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Prioritization of Concurrent Design Strategies Using the Multi-Criteria Decision-Making Approach

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Abstract

In recent years, design is becoming the core competence of companies and managing the interface between design and other activities has received a lot of attention. Effective co-ordination among these areas, therefore, is vital for the effectiveness of the organization. The ideal situation would be continuous inter-departmental contact with well-developed channels of communication. This paper proposes strategies that help to implementing concurrent design and uses TOPSIS method to provide appropriate concurrent design strategy, which is observed to be quite capable of solving such type of multi-criteria decision-making (MCDM) problems. The results of this study should provide a base for firms in evaluating the concurrent design strategies and a reference for them to strengthen their concurrent capabilities. This work aims at contributing to the concurrent design solutions implementation, which are appealing.

Keywords
Quality by design, Concurrent design, Strategy, MADM, TOPSIS

1. Introduction
Most studies show that referring to design, as a core competence is a privilege. There are tentative examples on the profitable design investments with evidences coming mainly from case studies of "winning" companies or successful projects. However, the expectation that design should be beneficial for a company's strategic initiatives in the competitive markets makes us think over two important dimensions of the argument. Principally, it is apparent that managerial support should be consistent with the context of the strategic management process-in our case, the product design and development, since individuals are required to engage in knowledge gathering, creativity, and development of ideas consistent with their organization's mission and strategic plan. Thus, profitable design effectively serving the strategic planning initiatives within the organizations drives us to investigate whether companies, which are in need of differentiation in the market by means of industrial design, really acknowledge the product design and development process a strategic tool. Secondly, contradicting conditions of product development are often claimed-engineers, who have to collaborate under time constraints, are expected to meet high quality requirements in an effective and efficient way. Hence, product design, as an essential part of a development project, is expected to comply with all tools, activities and ideas gathered across the organization (Berber and Aksel, 2007). This raises the question of how companies can consider customer needs and requirements at the highest possible level while deriving greater benefits from their product design and development process. Attempting to answer this question, this paper expands concurrent design concerning the strategic approach. The paper is organized as the follows. Section 2 describes concurrent design and its literature review. Section 3 presents the research methodology. Section 4 uses TOPSIS method to provide appropriate concurrent design strategy. The final section presents the results of the method, outlines some future research directions, and concludes the paper.

2. Literature Review
2.1. Concurrent design
The difficulties in designing complex engineering products do not arise simply from their technical complexity. The managerial complexity, necessary to manage the interactions between the different engineering disciplines, imposes additional challenges on the design process. In recent years, concurrent engineering (CE) has become increasingly important for product development. CE is a philosophy that suggests the need to consider design issues

simultaneously where they were considered sequentially in the past. The sequential design process has been considered inefficient, since this type of design process typically leads to greater development time, greater cost, and lower overall design quality, all of which lower the overall profit generated by the design. The remaining challenge of managerial complexity is to transform the product design process from a SE (sequential engineering) environment to a CE environment. The important transformation approach practically relevant to this paper is the product design process re-engineering. When applied to re-engineer the product development process, it is mainly concerned with the rationalization of the product development activities, with the belief that a rationalized product development process is more likely to result in better product design decision. The managerial complexity of the design process is contained by using management tools that model the interface and dependencies among the decomposed tasks. Assine et al. (1999) considered that managing the design process includes four major steps: (1) model the information and dependency structure of the design process; (2) provide a design plan showing the order of execution for the design tasks; (3) reduce the risk and magnitude of iteration between design tasks; (4) explore opportunities for reducing the project cycle time (Abdelsalam, 2009).

2.2. Quality by design

Quality-by-design principles are changing the way managers think and conduct business. Broadly defined, quality by design is the practice of using a multidisciplinary team to conduct conceptual thinking, product design, and production planning all at one time; it is also known as concurrent engineering or CE, simultaneous engineering, or parallel engineering. Quality by design has recently encouraged changes in management structures. The major functions within an organization would complete their task by "throwing it over the wall" to the next department in the sequence, and would not be concerned with any internal customer problems that might arise. Quality by design or CE requires the major functions to be performed at the same time. This system provides for immediate feedback, which prevents the occurrence of problems with quality and productivity. Figure 1 shows the flow diagram for sequential (traditional) engineering on the left and quality by design (concurrent design) on the right. Each of the specialist's early input to the product definition and specifications cost is minimized and performance is maximized. Thus, better-quality products are manufactured for less cost with shorter time to market.

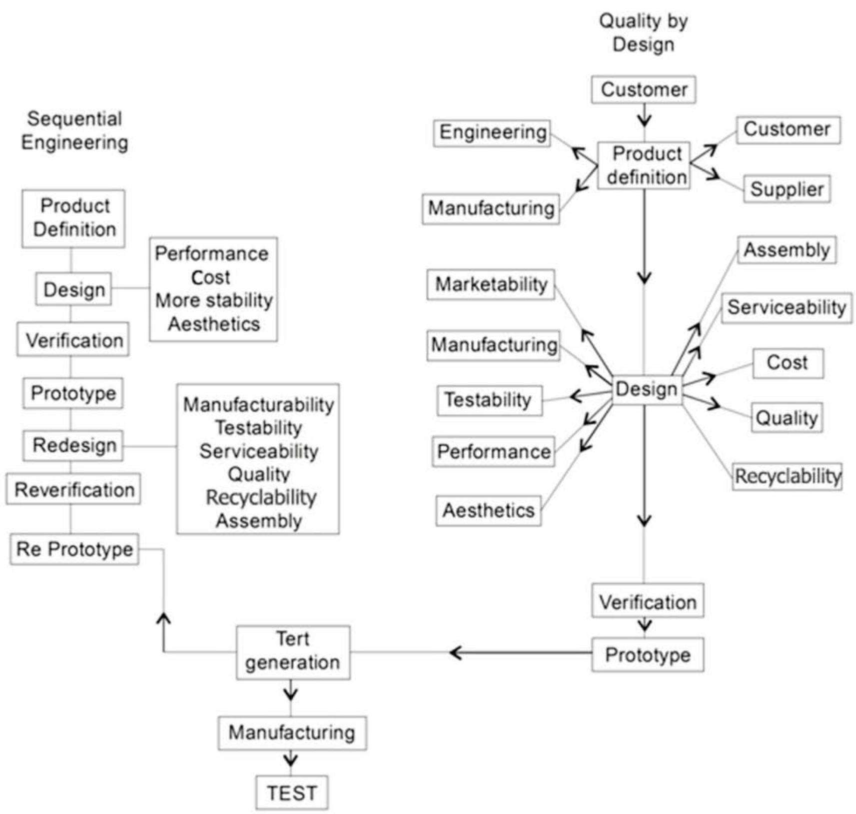

Figure 1: Product development flow diagram (Naidu et al., 2006)

The quality by design or concurrent design method combines all these steps. The product is designed to be successful at each stage of its life cycle. It is designed correctly the first time, considering all attributes and facets of its life, such as marketability, assembly, and serviceability, before release to testing and small production. The essence of CE is not only the concurrency of the activities but also the cooperative effort from all the involved teams, which leads to improving profitability and competitiveness. The measures for productivity are usually based on time to market, product cost, market share, and quality. In reality, these factors are interrelated and CE strategy is to target a mix of all these factors to give an overall framework to organizations (Naidu et al., 2006).

2.3. Rationale for Implementation of Quality by Design

Project budgets for all industries are becoming the most crucial factor in any product's marketability. Earlier, accounting methods and budgets were not as critical as they are today. In the past, consumers had only a few brands to choose from and the price was dictated by the demand for a quality product, with reasonable profit. Imported products helped balance the demand for quality products at reasonable prices and allowed consumers to set the market price. Quality by design helps control this by shifting all the design to the beginning of the project rather than throughout its lifecycle, as shown in Figure 2.

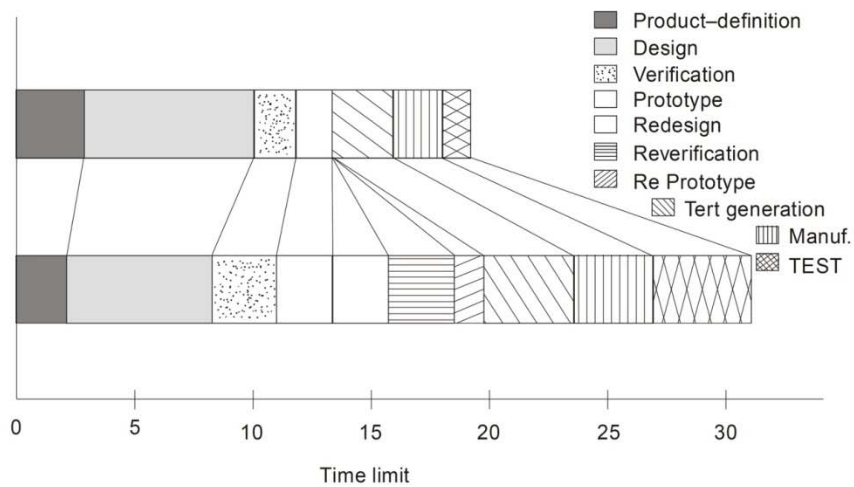

Figure 2: Hypothetical product development time life

According to Figure 2, the amount of time required in the quality-by-design model for product definition and specifications can be significantly greater than that required in the SE model.

By using quality by design, the product is designed within production capabilities in order for statistical process control to be effective. Producing products well within process capabilities will cause a chain reaction of customer satisfaction. Customers' returns will decrease and rework costs will decrease. Thus organizations are taking two steps forward and one step back every day they continuously inspect products that could have been designed within process capabilities rather than at or below process capabilities (Naidu et al., 2006).

2.4. Concurrent Engineering and Concurrent Design

Often referred to when discussing new product development (NPD), CE is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. Designers engaged in the product development process need information from each other, and from other actors related to the process, to be able to make proper decisions when there is any conflict among their designs. To make concurrent design successful, one needs an integrated framework, a well-organized design team, and adequate design tools. Eversheim et al. (1997) points out those departments usually act more or less independently, not knowing each other's demands and capabilities. General commercial information and communication systems only support a sequential workflow, but no parallelism. These general systems are designed to handle documents and exact information. Neither partial information (information units), nor the transmissions of uncertain, fuzzy, and incomplete information are supported by these systems, even if this type of data contains important and valuable information for succeeding activities. Particularly in the early stage, uncertain and incomplete information is typical at the product and process development stage. This information contains many constraints and determines the main part of the development process (Eversheim et al., 1997). Little attention has been paid to organizational issues, compared to the development of tools involved in CE (Jin and Levitt, 1995). Jin and Levitt indicate that research on CE has focused on developing design tools, product data models, and communication infrastructure. Some of the barriers to successful implementation and utilization of CE, they continue, are related to cultural, organizational, and technological issues (Jin and Levitt, 1995).

Finger et al. (1995) argue that CE requires both technical and organizational solutions. They believe that the essence of concurrent CE is the myriad of interactions, the results of which they call "concurrent design". According to them, the social process plays a major role in the articulation and realization of the product design, particularly in large projects. Finger et al. also state that for the engineering research community, CE means, for the most part, the use of computational techniques to build cooperating sets of tools from different areas of design and manufacturing by using specialized representation and coordination mechanisms. These "technical aspects" encompass engineering and computational issues. For industry, they continue, CE has been interpreted as the creation of cross-functional teams that include people responsible for all aspects of the product lifecycle. These "organizational aspects" encompass managerial, communication, and coordination aspects. They use the term "concurrent design" to include both the organizational and technical aspects. Concurrent design is therefore the link; i.e., concurrent design happens at the interfaces.

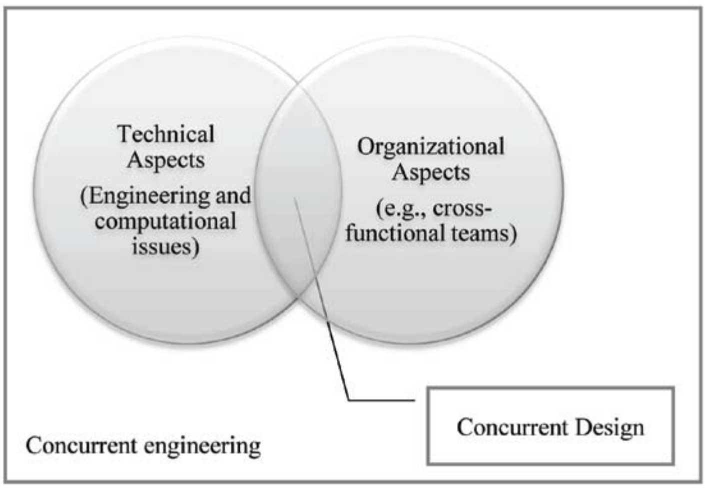

Figure 3: Concurrent design (according to Finger et al., 1995)

There are, however, barriers to concurrent design. Some are highlighted by Finger et al. (1995). These include communication problems, translation difficulties, multiple languages, and loss of design histories. Finger et al. point out that, unfortunately, solutions to these problems are being developed using traditional design and development approaches, i.e., out of the context of the work being supported. They mean that concurrent design depends strongly on context—that is, the links between participants, the processes being used, the artifact being developed—and, after all, consideration of all perspectives is the primary goal of concurrent design. An alternative way of looking at the situation is to recognize that there is no single correct way to do the linking in a concurrent design team across design contexts (Chroneer and Åkehörte, 1998).

2.5. Strategic design management

Peter Gorb (1990) defines design management as "the effective deployment by line managers of the design resources available to a company in order to help the company achieve its objectives." Design management is therefore directly concerned with the place of design within an organization, the identification of specific design disciplines that are relevant to the resolution of key management issues, and the training of senior managers to use design effectively. This definition underscores the point that design is simultaneously an end (putting design in the service of corporate objectives) and a means (contributing to solving management problems). Moreover, design management is the implementation of design as a formal program of activity within a corporation by communicating the relevance of design to long-term corporate goals and coordinating design resources at all levels of corporate activity to achieve the objectives of the corporation. The role of design management is also to foster an

understanding of the relevance of design to fulfilling the company's long-term goals and coordinating design resources at every level of the company.
The respective conceptual schemas and paradigms of design and management can serve as a starting point for building a convergent model of the development of design management based on two perspectives: reactive (managerial) and proactive (strategic) (Borja de Mozota, 1992). The *managerial approach* involves enhancing design by accommodating administrative and management concepts. The *strategic approach* involves examining design as a new paradigm in order to arrive at ideas and methods that can be used to enhance the efficiency of management in general and design management in particular. At the strategic level, design management has four essential roles (Seidel, 2000): visualizing the business strategy, searching for core competency, gathering market information, and innovating in management processes.

2.6. Design strategy in context
In business, the word "strategy" is commonly used at three levels: corporate strategy, business strategy, and functional strategy. Within this hierarchy, design strategy can appear in two places: first, at the corporate level, taking a broad view over a set of related or separate businesses; second, as one of the functional strategies at the business level. This article is predominantly concerned with design strategy at the business level. Design strategy has been defined as "a plan that helps diffuse design throughout the company." For a design strategy and "constructed" competitive design advantage, we will look at three strategies based on those of Michael Porter—three generic design strategies with three different types of aesthetic positioning in an industry (Table 1). These strategies express the relationship between strategy from the point of view of top-level management and the strategies of different operational activities between vision and implementation. Every strategy privileges one of the three "form dimensions": the cost-driven strategy privileges the structural dimension; the image-driven strategy, the symbolic dimension; and the market-driven strategy, the functional dimension. In sum, choosing a design strategy means choosing an aesthetic positioning that will be the expression of the company's approach to design. That choice will determine the position that design has in the company structure (Borja de Mozota, 2003).

Table 1: Design strategies according to porter generic strategies

Cost-driven design strategy	Image-driven design strategy	Market-driven design strategy
Strategy dominated by costs	Strategy of differentiation	Strategy of concentration
Design's role is to improve productivity	Design's role is to reinforce the company's market share through the quality of its image and brands	Design's role is to help position the company as a specialist that appeals to a certain kind of user
The company's aesthetic positioning favors the structural (or technical) dimension of the corporate design system	The company's aesthetic positioning favors the semantic dimension of the corporate design system	The company's aesthetic positioning favors the functional dimension of the corporate design system

Design strategy is shaped according to the focus of the company identity. As with strategy formulation, the design department participates in the selection of a route for implementing the chosen strategy, then develops design actions that will cohere to that route.

2.7. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)
There is a variety of multiple criteria techniques to aid selection in conditions of multiple criteria. TOPSIS is a widely accepted multiple criteria method to identify solutions from a finite set of alternatives. Chen and Hwang (1992), with reference to Hwang and Yoon (1981), first addressed TOPSIS. The basic principle is that the chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution in a geometrical (i.e. Euclidean) sense (Hwang and Yoon, 1981). The main steps of the TOPSIS algorithm are as follows (Hwang and Yoon, 1981; Önüt and Soner, 2007; Perçin, 2009):
Step 1. Calculating the normalized decision matrix. The normalized value r_{ij} is calculated as:

$$r = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{J} f_{ij}^2}} \quad j = 1,2,3, \dots ,J; \; i = 1,2,3, \dots, n. \qquad (1)$$

Step 2. Calculating the weighted normalized decision matrix. The weighted normalized value v_{ij} is calculated as:

$$v_{ij} = w_i * r_{ij} \quad j = 1,2,3, \dots, J; \; i = 1,2,3, \dots, n.$$

where w_i is the weight of the ith attribute or criterion, and $\sum_{i=1}^{n} w_i = 1$.

Step 3. Determining the ideal and negative-ideal solution:

$$A^* = \{v_1^*, \dots, v_n^*\} = \left\{\left(\max_{j} v_{ij} \middle| i \in I'\right), \left(\min_{j} v_{ij} \middle| i \in I''\right)\right\} \quad (2)$$

$$A^- = \{v_1^-, \dots, v_n^-\} = \left\{\left(\min_{j} v_{ij} \middle| i \in I'\right), \left(\max_{j} v_{ij} \middle| i \in I''\right)\right\} \quad (3)$$

where I' is associated with benefit criteria, and I'' is associated with cost criteria.

Step 4. Calculating the separation measures, using the n-dimensional euclidean distance. The separation of each alternative from the ideal solution is given as:

$$D_j^* = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^*\right)^2}, \quad j = 1,2,3, \dots, J. \quad (4)$$

Similarly, the separation from the negative ideal solution is given as:

$$D_j^- = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_i^-\right)^2}, \quad j = 1,2,3, \dots, J. \quad (5)$$

Step 5. Calculating the relative closeness to the ideal solution. The relative closeness of the alternative a_j with respect to A^* is defined as:

$$C_j^* = \frac{D_j^-}{\left(D_j^* + D_j^-\right)}, \quad j = 1,2,3, \dots, J. \quad (6)$$

Step 6. Ranking the preference order.

3. Research Methodology

The data for this study were collected from a questionnaire survey. A structured questionnaire was designed, pretested, and revised wherever necessary. Its content validity was tested through a theoretical review and a pilot test. In this research, data are collected through brainstorming and Delphi method. This paper used the Hierarchical Clustering Algorithm (HCA) as the classifier for internal and external factors. After determining the factors affecting SAPCO's design department, concurrent design strategies were developed using the SWOT matrix. Subsequently, their priorities were determined using the TOPSIS method.

4. Case Study and Findings

4.1. Company characterization

Supplying Automotive Parts Company (SAPCO) is the exclusive supplier of automotive parts for Iran Khodro Company (IKCO), the dominant car manufacturer in the Middle East with more than 600,000 cars produced annually and a turnover of seven billion dollars. Established in March 1994, SAPCO has fully accomplished its mission as a dependable source of "design engineering and automotive parts" for IKCO. With its well-qualified human resource capital of 1,380 persons, (73% of whom are holders of university degrees), the company is ranked as the first engineering company in Iran. Approximately 4,000 local manufacturers are identified by SAPCO and almost 500 suppliers have direct contracts with the company as TIER1s. SAPCO's supply chain is now locally producing more than 4,000 different parts, from bolts and nuts to complicated EMS components. The service offered by SAPCO and its main responsibility is supply chain management. The SAPCO's activities are: conducting design and improvement projects, supply planning, identifying potential auto-parts manufacturers and evaluating them, signing supply contracts with auto-parts manufacturers or vendors, controlling quality and inspecting parts, importing auto-parts directly or as complete knock-down (CKD), importing and distributing raw materials for auto-parts production, training auto-parts manufacturers in order to promote their technical and managerial knowledge, providing services such as precise measurement, simulation and consultation, and promoting and facilitating auto-parts export.

4.2. Determination of External and Internal Factors by Using Nominal Group Technique (NGT) and Hierarchical Clustering Method

The internal and external factors affecting SAPCO can be revealed through a NGT (a modified form of brainstorming). This led to a rich range of factors being proposed and avoided potentially dominant views of some participants biasing the outcomes. Subsequently, hierarchical clustering algorithm is used as the classifier for internal and external factors. Tables 2 and 3 indicate the internal and external factors of SAPCO.

Table 2: Internal factors

Strengths (S)	S1	Factors related to commitment and capability of the product design department
	S2	Factors related to organizational excellence and professional capabilities of human resources compared to the supply network
Weaknesses (W)	W1	Factors related to financial and technological resources and utilizing them to support the supply network
	W2	Factors related to organizational excellence and professional capabilities of human resources compared to supply network

Table 3: External factors

Opportunities (O)	O1	Factors related to supportive and legal governmental policies at macro level with positive influence (supporting auto manufacturers against foreign competitors in the country)
	O2	Factors related to the geographical position of the country
	O3	Factors related to international cooperation and foreign industrial development
	O4	Factors related to financing policies and domestic investments
	O5	Interactive factors
	O6	Factors related to experience in production and supply
Threats (T)	T1	Factors related to supportive and legal governmental policies at macro level with negative influence (consumer protection in the country)
	T2	Economic factors
	T3	Factors related to foreign financing and policies on control of financial risks
	T4	Energy-related factors and their limitations
	T5	Factors related to tariff barriers
	T6	Factors related to foreign competition
	T7	Factors related to quality standards and mandatory requirements
	T8	Factors related to interacting with the external supply network
	T9	Technological factors
	T10	Market factors
	T11	Factors related to domestic suppliers’ performance
	T12	Factors related to value creation

4.3. Determination of Concurrent Design Strategies by Using Delphi and SWOT Methods

The internal factors and external factors are matched pair by pair, with positive impacts (i.e., from Strengths and Opportunities) maximized and with negative impacts (i.e., from Weaknesses and Threats) minimized. The rational responses to the combinations of internal and external factors were summarized in the four quadrants. As we are in an era of changes, the SWOT analysis should be conducted at least annually (Koo & Koo, 2007). Table 4 indicates the concurrent design strategies retrieve from SWOT matrix.

Table 4: Concurrent design strategies retrieve from SWOT

Strategy area	Type	Code	Core strategies
Product Design (PD)	SO	PD01	Taking advantage of support policies in the country to develop products with national brands
		PD02	Steering the regional domestic market by harnessing the product design department's potential
		PD03	Utilizing the professional competence of human resources to support the competitive position of the country in the region
		PD04	Developing a long-term strategic approach to design
		PD05	Using multi-task teams to develop specification of the final product quality
	WO	PD06	Developing partnerships with universities and training centers based on international standards of competitiveness.
		PD07	Creating a strategic approach for using new investment opportunities in order to develop in the direction visualized by the design department
	ST	PD08	Creating a specific and centralized management body in the engineering design department of SAPCO/ IPCO/ Iran Khodro to increase synergy and promote the competitiveness level of automobiles
		PD09	Encouraging better communication with manufacturers and manufacturing groups that help to supply legal standards related to the environment
		PD10	Supporting technological investments and creation of computer integrated manufacturing (CIM)
		PD11	Developing cooperation between local companies in order to make synergetic use of capacities and abilities
		PD12	Increasing the proportion of the engineering design expectations in relation to authorities and capabilities
		PD13	Assuring effective diversity management in platforms of parts and sets, with the aim of reducing costs and improving quality; intelligent diversity and standardization (modular design, lower architecture costs, lower parts costs, and more models)
		PD14	Planning to convert manufacturers to full service suppliers (FSS) by creating design centers in selected manufacturers by various methods including R&D promotion (management of technical knowledge transfer among manufacturers).
		PD15	Creating and enhancing technical knowledge in SAPCO (micro) and Iran Khodro (macro) by creating pools of specialized design (management of technical knowledge transfer among manufacturers)
		PD16	Implementing quality improvement projects by designing and engineering methods
		PD17	Increasing efficiency by paying greater attention to special offers for employees
	WT	PD18	Acquiring and developing knowledge of world-class designs for green cars
		PD19	Acquiring the necessary skills and capabilities to work with export clients and compete with foreign competitors in the domestic market
		PD20	Receiving technical documents from manufacturers and retailers such as Peugeot (prior to contract)
		PD21	Developing partnerships with global automotive and engineering design companies and building strategic alliances with rival firms to achieve competitive advantages
		PD22	Promoting the competence of leaders and increasing the knowledge of staff through planned projects
		PD23	Managing financial and technological resources and utilizing available capacities in the automotive industry in an attempt to meet customer expectations in the area of design and innovation
		PD24	Using world-class manufacturing standards (and measuring performance through the products' acceptance rate in the market)

4.4. Evaluation of the concurrent design strategies

Questionnaire was prepared to evaluate the importance of each sub-criterion, and ten experts, including the professional management and scholars in the design-engineering field. Afterwards, by using the TOPSIS technique, concurrent design strategies are ranked. The calculations are performed by TOPSIS application written in Visual Basic for Application (VBA). In Table 5, the rank of each strategy and relative value of it, after calculation are shown. As it can be observed, PD14, PD15, and PD08 are ranked as first to third priorities, respectively.

Table 5: Final ranking of relative value of concurrent design strategies

Strategy	D_j^*	D_j^-	Relative Value (C_j^*)	Rank
PD01	0.174	0.076	0.304	17
PD02	0.239	0.011	0.043	23
PD03	0.207	0.044	0.174	20
PD04	0.120	0.131	0.522	12
PD05	0.109	0.141	0.565	11
PD06	0.044	0.207	0.826	5
PD07	0.131	0.120	0.478	13
PD08	0.022	0.228	0.913	3
PD09	0.163	0.087	0.348	16
PD10	0.033	0.218	0.870	4
PD11	0.218	0.033	0.130	21
PD12	0.250	0.009	0.034	24
PD13	0.065	0.185	0.739	7
PD14	0.008	0.250	0.968	1
PD15	0.011	0.239	0.957	2
PD16	0.098	0.152	0.609	10
PD17	0.141	0.109	0.435	14
PD18	0.228	0.022	0.087	22
PD19	0.196	0.054	0.217	19
PD20	0.076	0.174	0.696	8
PD21	0.054	0.196	0.783	6
PD22	0.152	0.098	0.391	15
PD23	0.185	0.065	0.261	18
PD24	0.087	0.163	0.652	9

To analyze the manner of the strategies under different criteria weights, a sensitivity analysis could be conducted. The idea of sensitivity analysis is to exchange each criterion's weight with another criterion's weight. It is important to note that the findings are limited to one case study, and therefore, extension of the results to other services and industries should be undertaken with care.

5. Conclusion

This paper applies TOPSIS method to prioritize concurrent design strategies. In future research, the strategies defined and ranked in this study can be used in different engineering design companies. As a future scope, a fuzzy TOPSIS based methodology may be developed to aid the decision makers to take decisions in presence of imprecise and incomplete data. On the request of the participating organizations and the team of experts, the researcher is now working on prioritization of concurrent design strategies using the fuzzy analytic network process (ANP) and convergence of concurrent design strategies with SAPCO business strategies.

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