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Enhancing Sustainability Attributes in New Product Design Insights from Automotive Industry

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Abstract: Product design is an innovative process that, through the stages of problem statement, concept, and initial and detailed design, meets the needs of customers, the requirements of companies, and their limitations. In the current process of product design and development, formulating design objectives plays a crucial role in objective setting, project implementation, product needs and requirements specification, and performing activities validation. Currently, the role of the design and development stages in the sustainability of products, identifying strategies for improving this stage is of particular significance, and paying attention to the product planning and definition process group and focusing on establishing sustainability principles in the target book and defining new attributes can be regarded as one of the sustainable product development strategies. Consequently, this research is a case study in the field of applying the sustainability principles in the target book as one of the deliverables at the stage of product planning. The present study proposes strategies towards developing the attributes of the target book as a tool for exerting sustainability pillars in the process of design and development by means of surveying automotive industry experts, applying the DEMATEL and Fuzzy ANP combined method, and evaluating and determining new attributes.

Keywords: new product development; sustainability; product attributes; design target; target book; sustainability pillars

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1. Introduction

According to APQC's (American Productivity & Quality Center) Open Standards Benchmarking (OSB®), product design and development process groups include the product planning and definition process group, product detail design process group, manufacturing process design and development process group, product/process validation process group, and product manufacturing process group. Following the authors' research Omidzadeh et al., (2021) [1], of these process groups, the product planning and development process group is known as the most effective in establishing sustainability pillars. Moreover, in another study by the authors, of a total of 40 deliverables, the target book, which is a tool for validating the new product development stages incorporating the definition of characteristics and attributes of the new product, was selected and determined as the most efficient deliverable in establishing sustainability pillars by ranking the deliverable in the product planning and definition process group.

In order to explain the importance of research, it can be explained that today, companies face many challenges due to the complexity of their products and their design and development activities, in addition to using innovative facilities and innovative technologies in new products, which as a result affect the entire cycle. Therefore, companies are obliged to pay more attention to some concepts in the field of sustainability, product life cycle management, and sustainable product development.

Based on this, the main goal of the current research is to develop the target book and the attributes mentioned in it in order to develop and establish sustainability pillars in the final product at various stages of the product life cycle. Finally, by addressing the current research gap, new attributes for the product target book are suggested.

The research method in this article, following the introduction, the problem is stated and definitions are provided in the context of product development processes and selected process group, deliverables are defined, and the most effective ones in establishing sustainability pillars are introduced. Product attributes are also introduced, and finally, new attributes are identified in the scope of the establishment of sustainability pillars in the target book and the new product design process group.

In this section, considering the purpose of the study, ranking of the new attributes, and the impact of the interchangeable interactions between these attributes on the stability criteria, while introducing the DEMATEL method and fuzzy network analysis process and using a combination of these two methods, the problem is analyzed. Furthermore, using the ranking capabilities of the DEMATEL method, the pattern of causal relations between the variables is identified, and the interrelationships between them are demonstrated in an understandable structural model using diagrams that can divide the factors involved into two groups of cause and effect. By applying the ANP approach, which can obtain combined weights through the formation of a "super matrix", the interdependence between the elements is eliminated, and the attributes are ranked.

It should be noted that this method is very useful for obtaining more accurate and effective results, including complex and fundamental decision-making problems, and uses three matrix analyzes: super matrix, weighted super matrix, and limited matrix. The super matrix specifies the relative importance of all components, and the weighted super matrix is used to find the value obtained by the super matrix values and the value of each cluster. The limited super matrix obtains the fixed value of every value by taking the required limit of the weighted super matrix. Finally, in the conclusion section, the new attributes of the target book are introduced as the innovation of the study. Additionally, a set of product attributes with the maximum impact on sustainability is achieved by applying the integrated DEMATEL and Fuzzy ANP techniques.

2. Literature Review

2.1. Importance of the New Product Design and Development Process

Although there are many design methods, the models and tools used in these design methods do not fully understand the coherence between the needs of customers, the needs of professionals and the solutions that can be found. In his article, Prudhomme G., Zwolinski P. & Brissaud D. (2003) [2] reviews a functional analysis method that was specifically developed to consider requirements during the design process.

Appelqvist et al. (2004) [3], and Dowlatshahi (1992) [4], believed that product design is a critical and effective process in product sustainability and approximately 70 percent of product cost and 80 percent of product quality are determined during the stage of product design, making it a significant challenge for companies.

Subsequently, Ernest h. (2002) [5], argued that new product development processes are a vital activity for the survival and constant improvement of companies.

In his paper, Storga M. et al. (2010) [6] presents a research on the nature, construction and practical role of a design ontology as a potential framework for data, information and knowledge, describing, explaining, understanding and reusing more efficient product development (PD). As a result of the previously described process, the content of the ontology is classified into six main subcategories divided between the physical and abstract worlds. As a next step, a computer thesaurus was created. Using a thesaurus, the knowledge evolved during PD is described, and the set of concepts and relationships created are used to check the consistency and refinement of the ontology model. The design ontology was evaluated through test product samples, and based on this evaluation and the proposed implementation framework, further research steps are suggested.

In their paper, Chu C. et al. (2012) [7] presents a computational framework for reducing the environmental impact of product development by considering product design, manufacturing, and supply chain simultaneously. This framework includes a number of factors that environmentally affect product life cycle activities in product architecture design.

Ganon B. et al. (2012) [8] in their article pointed out that the challenge of resetting the current path of development in a sustainable path is related to all sectors of society, including engineering. They stated that to move towards a sustainable engineering practice, the design process needs to be modified so that engineers can effectively deal with related issues. Such "sustainable design processes" (SDPs) have been proposed in the literature. By examining the conventional design process and sustainable design processes, the purpose of this paper is to identify the differences between both approaches.

In their paper, Vezzoli C. et al. (2015) [9] pointed out the great potential of sustainable product-service systems (S.PSS) to provide social and economic well-being while operating within the limits of our planet. Their studies provide information about "new design challenges for the widespread implementation of "sustainable product-service systems", the results of key studies: user satisfaction and acceptance of S.PSS solutions, how to design industrial partnerships and stakeholder interactions for environmental and social-ethical benefits. How knowledge of socio-technical change and transition management feeds S.PSS design processes, and the role of policy tools to strengthen their implementation and scale-up.

In his article, Bonvoision J. et al. (2016) [10] summarizes the published literature in order to introduce a common language in the field of product modularization and to establish the theoretical basis of a multipurpose approach—called "modularization for X".

According to him, product architecture has a significant impact on all stages of the product life cycle. Many literature sources claim that modular product design offers a range of advantages to address this effect.

It is based on a systematic literature review covering a collection of 163 publications, presents a structured set of stimuli, design principles and modularization criteria, and identifies challenges for further research efforts.

He B. & Yicheng H. (2017) [11] presented an article about the role and effects of conceptual design on the carbon footprint of a product. He believed that existing product models for conceptual design always focus on knowledge modeling and knowledge organization, etc. However, the traditional approach is not to provide a better understanding and reuse of low-carbon design knowledge for low-carbon conceptual design. This paper is dedicated to presenting a feature-based integrated modeling approach from the product model to the low-carbon conceptual design so that functional design knowledge can be effectively transferred to the main conceptual design and structure conceptual design and even the subsequent design process.

In his paper, Qiao L. et al. (2017) [12], a hybrid approach, based on multidimensional scaling (MDS) and clustering methods, is applied to component DSM for product architecture. The motivation is to facilitate better modularization that enhances different product features at different stages of the product life cycle. An empirical framework is developed to evaluate the performance of MDS clustering.

Renzi C. et al. (2017) [13] paper systematically examines how decision-making methods are used by automotive designers to solve the most common engineering problems involved during the design process. In particular, this paper proposes a basic classification of the most widely used decision-making methods in engineering design, the correspondence between such techniques to typical design processes, and a mapping of their application to the automotive context.

In this article, Chakraborti K. et al. (2017) [14] refers to the topic of re-production as one of these business proposals that has become very popular in the present era, where environmental issues, reuse, sustainability concepts in product design, end of life of products are taken into consideration. he does. For efficient and effective remanufacturing, product design plays an important role. The purpose of this paper is to identify the design criteria of a product that can increase its re-manufacturability and subsequently, using these design criteria, a hierarchical model is created to evaluate the re-manufacturability between product options.

Furthermore, Lumsakul P. et al. (2018) [15] discussed the challenges and problems in the design of products and manufacturing systems that are the result of changes in customer needs and increasingly frequent altercations in products and required resources. They believed that integrated design processes lead to the integrated development of products and sustainable manufacturing systems. Moreover, these researchers examined the relationship between the interactions of these design processes from a resource efficiency perspective, presented a new model of sustainable design, and discussed the environmental advantages of shared design products and manufacturing systems.

Perceived quality (PQ) is one of the most important product attributes in the automotive industry that defines successful vehicle design. In his paper, Stylidis K. et al. (2018) [16] present a new approach to PQ evaluation by examining PQ decomposed into a structure with a top-down approach to the level of essential features ("land") that covers almost every aspect of vehicle quality perception. They cover the engineering point of view. This paper proposes a new method to rank the relative importance of PQ features, which lead to a vehicle's PQ balance, under given conditions. The proposed method helps to balance the vehicle quality equation from the perspective of design effort, time and cost estimation. The authors introduce the Perceived Quality Framework (PQF), which is the classification system for PQ attributes and the core of the attribute importance ranking method. The research results are based on the findings of a qualitative exploratory study involving European and North American premium luxury car manufacturers. To validate the proposed method, an industrial pilot study was conducted with an automotive company to investigate the importance ratings of PQ attributes obtained from automotive industry experts. The results can significantly improve PQ assessment at all stages of product development.

Wats M. & Hallstedet S.I. (2018) [17] and his colleagues stated in the article that the trade-off between sustainability criteria and engineering design variables can lead to sub-optimizations and short-term costly priorities. This study examines how sustainability requirements can be identified and integrated into product requirements to guide strategic and tactical decisions in product development, including sustainability perspectives. Literature review and action research led to a proposed systematic approach that defines sustainability criteria and indicators. Use correlation analysis with QFD and add identified specific sustainability requirements to the list of requirements.

Borgianni Y. & Rotini F. (2018) [18] pointed out in their article that many researchers argue that the very early stages of design are not adequately supported in many ways, even though they are the cornerstone of successful new product development. Difficulties in developing suitable methods arise due to the need to consider the uncertainties and ambiguities related to the Front End fuzzy. This is probably the reason for the limited industrial acceptance of existing design methods, especially those aimed at supporting product planning. In this context, the aim of his article is to try to identify the key activities and functions of product planning. This study provides figures on the predictable growth of research intensity represented by classes of methods that support different functions in product planning. Also, this paper includes a reference framework that categorizes (sufficiently reviewed) product planning methods beyond the classical distinction between responsive and proactive approaches. Eddy D. et al. (2019) [19] introduce a Design for Any X Manufacturing (DFXM) method to be used in the early stages of design to identify the best process for a given product design where comprehensive current process databases may not yet be available to the designer. Screen Process Choices This DFXM method customizes targeted questions to break down concepts into key elements while capturing any known inconsistent process choices in consistent formulations. This method correlates any measurable criteria found for each criterion in the conceptual design in these formulations to evaluate them accordingly.

Physical architecture is important for designing complex products because it mediates between conceptual design and detail design. An efficient production and evaluation method for physical architecture is essential for successful design. In this study, Chen R. (2019) [20], an automatic generation and evaluation method for feasible and ranked physical architectures is proposed. First, an integrated knowledge model is created and the components that can realize the specified functionality in the functional architecture are identified. This automated method generates and ranks all applicable physical architectures, helping system designers make rapid trade-offs. A car case study is presented to demonstrate the feasibility of this method.

In the article, Liu Y. et al. (2019) [21] mentioned the issue of technological capability and technology management in product development. According to his belief, new product development (NPD) determines the current position of companies in the market and also has wide effects on the future development of companies. According to the resource-based perspective, technological capability and technology management capability are critical resources and capabilities for NPD. However, research to date has not examined the complementarity of these factors. Their paper uses fuzzy set qualitative comparative analysis (fs/QCA) to examine how technology capability and technology management capability combine to produce high NPD performance. The results of the analysis show that to achieve high NPD performance, technological capability and technology management capability should be combined.

In his article, Hoolohen C. & Browne A.L. (2020) [22] addresses the connection between design thinking and theories of social action and presents a tool to support the development of sustainability interventions and policies capable of encouraging sustainable practices. Key developments in theories of design thinking and social practice are critically examined, and a toolbox is presented that sensitively combines their conceptual and methodological insights.

In his review, Marzi G. et al. (2021) [23] presents the development of NPD management literature published in the last ten years (2008 to 2018) and with an evaluation in 1226 reviewed articles. By using bibliometric analysis, he adapted the existence of five research clusters focused on the following main subject areas. These include the NPD process, integrating diverse knowledge sources to optimize NPD, the relationship between NPD and corporate strategy, the role of users and consumers.

In another study, De Oliveira M. et al. (2021) [24], discussed to conduct a Systematic Literature Review about the future challenges for Product Lifecycle Management and Sustainable Development, considering the context of Industry 4.0.

In their article, Omidzadeh et al., (2021) [1] while reviewing product design and development processes, focused on ranking product development process groups and identifying the most effective process group in product sustainability through Delphi-GAHP and COCOSO methods. In order to perform this task, product life cycle, new product design and development process groups, gate planning, deliverable items, and elements of product sustainability have been introduced and the necessary data has been collected, and with the help of automotive industry experts, the most effective process group in product sustainability has been selected. And the deliverables were ranked in the selected process group to isolate the most effective deliverable in product life cycle sustainability. Based on the research findings, the product planning and definition process group has the highest-ranking score and the ability to create sustainability elements with the highest effectiveness in developing a sustainable final product.

2.2. Product Life Cycle and Its Importance

The effects of our increasingly unsustainable production and consumption have necessitated a fundamental shift in product design and development. This shift is embodied in the sustainability landscape achieved through Sustainable Life Cycle Design (SLCD).

In a research paper, Veshagh A. & Obagun A. (2007) [25] analyzes the current practice of SLCD in the UK manufacturing industry by conducting a survey of companies in five major sectors. A case study is also presented to discuss the implementation of SLCD strategies in practice. A critical analysis of the trends obtained from the survey and a comparison of the results are presented. This article ends by summarizing the main findings of the review and providing a set of guidelines and recommendations for planning and implementing sustainable life cycle design in the industry, thus suggesting a change of direction from conventional product design and manufacturing to sustainable production and consumption.

Since in the past years we have seen growing investments in the field of product life cycle management (PLM) by the automotive sector, Tang D. & Qian X. (2008) [26] claimed in his article that the PLM system must evolve to respond to this new trend. To support the management of collaboration and partnership between the automotive OEM and related suppliers, and to keep pace with these above tasks, a PLM framework is developed in a broader perspective in this paper, which integrates supplier and process partnership management. Enables vehicle development throughout the entire life cycle. Finally, an automotive case study is presented to illustrate how to implement PLM with a focus on supplier integration.

A study conducted by Cao H. & Folan P. (2011) [27], reviews relevant product life cycle models presented historically in the literature and divides them into two categories the long-established marketing product life cycle model, and the emergent engineering product life cycle model.

According to article of Go T.F, Wahab D.A. & Hishamaddin H. (2015) [28] the development process of product design is changing from "cradle to grave" to "cradle to cradle", which leads to the emergence of a multi-generation product life cycle. In his article, he reviewed the design guidelines from Design for X, which provides orientation criteria in design for multi-generational life cycles. Therefore, in this article, design for multiple life cycles is defined as a combination of environmental design strategies including design for the environment and design for restoration, which leads to other design strategies such as design for improvement, design for assembly, design for It is for separation.

In a study, Hsu C.W. et al. (2015) [29] investigated the use of decision-making experimental and evaluation approach (DEMATEL) to identify the effective criteria of carbon management in the green supply chain to improve the overall performance of suppliers in terms of carbon management. Thirteen carbon management criteria with three dimensions were identified from the literature review and interviews with three experts in an electronics manufacturer, and considering the mutual relationships between the criteria, the DEMATEL technique was used to address the importance and causal relationships between the supplier selection evaluation criteria.

In his article, Katsikeas C.S. et al. (2016) [30] addressed the issue of sustainability and product development. According to him, the integration of sustainability aspects in product development has long been recognized as a strategic priority for professionals. However, the literature reports mixed results on the product development effectiveness outcomes of sustainable product development strategies, while few studies have investigated how companies integrate environmental aspects into product development. This study develops a model that integrates effectiveness enhancement results and organizational inputs of environmentally friendly product development strategies.

In his article, Littell N. (2016) [31] addressed the issue of product life cycle management and product data management. According to him, modern manufacturing companies use advanced technologies to manage their engineering data so that they can produce products with advanced features faster than ever.

People, culture, product data management (PDM), process management and project management combine to achieve synergy in the enterprise. Technological automation of these parts is the core of Product Lifecycle Management (PLM). These components are discussed in terms of their contribution to the modern PLM landscape. Since PLM is a standard method for engineering data management, modern educators must be aware of the methods used in the modern manufacturing engineering environment to successfully train engineers.Tao et al. (2018) [32] pointed out that product life cycle assessment can contribute greatly to product design by predicting product impacts during its life cycle.

According to the author, Lou S. et al. (2020) [33], successful product development relies on an enterprise system (ES) to manage product life cycle data and support decision-making at various levels. As the amount of data generated in the Industrial Internet of Things (IIoT) is increasing dramatically, new ES paradigms are required to realize distributed intelligence. Recent advances in edge computing have enabled improvements in decentralized decision support systems. Although product design is a key stage of new product development, none of the recent studies on edge-based ES have shed light on this stage. Therefore, an edge-based ES framework for design plan evaluation is proposed in their paper.

In his research, Grenz J. et al. (2023) [34] seeks to develop a methodology that can be practically used in industry to integrate prospective life cycle assessments (PLCA) into the life cycle engineering of automotive components, considering relevant parameters and adaptive scenarios. Therefore, prospective life cycle methods are further developed to investigate the impact of future scenarios on the emissions of automotive components. A practical application is shown for an automotive component with different design options. This paper shows that different foreground and background system development paths can change the environmental optimality of design alternatives.

2.3. The Role of the Design and Development Process in Product Sustainability

Hopwood B. et al. (2005) [35] presents a classification and mapping of different trends of thought on sustainable development, their political and policy frameworks and their attitudes towards change and means of change.

In an article, Klopffer W. (2008) [36] talked about the importance of establishing sustainability in products. According to him, the goals of the background and scope of sustainability were accepted by UNEP in Rio de Janeiro (1992) as the main political goal for the future development of mankind. It should also be the ultimate goal of product development. According to the well-known interpretation of the original definition presented in the Brundtland report, sustainability includes three components: environmental, economic and social aspects. Also, according to his belief, if a new product is to be designed or an existing product is to be improved, these components or "pillars" of stability must be properly evaluated and balanced, and the methods are the responsibility of the researchers involved in the evaluation, providing appropriate and reliable tools. For the environmental sector there is currently an international standard tool: Life Cycle Assessment (LCA). Life cycle costing (LCC) is the logical counterpart of LCA for economic evaluation. LCC goes beyond purely economic cost calculation by considering usage and end-of-life stages and hidden costs. It is very important to point out that various life cycle-based methods (including social life cycle assessment "SLCA") use consistent ideally the same system boundaries for sustainability assessment. This requirement includes LCC's use of the physical life cycle ("from cradle to grave") rather than the often used marketing life cycle ("from product development to end of market life").

Petala E. et al. (2010) [37], points out in his article that organizations face challenges in integrating sustainability in the early stages of their new product development (NPD) processes. This paper examines these challenges in order to understand the barriers to incorporating well-defined sustainability objectives into NPD briefs.

In their paper, Fargnoli M. et al. (2014) [38] point out that the need for sustainable products has increased significantly in recent years, and although there are well-established tools to help designers deal with environmental problems (e.g., (environmental design) has been developed, a more user-centered approach that pursues design for sustainability issues has not yet been proposed.

Although new product development provides the possibility to deal with sustainable features in the product life cycle, but since the aspect of sustainability is often neglected in new product development, Gmelin H & Seuring S. (2014) [39] presented in their article the link between sustainability and new product development. By providing a conceptual framework, this framework focuses on the interrelationships of sustainability and new product development with a product and life cycle perspective.

Romli A. et al. (2015) [40] present an integrated environmental design decision-making method (IEDM) that is formed using three steps: life cycle assessment, an eco-process model, and an eco-design quality performance deployment process.

In his research, Eddy D. et al. (2015) [41] stated that the selection of materials significantly affects the environmental impacts and other product design goals. Life Cycle Assessment Methods (LCA) for early design stages for pruning a design space are not efficient enough. The material properties are composed of discrete data set, which are more complex when incorporating LCA data, so they create an important challenge in the construction of successive models to predict all relevant behaviors and numerical optimization. In this work, he has addressed the unique challenges of choosing materials in sustainable product design from some important methods.

Multi-criteria decision making methods (MCDM) and fuzzy set theory are the two best approaches to deal with the multi-criteria nature of the personnel selection problem and the vagueness of predictions. Kabak M. (2015) [42] for this purpose, this paper proposes an effective model based on fuzzy DEMATEL (decision-making experimental and evaluation laboratory) and fuzzy ANP (analytical network process) to help organizations that need to evaluate and select applicants for the described job. This model first applies DEMATEL to deal with interdependencies between evaluation criteria. Then, it uses fuzzy ANP to calculate the weight for each criterion and evaluate the applicants.

In their research, Ameli M., Mansour S. & Ahmadi-Javid A. (2016) [43] pointed out that sustainable product design, which focuses on evaluating the future effects of products in the design phase, is an important task to achieve sustainability goals. They claimed in their paper that the product designer has considerable freedom in the design phase, so end-of-life (EOL) considerations can be taken into account at this stage. This paper presents a two-criteria stochastic optimization model based on the developed individual responsibility of the manufacturer to improve product EOL management by considering life cycle issues in the product design stage.

Ceschin F. and Gaziulusoy I. (2016) [44] explore the evolution of Design for Sustainability (DfS) in their paper. Following a pseudo-chronological pattern, our exploration provides an overview of the DfS field and categorizes the design approaches developed in the past decades into four levels of innovation: product, product-service system, spatial-social and socio-technical system.

Ameli M., Mansour S. & Ahmadi-Javid A. (2016) [43] claimed that discussing sustainable product design and manufacture is a crucial strategy in achieving sustainability and new manufacture objectives. They believed that one can define sustainability as the ability of a product to work constantly with minimum environmental impacts, providing economic and social benefits. Meanwhile, today, new product design and development, which is an exhaustive concept, is gaining more attention.

Tai Y.M. (2016) [45] studied the impact of product life cycle management systems (PLM) on the performance of the new product development (NPD), and this study created a conceptual model that enables companies to publish and conventional PLM systems in NPD processes (called "PLM system capability" created process management, coordination and absorption capabilities. The study assumed that the selected management capabilities mediated the impact of PLM capability on NPD performance. Experimental results support theoretical relationships, showing that PLM system capabilities form corporate capabilities for managing the NPD process, partner coordination and knowledge absorption, which subsequently affects NPD performance. Therefore, in order to improve NPD performance, managers need to create the right conditions for implementing PLM systems to enhance the management capabilities required by NPD.

Schöggl J.P. et al. (2017) [46] believes that in the early stages of product development, it is important to reduce costs and improve product sustainability performance, and to have sufficient data on the costs and sustainability aspects of innovative concepts such as lightweight vehicle design, which require the use of new materials and processes. Not available. The tools used in environmental design and sustainable design have disadvantages because they either focus on only one dimension of sustainability, require little data on materials and processes, or cannot be applied by designers and engineers. In order to overcome these disadvantages, he proposed a new checklist for sustainable product development, which provides the possibility of qualitative assessment of environmental, economic and social aspects in the early stages of product development, and at the same time considers the full life cycle perspective. This case study showed that the developed tool helped designers and engineers to evaluate and improve the sustainability performance of a technology and stimulated collaboration and information exchange processes within and between organizations.

In order to develop methods of evaluating and classifying criteria, Chou Y.C. (2017) [47] and colleagues in an article created a set of dimensions and criteria for evaluating green project management. An integrated approach combining the Decision Testing and Evaluation Laboratory (DEMATEL) and the Analytical Network Process (ANP) is used to determine the structure of interrelationships and the priority of each dimension and each criterion in a green project management. Six dimensions and twenty-four criteria of a green project management have been identified based on relevant research in the fields of environmental sustainability and supply chain management. The empirical results show the structure of mutual relations and the priority of each dimension and each criterion in green project management.

Ahmad S. et al. (2018) [48] proposes a more general and broad classification scheme to enhance the understanding of product design tools. Those that included two aspects of sustainability were classified as partial sustainable product design tools (P-SPD) and those that covered three aspects of sustainability were classified as sustainable product design tools (SPD). The analysis showed that SPD instruments were more mature and standardized compared to P-SPD instruments.

According to Zolfani S.H., Chatterjee P. & Yazdani M. (2019) [49] the issue of sustainability in industrial organizations has become one of the dominant concepts in the field of modern industrialization due to global warming, economic importance and social awareness, and these are a great concern for sustainable supply chain management (SSCM). has created to be adopted and promoted as an innovative business model. According to him, supplier evaluation and selection plays an important role in SSCM to make appropriate procurement decisions. His research method is a hybrid MADM model based on the best worst method (BWM) and hybrid solution (CoCoSo).

Kim S. & Moon S.K. (2019) [50] stated in an article that a product family is used to minimize development costs and maximize profits. Because the products in a product family have similar product functions and architecture, the product family has a high potential for stable product to extend the life of the products by sharing new and refactored modules. Therefore, this paper proposes a method to identify a sustainable product family configuration by integrating sustainability performance and a platform strategy. The concept of a sustainable platform is introduced to increase reusability based on high compatibility in terms of space, performance and interface. Stable platform and rebuildable modules are used as limitations in the proposed method. A multi-objective design optimization approach is then applied to determine the optimal configuration of the product family in terms of sustainability. Sustainability is mathematically modeled to quantify three types of performance: environmental impact as an environmental performance, profit as an economic performance, and customer demand as a social performance.

Omidzadeh D., et al. (2022) [51], developed a mathematical model to establish sustainability pillars in the design and development process of a car platform. By collecting various data from 15 modules of a vehicle platform and using multi-objective planning with the enhanced epsilon constraint method, they presented a solution to select the most sustainable vehicle platform.

In their review article, Asyraf M.R.M. et al. (2022) [52] have addressed the topic of new product development with the aim of integrating design principles for sustainability and integrating sustainability into engineering plans to produce greener products, system innovation, and services in line with current market demand. By conducting a case study on polymer composites reinforced with natural fibers related to sustainability, they have developed the application of design for sustainability techniques by professional designers.

In research, Scharmer W.M. et al. (2023) [53] provided a structure for the issue of sustainable production, helping to understand and categorize ongoing activities and identify starting points for future research and development. In this research, extensive literature review is presented. A framework for sustainable manufacturing that serves as a call to action for academia and operations management in industry alike is derived from this literature review and this publication contributes to a common and clear understanding of sustainability and the various aspects of sustainability in manufacturing.

In their article, Bas S.A. (2024) [54] pointed out that with the increase in global trade, businesses must manage their supply chain and at the same time consider not only costs, but also environmental consequences. Green supplier selection (GSS) decision-making is a strategic priority for companies to survive in challenging market conditions and effectively and sustainably manage their supply chains in an increasingly polluted and resource-poor world. Environmental sustainability can be enhanced with appropriate criteria when selecting green suppliers

As explained in the literature review, according to the authors' research, in the process of designing and developing new products, out of 4 main process groups, the product definition and planning process group has the greatest impact on the establishment of sustainability components in the process of designing and developing new products. The authors also pointed out that out of 39 deliverable items in the product definition and planning process group, the product objectives book has the greatest impact on establishing sustainability components and providing a sustainable product in the automotive industry.

Finally, based on the studies conducted in the processes of product design and development, gate planning and deliverable, sustainability, and its pillars, product life cycle management, and product attributes, we find that, to date, no studies have been conducted on the development of product targeting books and the implementation of new features in order to establish the components of sustainability. Accordingly, in this study, we will try to discuss this research gap.

3. Problem Statement

In this research, we introduce the group of new product design and development processes, the gateways in each process group, deliverable, and the main criteria of sustainability, and then we introduce the product target book as one of the deliverables that has the greatest impact on establishing sustainability in the product design and development process.

In the next stage, with the cooperation and survey of automotive industry experts, we identify new product attributes with respect to the pillars of sustainability (economic, environmental, and social). Then, by performing pairwise comparisons, using the opinions of automotive industry experts, considering the mutual influence of these attributes on the criteria of sustainability, and using an integrated DEMATEL and Fuzzy ANP techniques, we rank the new attributes and develop the product target book.

The product design and development process is a comprehensive and integrated method for designing and developing new products, ensuring compliance with the requirements, and achieving the objectives and items set in specific stages of the project. While new product design and development departments in different companies vary in the development process they employ, they are quite similar as well. A set of new product design and development process groups have been defined on the basis of conducted research, the exhaustive APQC (American Productivity & Quality Center) approach, APQP (Advanced Product Quality Planning) standard, and the experience of different car manufacturing companies from all around the world, which mainly include 6 process groups: product planning and definition process group, product detail design process group, manufacturing process design and development process group, product/process validation process group, and product manufacturing process group. The mentioned process groups are largely similar in their pillars and principles. Based on the examinations, the set of new product design and development process groups discussed in this study is one of the common process groups in car manufacturing companies, which is founded on gateway planning and the realization of the deliverable at every gateway.

In addition to the described process group, this model includes various gates and milestones, and passing through each gate requires the realization of a set of project activities, the realization of inputs and outputs, and the realization of deliverable and project activities. Also, in product design and development planning, a concept called gateway and gateway planning is used as one of the pillars of controlling the various stages of the product design and development process.

Each gateway is a stage of project implementation through which a set of project activities, inputs and outputs, and deliverables must be realized, and the passage of each gate is subject to the realization and delivery of delivery items and approval of stakeholders. At the closing session, it is the gate. In fact, each gateway review session is held at the end of each gate in order to review and review the activities and items that can be delivered to that gate.

Figure 1 shows the status of the four product development processes, the main activities in each of these processes, and the designated gateways to pass each stage.

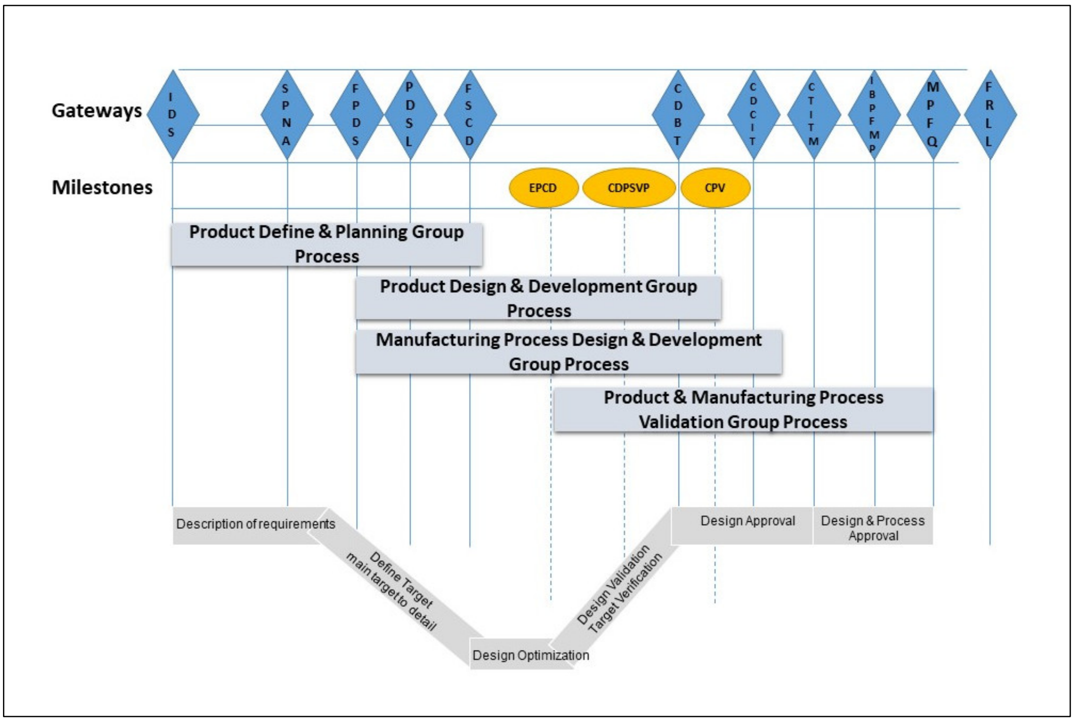

Figure 1. New product design and development processes group in a gateway system.

As mentioned earlier, in order to go through each gateway, the manufacturer is required to fulfill a set of targets, conditions, indicators, needs, outputs, deliverables, and other measurable items. These items can include any data, evidence, information, or any activity done on the input.

Furthermore, the gateway review meeting refers to a session held at the end of each gateway to review and revise the activities and deliverables of that gateway. The decision regarding the fulfillment of the mentioned gateway's objectives is made by a committee of all units associated with the project. The gateways of a new car design and development project are demonstrated in Table 1.

Table 1. The gateways and Milestone of new product design and development process groups.

The Gateway & Milestone		Description of Events and Deliverables
IDS	Initiation and description of product and process macro strategies gateway	The official studies for a new product project is initiated by altering a general product plan into a specific product plan.
SPNA	Strategic planning and needs analysis gateway	The first checkpoint in which the performance compatibility of product and process is examined. (Here, the scope of the new product is determined.)
FPDS	Finalization of product and style definition and first step style selection gateway	In this gateway, the scope of the product objectives becomes completely consistent at the product level. The execution strategy becomes the execution plan, the manufacturing site is specified, and all the vendors or suppliers of phase one are selected.
PDSL	Product definition at system level gateway	Product definition at system level gateway and the selection of the final style based on two physical prototype 1/1.
FSCD	Finalization the physical style and concept design gateway	Style, concept design, and the definition of the product as all levels of the car, system, and parts are finalized (completion of technical and economic evaluation). This gateway is one of the most important checkpoints in the gateway planning method and includes a considerable number of deliverables.
EPCD	Design check out and prototype evaluation milestone	The design is completed at this point and the evaluation prototype is ready to be manufactured.
CDPSVP	Completing the design of powertrain and start making validation prototype gateway	The design of powertrain is complete and ready to be industrially manufactured and validated (T-release), and the manufacture of validation prototypes is initiated.
CDBT	Completing the design of body and trim for industrialization and validation gateway	The design of the car body and decorations are complete and are ready to be industrially manufactured and validated (T-release), and the manufacture of validation prototypes is initiated.
CPV	Completing the manufacture of prototypes and initiating the validation tests gateway	The manufacture of VP (offline) prototypes is completed, and the validation tests are initiated.
CDCIT	Completing the design changes and the initiation of testing the equipment and molds gateway	The changes in the design are made and the tryout of the equipment and molds is initiated.
CTITM	Completion of testing and initiation of trial manufacture gateway	The equipment and molds testing, and tryouts are completed and trial manufacture (online) is initiated.
IBPFMP	Initial batch production and finalization of manufacture and process gateway	Production is done through batch method and manufacture and process are finalized.
FPPQ	Achieving final product and process quality	Product and process quality is achieved based on nominal capacity and mass production.
FRLL	Feedback and records of the learned lessons gateway	The feedback and learned lessons are recorded.

According to the author's research, generally up to a total of 80 deliverables are defined in a new car design and development project. Additionally, the author believes that if the sustainability pillars are applied in every one of the said deliverables, it is expected that the three aspects of sustainability, namely economic, environmental, and social, are exercised throughout the new product design and development process.

On the other hand, as the global economy grows increasingly over time, the global demand for fuel and consumables is escalating coordinately, and as a result, more greenhouse gases are emitted. Consequently, directing attention towards the principles of sustainability is of vital significance. The World Commission on Environment and Development defines the development of sustainable products as the process of meeting the current needs of customers without compromising the ability of future generations to meet their own needs. In 1994, the U.S. Environmental Protection Agency defined sustainability as customer satisfaction with current and future economic, social, and security needs without compromising the natural and qualitative attributes of the environment. Today, as the customer information level is evolving and their expectations of the product attributes are rising, and the community is paying more attention to economic, environmental, and social matters, product sustainability and achieving an optimal combination of these three mentioned principles in all stages of the product life cycle, from exploiting the raw materials, design and development, manufacture, to use, and post-use has gained substantial attention. Hence, sustainable product design means that economic, environmental, and social principles must be taken into account during the product design process and throughout the product life cycle. In other words, sustainable design and development aims at leading the design and development of the traditional product towards a final product in which the economic, environmental, and social principles are applied and the problems associated with them that existed in the traditional product are fixed. In this design, aspects such as the impact of materials or energy in the manufacture process, consumption, and recyclability of the final product with minimum negative impacts on the environment are considered. Accordingly, in order to maintain sustainability in product design, a variety of methods and tools have been developed.

Therefore, it can be said that sustainability includes the process of maintaining the balance of changes, the use of resources and capital, technology development and organizational change in a coordinated manner and enhancing current and future potential in order to meet human needs without harming future generations. For instance, in addition to product design, choosing the materials is an important task in product sustainability, and designers particularly focus on this task by assessing the environmental impacts of a product and analyzing its life cycle (stages of exploiting and processing the raw materials, manufacture, distribution, use, recycle, and final disposal).

Also, as mentioned in the review of the literature, life cycle assessment is a procedure for evaluating the impacts of a product as well as the resources used during its life cycle. This procedure can predict many advantages for product design in terms of life cycle impacts. Moreover, companies can identify the environmental impacts of their products and processes by relying on product life cycle assessment. On the other hand, in recent years, promoting sustainability through the constant sharing of information at various stages of the product life cycle in a mechanized product life cycle management system has been attracting considerable attention. In this process, the knowledge gained is preserved properly and boosts the enhancement of the final product's sustainability. Hence, sustainability can be considered an equivalent for optimizing the use of resources throughout the product life cycle while maintaining the quality of products and services.

In a separate study, modularity has been proposed as a method to simplify life cycle assessment that views product life cycle assessment from a module perspective, in which each module is analyzed individually. Therefore, changes made to a module influence its life cycle but do not involve the entire product, and development teams can construct a library of modules and the product life cycle assessment of new products can be more practical.

According to the author, the concept of using common platforms and modularity in different products with economic approaches in design and development of new products resulting in a significant reduction in time and cost is still new; therefore, provided enough attention is allocated to social and environmental aspects of platform and modules in addition to their economic aspects, the sustainability index of a set of products with shared platforms would enhance and consequently, customer requirements and low-cost business success would follow.

Keeping what was mentioned above in mind, the new sustainable product design and development process involves sustainability enhancement solutions with economic, social, and environmental approaches. Additionally, based on the author's research, the product planning and definition process group and its chosen deliverables have the most effect on establishing sustainability pillars in new product development, and applying the sustainability principles in this process group plays the most influential role in the manufacture of a sustainable product. Thus, if sustainability pillars and their likes are properly included and adapted in all stages and all deliverables of product design and development process and are reflected in product attributes, the sustainability approach would be applied in various stages of design, analysis, prototyping, testing and validation and as a result, one can claim that the sustainable design and development process has been achieved.

Furthermore, the conducted studies show that out of a total of chosen deliverables of product planning and definition process group, target book can have the most efficient influence on the establishment of sustainability pillars in the manufactured products. This book is one of the deliverables of a strategic planning gateway in which the product requirements and objectives of each product attribute are specified and inserted. In the automotive industry, all corporate and government needs and requirements identified by 15 main attributes and their sub-attributes are specified and inserted. These 15 car attributes include ergonomics and packaging, car style or appearance, customer life cycle, car dynamics, sound, vibration and stiffness, performance and fuel consumption, indoor air conditioning, car safety, electronics, heating and aerodynamics, cost, weight, customer safety, pollution, and product and process design compliance.

In the present study, the matters of applying sustainability pillars in the target book and identifying and determining new attributes throughout the product life cycle for developing product sustainability in automotive manufacturing companies are discussed. New attributes associated with sustainability throughout the product life cycle that have the most effect on the sustainability of the final product are identified and determined through surveying automotive industry experts and applying integrated DEMATEL and Fuzzy ANP techniques.

4. Methodology

In order to rank criteria, the DEMATEL method, as one of the decision-making methods, is used as an efficient technique in multi-criteria decision making. This method was proposed by Fonetla and Gabus in 1971 to identify the pattern of causal relations between the variables of a study. The DEMATEL method, which is a decision-making method based upon pairwise comparisons, provides a hierarchical structure of factors in a system along with casual relations between these factors using the surveys of experts and principles of graph theory in extracting the factors of a system and then structuring them systematically. This hierarchical structure determines the intensity of the effect of the mentioned relations in the form of numerical scores. The DEMATEL method is used to identify and examine the interrelationships of criteria to construct a network relationship map. Considering that directed graphs illustrate the relationships between the elements of a system much more accurately, the fuzzy DEMATEL method is based on graphs that can divide the involved factors into two groups of cause and effect and turn the relations between them into an understandable structural model. This method was mainly created for solving and organizing extremely complex global problems. Moreover, it is used to structure a sequence of hypothetical information, examining the intensity of relations by scoring them, scrutinizing important feedback, and accepting non-transferable relationships.

The DEMATEL method is a well-known and comprehensive technique for creating a structural model that represents the interrelationships among complex real-world factors, and it has the edge over other methods such as the Analytic Hierarchy Process (AHP), for it considers the interdependence between the factors of a system through a causal diagram that has been overlooked in traditional methods.

Furthermore, in the fuzzy DEMATEL method, the relationships between the criteria and sub-criteria are explored, and all relations between effect and effected, or in other words cause and effect criteria, are determined by the relationship matrix. This method is one of the multi-criteria decision-making methods, and as implied by the name, all computations are done in a fuzzy environment.

The DEMATEL method is generally integrated with other methods, such as the ANP method. This approach is able to eliminate the interdependence of the elements by obtaining the combined weights developing a "super matrix". A node or a cluster shows the relationships of the elements inside the factor. A straight line or curve represents interactions between two factors, and a loop represents interdependence between the elements within a factor.

Due to the interaction between different criteria and the relationships between sub-criteria of a cluster, the ANP method is very useful in obtaining more accurate and effective results, including complex and fundamental decision-making problems. This method utilizes three matrix analysis, super matrix, weighted super matrix, and limited super matrix. The super matrix provides the relative importance of all factors, and the weighted super matrix is used to find the value obtained by the super matrix values and the value of each cluster. In the limited super matrix, the fixed values of each value are determined by considering the required limit of the weighted super matrix.

The present study is conducted by utilizing the fuzzy ANP method, which is one of the multi-criteria decision-making techniques in fuzzy environments. The fuzzy ANP method employs the super matrix technique, and the weights of the criteria can be computed by methods such as the Chang method or the improved AHP method. Then, the final weight is computed by the ANP super matrix technique. This method is based on a reliable base research paper.

Interrelationships differentiate the fuzzy ANP method from the fuzzy AHP method. Hence, the first step in the fuzzy ANP method is to determine the interrelationships between the criteria or sub-criteria. These interrelationships are derived from techniques such as the fuzzy DEMATEL method, surveying the experts, or research papers relative to the subject matter. Then, based on these interrelationships, pairwise comparisons are done and weights are obtained. The first step here is to extract and confirm the research factors that are usually presented in various categories. Subsequently, the interrelationships between these factors must be detected, and final weights are computed by creating ANP super matrices.

The fuzzy DEMATEL method, here, aims at determining the interrelationships between factors, indicators, and their mutual effects in order to employ them in the fuzzy ANP method. In order to obtain the fuzzy DEMATEL results of the main criteria, experts were provided with the DEMATEL matrix so that the affect-ability of each criterion on other criteria is determined on a fuzzy DEMATEL table scale of 0 to 4, and the relation matrix is formed.

In this step, the participants were asked to show the effect of criterion i on criterion j using Table 1.

To take the opinions of all experts into account based on formula (1), an arithmetic mean is computed.

$$\tilde{z} = \frac{\tilde{x}^1 \oplus \tilde{x}^2 \oplus \tilde{x}^3 \oplus \ldots \oplus x^p}{p} \quad (1)$$

In this formula, p is the number of experts, $\tilde{x}^1$. $\tilde{x}^2$ .and $\tilde{x}^p$ are pairwise comparison matrices of expert 1, expert 2, and expert p, and $\tilde{z}$, the triangular fuzzy number, is in the following form: $\tilde{z}_{ij} = \left(l'_{ij}.m'_{ij}.u'_{ij}\right)$. The five level scales of the fuzzy DEMATEL method are presented in Table 2.

Table 2. The five level scales of the fuzzy DEMATEL method.

Triangular Fuzzy Number	Influence Score	Variable
(0, 0, 0.25)	0	No influence (NO)
(0, 0.25, 0.5)	1	Low influence (L)
(0.25, 0.5, 0.75)	2	Medium influence (M)
(0.5, 0.75, 1)	3	High influence (H)
(0.75, 1, 1)	4	Very high influence (VH)

The average matrix is normalized in accordance with Equation (2)–(4) and is called matrix H.

Formulas (1) and (2) are used to normalize the obtained matrix.

$$\widetilde{H}_{ij} = \frac{\widetilde{z}_{ij}}{r} = \left(\frac{l'_{ij}}{r}.\frac{m'_{ij}}{r}.\frac{u'_{ij}}{r}\right) = \left(l''_{ij}.m''_{ij}.u''_{ij}\right) \quad (2)$$

"r" is calculated through the following equation:

$$r = \max_{1\le i\le n}\left(\sum_{j=1}^{n} u'_{ij}\right) \quad (3)$$

Having calculated all the normalized matrix of direct relationship of criteria, the total fuzzy relation matrix is obtained based on Formulas (3) to (7) and Formula (8).

$$T = \lim_{k\to+\infty}\left(\widetilde{H}^{1} \oplus \widetilde{H}^{2} \oplus \ldots \oplus \widetilde{H}^{k}\right) \quad (4)$$

Each entry is a fuzzy number in the form of: $\widetilde{t}_{ij} = \left(l^{t}_{ij}.m^{t}_{ij}.u^{t}_{ij}\right)$

$$\left[l^{t}_{ij}\right] = H_l \times (I - H_l)^{-1} \quad (5)$$

$$\left[m^{t}_{ij}\right] = H_m \times (I - H_m)^{-1} \quad (6)$$

$$\left[u^{t}_{ij}\right] = H_u \times (I - H_u)^{-1} \quad (7)$$

In these formulas, 1 is the unit matrix, and $H_l.H_m.\text{and}H_u$ are $n \times n$ matrices whose entries are the triangular fuzzy lower, middle, and upper numbers of the matrix H.

Finally, using Equations (5) to (7), the total-relations matrix (T) is formed. To do that, first, an identity matrix (I_{7+7}) must be formed. Then the identity matrix is subtracted from the normal matrix, and the result is inverted.

4.1. Formulation and Analysis of the Casual Graph

In this step, the sum of row (D) and column (R) of the total-relation matrix is obtained, and then the values of D + R and D − R are computed. In this step, Equation (10) is used to de-fuzzy the values.

The values of the cj and ri indicators are computed according to Equations (8) and (9). the ri indicator represents the sum of the ith row, and the cj indicator represents the sum of the jth column of the total-relation matrix (T). To draw and analyze the graph, two indicators are required, the intensity of affectability and the direction of impact, which are calculated using ri and cj.

$$\widetilde{D} = (\widetilde{D}_i)_{n\times 1} = \left[\sum_{j=1}^{n} \widetilde{T}_{ij}\right]_{n\times 1} \quad (8)$$

$$\tilde{R} = (\tilde{R}_i)_{1\times n} = \left[\sum_{j=1}^{n} \tilde{T}_{ij}\right]_{1\times n} \quad (9)$$

For each i = j, $\tilde{D}$ *and* $\tilde{R}$ are $n \times 1$ and $1 \times n$ respectively.

Next, the importance of indicators ($\tilde{D}_i + \tilde{R}_i$) and the relationship between the criteria ($\tilde{D}_i - \tilde{R}_i$) are computed. If $\tilde{D}_i - \tilde{R}_i > 0$, the associated criterion is effective, and if $\tilde{D}_i - \tilde{R}_i < 0$, the associated criterion is ineffective.

- ri + dj: the intensity of affect-ability (i.e., the more the value of a factor's ri + dj, the more that factor interacts with other factors in the system).
- ri − dj: the direction of affect-ability, (i.e., if $ri - dj > 0$ the associated criterion is effective, and if $ri - dj < 0$, the associated criterion is ineffective).

Values of ri + dj and ri − dj indicators for criteria and $\tilde{D}_i + \tilde{R}_i$ and $\tilde{D}_i - \tilde{R}_i$ for dimensions are computed according to the above calculations. Then, the results are defuzzified using the following formula:

$$\text{defuzzify} = \frac{((u-l)+(m-l))}{3} + l \quad (10)$$

4.2. The Fuzzy ANP Method

The AHP method is suggested for solving problems in which the alternatives and criteria are independent from each other, and the ANP method is used for solving problems in which the alternatives and criteria are dependent on each other. Just as the AHP provides a bedrock for hierarchical structures with one-way relationships, the ANP makes way for complex interrelationships between different levels of decisions and criteria. The structural difference between ANP and AHP is demonstrated in Figure 2.

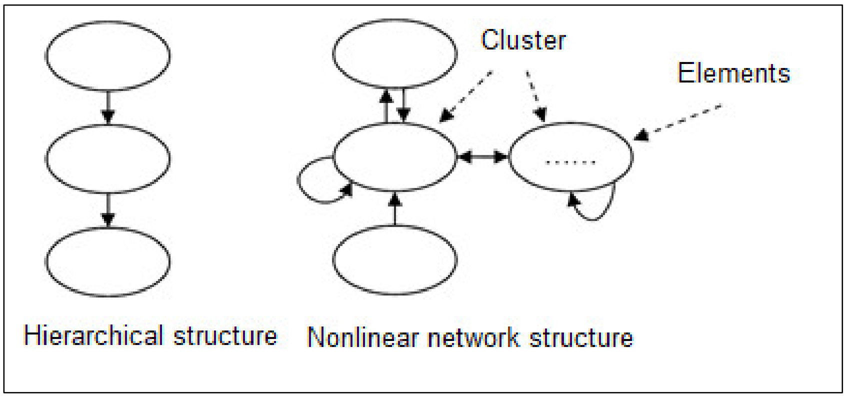

Figure 2. Structural differences between ANP and AHP.

Figure 3 shows the structure of an ANP network. Clusters represent levels of decision making, and straight lines or curves represent interactions between the said levels. The direction of the curves determines dependence, and the loops represent interdependence of each cluster's elements.

Also, the ANP method employs a pairwise-comparison matrix, whose input data are definite numbers in order to rank the preferences. This matrix cannot be used in cases where the input data are ambiguous. To solve this problem, the researchers suggested a model that uses the ANP method in a fuzzy environment. While all other steps of the suggested model are the same as the normal ANP method, they differ in extracting the weights of importance from the pairwise-comparison matrix.

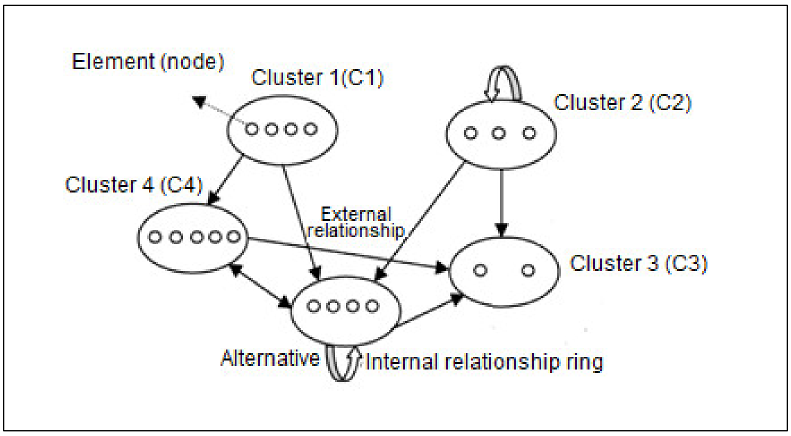

Figure 3. ANP network structure.

To implement the fuzzy ANP method, firstly, the weights in pairwise comparisons are obtained through the Buckley Geometric Mean method. Then, to obtain the final weights of the fuzzy ANP, the weighted and limit super matrices are computed by placing these weights in the initial ANP super matrix (Mohanty et al., (2005) [55]). The total-relation matrix is also normalized in columns; each element is divided by the sum of the column elements, and then they are placed as the interrelationships of the factors in the ANP super matrix (Sharmal et al., (2015) [56], Yousefi et al., (2019) [57]).

4.3. The Buckley Geometric Mean Method Results

After devising a pairwise comparison questionnaire, it was presented to 8 automotive industry experts. Subsequently, the responses were collected, and the incompatibility rates of the tables were calculated, all of which were less than 0.1. That is, the stability and reliability of the pairwise comparisons are acceptable. Then, using the Geometric Gean method, the responses were merged into the merged pairwise comparisons, which are provided below.

It must be mentioned that in the Buckley Geometric Mean method, the relative weights are used in fuzzy pairwise comparisons (Vinogradova-Zinkevic I., 2023) [58] The steps of this method are provided below.

Suppose $\widetilde{P}_{ij}$ is a set of decision-makers' preferences for one indicator over others. The pairwise comparison matrix is formed as follows:

$$\widetilde{A} = \begin{bmatrix} 1 & \widetilde{P}_{12} & \widetilde{P}_{1n} \\ \widetilde{P}_{21} & 1 & \widetilde{P}_{2n} \\ \widetilde{P}_{n1} & \widetilde{P}_{n2} & 1 \end{bmatrix} \tag{11}$$

In this matrix, n is the number of associated elements in every row. The fuzzy weights of every indicator in the pairwise-comparison matrix are calculated through the Buckley Geometric Mean method (Vinogradova-Zinkevic I., 2023) [58] The geometric mean of the value of the fuzzy comparisons of indicator i over every other indicator is computed using Equation (12).

$$\widetilde{r}_i = \left(\Pi_{j=1}^{n} \widetilde{P}_{ij} \right)^{\frac{1}{n}} i = 1.2.3.\ldots.n \tag{12}$$

Then, the fuzzy weight of the ith indicator is displayed by a fuzzy triangular number.

$$w_i = r_i \bigotimes (r_1 \oplus r_2 \oplus \ldots \oplus r_m)^{-1} \tag{13}$$

After having computed the factors of the fuzzy weights, they are de-fuzzified and then normalized through the following equation:

$$w_{crisp} = \frac{l + 2m + u}{4} \tag{14}$$

In the present study, in calculating the weights of pairwise comparisons, the linguistic terms and fuzzy triangular numbers in Table 3 are employed.

Table 3. Linguistic terms and fuzzy triangular numbers for weighting the criteria.

Code	Priorities	Fuzzy Equivalent of Priorities		
		Lower Limit (L)	**Middle Limit (M)**	**Upper Limit (U)**
1	Equally important	1	1	1
2	Equally to weakly important	1	2	3
3	Fairly important	2	3	4
4	Fairly to very important	3	4	5
5	Very important	4	5	6
6	Very important to strongly important	5	6	7
7	Strongly important	6	7	8
8	Strongly to absolutely important	7	8	9
9	Absolutely important	8	9	10

4.4. Formation of the Pairwise Comparisons

Similar to the AHP method, in the ANP method, the relative importance of the decision element pairs in each cluster is obtained directly through judgments made by employing pairwise comparisons under the control of the relevant criteria. A number of responses of decision makers are collected that are about a series of pairwise comparisons between two elements or two clusters based on their degree of importance in the high-level criteria associated with them. Moreover, the interrelationships between the elements of a cluster must be examined in pairs, and the effect of each element on the other must be displayed by a particular vector. Consequently, by forming pairwise comparison matrices for each element and then obtaining their corresponding particular vectors, the importance and the effect of every element on others are acquired. As with the AHP method, pairwise comparisons in the ANP method are done within a matrix as well. In the fuzzy ANP method, the relative importance of each pair of elements and the decision-maker's preferences are demonstrated using triangular fuzzy numbers. Through pairwise comparisons, the fuzzy judgment matrix A′ is created, where $a'_{ij} - \left(m'_{ij} .u'_{ij}\ \mathrm{l'_{ij}}\right)$ denotes the importance of the compared attributes (importance of i over j).

$$\mathrm{A'} = \begin{pmatrix} \mathrm{a'_{11}} & \cdots & \mathrm{a'_{1n}} \\ \vdots & \ddots & \vdots \\ \mathrm{a'_{m1}} & \cdots & \mathrm{a'_{mn}} \end{pmatrix} \tag{15}$$

There are various methods for determining the priority vectors obtained from each pairwise comparison matrix, such as the Development Analysis and Logarithmic Least Squares method, one of which can be selected to perform the calculations.

4.5. Formation of Super Matrices

In the ANP method, super matrices are used to illustrate the interactions and dependencies between the decision-making levels, to determine the relative importance of the criteria, and to prioritize the problem alternatives. To fill in the various matrices in the super matrix, the priority vectors associated with each pairwise comparison matrix must be calculated. Once the compatibility of the pairwise comparisons is ensured, the weights associated with the relative importance of each pairwise comparison matrix are obtained. It is worth mentioning that for obtaining the priority vectors, many methods exist, such as the Logarithm Least Squares method and Chang Development method, one of which is ultimately selected for obtaining the general priorities in a system along with the effects dependent on them by taking the situation into consideration.

The obtained priority vectors are placed in the corresponding column of the super matrix. Figure 4 illustrates the general form of a super matrix with a network structure.

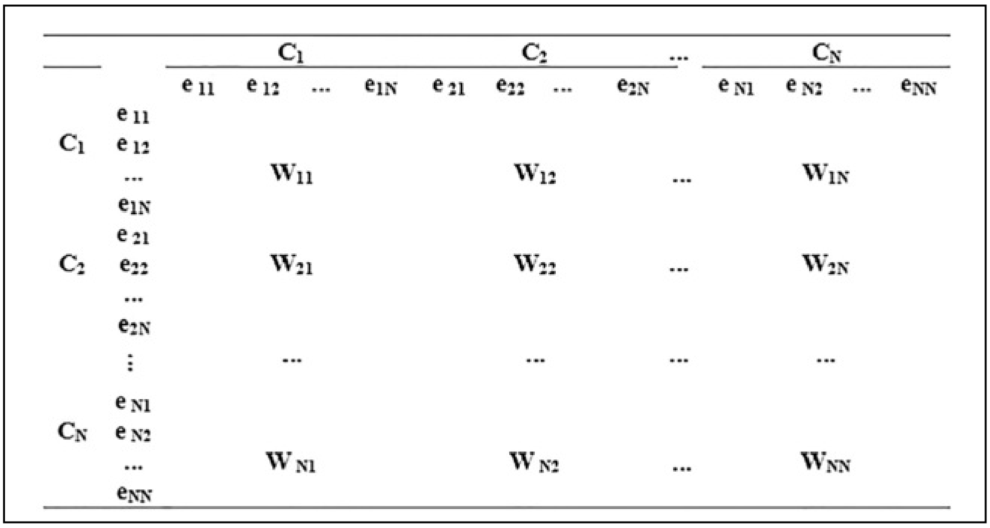

Figure 4. Super matrix with a network structure.

A super matrix is actually a segmented matrix in which each part of the matrix displays the relationship between two clusters or the decision-making level in the entire decision-making problem, with c representing the clusters and e representing the elements within the clusters. The W vectors within the matrix are the weight vectors obtained from pairwise comparisons of the elements of the clusters with each other.

5. Data Analysis

5.1. Criteria, Sub-Criteria, and Comparisons

The present study aims at providing a new edition of the target book as one of the crucial deliverables procured at the stage where new product planning and definition with sustainability approach is done.

According to the product target books used in a car design and development company, 15 features were mentioned as the main attributes expected in the new product.

These attributes include:

- Passenger safety;
- Car security;
- Ergonomics and packaging;
- Heat and aerodynamics;
- Car dynamics;
- Environmental protection;
- Fuel consumption;
- Noise, vibration, and hardness;
- Electric/electronics;
- Internal environment;
- Weight;
- Product and process design adaptation;

- Life cycle;
- Style/appearance of the car.

Therefore, the goal is to assess, select, and add a set of new attributes in order to establish sustainability requirements in all design stages, from product definition to product validation and manufacture.

The relationships among the 15 attributes of the existing car with the main pillars of sustainability based on views and surveys of experts in the field of car design and development are demonstrated in Table 4.

Table 4. Relationship between vehicle attributes and the main pillars of sustainability.

Car Attributes	Economic Pillar	Environmental Pillar	Social Pillar
Passenger safety	√		√
Car security	√		√
Ergonomics and packaging	√		
Heat and aerodynamics		√	√
Car dynamics	√		√
Environmental protection	√	√	√
Fuel consumption	√	√	√
Noise, vibration, and hardness	√	√	
Electric/electronics	√		√
Internal environment	√		
Weight		√	√
Product and process design adaptation		√	√
Life cycle	√	√	√
Style/appearance of the car	√		
Cost			√

After reviewing these attributes and their relationship with sustainability pillars, it is concluded that new attributes associated with the said pillars must be identified and assessed. In order to fulfill this task, a questionnaire was designed and experts in the automotive industry were asked to fill it out. They were surveyed on the indicators and objectives for enhancing the sustainability of the final product throughout the entire life cycle stages.

According to industry experts, in different areas of the product life cycle, the most important main attributes and relevant detailed attributes applicable to targeting the vehicle at different stages of the product life cycle are presented in Table 5.

Table 5. New attributes in promoting the stability of the final product in the product life cycle.

Life Cycle Stage	Main Attribute	Detail Attribute
Design	Cooperation strategy	• Reduce design time resulting from the acquisition and participation of other companies' data • Joint projects with other companies
Design	Common platform	• Modularity rank • Products with a common platform

Table 5. *Cont.*

Life Cycle Stage	Main Attribute	Detail Attribute
Design	Diversity capability	• Variety of parts with the possibility of replacement • Number of bodies designed (product) on a platform
Design	Design to optimize raw materials	• Minimum consumables for weight loss and cost reduction • Minimum variety of raw materials used • Minimal environmental impacts • Increase material compliance
Design	Design for sustainability	• Reducing economic effects • Reducing environmental effects • Increasing social impact
Design	Design for energy efficiency	• Energy consumption in the process of preparing raw materials • Energy consumption in the production process of parts and assemblies • Energy consumption in the car production process (body building, assembly, and paint) • Energy consumption in the car use phase • Energy consumption in the separation and recycling phase • Recovered energy from material recycling
Use	Upgrade-ability	• Possibility of upgrading equipment • Continuity of development • Development of performance and capabilities

In this section, we implement the DEMATEL technique for the criteria, sub-criteria, and research indicators given in Table 6.

Table 6. Introduction of attributes.

Main Attribute		Detail Attribute	
Criteria No.	**Criteria**	**Sub-Criteria No.**	**Sub-Criteria**
A	Cooperation strategy	A1	Reduce design time resulting from the acquisition and participation of other companies' data
		A2	Joint projects with other companies
B	Common platform	B1	Modularity rank
		B2	Products with a common platform
C	Diversity capability	C1	Variety of parts with the possibility of replacement
		C2	Number of bodies designed (product) on a platform
D	Design to optimize raw materials	D1	Minimum consumables for weight loss and cost reduction
		D2	Minimum variety of raw materials used
		D3	Minimal environmental impacts
		D4	Increase material compliance

Table 6. *Cont.*

Main Attribute		Detail Attribute	
Criteria No.	**Criteria**	**Sub-Criteria No.**	**Sub-Criteria**
E	Design for sustainability	E1	Reducing economic effects
		E2	Reducing environmental effects
		E3	Increasing social impact
F	Design for energy efficiency	F1	Energy consumption in the process of preparing raw materials
		F2	Energy consumption in the production process of parts and assemblies
		F3	Energy consumption in the car production process (body building, assembly and paint)
		F4	Energy consumption in the car use phase
		F5	Energy consumption in the separation and recycling phase
		F6	Recovered energy from material recycling
G	Upgrade-ability	G1	The possibility of upgrading equipment
		G2	Continuity of development
		G3	Development of performance and capabilities

Subsequently, using Equation (3), the data collected from the participants were integrated, and the results are illustrated in Table 7.

Table 7. Criteria direct correlation matrix.

	A	**B**	**C**	**D**	**E**	**F**	**G**
A	(0,0,0.25)	(0.594,0.844,0.969)	(0.594,0.844,0.938)	(0.188,0.438,0.688)	(0.219,0.469,0.719)	(0.188,0.438,0.688)	(0.188,0.438,0.688)
B	(0.625,0.875,1)	(0,0,0.25)	(0.531,0.781,1)	(0.688,0.938,1)	(0.625,0.875,1)	(0.656,0.906,1)	(0.563,0.813,0.969)
C	(0.594,0.844,0.969)	(0.625,0.875,1)	(0,0,0.25)	(0,0.094,0.344)	(0,0.094,0.344)	(0,0.063,0.313)	(0.625,0.875,1)
D	(0.5,0.75,1)	(0.531,0.781,0.938)	(0,0.031,0.281)	(0,0,0.25)	(0.531,0.781,1)	(0.688,0.938,1)	(0,0.156,0.406)
E	(0.438,0.688,0.906)	(0.563,0.813,0.969)	(0,0.063,0.313)	(0,0,0.25)	(0,0,0.25)	(0.531,0.781,1)	(0,0.125,0.375)
F	(0.313,0.563,0.781)	(0.656,0.906,1)	(0,0.031,0.281)	(0.594,0.844,1)	(0.219,0.469,0.719)	(0,0,0.25)	(0,0.125,0.375)
G	(0.469,0.719,0.938)	(0.031,0.125,0.375)	(0.688,0.938,1)	(0,0.094,0.344)	(0,0.156,0.406)	(0.031,0.156,0.406)	(0,0,0.25)

In order to normalize the matrix, the maximum sum of the upper rows of the direct-relation matrix must be calculated, which in this case is equal to 6.219. Following this, all elements in the direct-relation matrix (Table 6) are divided by 6.219. The results are presented in Table 8.

Table 8. Normalized matrix of the direct relationship of criteria.

	A	**B**	**C**	**D**	**E**	**F**	**G**
A	(0,0,0.04)	(0.095,0.136,0.156)	(0.095,0.136,0.151)	(0.03,0.07,0.111)	(0.035,0.075,0.116)	(0.03,0.07,0.111)	(0.03,0.07,0.111)
B	(0.101,0.141,0.161)	(0,0,0.04)	(0.085,0.126,0.161)	(0.111,0.151,0.161)	(0.101,0.141,0.161)	(0.106,0.146,0.161)	(0.09,0.131,0.156)
C	(0.095,0.136,0.156)	(0.101,0.141,0.161)	(0,0,0.04)	(0,0.015,0.055)	(0,0.015,0.055)	(0,0.01,0.05)	(0.101,0.141,0.161)
D	(0.08,0.121,0.161)	(0.085,0.126,0.151)	(0,0.005,0.045)	(0,0,0.04)	(0.085,0.126,0.161)	(0.111,0.151,0.161)	(0,0.025,0.065)
E	(0.07,0.111,0.146)	(0.09,0.131,0.156)	(0,0.01,0.05)	(0,0,0.04)	(0,0,0.04)	(0.085,0.126,0.161)	(0,0.02,0.06)
F	(0.05,0.09,0.126)	(0.106,0.146,0.161)	(0,0.005,0.045)	(0.095,0.136,0.161)	(0.035,0.075,0.116)	(0,0,0.04)	(0,0.02,0.06)
G	(0.075,0.116,0.151)	(0.005,0.02,0.06)	(0.111,0.151,0.161)	(0,0.015,0.055)	(0,0.025,0.065)	(0.005,0.025,0.065)	(0,0,0.04)

Ultimately, the normal matrix is multiplied by the inverted matrix which is presented in Table 9.

Table 9. Criteria complete relationship matrix.

	A	B	C	D	E	F	G
A	(0.039,0.131,0.473)	(0.126,0.249,0.557)	(0.116,0.211,0.46)	(0.051,0.145,0.41)	(0.055,0.158,0.45)	(0.055,0.163,0.46)	(0.054,0.152,0.422)
B	(0.154,0.304,0.677)	(0.066,0.18,0.545)	(0.118,0.228,0.535)	(0.136,0.243,0.519)	(0.129,0.249,0.564)	(0.144,0.269,0.582)	(0.113,0.224,0.526)
C	(0.124,0.231,0.52)	(0.122,0.224,0.5)	(0.035,0.092,0.329)	(0.019,0.081,0.319)	(0.019,0.087,0.348)	(0.021,0.088,0.354)	(0.119,0.205,0.429)
D	(0.114,0.235,0.58)	(0.126,0.246,0.557)	(0.024,0.086,0.361)	(0.031,0.09,0.351)	(0.11,0.212,0.498)	(0.14,0.247,0.514)	(0.017,0.097,0.373)
E	(0.094,0.196,0.501)	(0.117,0.217,0.497)	(0.021,0.078,0.322)	(0.026,0.075,0.31)	(0.021,0.073,0.333)	(0.105,0.194,0.455)	(0.015,0.08,0.326)
F	(0.083,0.198,0.517)	(0.135,0.247,0.532)	(0.021,0.079,0.336)	(0.116,0.204,0.437)	(0.063,0.162,0.433)	(0.035,0.104,0.378)	(0.017,0.088,0.346)

The results are provided in Table 10.

Table 10. Table of values of the D and R criteria.

	Di	**Ri**	**$(Di)^{defuzzy}$**	**$(Ri)^{defuzzy}$**	**Di + Ri**	**Di − Ri**
A	(0.496,1.208,3.233)	(0.701,1.479,3.732)	1.646	1.970	3.616	−0.325
B	(0.86,1.697,3.947)	(0.721,1.465,3.559)	2.168	1.915	4.083	0.253
C	(0.46,1.008,2.799)	(0.459,0.974,2.738)	1.422	1.390	2.812	0.032
D	(0.561,1.213,3.234)	(0.386,0.895,2.625)	1.670	1.302	2.972	0.368
E	(0.399,0.913,2.746)	(0.404,1.011,2.94)	1.353	1.452	2.804	−0.099
F	(0.47,1.082,2.979)	(0.513,1.14,3.066)	1.511	1.573	3.083	−0.062
G	(0.291,0.746,2.424)	(0.354,0.905,2.703)	1.153	1.321	2.474	−0.167

In Table 10, the sum of the elements on each row signify the effect of that factor on other factors in the system. Accordingly, the criterion of using a shared platform (B) has the most effectiveness. The sum of the elements on each column for each factor represents the effect it receives from other factors in the system. Accordingly, the participation strategy criterion (A) receives a very high degree of effect. The horizontal (D + R) vector represents the degree of affectability of a certain factor in the system. In other words, the higher the value of D + R factor, the more it interacts with other factors in the system. Hence, using a shared platform (B) has the most interaction with other factors in the study. The vertical vector (D − R) represents the power of each factor. In general, if the D − R is positive, the variable is a causative variable, and if it is negative, it is an effectual variable. In Figure 5, the criteria above the horizontal axis have a causative aspect, and the criteria below the horizontal axis have an effectual aspect.

5.2. The Interrelationship of the Criteria

In this step, to plot the reliable relationships, the fuzzy total-relation matrix is defuzzified (Table 11), and then the threshold (arithmetic mean of the entries) is specified. The numbers that are higher than the threshold indicate a meaningful relationship between the criteria of row i and column j of that cell. The threshold here is equal to 0.223; therefore, the entries that are higher than this number, which are marked with an asterisk (*), indicate a meaningful relationship. For instance, in the row of criterion A, cells B, C, and F are marked, indicating that criterion A affects these meaningful criteria.

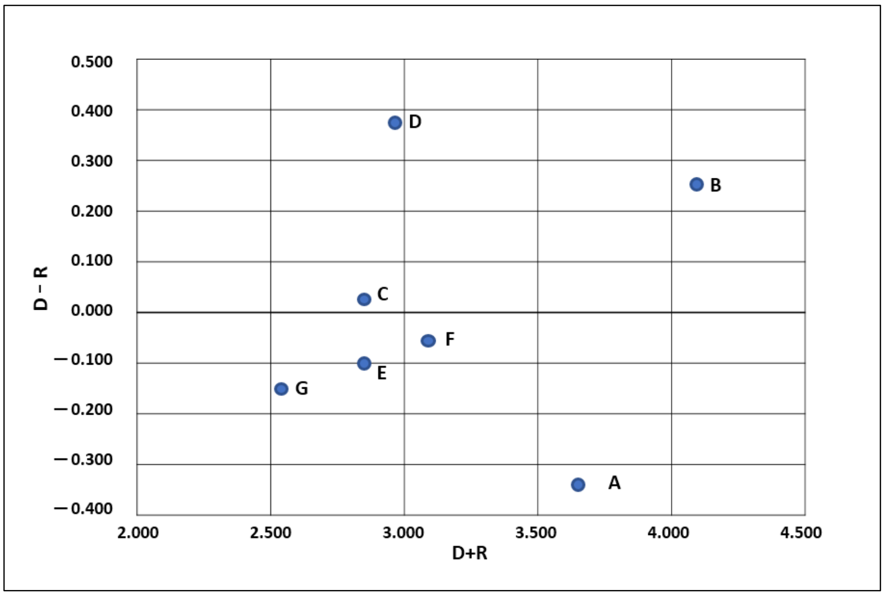

Figure 5. Causal diagram of the criteria.

Table 11. Non-fuzzy relationship matrix of all criteria.

	A	B	C	D	E	F	G
A	0.214	0.311 *	0.262 *	0.202	0.221	0.226 *	0.209
B	0.378 *	0.222	0.294 *	0.299 *	0.314 *	0.332 *	0.288 *
C	0.291 *	0.282 *	0.152	0.14	0.152	0.154	0.251 *
D	0.309 *	0.31 *	0.157	0.157	0.273 *	0.3 *	0.163
E	0.264 *	0.277 *	0.14	0.137	0.142	0.252 *	0.141
F	0.266 *	0.305 *	0.146	0.252 *	0.219	0.172	0.15
G	0.247 *	0.167	0.239 *	0.115	0.13	0.136	0.119

5.3. Drawing and Analyzing the Casual Diagram

In this step, the sum of row (D) and the sum of column (R) of the total-relation matrix is computed. Afterwards, the value of D + R and D − R are calculated. At this stage, in order to de-fuzzify the values, Equation (3)–(15) is employed. The results are illustrated in Table 12.

In Table 12, the sum of the elements of each row (D) denote the affect-ability of that factor on other factors in the system. On that basis, the minimum environmental impacts (D3) affect the factors the most. The sum of the elements of column (R) indicates the effect the factor receives from other factors in the system. Consequently, the variety of parts with replace-ability (C1) receive the most effect. The horizontal (D + R) vector represents the degree of affect-ability of a certain factor in the system. In other words, the higher the value of D + R factor, the more it interacts with other factors in the system. The vertical (D − R) vector represents the affect-ability of each factor. Generally, if the value of D − R is positive, the variable is the cause, and if it is negative, the variable is the effect. Figure 6 demonstrates a casual diagram of the criteria.

Table 12. Table of values of the D and R criteria.

	Di	Ri	$(Di)^{defuzzy}$	$(Ri)^{defuzzy}$	Di + Ri	Di − Ri
A1	(0.335,0.927,3.072)	(0.408,1.064,3.334)	1.445	1.602	3.047	−0.157
A2	(0.514,1.279,3.722)	(0.557,1.403,4.017)	1.839	1.992	3.831	−0.154
B1	(0.672,1.572,4.29)	(0.657,1.583,4.322)	2.178	2.187	4.365	−0.009
B2	(0.424,1.183,3.619)	(0.702,1.65,4.349)	1.742	2.234	3.976	−0.492
C1	(0.773,1.737,4.385)	(0.768,1.798,4.56)	2.298	2.375	4.674	−0.077
C2	(0.815,1.881,4.761)	(0.643,1.563,4.212)	2.485	2.139	4.625	0.346
D1	(0.595,1.415,3.878)	(0.573,1.418,4.071)	1.963	2.021	3.983	−0.058
D2	(0.597,1.509,4.322)	(0.674,1.613,4.295)	2.143	2.194	4.337	−0.051
D3	(0.952,2.098,5.026)	(0.743,1.696,4.329)	2.692	2.256	4.948	0.436
D4	(0.668,1.618,4.511)	(0.76,1.743,4.526)	2.266	2.343	4.609	−0.077
E1	(0.725,1.745,4.462)	(0.774,1.797,4.594)	2.311	2.388	4.699	−0.078
E2	(0.407,1.044,3.307)	(0.791,1.761,4.487)	1.586	2.346	3.932	−0.760
E3	(0.602,1.488,4.056)	(0.605,1.528,4.246)	2.049	2.127	4.175	−0.078
F1	(0.563,1.407,3.95)	(0.358,0.992,3.261)	1.973	1.537	3.510	0.436
F2	(0.843,1.89,4.593)	(0.545,1.351,3.852)	2.442	1.916	4.358	0.526
F3	(0.251,0.914,3.152)	(0.397,1.107,3.513)	1.439	1.673	3.111	−0.234
F4	(0.594,1.449,4.032)	(0.373,1.059,3.255)	2.025	1.563	3.588	0.463
F5	(0.522,1.362,3.953)	(0.472,1.25,3.745)	1.945	1.822	3.768	0.123
F6	(0.603,1.485,4.266)	(0.523,1.322,3.711)	2.118	1.852	3.970	0.266
G1	(0.388,1.079,3.49)	(0.598,1.43,4.027)	1.652	2.018	3.670	−0.366
G2	(0.581,1.406,3.96)	(0.61,1.488,4.154)	1.983	2.084	4.067	−0.101
G3	(0.743,1.632,4.185)	(0.635,1.505,4.133)	2.187	2.091	4.278	0.096

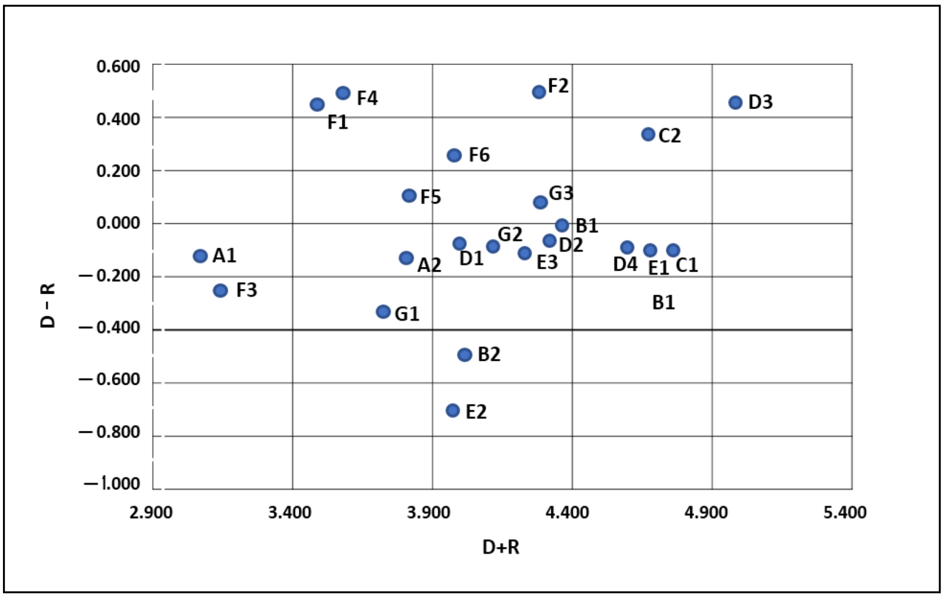

Figure 6. Causal diagram of criteria.

In this section, pairwise comparisons of the main criteria are presented as an example.

These pairwise comparisons are performed based on a fuzzy scale of 1 to 9, which were completed by 8 experts and were ultimately merged by the Geometric Mean method. The results are presented in Tables 13 and 14.

Table 13. Pairwise comparisons of criteria.

	A	B	C	D	E	F	G
A	(1,1,1)	(0.302,0.392,0.518)	(0.319,0.42,0.577)	(0.45,0.616,0.872)	(0.639,0.917,1.364)	(0.447,0.545,0.662)	(0.917,1.147,1.414)
B	(1.929,2.552,3.31)	(1,1,1)	(1.732,2.594,3.376)	(0.985,1.646,2.539)	(1.189,1.565,1.861)	(1.075,1.456,2)	(1.414,2.06,2.632)
C	(1.732,2.378,3.137)	(0.296,0.386,0.577)	(1,1,1)	(1.51,2,2.734)	(0.687,0.931,1.414)	(1.316,2,2.59)	(1,1.297,1.51)
D	(1.147,1.622,2.225)	(0.394,0.607,1.015)	(0.366,0.5,0.662)	(1,1,1)	(2,2.59,3.13)	(0.5,0.577,0.707)	(0.281,0.356,0.493)
E	(0.733,1.091,1.565)	(0.537,0.639,0.841)	(0.707,1.075,1.456)	(0.319,0.386,0.5)	(1,1,1)	(0.23,0.299,0.429)	(0.286,0.334,0.408)
F	(1.51,1.834,2.236)	(0.5,0.687,0.931)	(0.386,0.5,0.76)	(1.414,1.732,2)	(2.328,3.342,4.349)	(1,1,1)	(1.091,1.622,2.34)
G	(0.707,0.872,1.091)	(0.38,0.485,0.707)	(0.662,0.771,1)	(2.03,2.81,3.557)	(2.449,2.991,3.5)	(0.427,0.616,0.917)	(1,1,1)

Table 14. Fuzzy and non-fuzzy weight calculations of the main criteria.

Criteria	$\left(\left(\prod_{j=1}^{n}\tilde{P}_{ij}\right)^{\frac{1}{n}}\right)$ Geometric Mean	$(\tilde{W})$ Fuzzy Weight	Non-Fuzzy Weight	Normal Weight
A	(0.527,0.666,0.855)	(0.055,0.089,0.148)	0.096	0.090
B	(1.29,1.754,2.234)	(0.135,0.235,0.387)	0.248	0.233
C	(0.95,1.237,1.605)	(0.1,0.166,0.278)	0.177	0.167
D	(0.645,0.826,1.072)	(0.068,0.111,0.186)	0.119	0.112
E	(0.48,0.603,0.775)	(0.05,0.081,0.134)	0.087	0.081
F	(1.007,1.289,1.642)	(0.105,0.173,0.285)	0.184	0.173
G	(0.87,1.078,1.364)	(0.091,0.145,0.236)	0.154	0.145
$\sum\left(\prod_{j=1}^{n}\tilde{P}_{ij}\right)^{\frac{1}{n}}$	(5.769,7.453,9.548)			

After calculating the weight of the factors, three super matrices, initial, weighted and limited, should be formed in order to obtain the final weights, which are presented in Tables 15 and 16.

Table 15. Final weight of factors.

Main Attribute		Super Matrix Weight	Normal Weight	Rank
Criteria Code	Criteria			
A	Cooperation strategy	0.01901	0.1521	2
B	Common platform	0.02473	0.1980	1
C	Diversity capability	0.01605	0.1291	5
D	Design to optimize raw materials	0.01551	0.1237	6
E	Design for sustainability	0.01902	0.1517	3
F	Design for energy efficiency	0.01762	0.1407	4
G	Upgrade-ability	0.01306	0.1047	7

Table 16. Final weight of sub-criteria.

Sub-Criteria No.	Sub-Criteria	Super Matrix Weight	Normal Weight	Rank
A1	Reduce design time resulting from the acquisition and participation of other companies' data	0.03214	0.0321	22
A2	Joint projects with other companies	0.04057	0.0406	17
B1	Modularity rank	0.04852	0.0485	7
B2	Products with a common platform	0.03881	0.0388	18
C1	Variety of parts with the possibility of replacement	0.05219	0.0522	4
C2	Number of bodies designed (product) on a platform	0.05509	0.0551	2
D1	Minimum consumables for weight loss and cost reduction	0.04437	0.0444	14
D2	Minimum variety of raw materials used	0.04801	0.0480	9
D3	Minimal environmental impacts	0.06036	0.0604	1
D4	Increase material compliance	0.05063	0.0506	6
E1	Reducing economic effects	0.05131	0.0513	5
E2	Reducing environmental effects	0.03527	0.0353	20
E3	Increasing social impact	0.04592	0.0459	11
F1	Energy consumption in the process of preparing raw materials	0.04461	0.0446	13
F2	Energy consumption in the production process of parts and assemblies	0.05442	0.0544	3
F3	Energy consumption in the car production process (body building, assembly and paint)	0.03249	0.0325	21
F4	Energy consumption in the car use phase	0.04533	0.0453	12
F5	Energy consumption in the separation and recycling phase	0.04354	0.0435	16
F6	Recovered energy from material recycling	0.04748	0.0475	10
G1	The possibility of upgrading equipment	0.03663	0.0366	19
G2	Continuity of development	0.04401	0.0440	15
G3	Development of performance and capabilities	0.04830	0.0483	8

6. Discussion, Conclusions, and Future Studies

As the designer's knowledge of the economic, environmental, and social impacts of products has expanded, more attention has been directed towards sustainable product development. Currently, the automotive industry is one of the most vital industries in the world; hence, car manufacturers and customers seek products that are more durable in terms of performance with minimal environmental impacts, reasonable cost and socially fitted effectiveness. To reach this aim, the present study discusses the main subject matters with respect to sustainability in the automotive industry. Therefore, going back to what was discussed at the beginning of the study, most of the car manufacturers define 15 attributes in car design and development, and the values of these attributes are what designers keep in view as the objectives of design throughout the entire stages of concept design, detail design, prototyping, and validating. Based on the studies conducted in this research and the evaluation of new features with the help of automotive industry experts, it is suggested that companies designing and developing new products, in addition to the previous features, have the following three features that have the highest priority over other new features:

1. Using a common platform;
2. Cooperation strategy;
3. Design for sustainability.

The executive approach of this research and the obtained results can lead to the development of management approaches, especially in long-term planning in new product design and development centers, and in addition to the automotive industry, it can lead to the expansion of the concept of sustainability in other manufactured products.

In this research, various managers participated in the departments of automotive engineering, automotive design, and testing and validation. Also, this research was based on the current documentation used in a car design and development company.

Since this research was done based on the current process in a car design company and the participation of different managers, the limitations related to the level of knowledge and experience of the managers, as well as the use of existing processes, govern this research.

The current study, one of the deliverables in the planning and product definition process group, was developed with an approach to sustainability, but since this process group, in addition to other process groups, have sub-processes and various deliverables in the product development stages, it is suggested that in future research, the principles of sustainability be developed and applied in the other deliverables of the product planning process and in others sub-processes of new product design and development.

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