Jurnal Sistem Teknik Industri (JSTI) Vol. 26, No. 1, 2024 | 22 – 34

talenta PUBLISHER

JSTI
Jurnal Sistem Teknik Industri

Integrated Value Engineering with QFD and DFA as Product Design and Development Techniques: Literature Review

Handa Rivaldi Husal[1], Rosnani Ginting[2], and Anizar Anizar[3]

[1,2,3]Department of Industrial Engineering, Faculty of Engineering, Universitas Sumatera Utara, Jl. Dr. T. Mansur No.9, Medan, 20155, Indonesia

Abstract. Value engineering is an organized, rigorous strategy that assesses the performance, noise, quality, safety, and compatibility of systems, outfits, installations, services, and inventories to deliver necessary functionalities at the lowest life cycle cost. Eliminating unnecessary expenses from design, testing, production, operations, procedures, accounting, conservation, and other areas is the best course of action. The purpose of the paper's initial investigation was to list the drawbacks of value engineering in product creation. These transgressions highlight the necessity for alternative methods when implementing value engineering techniques. To address critical inverse issues throughout the process, from the stage of product demand analysis to product design, product, and operation, value engineering is combined with various engineering methods. The results demonstrate that there are distinct paths in which the benefit of integration engineering using QFD or DFA may be used. Even so, this integration is providing a better option for the planning of products or services through a process that not only means providing a better value for client satisfaction but also lowers expenses, shortening development times, and reducing the need for rework conditions—all without compromising performance, reducing anxiety, or lowering the quality of the final product.

Keywords: DFA, Product Design, Product Development, QFD, Value Engineering

Received 1 May 2023 | Revised 11 January 2024 | Accepted 17 January 2024

1. Introduction

Intense competition during globalization encourages companies to continue developing products. Instead of only concentrating on business-related issues, the rivalry in ultramodern frugal living is to acquire more skills in producing value-added goods and services [1]. To remain competitive, several businesses have experimented with bright new approaches to product design [2]. To satisfy customers, they appropriate quality as a means of making money [3]. Throughout the product development process, meeting customer criteria is of utmost importance.

The steps of the product development process, which include testing, system-position design, detailed design and integration, and conceptual development, can be repeated flexibly [4] (Figure

*Corresponding author at: [Universitas Sumatera Utara, Jl. Dr. T. Mansur No.9, Medan, 20155, Indonesia]
E-mail address: [rivaldihanda@gmail.com]

p-ISSN: 1411-5247 | e-ISSN: 2527-9408 | DOI 10.32734/jsti.v26i1.11901
Journal Homepage: https://talenta.usu.ac.id/jsti

1). In actuality, the procedure is more difficult as it necessitates the simultaneous consideration of several product components (specialized, lucrative, ergonomic, and environmental), requiring the participation of specialists from several departments and disciplines [2]. Some of the issues that occur during the creative phase are caused by the absence of an abstract system that gauges the client's perceived value for each function in the absence of design generalities and styles. This is the reason that different product design situations need to be combined to take into account cost, quality, and time and allow for effective product design, process, and manufacturing.

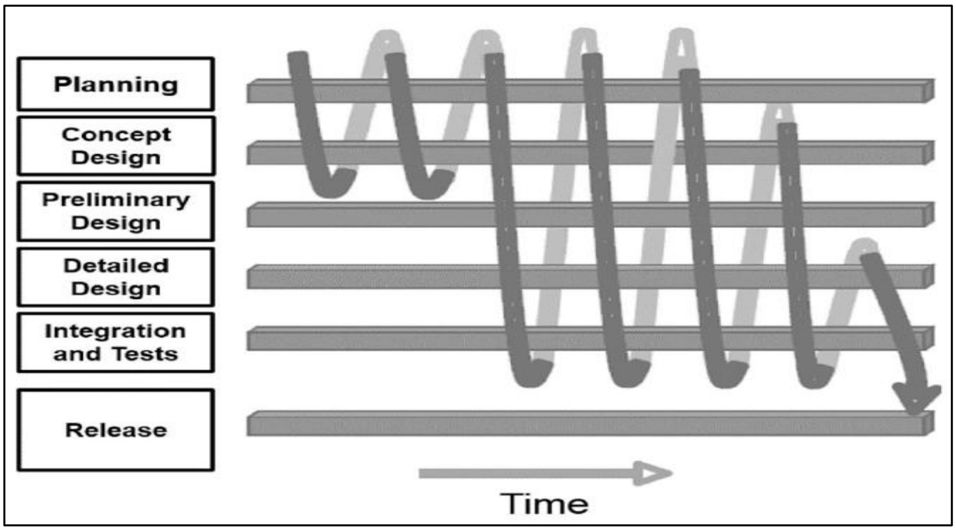

Figure 1 Product Life Cycle Phases (Unger, [4])

Value engineering is an organized, rigorous strategy that assesses the performance, noise, quality, safety, and compatibility of systems, outfits, installations, services, and inventories to deliver necessary functionalities at the lowest life cycle cost. Eliminating unnecessary expenses from design, testing, production, operations, procedures, accounting, conservation, and other areas is the best course of action [5],[6],[7]. Competition is one of the most useful instruments available for product design and development [8]. Elegant tools are the outcome of a methodical process that focuses on providing guests with what they require [9]. The best method for connecting and reducing wasteful expenses in process, es, operations, manufacturing, design, testing, accounting, conservation, etc. [10]. This paper's novel and thorough analysis aims to pinpoint the flaws in the application of value engineering to product design. Table 1 lists the sins of value engineering in order of occurrence.

These downsides drive the need for a different approach when enforcing value engineering styles. Generating generalities to improve living bones or create new designs may be done in a variety of ways. Generally, experimenters focus exclusively on evaluating how value engineering functions in product design and development by using the references they have gathered. Value engineering may serve as a foundation for future research and assist in overcoming sins when combined with other techniques. An integrated innovation system solves critical opposite problems from the product demand analysis stage to the product design, product, and operation by combining value engineering with other engineering methods.

Table 1 Literature Review of Value Engineering Weaknesses

Value Engineering flaws	Reference
Focusing on cost without considering the function the product provides	Farsi and Noraddin [7]
Idea generation during value research may not be effective using only conventional free-form techniques, such as brainstorming, and too much time may be wasted understanding the essence in an unnecessarily intuitive way.	Park, et al [11] and Harvey and Aubry [12]
The balance between the cost function and the value provided to consumers	Setti, et al [13]
A value engineering program's ability to succeed is contingent upon the caliber of the team, or qualifying experience.	Chhabra and Brajesh [14]
Evaluating functions without seeing them from the user's point of view and classifying functions are lacking in depth.	Peng, et al [15]
Products must not only be mechanically efficient but also satisfy human needs, which are often irrational.	Niraj [6]
The cost value is predicated on the lowest amount necessary to do the task.	Chougule and Kallurkar [16]

This study focuses on the following areas: (a) Analysis and identification (investigate, analyze, and review) of problem findings, especially value engineering integrated with QFD and value engineering integrated with DFA; and (b) Discussed and identified developments in theory and practice in the integration of value engineering methods with QFD/DFA.

2. Research Methodology

One of the first areas of library science, bibliometric analysis, is the approach employed in this work. This field of study emerged as a result of a small group of scientists' curiosity about how science was mirrored in literary creation around the start of the 20th century. Books, international journals, and international proceedings serve as the foundation for paper writing. The study flowchart in Figure 2 represents the journal selection procedure.

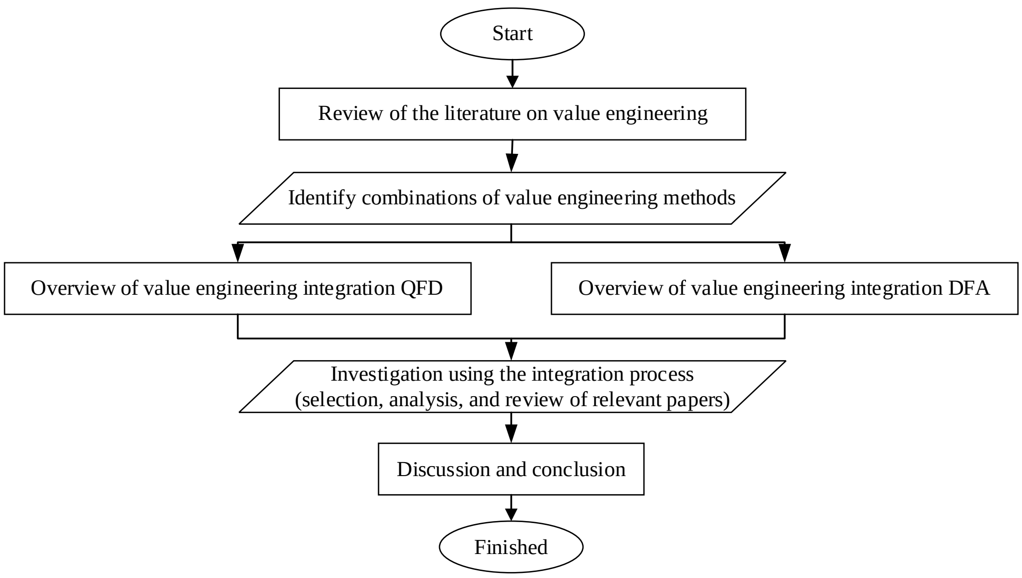

Figure 2 A Flowchart for Research

Note that only journal papers to develop theoretical-conceptual works, literature reviews, case studies, or theoretical modeling are considered and focused on in this paper (keywords in the title, abstract, and introduction are studied). Despite using the aforementioned identification techniques, there were a lot of published papers, making it impossible to examine them throughout the course of the search. To minimize the risk of falling behind current advancements, the research focuses mostly on material released during the previous two decades (2002–2022).

Limiting works that examine the integration or fusion of value engineering with QFD and/or DFA methodologies requires a screening procedure. We searched the Science Direct, Google Scholar, Taylor & Francis, Emerald, and Academia databases in great detail. When doing searches, terms like "value engineering," "value engineering with QFD/DFA," "product design," and "product development and design" are commonly utilized.

The introduction and methods are covered in this essay's first and second sections. The value engineering approach is covered in detail in the third paragraph. The fourth section examines how value engineering and QFD are combined. Value engineering and DFA integration are covered in the sixth part. Discussion and conclusion are the topics of the final, or sixth, portion.

3. Result and Discussion

3.1. Value Engineering and Application

Value engineering is an organized, rigorous strategy that assesses the performance, noise, quality, safety, and compatibility of systems, outfits, installations, services, and inventories to deliver necessary functionalities at the lowest life cycle cost. Eliminating unnecessary expenses from design, testing, production, operations, procedures, accounting, conservation, and other areas is the best course of action [5],[6],[7]. Function-based organization to find and cut down wasteful expenses [8],[17]. A methodical approach to problem-solving using a multidisciplinary team. Value engineering is a multi-stage process, as Figure 3 illustrates.

The following is a description of the steps in the VE method:

1. Information Stage: To comprehend the product's present status and the limitations affecting it, it is crucial to have product data, information, and papers [19].
2. Functional Analysis Stage: Analysis by making a function diagram by breaking down each element into components according to their function [20].
3. Creativity Stage: Generates several ideas about other ways to perform functions [19]. Brainstorming and concentrating on cost-effective development options are the methods utilized to stimulate creative thinking [20].
4. Evaluation Stage: Classification, selection, and selection of priority ideas that have a high potential for product improvement [19].
5. Development Phase: designing the final scenario and developing an investment program that will provide updated information and capabilities for developing the selected alternative [19].

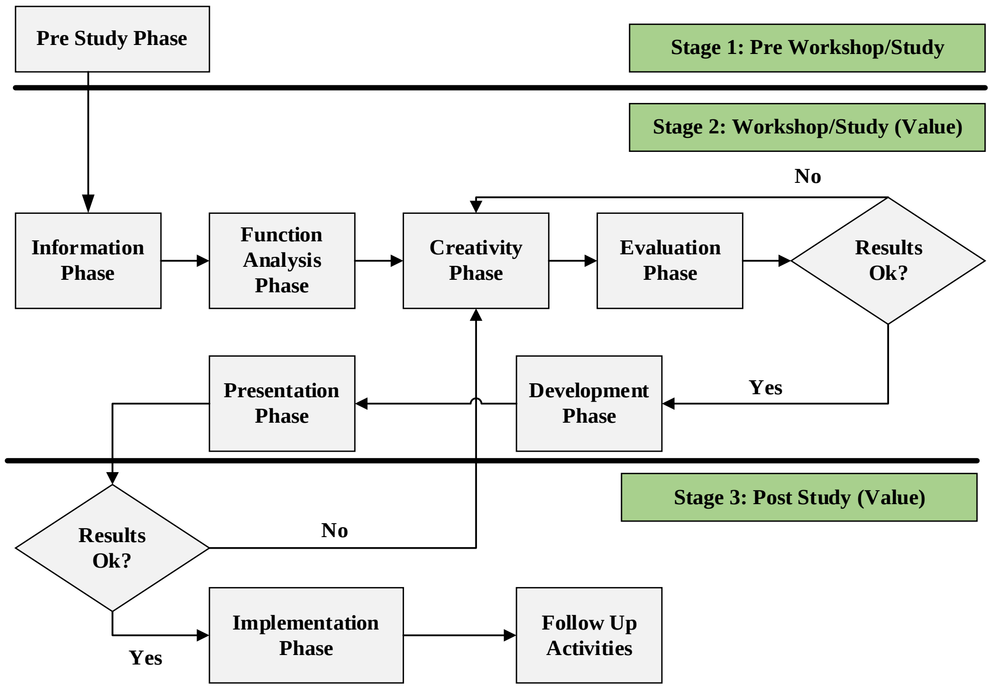

Figure 3 Value Engineering Flowchart (Mahdi [18])

Al-rikabi [19], asserts that four conditions must be met to raise the value of a product's functions:

1. Lower expenses while maintaining performance at the same level.
2. Prices are decreased while performance levels are raised.
3. Rise prices while enhancing performance, making sure that the performance level improves more than the cost rise.
4. Increase performance while maintaining the same level of expenditures.

Value engineering was initially utilized by the General Electric Company to find less expensive substitutes for necessary materials. The engineering development, engineering procurement, and value analysis departments were placed under the leadership of Mr. Lawrence D. Miles, a staff engineer of General Electric, in 1947. The US Navy Bureau of Ships used the phrase "value engineering" in 1954 to refer to the use of value analysis to save costs during the design phase [21]

3.2. Integration of Value Engineering and QFD

Yegenegi et al. [22], first introduced QFD and value engineering as proposed in Figure 4. Quality Function Deployment chooses the lucrative (lower cost) and advantageous option (in terms of conformity with organizational capabilities). In addition, the second quality house's solutions and relative values are included in the second value engineering stage, rather than adhering to the value engineering process rigorously. Value engineering is applied at the planning stage as this is when most future production costs are decided. The optimal choice is chosen based on a comparison of the implementation costs with estimated values, which are first computed. The model's use in service-based facilities attests to its ease of use and the executives' approval of the outcomes, or, to put it another way, their dependability.

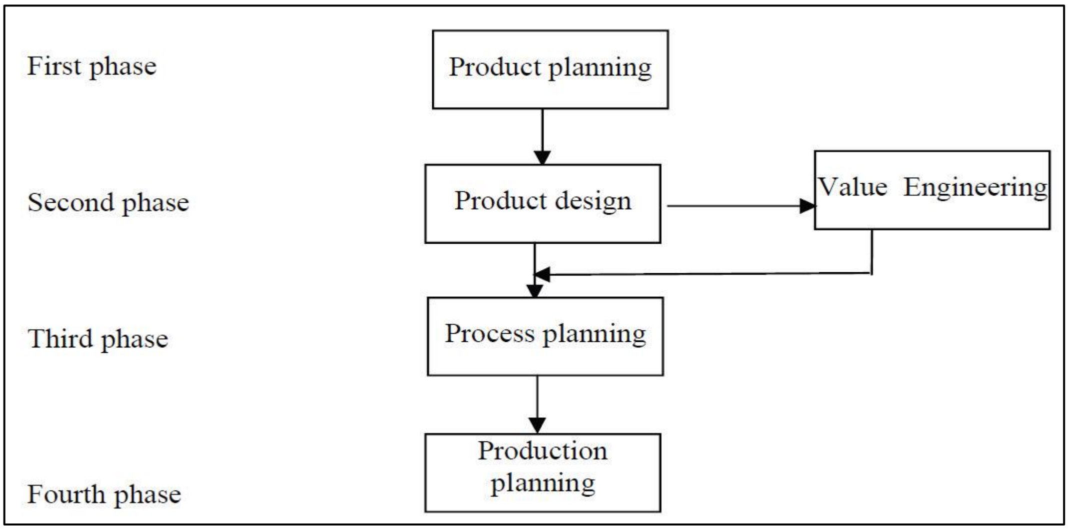

Figure 4 Value Engineering and QFD Integration Conceptual Model (Yegenegi et al. [21])

Value engineering, target costing, and quality function deployment (QFD) are three well-known management strategies that excel in the field of cost control. To get the optimal results for each of these methods integrate these strategies into a mathematical programming model [23]. The strategy attempts to maximize customer satisfaction based on targeted expenditures.

Soy milk machines are designed using a sustainable value-based life cycle design approach provided by Tao & and Yu [24]. It was discovered that the suggested framework might unite ecologists, business owners, and practitioners of process and product engineering around a common set of values. Solutions that are integrated throughout life cycles and products are also advantageous since they lead to a better, more sustainable business.

Berawi et al. [25], concluded that problems with value and quality persist throughout the construction project, not only with the finished product. Enhancing accomplishment via quality and value management is crucial, and it may be tracked at regular intervals from the planning and design phases of the project until its completion by adding new elements. Academics note that several nations have used quality and value management in building projects. Many thought

Durga Prasad et al. [26], provided a multi-objective optimization framework to enhance product development to balance customer satisfaction, cost, and usage using a case study of home refrigerator items. In the second phase of the QFD process, the actual design process is executed. The part planning matrix is reflected in the model to assess the component characteristics based on customer demands. When used in conjunction with value engineering, target costing helps manage or control production costs throughout the conceptual design phase. The multi-objective approach of the proposed technique allows the firm to ensure higher-quality, more affordable products. Analyzing the third phase (process planning matrix) as QFD is also necessary when applying the recommended technique to the manufacturing sector.

In their study, Prasad, Subbaiah, and Rao [27], proposed a model that aims to worsen product development while balancing cost, customer happiness, and product functionality. They concluded that parts may have their features altered to suit the needs of the consumer. Target costing works well for monitoring product costs throughout the design phase when combined with value engineering.

Gunnam and Eneyo [28], researched the value engineering and quality function deployment combination in the smartphone product planning process. Next, the QFD approach is applied for product planning and predicting product projections in the market utilizing specific solutions from quality houses. Value engineering is used to establish costs, and the best option is selected by calculating the outcome of a cost-to-value analysis.

Rajiv et al. [29], state that Indian enterprises that produce electronic switches have seen an increase in product market sales as a result of applying value engineering ideas to the deployment of quality functions. The creation of an integrated QFD model has addressed economic competitiveness by highlighting the importance of providing products with improved designs at low costs that will continue to benefit both seasoned business professionals and aspiring product developers.

A methodical technique to target costing was used by Gandhinathan et al. [30], for an air horn model product produced by the Jaishree company. Value Engineering is utilized in conjunction with fuzzy logic to meet cost objectives, while QFD is used to fulfill the technical requirements of customer needs. They concluded that value engineering and the deployment of quality functions were essential for the successful use of fixed target costing.

QFD was used by Ni et al. [31], to examine how product technical features and customer needs relate to one another. To cut down on waste, non-essential product qualities might have their functions removed. A value engineering technique may be used to compare different design resolutions. Integration successfully raises design accuracy while balancing the expenses of the product life cycle with its utility quality.

Gavareshki et al. [32], used value engineering techniques and QFD that are appropriate with the utilization of lean approaches to increase the efficiency of product design. They developed and documented control tests of product design. The lean approach assessment table, the value engineering matrix, and the QFD (four matrices) apply the application of the four quality houses in the form of a combinational process.

Sharma [33], combined the many tools of customer direction, financial concern, and value development in an attempt to include target costing and value engineering into a quality function deployment framework. The suggested strategy integrates the organizational and functional aspects of the development process to optimize value development. Through the use of a case study involving a refrigerator product, the difficulties of employing a cross-disciplinary approach were demonstrated from the perspective of a business expert. This approach is suitable to support a broad range of services and products and performs effectively in several product development contexts.

3.3. Integration of Value Engineering and DFA

According to Setti et al. [13], integrating this strategy can assist in saving costs and time associated with product development, enhance product quality, and boost customer happiness. The authors found that the combination of value engineering and design for assembly (DFA) allowed for a deeper comprehension of the product and its components. This makes it possible to find extraneous expenses and complexity, which can subsequently be eliminated from the design. This methodology also makes it easier to put into practice a customer-centric approach to product creation.

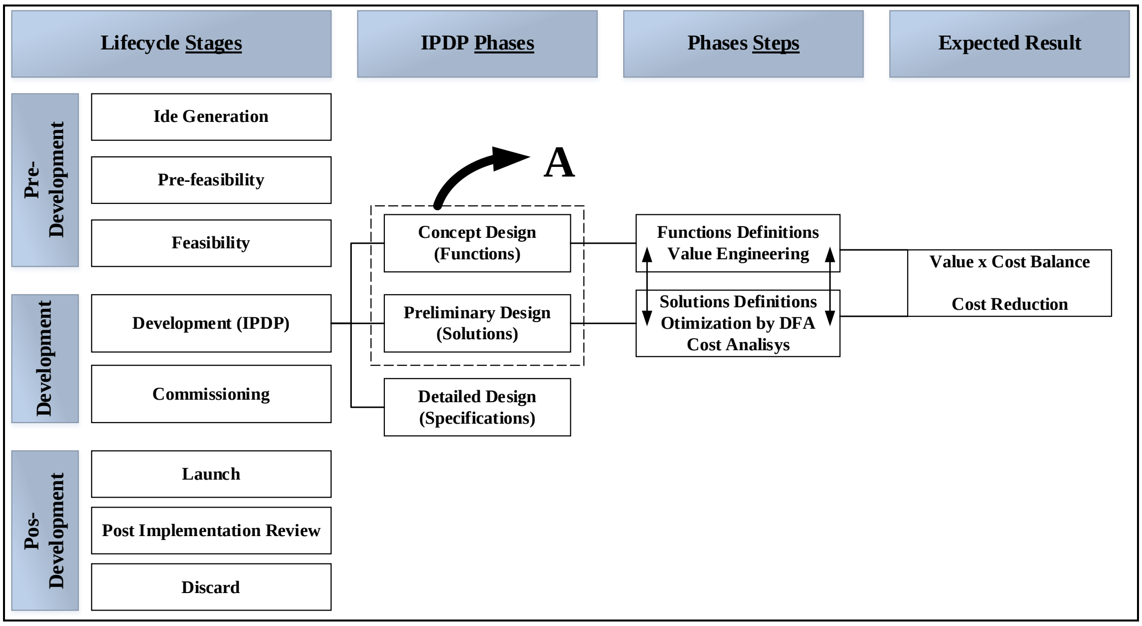

Figure 5 As an Integrated Product Development Method, the Value Engineering Conceptual Model (Setti et al. [13])

Product development strives to structure the design process for goods that are more evenly distributed between the real cost of each function and the value that customers perceive in them [34]. In the first iteration of the design idea (Figure 5), a new development function is described as an operation performed by a material item to modify or preserve the characteristics of another material object [35],[36]. Thus, identifying and highlighting the functional benefits and drawbacks of an engineering system or product is the aim of functional analysis. As a result, design conceptualization continues until all of the new product's functionalities are specified. Furthermore, every additional value is determined with the end user in mind. Since the link between perceived significance, cost, period, and breadth forms the foundation of the concept [37].

Three separate processes are involved in the fundamental execution of VE and VA techniques: assigning a function, evaluating a function through comparison, and developing substitute solutions that aim to find value for the cost. Therefore, value engineering is positioned as a bridge between the conceptual design and the early stages of design. This is so because the former prioritizes function while the latter focuses on solutions. In summary, the value of a product may be expressed as follows: value = function/cost. Its value may be increased by reducing expenses and improving the product's perceived functionality at the same time, which will help it better accomplish its goals [38].

The market value of a product and its many functions might be interpreted differently by each consumer, making it difficult to strike a balance between them. The reduction of the solution's cost is not the only way to enhance the value balance of a product or product function. In certain cases, raising the price of a certain feature might also raise the product's worth. It is not always possible to ensure that a product's market value will rise by only cutting component costs. Because DFA needs technical information and solutions, it is used in the early design. [39],[40],[41].

Knowledge or rule reasoning is engaged in the creation of assembly sequences, dimensional chains, compound type configurations, tolerance limit allocation, and qualitative simulations, according to Kretschmer et al. [42], these processes are supported by heuristic and empirical data. A knowledge-based system for product assembly design can offer simultaneous integration between the concept and detail design stages through qualitative simulation, enhancing the quality of the assembly idea. This method can assist design teams in striking a balance between the estimated value of each function of the new consumer product to be developed and the real costs of the solutions, helping them come up with designs that have the least amount of components and assembly-process-minimizing solutions.

The DFA approach demands more work upfront but ultimately yields benefits, including substantial cost savings and a shorter time to market [43]. The capacity of the product to be assembled from its functional defects can be analyzed [44]. According to Favi et al. [45], DFA provides more benefits than just reducing assembly time, and it does so while supporting a reduction in product manufacturing costs.

Products for coffee makers are created by Frizziero [46], employing cutting-edge techniques including value analysis, QFD, and DFA. He concludes that thorough information is crucial for design, and the value analysis demonstrates the importance of costs in design. It can locate items more quickly and satisfy customers' particular wants by using an organized flow of information [47],[48],[49],[50].

4. Conclusion

This study's goal is to review and assess several publications in the field that discuss value engineering methods in conjunction with other methods to improve and speed up product design throughout the development process. When used together, the three established approaches—value engineering, QFD, and DFA—are the focus of the investigation.

Value engineering works better when applied early in the design process to make sure that every option serves the intended purpose. Consequently, it is imperative to increase achievement that is consistently visible at all stages of the project life cycle, from planning and design to product innovation via the inclusion of new features. A vision of common values and a direction toward a stronger, more sustainable firm may also be produced through value engineering. The results indicate that there are distinct directions for the combination of QFD and value engineering. Nonetheless, this integration turns into a more desirable option when it comes to organizing or processing goods or services, which entails not only offering a better value for customer satisfaction but also keeping product costs stable without sacrificing product quality, performance, or reliability. By integrating value engineering with DFA, manufacturing costs may be minimized and project solutions with true costs that correspond to customer value can be provided. Product function and manufacturability factors are evaluated.

By putting this integration into practice, expenses, development times, and rework needs for goods and services may all be decreased. It would be beneficial for future studies if the aforementioned approach could be combined with other approaches, including design for dependability, safety, or other approaches.

REFERENCES

[1] U. Ibusuki dan P. C. Kaminski, "Product development process with a focus on value engineering and target-costing: A case study in an automotive company," *Int. J. Prod. Econ.*, vol. 105, no. 2, hal. 459–474, 2007, doi: 10.1016/j.ijpe.2005.08.009.

[2] R. Ginting dan A. Y. Ali, "TRIZ or DFMA combined with QFD as product design methodology: A review," *Pertanika J. Sci. Technol.*, vol. 24, no. 1, hal. 1–25, 2016.

[3] X. Lai, K. C. Tan, dan M. Xie, "Optimizing product design using quantitative quality function deployment: A case study," *Qual. Reliab. Eng. Int.*, vol. 23, no. 1, hal. 45–57, 2007, doi: 10.1002/qre.819.

[4] D. Unger dan S. Eppinger, "Improving product development process design: A method for managing information flows, risks, and iterations," *J. Eng. Des.*, vol. 22, no. 10, hal. 689–699, 2011, doi: 10.1080/09544828.2010.524886.

[5] R. Ginting, U. Tarigan, dan N. Panjaitan, "Integration of quality function deployment and value engineering: A case study of designing a texon cutting tool," *Songklanakarin J. Sci. Technol.*, vol. 42, no. 4, hal. 771–779, 2020.

[6] M. Niraj, "Selection of Maintenance Practice through Value," *Int. J. Sci. Eng. Res. Vol. 2, Issue 12, December-2011*, vol. 2, no. 12, hal. 1–4, 2011.

[7] J. Y. Farsi dan N. Hakiminezhad, "The integration of QFD technique, Value Engineering and design for manufacture and assembly (DFMA) during the product design stage," *Adv. Environ. Biol.*, vol. 6, no. 7, hal. 2096–2104, 2012.

[8] D. Alwerfalli dan A. Ali, "An Overview of Value Engineering in Product Development and Design," *IIE Annu. Conf. Proc.*, no. December, hal. 1–7, 2021.

[9] A. Jamwal, S. M. Towhidul Islam Nayim, R. K. Shukla, R. Agrawal, dan S. Gupta, "Assessment of barriers in lead time improvement: An exploratory study of electronics manufacturing companies in Himachal Pradesh (India)," *Int. J. Bus. Syst. Res.*, vol. 15, no. 2, hal. 182–199, 2021, doi: 10.1504/IJBSR.2021.113422.

[10] V. K. Singh, R. Kumar, dan M. K. Arya, "Automotive product development lifecycle optimization through value engineering and value analysis (VAVE) techniques," *2017 Int. Conf. Adv. Mech. Ind. Autom. Manag. Syst. AMIAMS 2017 - Proc.*, vol. 6, no. 5, hal. 349–354, 2017, doi: 10.1109/AMIAMS.2017.8069236.

[11] C. S. Park, H. J. Kim, H. T. Park, J. H. Goh, dan A. Pedro, "BIM-based idea bank for managing value engineering ideas," *Int. J. Proj. Manag.*, vol. 35, no. 4, hal. 699–713, 2017, doi: 10.1016/j.ijproman.2016.09.015.

[12] J. Harvey dan M. Aubry, "Project and processes: a convenient but simplistic dichotomy," *Int. J. Oper. Prod. Manag.*, vol. 38, no. 6, hal. 1289–1311, 2018, doi: 10.1108/IJOPM-01-2017-0010.

[13] P. H. P. Setti, O. Canciglieri Junior, dan C. C. A. Estorilio, "Integrated product development method based on Value Engineering and design for assembly concepts," *J. Ind. Inf. Integr.*, vol. 21, 2021, doi: 10.1016/j.jii.2020.100199.

[14] J. Chhabra dan B. Tripathi, "Value Engineering: a Vital Tool for Improving Cost & Productivity," *Int. J. Ind. Eng. Technol.*, vol. 4, no. 6, hal. 1–10, 2014.

[15] H.-M. PENG, J.-H. TIAN, dan J.-L. GAO, "Mechanical Product Design Based on Value Engineering," *DEStech Trans. Soc. Sci. Educ. Hum. Sci.*, no. mess, 2017, doi: 10.12783/dtssehs/mess2016/9770.

[16] M. Chougule dan S. Kallurkar, "Application of value engineering for cost reduction-a case study of universal testing machine," *Int. J. Adv. Eng. Technol.*, vol. 4, no. 1, hal. 618–629, 2012.

[17] M. Prilutskaya, A. Murukina, dan T. Dashkova, "Mechanical Engineering Product Value Design Applying the Value Engineering Method," *MATEC Web Conf.*, vol. 346, hal. 3038, 2021.

[18] I. Mahdi, K. Heiza, dan N. Abo Elenen, "Value Engineering and Value Analysis of Vertical Slip Form Construction System," *Int. J. Appl. or Innov. Eng. Manag.*, vol. 4, no. 6, hal. 200–212, 2015.

[19] D. N. S. Al-rikabi, "Integration Value Engineering with Target Costs into the Design and Development Stage from the Product Lifecycle A case study of the Electronic Industries Company – Baghdad," *Acc. Financ. Manag. J.*, vol. 07, no. 09, 2022, doi: 10.47191/afmj/v7i9.04.

[20] R. Ginting, *Perancangan dan Penegembangan Produk.* Medan: USU Press. 2022.

[21] Younker D., *Value engineering: analysis and methodology.* New York: CRC Press. 2003.

[22] K. Yeganegi, "The integration of QFD Technique and Value Engineering and its Applying in a Healthcare Center," *SSRN Electron. J.*, 2020, doi: 10.2139/ssrn.3601792.

[23] F. Jariri dan S. H. Zegordi, "Quality function deployment, value engineering and target costing, an integrated framework in design cost management: A mathematical programming approach," *Sci. Iran.*, vol. 15, no. 3, hal. 405–411, 2008.

[24] J. Tao dan S. Yu, "Product life cycle design for sustainable value creation," *Value Creat. through Eng. Excell. Build. Glob. Netw. Capab.*, hal. 297–326, 2017, doi: 10.1007/978-3-319-56336-7_12.

[25] M. A. Berawi, B. Susantono, H. Abdul-Rahman, M. Sari, Sesmiwati, dan H. Z. Rahman, "Integrating quality management and value management methods: Creating value added for building projects," *Int. J. Technol.*, vol. 4, no. 1, hal. 45–55, 2013.

[26] K. G. Durga Prasad, K. Venkata Subbaiah, dan K. Narayana Rao, “Multi-objective optimization approach for cost management during product design at the conceptual phase,” *J. Ind. Eng. Int.*, vol. 10, no. 1, 2014, doi: 10.1007/s40092-014-0048-8.

[27] K. G. D. Prasad, K. V. Subbaiah, dan K. N. Rao, “Cost engineering with QFD: A mathematical model,” *Int. J. Qual. Res.*, vol. 5, no. 11, hal. 33–37, 2011.

[28] S. C. Gunnam dan E. S. Eneyo, “Quality Function Deployment and Value Engineering Applications in Smartphone Cost Management,” *Int. J. Emerg. Eng. Res. Technol.*, vol. 4, no. 8, hal. 1–8, 2016.

[29] P. Rajiv, R. Logesh, S. Vinodh, dan D. Rajanayagam, “Financial feasibility and value engineering principles integrated quality function deployment for a manufacturing organization: A case study,” *J. Eng. Des. Technol.*, vol. 12, no. 1, hal. 71–88, 2014, doi: 10.1108/JEDT-11-2010-0070.

[30] R. Gandhinathan, N. Raviswaran, dan M. Suthakar, “QFD- and VE-enabled target costing: A fuzzy approach,” *Int. J. Qual. Reliab. Manag.*, vol. 21, no. 9, hal. 1003–1011, 2004, doi: 10.1108/02656710410561817.

[31] et al. Ni, Yanrong, “Value engineering-driven lean product development.,” *Adv. Sci. Lett.*, vol. 4, no. 6–7, hal. 2440-2445., 2011.

[32] M. H. Karimi Gavareshki, M. Abbasi, dan R. Rostamkhani, “Application of QFD & VE & lean approach for control tests in a product design,” *Arch. Mater. Sci. Eng.*, vol. 84, no. 2, hal. 65–78, 2017, doi: 10.5604/01.3001.0010.0980.

[33] J. Sharma, “A cross-disciplinary approach to product development and design through quality function deployment, target costing and value engineering,” *Int. J. Product. Qual. Manag.*, vol. 9, no. 3, hal. 309–331, 2012, doi: 10.1504/IJPQM.2012.046365.

[34] and S. L. D. S. Jugend, Daniel, “Product-portfolio management: A framework based on methods, organization, and strategy.,” *Concurr. Eng.*, vol. 22, no. 1, hal. 17–28, 2014.

[35] C. C. A. Estorilio, F. R. M. Rodrigues, O. Canciglieri, dan K. Hatakeyama, “Preventing problems in technology transfer: A case study,” *J. Ind. Integr. Manag.*, vol. 2, no. 1, hal. 1750006, 2017, doi: 10.1142/S2424862217500063.

[36] Y. T. Ko, C. C. Yang, dan P. H. Kuo, “A problem-oriented design method for product innovation,” *Concurr. Eng. Res. Appl.*, vol. 19, no. 4, hal. 335–344, 2011, doi: 10.1177/1063293X11425091.

[37] Project Management Institute, *A Guide to the project management body of knowledge*, vol. 34, no. 03. 2017.

[38] I. Michalakoudis, P. Childs, M. Aurisicchio, dan J. Harding, “Using functional analysis diagrams to improve product reliability and cost,” *Adv. Mech. Eng.*, vol. 9, no. 1, 2016, doi: 10.1177/1687814016685223.

[39] M. J. Cabello Ulloa *et al.*, “New integrative approach to existing design for assembly (DFA) methodologies: Application on elevator components,” *Proc. Int. Des. Conf. Des.*, vol. 1, hal. 215–224, 2018, doi: 10.21278/idc.2018.0381.

[40] A. L. Szejka, O. C. Júnior, E. R. Loures, H. Panetto, dan A. Aubry, “Proposal of a model-driven ontology for product development process interoperability and information sharing,” *IFIP Adv. Inf. Commun. Technol.*, vol. 492, hal. 158–168, 2016, doi: 10.1007/978-3-319-54660-5_15.

[41] A. L. Szejka, O. Canciglieri, E. R. Loures, H. Panetto, dan A. Aubry, "Requirements interoperability method to support integrated product development," *Proc. - CIE 45 2015 Int. Conf. Comput. Ind. Eng.*, 2015.

[42] R. Kretschmer, A. Pfouga, S. Rulhoff, dan J. Stjepandić, "Knowledge-based design for assembly in agile manufacturing by using Data Mining methods," *Adv. Eng. Informatics*, vol. 33, hal. 285–299, 2017, doi: 10.1016/j.aei.2016.12.006.

[43] R. Bogue, "Design for manufacture and assembly: Background, capabilities and applications," *Assem. Autom.*, vol. 32, no. 2, hal. 112–118, 2012, doi: 10.1108/01445151211212262.

[44] R. B. Stone, D. A. McAdams, dan V. J. Kayyalethekkel, "A product architecture-based conceptual DFA technique," *Des. Stud.*, vol. 25, no. 3, hal. 301–325, 2004, doi: 10.1016/j.destud.2003.09.001.

[45] C. Favi, M. Germani, dan M. Mandolini, "Development of complex products and production strategies using a multi-objective conceptual design approach," *Int. J. Adv. Manuf. Technol.*, vol. 95, no. 1–4, hal. 1281–1291, 2018, doi: 10.1007/s00170-017-1321-y.

[46] L. Frizziero, "A coffee machine design project through innovative methods: QFD, value analysis and design for assembly," *ARPN J. Eng. Appl. Sci.*, vol. 9, no. 7, hal. 1134–1139, 2014.

[47] L. Piancastelli, N. E. Daidzic, L. Frizziero, dan I. Rocchi, "Analysis of automotive diesel conversions with KERS for future aerospace applications," *Int. J. Heat Technol.*, vol. 31, no. 1, hal. 143–153, 2013.

[48] L. Piancastelli dan L. Frizziero, "How to adopt innovative design in a sportscar factory," *ARPN J. Eng. Appl. Sci.*, vol. 9, no. 6, hal. 859–870, 2014.

[49] L. Frizziero dan F. R. Curbastro, "Innovative methodologies in mechanical design: QFD vs TRIZ to develop an innovative pressure control system," *ARPN J. Eng. Appl. Sci.*, vol. 9, no. 6, hal. 966–970, 2014.

[50] L. Piancastelli, L. Frizziero, dan I. Rocchi, "An innovative method to speed up the finite element analysis of critical engine components," *Int. J. Heat Technol.*, vol. 30, no. 2, hal. 127–132, 2012, doi: 10.18280/ijht.300218.