Comparison and Integration of Axiomatic Design with Quality Function Deployment as a Design Method: a Literature Review

Alfin Fauzi Malik¹, Humala L Napitupulu² and Rosnani Ginting³

¹,²,³Department of Industrial Engineering, Faculty of Engineering, Universitas Sumatera Utara, Medan, Indonesia 20155

E-mail: alfinfm@gmail.com

Abstract. This paper focus on certain design methods: Axiomatic Design (AD) and its comparisons with Quality Function Deployment (QFD). While there are other methods such as QFD is more suitable for problem identification, AD is more suitable for decision making of product development with high quality needs. The general observations on the similarities and differences among the two design methods based on steps are discussed, contrasting the basic performances of the design method. We can conclude that Axiomatic Design is more suitable for the decision stage on planning phase while QFD is more suitable as a tool of problem inquisition.

1. Introduction

Ulrich and Eppinger states that the product as an object that is created with the aim to meet the needs of consumers who are hard to please and always want better than ever [1-2]. Therefore, none of the products that can be regard as a perfect product. Progress and development of technology demands that manufacturers can make products which have the "better" (better, stronger, more modern, more convenient, etc.) according to the needs of consumers who are becoming more widely [3-4].

In essence, the design and development of this product provides methods that aim to develop and design products to meet customer needs by involving the functions of marketing, design drafting, and manufacturing [5]. From the perspective of a company that saw profits (earnings) as an important factor, says product development and success if the product can be manufactured and sold at a profit [6]. But often just by looking at the income alone is not sufficient to make a proper assessment and direct. The five specific dimensions used to evaluate the development effort of the product, namely [7]: (i) Products quality, (ii) Cost of product, (iii) Time spent during product development, (iv) Costs of development and (v) Development capability

In this paper, we will study how Axiomatic Design (AD) and Quality Function Deployment (QFD) is applied to design the product to get the maximum value, both in terms of comparisons and combination. In general, there are several phases on the product design, among others, is to do the planning needs of a draft in the first step. Then proceed to the stage of conceptual design to prototyping test. The step of product design in general is shown in Figure 1 [8].
2. Axiomatic design
Axiomatic design is a methodology for system design by utilizing a matrix method to analyze the transformation of customer requirements systematically into functional requirements, process variables, and design parameters [10]. The term itself is derived from the axiomatic usability design principles or axioms that affect the design and analysis of the decision-making process during the development of a system design or a high-quality product [11]. Allegedly, Axiomatic design a method that addresses the design of the fundamental problems in Taguchi Methods [12].

This methodology was developed by a doctor of the Department of Mechanical Engineering at MIT, Dr. Suh Nam Pyo since the 1990s [13]. Several series of academic conferences have been held to add the necessary development in this methodology [14]. The last conference was held was the International Conference on axiomatic Design (ICAD) carried out in the past 2009 years in the State of Portugal. There are four fundamental theory used in axiomatic design: (i) Domain, (ii) Hierarchy, (iii) Zigzagging and (iv) Design axiom. The basic concept of axiomatic design is the domain. Each domain will have an important role in design activity.
• Axiom One: The axiom of independence. Alternative statement One: The optimal design will always be maintained by the independence of FR. Alternative statements Two: Within a tolerable design, DPS and FRS related as particular DP can be accommodated to meet the correspondence with the FR without effect on the other.

• Axiom Two: The axiom of information. Alternative statement: the finest design is the design functionally unpaired containing a minimum of information [15].

There are seven result (corollary) key can be derived from two basic axioms. We can see the following statement as a very useful design rules in design decisions.

• Corollary One: Decoupling of Coupled Design. Separation of components or aspects of the design solution if the FRS pairs or become an intertwined proper design.

• Corollary Two: Minimize FRS. Minimization of FRS and obstacles. Increased elements that one can add to the content of information. Do not try to create a design that exceeds the needs (overdesign). The design that performs the function of the excess is required, will be more expensive to operate or made. And also low reliability.

• Corollary Three: Integration of Physical Parts. Integrating physical design features in one design are recommended, as long as FRS can independently design should meet.

• Corollary Four: Use of Standardization. The use of standardized components that allow the turn easier and cheaper components. As long as he is still running the proper design.

• Corollary Five: Use of Symmetry. Utilize the form or preparation of symmetry if coherent with the FRS and constraints of design.

• Corollary Six: Wider Tolerance. Determine the largest admissible tolerance.

• Corollary Seven: Uncoupled Design with limited Information. Explore an uncoupled design that takes less information than coupled ones to meet the FRS. Always do uncoupled design that contains little information. The significance of this result is that when a designer put forward an uncoupled design, but contains more information than the coupled one, then the designer should start again from scratch because a good design may be scattered elsewhere [15].

3. Comparison and integration with QFD

3.1. QFD vs axiomatic design

QFD is a tool to enhance the quality of services or goods by knowing consumer needs and then link it to the technical characteristics to produce a service or good at each phase of manufacture of services or goods produced [16]. QFD is utilized to help companies focus on their customers’ needs during developing specifications of design and manufacturing. Quality Function Deployment (QFD) was first developed by Mitsubishi in 1972 in their shipyard at Kobe, Japan. The QFD’s essence is a large matrix that will relate what the customer desires (What) and manufacturing process (How) [17].

The main core of QFD is to involve customers as early as possible in the process of product development, in which the needs and desires from the costumers provide as a starting step of the QFD process. Accordingly, it is referred to as the voice of customer for QFD. The basic thinking is that the customer will not always content with the product albeit it has been created to perfection [18-19].

QFD has several benefits such as: (i) Focusing on the design of new services and products to customer requirements. Establish that customer needs are comprehended and the design process is directed by customer needs. (ii) Prioritize design activities. This assures that the process of design is concentrated on primary customer needs. (iii) Analysing the accomplishment of the company's major output to meet the needs of key customers. (iv) By concentrating their efforts on the design, it will diminish the total time required for the overall cycle of design, shorten the time to market of new products. Recent estimates showed a retrenchment of between a third and half of that before the application of QFD. (v) Reducing the sum of design changes after being sent to ensure efforts are
focused on the planning stage. The important thing is reducing the cost of introducing a new design. 
(vi) Encourage the practice of work teams and through the obstacles between the parts embroil the engineering, manufacturing and marketing since the start of the project. Each team member is as important and has something to contribute to the process. (vii) Provides a method to make the documentation process and set a strong fundamental for design decisions [20, 35-42].

QFD is similar to AD in terms of the needs of customers who are on the left part of the matrix and the technical requirements contained in the upper part HOQ. From this matrix, the design team can notice the conflict to be settled. However, QFD is very idiosyncratic [21]. QFD also showed no mathematical connection between design parameters and functional requirements, such as the design of the AD. QFD is one famous design methodology. AD is more suitable for designing products that are very different from existing products [22]. On the other hand, suggests the possibility of a large QFD when we want to improve existing solutions [23-24]. The Table 1. will show the differences between QFD and Axiomatic Design.

AD and QFD is a very systematic design methodology which provides a methodology that covers the whole design process from conceptual design to detailed design methodology of defining the relationship between the domains. However, there are some differences between the two methodologies. AD is mapping the customer requirements into functional requirements, constraints, and selection criteria, but there is no systematic procedure for this. In QFD, the HOQ concept can be used for the process. Therefore, the process of mapping the customer requirements in QFD more structured. In many of the design methodology, a structured method for decomposition does not exist. However, AD uses the zigzagging process. Another difference is in how to handle the relationship between the domains [25].

Table 1. Different of QFD and AD [23-24]

|                  | QFD                                                                 | AD                                                                 |
|------------------|----------------------------------------------------------------------|----------------------------------------------------------------------|
| Mapping customer needs (CN) | Defining customer needs and mapping of the technical characteristics. In the process of mapping, the matrix can be used. Therefore, structural mapping process allowed. | Defining customer needs and mapping of FR, DP, and PV. However, no structural mapping process between customer requirements (CN) to FR, DP, PV |
| The process of decomposition | No decomposition structure recommended. | We decompose the FR and the DP, using the zigzagging |
| The relationship between domain | Using HOQ, the relationship between the domains considered / assessed. But there is no connection recommended elimination. | Using the design matrix, the relationship between DP and FR considered / assessed. And also try to eliminate the relationship. |
| Solution range | Have limitations when designing new products as it focuses on a combination of existing design. | Open to a wide variety of solutions due to the focus of the solution is neutral. Therefore, it is suitable to develop a new design. |
| Application (ease of use) | Relatively easy to understand and suitable for the general idea. As well as widely spread which has a lot of people is already using it. | It is difficult to understand the overall methodology. It takes time and effort using this methodology. Because this methodology is not widely spread and more use of new concepts and ideas |
| How to improve the design | Increasing the parameters that have a major impact in some perspective | Trying to eliminate the relationship between function (coupling) |
AD and QFD is a very systematic design methodology which provides a methodology that covers the whole design process from conceptual design to detailed design methodology of defining the relationship between the domains. However, there are some differences between the two methodologies. AD is mapping the customer requirements into functional requirements, constraints, and selection criteria, but there is no systematic procedure for this. In QFD, the HOQ concept can be used for the process. Therefore, the process of mapping the customer requirements in QFD more structured. In many of the design methodology, a structured method for decomposition does not exist. However, AD uses the zigzagging process. Another difference is in how to handle the relationship between the domains [25].

In methodology QFD, the relationship between the domains is defined using the HOQ, but the relationship is not recommended for elimination. This AD differs from advocating that we eliminate the relationship between the domains. Solution range is one of the biggest differences between AD and QFD. QFD tries to find a solution from new combinations of existing technology, so it has its limitations when designing an entirely new product. While the army has a variety of open solutions for neutrality solution because of this characteristic, AD is more suitable for the development of new designs although there are differences in how to improve the design. AD tries to eliminate the negative relationship between the functions. While QFD improves the parameters have a great effect in some areas [26].

Finally, QFD has striking advantages in point of application. QFD has become prevalent among researchers in the field so designers may feel more familiar using QFD than AD [27]. To fully understand AD, the time and effort really are needed as well as the development of this methodology is relatively new, this method has not been widely spread on researchers in the field. AD is not the tools that are familiar for designer for the conceptual design stage [28].

3.2. Equitable QFD phase with AD
Phases of the design process in AD and QFD is described as follows:

- Planning and defining the role (blueprint of the information in the list of needs): Markets, firms, and the economy are noted for creating and selecting a suitable product idea. Later, needs and constraints will be arranged into a list of needs.
- Conceptual design (blueprint of the Principle): The purpose of this stage is to specify the solution principle. For its implementation, key issues will be formulated, the structure-function will be established, appropriate working principles to be searched, structural work is incorporated, and the last solution concepts are appraised for economic and technical criteria.
- Manifestation design (blueprint of Layout): In this stage, the working principle described in terms of the initial layout then appraised and dropped and/or mixed to produce a layout for sure.
- Detailed design (production specification): At this stage, all production is documented [28].

3.3. Proper Integration between AD and QFD
QFD is best used at the planning and problem-solving tool that lists related to customer wants and needs and technical functional requirements, albeit often in more than just one stage. The application of QFD enable us to explored the possible relationship between the characteristics stated by customers and the quality needs stated by the design team [29]. Meanwhile, at the conceptual design stage, the best approach is AD [30]. In the process and physical mapping methodology axiomatic design, design teams can begin to develop a test matrix for the purpose of validation and continuously updated as more details will be attained. Researchers need to build a test that includes all the attributes of customers and abolish redundant and unnecessary tests [31].

Gonçalves-Coelho concluded that while they differ in their format, the QFD relationship matrix and the AD design matrix represent essentially the same reality. The main benefit of integrating AD principles into QFD is to avoid deep multilevel iterations. Significantly, this fact can reduce waiting
times and thus lower costs and increase organizational competence [28]. Mullens et al [27], applied the QFD-AD combination model to produce a better product design that meets customer needs. Meanwhile, Sergio Rizzuti et. al [10], argues that Axiomatic Design integrated into the QFD method supports the Designer to produce a valid and non-contradictory Design. Furthermore, Pai Zheng, et al [32], applied the QFD-Axiomatic Design combination model to shorten the design process and help ensure that the voice of customer is molded in the conceptual design and application of QFD and Axiomatic Design provides design solutions that can meet all customer expectations.

Gilbert et al. demonstrate smooth and integrated QFD and AD applications for specific applications and are used to direct the process of creating a conceptual temporary house systematically with stakeholder needs in mind. The seamless integration of both methods takes advantage of the strengths of each. After the adjustment made to the QFD and AD processes were introduced, Gilbert presented a case study to demonstrate the use of the process in the design. Although not presenting a complete design, the case study demonstrated the ability of the combined methodology to capture voice of costumer in a systematic design process. The integration of the QFD-AD method in the case study shows that the design process has been streamlined, and helps ensure that all conceptual design creation is directed by VoC [33].

Ashtiany and Alipour illustrated the applicability of the Axiomatic Design method that integrate with QFD. The Axiomatic Design method was implemented to find a better configuration in the initial conceptual design of the tail of an airplane. Ashtiany integrated it with two proven design methodologies, Sustainability and QFD. To clarify the minimum set of independent FRs, CNs and Sustainability are plotted into FR and DP based on the Axiomatic rules by QFD. The result is two designs that link the DPs and FRs and also satisfy the Independence Axiom [34].

4. Conclusion

Axiomatic design is a system design methodology that uses a matrix method to systematically analyze changes in customer requirements into process variables, design parameters and functional requirements. Where there is QFD method is used to identify the problem that occurs early in the design. An example is the planning of design requirements based on the voice of the customer. We can addresses that Axiomatic Design is more suitable for the decision making of product development with high quality. By integrating both of methods, then the axiomatic design is used to analyze the systematic changes of customer requirements into design parameters, functional requirements and process variables from the house of quality. Its benefits are to reduce time in the design process, reduce costs and increase organizational capabilities.

References

[1] Seman S Z W A 2010 Integration of Design for manufacturing and assembly (DFMA) and theory of inventive problem solving (TRIZ) for design improvement (Doctoral dissertation, Universiti Teknologi Malaysia)
[2] Rozali A 2010 Product Design Improvement Through Design for Manufacture and Assembly (DFMA) and Theory of Inventive Problem Solving (TRIZ) (Doctoral dissertation, Universiti Teknologi Malaysia)
[3] Magrab E B, Gupta S K, McCluskey F P and Sandborn P 2009 Integrated product and process design and development: the product realization process (Florida: CRC Press)
[4] Kang N, Kim J and Park Y 2007 Industrial Management & Data Systems 107 (6) pp 780–801
[5] González F J M and Palacios T M B 2002 Industrial Marketing Management 31 (3) pp 261-271
[6] Estorilio C and Simião M C 2017 Product: Management and Development, 4 (2) pp 95-103
[7] Xie X 2003 Design for Manufacture and Assembly (Department of Mechanical Engineering: University of Utah)
[8] Johnson D D and Srivastava R 2008 Proceedings of the 39th Annual Meeting of the Decision Sciences Institute pp 1711-1716
[9] Rio, M, Reyes T and Roucoules L 2011 International Journal of Engineering 9 (1) p 121
[10] Rizzuti S, De Napoli L, Giampà F and Lofranco F 2009. *Proceedings of the Fifth International Conference on Axiomatic Design*, ICAD pp 25-27
[11] Shin M, Azhar M, Morrison J R, Lee T and Suh, H W 2011 *Proceedings of the 6th International Conference on Axiomatic Design* p 79
[12] Matt D T 2011 *Proceedings of the 6th International Conference on Axiomatic Design* pp 127-133
[13] Arsenyan J and Büyüközkan G 2009 *IAENG International Journal of Computer Science* 36 (3) pp 234-239
[14] Dickinson A and Brown C A 2009 *Proceedings of ICAD 09 The Fifth International Conference on Axiomatic Design* 25-27
[15] Belokar R M and Nauhria R N 2009. *Proceedings of the World Congress on Engineering 2009* I 634-639
[16] Mehrjerdi Y Z 2010 *International Journal of Quality & Reliability Management* 27 (6) 616-640
[17] Asadabadi M 2014 *International journal of industrial engineering computations* 5 (4) 543-560
[18] Sakao T 2007 *International journal of production research* 45 (18-19) 4143-4162
[19] Chan L K and Wu M L 2002 *European journal of operational research* 143 (3) 463-497
[20] U Tarigan et al 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* 309 012103
[21] Miguel P A C, Carnevalli J A and Calarge F A 2017 *Product: Management and Development* 5 (2) pp 127-132
[22] Del Taglia A and Campatelli G 2006 *Proceedings of ICAD 2006 4th International Conference on Axiomatic Design*
[23] Arcidiacono G, Capitani R, Citti P, Panichi C, and Rosti D 2006 *Proceeding of ICAD 4th International Conference on Axiomatic Design*
[24] Dickinson A L 2006 *Proceedings of ICAD06, International Conference on Axiomatic Design*
[25] Moon Y R and Cha S W 2000 *Proceedings of ICAD 2000 First International Conference on Axiomatic Design* pp 259-263
[26] El-Haik B 2000 *Proceedings of ICAD2000 First International Conference on Axiomatic Design* pp 62-69
[27] Mullens M A, Arič M, Armacost R L, Gawlik T A, and Hoekstra R L 2005 *Productions and Operations Management* 14 (3) 286-300
[28] Gonçalves-Coelho A M, Mourão A J F and Pereira Z L 2005 *Concurrent Engineering* 13(3) 233–239
[29] Cohen L 1988 *National Productivity Review* 7 (3) 197-208
[30] Hu M, Yang K and Taguchi S 2000 *The TRIZ Journal* pp 8-22
[31] Ferrer J B, Negny S, Robles G C and Le Lann J M 2012, *Computers & Chemical Engineering* 45 137-151
[32] Zheng P, Torres V H, Rios J and Zhao G 2013 *Applied Mechanics and Materials* 271 974-980
[33] Gilbert III L R, Omar M and Farid A M 2014 *Proceedings of ICAD2014 The Eighth International Conference on Axiomatic Design* pp 71-78
[34] Ashtiany M S and Alipour A 2016 *Procedia CIRP* 53 pp 142-150
[35] Rosnani Ginting 2020 *Integrated Model of Product Design Methods* [Online First], IntechOpen, DOI: 10.5772/intechopen.92059. Available from: https://www.intechopen.com/online-first/integrated-model-of-product-design-methods
[36] Rosnani Ginting et al 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* 801 012108
[37] Ginting R et al 2020 *Songk Lanakarin J. Sci. Technol.* 42(4) 771-779
[38] Rosnani Ginting et al 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* 505 012090
[39] R. Ginting et al 2019 *IOP Conf. Ser.: Mater. Sci. Eng*. 495 012009
[40] Ginting R, Ishak A, and Malik A F 2020 *AIP Conference Proceedings* 2217 030159
[41] Ginting R, Pane E P and Malik A F 2020 *AIP Conference Proceedings* 2217 030147
[42] R Ginting and Widodo 2019 *IOP Conf. Ser.: Mater. Sci. Eng* 602 012048