +(0.015*1) =0.125. Relative importance degree of each EC is calculated by dividing the degree of importance of each EC to the sum of cumulative degree of importance. For example, for EC4 0.125/3.295*100=3.789. According to relative absolute importance scores, drag resistance with 13.979, aeroelasticity with 13.888 and mechanical strength with 9.375 are determined to be the most important engineering needs.



WHATS / HOWS			Importance Evaluations	Mechanical strength EC1	Fatigue strength EC2	Corrosion resistance EC3	Weight EC4	Dimensional stability EC5	Thermal insulation EC6	Electrical conductivity EC7	Thermal expansivity EC8	Stiffness EC9	Moisture resistance EC10	Aeroelasticity EC11	Surface geometry EC12	Wear tolerance EC13	Abrasion resistance EC14	Drag resistance EC15	Projection area EC16
Customer needs	CN1	Ease of installation and integrity	0.02					0.267				0.267		0.069	0.267	0.267			0.069
	CN2	It must be perform flight control mission	0.325	0.267	0.267		0.267				0.267			1	0.518	0.267		1	0.267
	CN3	No corrosion	0.036	0.267		1							0.518				0.267		
	CN4	Resistant to environmental conditions while performing the flight mission	0.042	0.518	0.518	1			0.518		0.518		1				0.267		
	CN5	Strength to flight loads	0.085	0.267	0.267		0.267				0.267			1	0.518	0.267		1	0.267
	CN6	Easy to repair	0.041	0.267	0.267	0.267				0.267			0.267			0.267	0.518		
	CN7	No surface damage and edge delamination	0.041	0.267	0.267	0.267				0.267			0.267			0.267	0.518		
	CN8	Electrical property suitability	0.033							1									
	CN9	Resistant to shock loads and blast	0.076	0.518	0.518	0.518				0.267	0.267		0.267		0.267	0.267	0.267	0.267	
	CN10	Interchangeability	0.065					0.267		0.267				0.267	0.267				0.267
	CN11	Accuracy in horizontal stabilizer width&heigth&thickness	0.016					1			0.518	0.518							0.267
Sustainability requirements	SR1	Long life cycle	0.031	1	1	1					0.267		0.267			0.267	0.267		
	SR2	It can be provide fuel savings	0.015				1	0.267							1			1	
	SR3	Low manufacturing cost	0.054	0.267		0.267		0.267	0.267	0.267			0.267	0.518	0.518	0.518	0.267	0.267	0.267
	SR4	Suitable for flight safety	0.118	0.518	0.518	0.518				0.267	0.267		0.267			0.267	0.267		
Absolute importance				0.309	0.285	0.246	0.125	0.057	0.036	0.139	0.2	0.014	0.157	0.458	0.299	0.225	0.138	0.461	0.147
Relative absolute importance (%)				9.375	8.646	7.457	3.789	1.744	1.098	4.219	6.065	0.415	4.762	13.888	9.078	6.832	4.182	13.979	4.470

Figure 5. HOQ of the case study

6. Conclusion

There is a growing demand and interest in considering social and environmental effects of the products. Therefore, companies need to have a sustainable approach to determining which engineering characteristics are the most important while designing products. In this study, an extended QFD with sustainability is proposed by combining customer needs and sustainability requirements to achieve long term competitiveness. Aircraft industry face more challenges to achieve sustainability in the product design phase while considering of having safety, reliability, environmental and cost requirements. For this reason, the proposed approach is applied for a composite horizontal stabilizer of an aircraft. In literature, studies mainly focus on environmental design aspect sustainability. In this study, combining customer needs and all aspects of sustainability has addressed in an integrated manner. In the future study, other charts will be employed in QFD. Also, a model using fuzzy numbers can be presented instead of crisp values.

References

Bhattacharya, A., Sarkar, B., and Mukherjee, S. K., Integrating AHP with QFD for robot selection under requirement perspective, *International Journal of Production Research*, vol. 43, no. 17, pp. 3671–3685, 2005.

Bovea, M. D. and Wang, B., Identifying environmental improvement options by combining life cycle assessment and fuzzy set theory, *International Journal of Production Research*, vol. 41, no. 3, pp. 593–609, 2003.

Büyüközkan, G. and Berkol, C., Designing a sustainable supply chain using an integrated analytic network process and goal programming approach in quality function deployment, *Expert Systems with Applications*, vol. 38, pp. 13731–13748, 2011.

Carter, C.R. and Rogers, D. S., A framework of sustainable supply chain management: moving toward new theory, *International Journal of Physical Distribution & Logistics Management*, vol. 38, no. 5, pp. 360–387, 2008.

Chan, L. K. and Wu, M. L., Quality function deployment: A literature review, *European Journal of Operational Research*, vol. 143, no. 3, pp. 463–497, 2002.

Chetan, J., Khushbu, P. and Nauman, M., The fatigue analysis of a vehicle suspension system-a review article, *International Journal of Advanced Computer Research*, vol. 2, no. 4, pp. 386-390, 2012.

Cui, J. and Forssberg, E., Mechanical recycling of waste electric and electronic equipment: a review, *Journal of Hazardous Materials*, vol. 99, no. 3, pp. 243-263, 2003.

Çelik, M., Cebi, S., Kahraman, C. and Er, I. D., An integrated fuzzy QFD model proposal on routing of shipping investment decisions in crude oil tanker market, *Expert Systems with Applications*, vol. 36, pp. 6227–6235, 2009.

Flight, J., Jal123: an illustration of the impact of acute hypoxia on measures of speech, *J. Australasian Soc. Aerospace Med.,* vol. 5 no. 1, pp. 14–18, 2010.

Gurauskiene, I. and Varzinskas, V., Eco-design methodology for electrical and electronic equipment industry, *Environmental Research, Engineering and Management*, vol. 3, no. 37, pp. 43-51, 2006.

Halog, A., Schultmann, F. and Rentz, O., Using quality function deployment for technique selection for optimum environmental performance improvement, *Journal of Cleaner Production*, vol. 9, pp. 387–394, 2001.

ISO 16355-1:2021 Application of statistical and related methods to new technology and product development process. Part 1: General principles and perspectives of Quality Function Deployment, International Organization of Standards, Available: https://www.iso.org/standard/74103.html, Accessed on Jan 5, 2021.

Koksal, G. and Egitman, A., Planning and design of industrial engineering education quality, *Computers and Industrial Engineering*, vol. 35, pp. 639–642, 1998.

Kuo, T. C., Wub, H. H. and Shieh, J. I., Integration of environmental considerations in quality function deployment by using fuzzy logic, *Expert Systems with Applications*, vol. 36, pp. 7148–7156, 2009.

Lee, A. H. I., Kang, H., Hsu, C. and Hung, H., A green supplier selection model for high-tech industry, *Expert Systems with Applications*, vol. 36, pp. 7917–7927, 2009.

Lin, Y. H., Cheng, H. P., Tseng, M. L. and Tsai, J. C. C., Using QFD and ANP to analyze the environmental production requirements in linguistic preferences, *Expert Systems with Applications*, vol. 37, no. 3, pp. 2186–2196, 2010.

Linton, J. D., Klassen, R. and Jayaraman, V., Sustainable supply chains: An introduction, *Journal of Operations Management*, vol. 25, no. 6, pp. 1075–1082, 2007.

Lu, M. H., Madu, C. N., Kuei, C. and Winokur, D., Integrating QFD, AHP and benchmarking in strategic marketing, *Journal of Business and Industrial Marketing*, vol. 9, no. 1, pp. 41–50, 1994.

Madu, C. N., Kuei, C. H. and Madu, I. E., A hierarchic metric approach for integration of green issues in manufacturing: A paper recycling application, *Journal of Environmental Management*, vol. 64, no. 3, pp. 261–272, 2002.

Masui, K., Sakao, T., Kobayashi, M. and Inaba, A., Applying quality function deployment to environmentally conscious design, *International Journal of Quality and Reliability Management*, vol. 20, no. 1, pp. 90–106, 2003.

McLean, D., Automatic Flight Control Systems, Prentice Hall, New York, 1990.

Omer, A.M., Energy, environment and sustainable development, *Renewable and Sustainable Energy Reviews*, vol. 12, no. 9, pp. 2265-2300, 2008.

Partovi, F. Y., A quality function deployment approach to strategic capital budgeting, *Engineering Economist*, vol. 44, no. 3, pp. 239–260, 1999.

Rajesh, G. and Malliga, P., Supplier selection based on AHP QFD methodology, *Procedia Eng.,* vol. 64, pp. 1283–1292, 2013.

Reyes, D. E. S. and Wright, T. L., A design for the environment methodology to support an environmental management system, *Integrated Manufacturing Systems*, vol. 12, no. 5, pp. 323–332, 2001.

Roach D.C., Designing Sustainable Products with QFD, *Proceedings of the 26th Symposium on QFD*, Charleston, SC, USA, December, 2014, pp. 1-15.

Saaty, T.L., *The Analytic Hierarchy Process*, McGraw-Hill, New York, NY, 1980.

Sakao, T., A QFD-centred design methodology for environmentally conscious product design, *International Journal of Production Research*, vol. 45, no. 18, pp. 4143–4162, 2007.

Sepúlveda, A., Schluep, M., Renaud, F.G., Streicher, M., Kuehr, R., Hagelüken, C. and Gerecke, A.C., A review of the environmental fate and effects of hazardous substances released from electrical and electronic equipments during recycling: examples from China and India, *Environmental Impact Assessment Review*, vol. 30, pp. 28-41, 2010.

Shillito, M.L., *Advanced QFD – Linking Technology to Market and Company Needs*, Wiley, New York, 1994.

Utne, I. B., Improving the environmental performance of the fishing fleet by use of quality function deployment (QFD), *Journal of Cleaner Production*, vol. 17, pp. 724–731, 2009.

Vinodh, S. and Chintha K.S., Application of fuzzy QFD for enabling sustainability, *International Journal of Sustainable Engineering*, vol. 4, no. 4, pp. 313-322, 2011.

Wong, D.K.Y., Pitfield, D.E., Caves, R.E. and Appleyard, A.J., Quantifying and characterising aviation accident risk factors, *Journal of Air Transport Management*, vol. 12, no. 6, pp. 352–357, 2006.

Zakarian, A. and Kusiak, A., Forming teams: An analytical approach, *IIE Transactions*, vol. 31, pp. 85–97, 1999.

Zhang, Y., Wang, H.-P. and Zhang, C., Green QFD-II: A life cycle approach for environmentally conscious manufacturing by integrating LCA and LCC into QFD matrices, *International Journal of Production Research,* vol. 37, no. 5, pp. 1075–1091, 1999.

Biographies

Sezen Ayber is currently a PhD candidate of Industrial Engineering, under the supervision of Prof. Dr. Nihal Erginel at Eskisehir Technical University, Turkey. She earned her B.S. degrees in Industrial Engineering and in Business Administration, also minor degree in Computer Engineering from Anadolu University, Turkey. She took her master's degree in Industrial Engineering from Eskisehir Osmangazi University in Turkey. She is a product planning engineer at an aircraft factory since 2011. Her research interests include total quality management, quality improvement, process improvement, fuzzy set theory, text mining and patent mining.

Prof. Dr. Nihal ERGİNEL, She graduated from Anadolu University, Industrial Engineering Department. She took her BS degree from Anadolu University, and PhD (1999) is from Eskisehir Osmangazi University in Turkey, Industrial Engineering. She had worked at Arcelik refrigerator factory that is an appliance firm between 1995 and 2001. She was an academic member of Anadolu University till 2018, and is a professor at Eskisehir Technical University. She is a Black Belt and expert on ISO9001. Her interested area and courses are probability, statistics, quality control, total quality management, six sigma, and fuzzy set theory. Also she is interested in clustering and text mining on big data.