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An integrated approach to concept evaluation in a new product development

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Abstract A new product development (NPD) process can be thought as a comprehensive process in which the design is progressively detailed through a series of phases. At the end of each phase a design review is held to approve the design and release or not it to the next level. As one of these phases, concept selection aiming to select the most appropriate concept for further development, is conducted earlier in the process. As the further development progresses on a selected concept, it becomes more difficult to make design changes in terms of cost and schedule dimensions, and therefore, selecting the best concept among a set of available alternatives has been an important issue for companies. On the other hand, in the presence of many alternatives and selection criteria, the selection problem becomes a multiple-criteria decision making concept selection problem. To solve this problem, in this work, an integrated approach bringing two popular methods together: the modified technique for order preference by similarity to ideal solution (TOPSIS) and the analytical network process (ANP). The ANP method is used to determine the relative weights of a set of quantitative and qualitative evaluation criteria, as the modified TOPSIS method utilized to rank competing concept alternatives. In addition, a real example is presented to demonstrate the effectiveness and applicability of the proposed approach for potential practitioners and readers.

Keywords Concept selection · Multiple-criteria decision making (MCDM) · Modified TOPSIS · Analytic network process (ANP) · Hot runner systems

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Introduction

Today's world is characterized by major changes in market and economic conditions, coupled with rapid advances in technologies. As the natural result of this, companies have been forced to develop new products for current markets, most of all technology-driven or high-tech markets. The changing economic conditions and technologies combined with increased domestic and global competition, changing customer needs, rapid product obsolescence and the emergence of new markets, require very fast innovation process. The innovation process can be divided into three main areas such as fuzzy front end (FFE) or project planning, new product development (NPD) process, and commercialization.

A NPD environment is a strategic business activity by intent or by default (Whitney 1988). It is not only the critical linkage between a business organization and its market, but it is also fundamental to business success. Business organizations need to manage their product development activities strategically to gain competitive advantage in the market place. Firms that fail to manage their product development activities strategically are not only running their business from a position of disadvantage but also risking their future (Fitzsimmons et al. 1991). The critical role of NPD in the survival and success of business organizations and the need for managing it strategically is being recognized increasingly in both the academic (Finger and Dixon 1989a, b; Brown and Eisenhardt 1995; Griffin and Hauser 1996; Krishnan and Ulrich 2001) and practitioner (Gates 1999; Chesbrough and Teece 2002; Welch and Kerwin 2003) literature.

A NPD process is the sequence of steps or activities which an enterprise employs to conceive, design and commercialize a product. This development process typically includes the following activities as seen in Fig. 1: identifying customer needs, establishing target specifications, concept

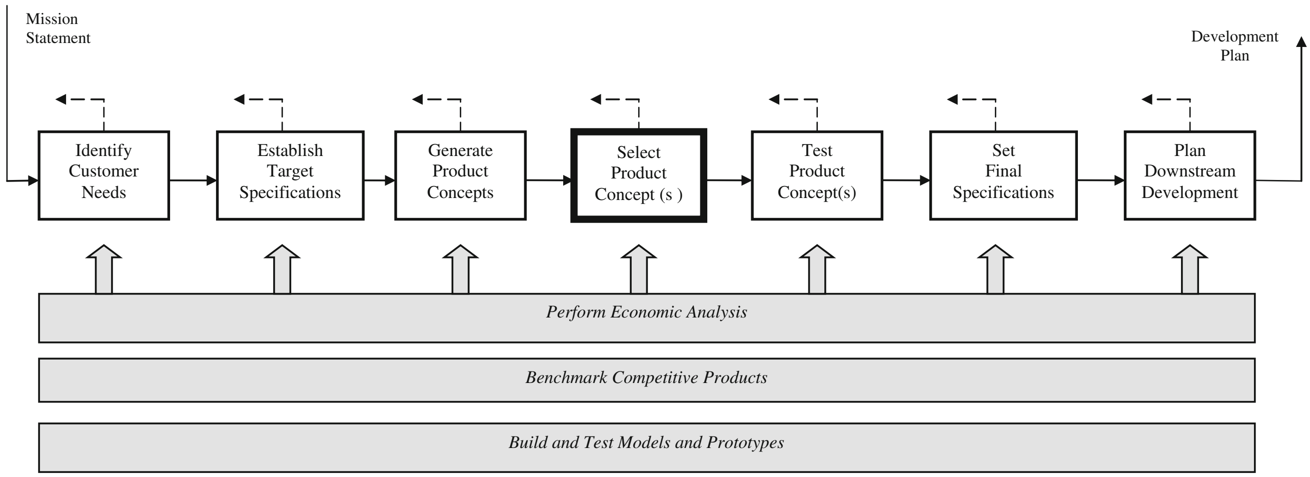

Fig. 1 The concept development process (Ulrich and Eppinger 2000)

generation, concept selection, concept testing, setting final specifications, project planning, economic analysis, benchmarking of competitive products, modeling and prototyping. In the process, in concept generation, various concepts are introduced and needs to be evaluated in terms of the criteria (i.e., highest performance and lowest cost) (Ayag 2005b). This process is called *concept selection* and explained next.

Concept selection is often the Rubicon in the product design process. It is so vital that the best initial concepts are selected, as they determine the direction of the design embodiment stage. It is often said in the literature that about 60 or 80 % of the cost is committed at this stage (Duffy et al. 1993). After this stage has been passed, the design process will diverge towards a detailed solution. Concept selection is therefore a vital part in the design process. It is recognized that the ability to rapidly evaluate design ideas, throughout their development within the design process, is an essential element in the goal to increase design productivity. Given the need for companies to produce more and more innovative products in an increasingly competitive market place, it follows that designers have to consider an increased number of design options (for example: based on the product type and sector, here it can be min.10). The activity of judging between and selecting from a range of competing design options is referred to as evaluation. As the number of options to evaluate increases and the time available decreases, it is evident that human evaluators will require increasing assistance in selecting the most satisfying design alternative. Due to the fact that evaluation process of the design alternatives becomes a multiple-criteria decision making (MCDM) problem in the existence of many criteria and alternatives, a decision-maker(s) needs to utilize MCDM methods currently used in practice.

Therefore, in this work, in literature, two of the most commonly-used methods: the modified TOPSIS (the technique for order preference by similarity to ideal solution) and the ANP (analytical network process) are brought together to solve the concept selection problem. The ANP method is used to determine the relative weights of a set of quantitative and qualitative evaluation criteria, as the modified TOPSIS approach using a new *weighted Euclidean distance* is utilized to rank competing alternatives in terms of their overall performance on evaluation criteria in order to reach to the best one satisfying the customer expectations and the engineering specifications of company. If this integrated approach is compared with other MCDM methods, especially utility methods, none of which in current literature accommodates coupled decisions within the calculation, although they are a reality in most design situations. On the other hand, this integrated approach dramatically reduces the number of the steps of evaluation process resulting in less computational time in the presence of more concept alternatives. It also provides better and reliable way to reach to the required solution.

In addition, a real-life example, realized in a leading hot runner system manufacturer in Canada, is presented to demonstrate the applicability of the proposed approach for potential practitioners and readers.

The rest of the paper is structured as follows: Next, the related literature and the proposed approach are presented in Sects. 2 and 3. Then, in Sect. 4, a case study is given to show the applicability of the proposed approach. Last, in Sect. 5, the conclusions on the reported results of the proposed approach is presented.

Related literature

In literature, many MCDM methods have been introduced to solve different types of MCDM problems, some them are listed as follows: Aggregated indices randomization method

(AIRM), data envelopment analysis, decision expert (DEX), dominance-based rough set approach (DRSA), ELECTRE (Outranking), the evidential reasoning approach (ER), goal programming, grey relational analysis (GRA), inner product of vectors (IPV), measuring attractiveness by a categorical-based evaluation technique (MACBETH), disaggregation-aggregation approaches (UTA, UTAII, UTADIS), multi-attribute global inference of quality (MAGIQ), multi-attribute utility theory (MAUT), multi-attribute value theory (MAVT), new approach to appraisal (NATA), non-structural fuzzy decision support system (NSFDSS), potentially all pairwise rankings of all possible alternatives (PAPRIKA), PROMETHEE (Outranking), superiority and inferiority ranking method (SIR method), value analysis (VA), value engineering (VE), VIKOR method, weighted product model (WPM), weighted sum model (WSM), DAMETAL, SMART and SMARTER.

But, only group of them (a.k.a. concept selection methods, CSMs) have been used for concept selection problems in a NPD environment. In a study, King and Sivaloganathan defined the CSMs methods as five main types as follows (King and Sivaloganathan 1999);

Utility CSMs Utility theory has formed the basis for the majority of CSMs in the literature. The method was first developed for economic decision-making and has since been incorporated into a number of systematic design models. Other work by Thurston et al. (1991) has concentrated on optimization of the utility function, while Reddy and Mistree's method (Reddy and Mistree 1992) develops uncertainty modeling. The core principle in the theory is a mapping of how criteria will vary across the range of each criterion. This relationship is governed by a utility function. Pahl and Beitz (1984) were among the first to incorporate utility theory into a systematic design method. In their method the decision regarding different concepts is based on the requirements list. Pahl and Beitz's method provides a workable example of utility theory. However, none of the utility methods given in the literature ignores coupled decisions within the calculation, although they are a reality in most design situations.

AHP CSMs Saaty (1981) first developed the analytic hierarchy process (AHP) method for decision making, and Marsh et al. (1991) developed a more specific method directly for design decision-making. The Marsh's AHP has three steps ordering the factors (i.e. attributes) of a decision such that the most important ones receive greatest weight.

Graphical CSMs Pugh's evaluation method: Pugh (1991) gives a simple graphical technique that centers around a matrix with columns (showing concepts) and rows (giving decision criteria) Pugh's evaluation matrix is very simple and fast. However, no measure is given of the importance of each of the criteria and it does not allow for coupled decisions. Therefore, there is a danger that the final concept can be distorted. The simplicity of Pugh's evaluation matrix makes the method a good screening process against highly unfeasible concepts and can allow the designer to focus on the best concepts using a different CSM.

Quality function deployment (QFD) matrices QFD invented by Akao (1990) is a graphical adaptation of Utility Theory with several additions to assist decision-making building block of the method is a matrix chart known as a "House of Quality (HOQ)" and columns follow the method of utility as given earlier in this paper. While the matrix follows Utility Theory in many ways, the interaction chart gives a measure of coupled decisions. However, no numerical method is given to this measure into the QFD calculation. Without a numerical method, this become complex for most design situations where many concepts are visual comparison would be almost impossible.

Fuzzy Logic CSMs Fuzzy logic is a concept used when a decision needs to be made near the boundary of two outcomes. Thurston and Carnahan (1992) proposed the application of fuzzy set theory to multiple criteria engineering design evaluation process. They do not use normalized weights in order that the extended division will not be needed in the calculation. They developed a fuzzy logic CSM. The method of fuzzy sets does require a rather lengthy methodology and is by no means easy to use. It is still necessary to determine the mathematical equation in order to establish a solution. In the field of design decision-making, many decisions are not based upon known (or definable) mathematical equations. The methodology therefore has a very limited advantage when considered as a general methodology for a CSM.

The above-mentioned CSMs can be compared on each other as follows: Decision matrices are systematic tools and efficiently used for pre-screening concept alternatives relative to one another, such as those of Pahl and Beitz (1984) and Pugh (1991). Most methods reviewed allow for multiple attributes to a decision, although the QFD matrix method represents this facility with greatest clarity because of its graphical template. The QFD method provides a qualitative interaction table, but this is used for "optimal conflict information", and does not provide a quantitative analysis of how one decision affects another. A choice to use one technology or component will significantly affect the rest of the design (King and Sivaloganathan 1999). On the other hand, fuzzy logic methods do require a rather lengthy methodology and is by no means easy to use. It is still necessary to determine the mathematical equation in order to establish a solution. In the field of design decision-making, many decisions are not based upon known (or definable) mathematical equations. The methodology therefore has a very limited advantage when considered as a general methodology for a CSM. In addition, none of the utility methods given in the literature accommodate coupled decisions within the calculation, although they are a reality in most design situations.

In another study, Okudan and Tauhid (2008) reviewed prior literature and classified the concept selection methods into the following categories:

1. CSMs based on decision matrices (pugh method, quality function deployment),
2. CSMs based on the analytic hierarchy process and its general form, analytic network process (AHP/ANP),
3. CSMs based on uncertainty modelling: To make decision-making tools to be more flexible allowing for uncertainties in the concept selection process, uncertainty can be incorporated into decision-making using three different branches of mathematics (i.e. non-classical mathematics, probabilistic mathematics, and fuzzy clustering),
4. CSMs based on decision theory and economic models,
5. CSMs based on optimization concepts: in the presence of multiple objectives (multi-objective optimisation), there is often an infinite number of candidate optimal solutions (referred to as Pareto optimal solutions). Optimisation techniques try to identify and select these Pareto optimal solutions. During concept evaluation process, each non-dominated concept can be thought as a candidate 'design solution' to a discrete optimisation problem
6. CSMs based on heuristics (i.e. genetics algorithms, simulated annealing).

As one of the above-mentioned CSMs, AHP has been widely used for MCDM problems in literature (i.e. Ayag 2002, 2005a; Scott 2002; Zahedi 1986) since it was first introduced by Saaty (1981). In AHP, a hierarchy considers the distribution of a goal amongst the elements being compared, and judges which element has a greater influence on that goal. In reality, a holistic approach like ANP is needed, if all criteria and alternatives involved are connected in a network system that accepts various dependencies. Several decision problems cannot be hierarchically structured because they involve the interactions and dependencies in higher or lower level elements (primary criteria, criteria and alternatives). Not only does the importance of the criteria determine the importance of the alternatives as in AHP, but the importance of alternatives themselves also influences the importance of the criteria. In other words, ANP incorporates feedback and interdependent relationships among decision attributes and alternatives (Saaty 1996). This provides a more accurate approach for modeling complex decision environment (Meade and Sarkis 1999; Lee and Kim 2000; Agarwal and Shankar 2003; Yurdakul 2003).

As another method among various MCDM methods developed to solve real-world decision problems, the TOPSIS (the Technique for Order Preference by Similarity to Ideal Solution) has been used in diverse application areas. Hwang and Yoon (1981) originally proposed TOPSIS to help select the best alternative with a finite number of criteria. TOPSIS bases on the concept that the best alternative should have the shortest distance from the positive-ideal solution and the farthest distance from the negative-ideal solution. Although its concept is rational and understandable, and the computational steps involved are uncomplicated, the inherent difficulty of assigning reliable subjective preferences to the criteria is worth of noting. As a well-known classical MCDM method, TOPSIS has received much interest from researchers and practitioners. The global interest in the TOPSIS method has exponentially grown, which we wish to document in this paper (Behzadian et al. 2010).

In literature, many works have been introduced to solve MCDM problems using AHP/ANP and TOPSIS together. Some of them recently published can be summarized as follows: Kahraman et al. (2007) aimed at improving the quality and effectiveness of decision-making in a new product introduction. They proposed a systematic decision process for selecting more rational new product ideas, and used fuzzy heuristic multi-attribute utility method for the identification of non-dominated new product candidates and a hierarchical fuzzy TOPSIS method for the selection of the best new product idea. Sheu (2007) presented a hybrid neuro-fuzzy methodology to identify appropriate global logistics operational modes used for global supply chain management, by integrating fuzzy AHP and TOPSIS. Ertugrul and Karakasoglu (2009) developed a fuzzy model to evaluate the performance of the firms by using financial ratios, and taking subjective judgments of decision makers into consideration. Their proposed approach is based on fuzzy AHP and TOPSIS. Işıklar and Buyukozkan (2007) used AHP and TOPSIS to evaluate mobile phone options in respect to the users' preferences order. Onut and Soner (2008) also used AHP and fuzzy TOPSIS to solve the solid waste transshipment site selection problem. Lin et al. (2008) presented a framework that integrates the AHP and TOPSIS methods to assist designers in identifying customer requirements and design characteristics, and help achieve an effective evaluation of the final design solution. Tsaur et al. (2002) applied AHP in obtaining criteria weights and TOPSIS in ranking to evaluate of airline service quality. Shyur and Shih (2006) proposed a hybrid model for supporting the vendor selection process in new task situations. They used both modified TOPSIS method to adopt in order to rank competing products in terms of their overall performances, and the ANP to yield the relative weights of the multiple evaluation criteria, which are obtained from the nominal group technique (NGT) with interdependence. In another work, Shyur (2006) modeled the COTS evaluation problem using modified TOPSIS and ANP. They used the ANP to determine the relative weights of multiple evaluation criteria and the modified TOPSIS to rank competing alternatives in terms of their overall criteria. Kang et al. (2012) proposed an ANP model integrated with fuzzy logic for supplier selection problem in an IC packaging company. Ozaki et al. (2012) also used minor ANP for finding the best supplier from a set of supplier alternatives. Dagdeviren (2008) utilized AHP and PROMETHEE together for equipment selection problem. Sharma and Balan (2013) used Taguchi loss function, TOPSIS, and multi criteria goal programming for the same problem; supplier selection. Taha and Rostam (2012) proposed a hybrid fuzzy AHP-PROMETHEE approach for machine tool selection problem in a flexible manufacturing cell. Ayag and Ozdemir (2011) also proposed an intelligent approach to machine tool selection problem using fuzzy ANP.

Research gap

In literature, as mentioned before, many approaches have been proposed and implemented for concept selection problem, however, most do have limitations relating to three issues: (i) functional decomposition and potential couplings among various functional areas (and hence generated concepts) are not taken into account, (ii) despite rigor and increased computational complexity some solution methods do not warrant improved solutions, and (iii) most methods do not incorporate uncertainty to the concept selection process (Okudan and Shirwaiker 2012). To overcome these limitations, in this study, an integrated approach using ANP and TOPSIS is proposed to concept selection problem.

On the other hand, in literature, to the best of our knowledge, we have not come cross any kind of work that the methods, the ANP and the modified TOPSIS methods are used together for concept selection problem. On the other hand, using full ANP (realizing its all 4-steps) is a relatively more complicated compared with other existing methods (i.e. AHP, QFD) in the decision making, and it creates a great deal of pairwise calculations, especially if the number of alternatives (min.10) and evaluation criteria (min.25) are very large. In short, in this study, the certain part of the ANP method (only first 2-steps) that has been used to determine the weights of evaluation criteria by considering the interactions and dependencies in higher or lower level elements in various studies in the latest literature, creates more reliable solutions. It also accommodates coupled decisions. On the other hand, in literature, the modified TOPSIS has been widely used for large-size problems to rank competing alternatives (min.10 alternatives). In short, the proposed idea of bringing ANP and the modified TOPSIS provides a new point of view on solving concept selection problems because;

1. The full ANP method gets cumbersome, especially if the number of alternatives (min.10) and evaluation criteria (min.25) are very large based on the product type and sector. It means that more time and efforts to construct pairwise comparison matrix and supermatrix are needed to reach to the required solution, even if specially-designed software, *Super Decisions* is used. Moreover, ANP is not practically usable since the repetitive assessments may cause fatigue in decision-makers (Briand 1998).
2. On the other hand, the ANP is well-known method in determining the weights of a reasonable number of evaluation criteria because it allows decision-makers to model interrelationships of criteria clusters and internal relations in each cluster. However, the evaluation criteria for concept selection problem are not always independent of each other, but often interact. An invalid result can be made in the face of this complexity. On the other hand, ANP has become a popular MCDM method in the last couple of years and has been applied for heavy utilization in combination with other methods. Due to certain shortcomings in AHP, the ANP studies have increased, especially in combination with other MCDM methods (i.e. TOPSIS).
3. Therefore, TOPSIS is one of the most commonly-used method, is chosen to rank a set of alternatives because it provides: (i) a sound logic that represents the rationale of human choice, (ii) a unique visualization of the alternatives on a polyhedron, (iii) a scalar value that accounts for the best and worst alternative choices simultaneously, (iv) a simple computation process that can easily be programmed into a spreadsheet. In addition, it requires at a reasonable effort and time without more complicated calculations. The mathematical model in the modified TOPSIS is relatively easier for the decision-makers to understand. It is also closely coinciding with human perspectives and can easily find out the preferences among multiple decisions. Although the TOPSIS is rational and understandable, and the computational steps involved is uncomplicated, the inherent difficulty of assigning reliable subjective preferences to the criteria is worth of note. Furthermore, many of the studies in literature, have showed that TOPSIS confirms the answers obtained by other MCDM methods. Because the advantage of its simplicity, easy to use, programmable, and its ability to maintain the same amount of steps regardless of problem size has allowed it to be utilized quickly in order to review other methods or to stand on its own as a decision-making tool.

As explained above in detail, this integrated approach, the ANP-based modified TOPSIS, dramatically reduces the number of the steps of evaluation process resulting in less computational time in the presence of more concept alternatives.

Proposed approach

A NPD can be thought as a comprehensive process in which the design is progressively detailed through a series of phases.

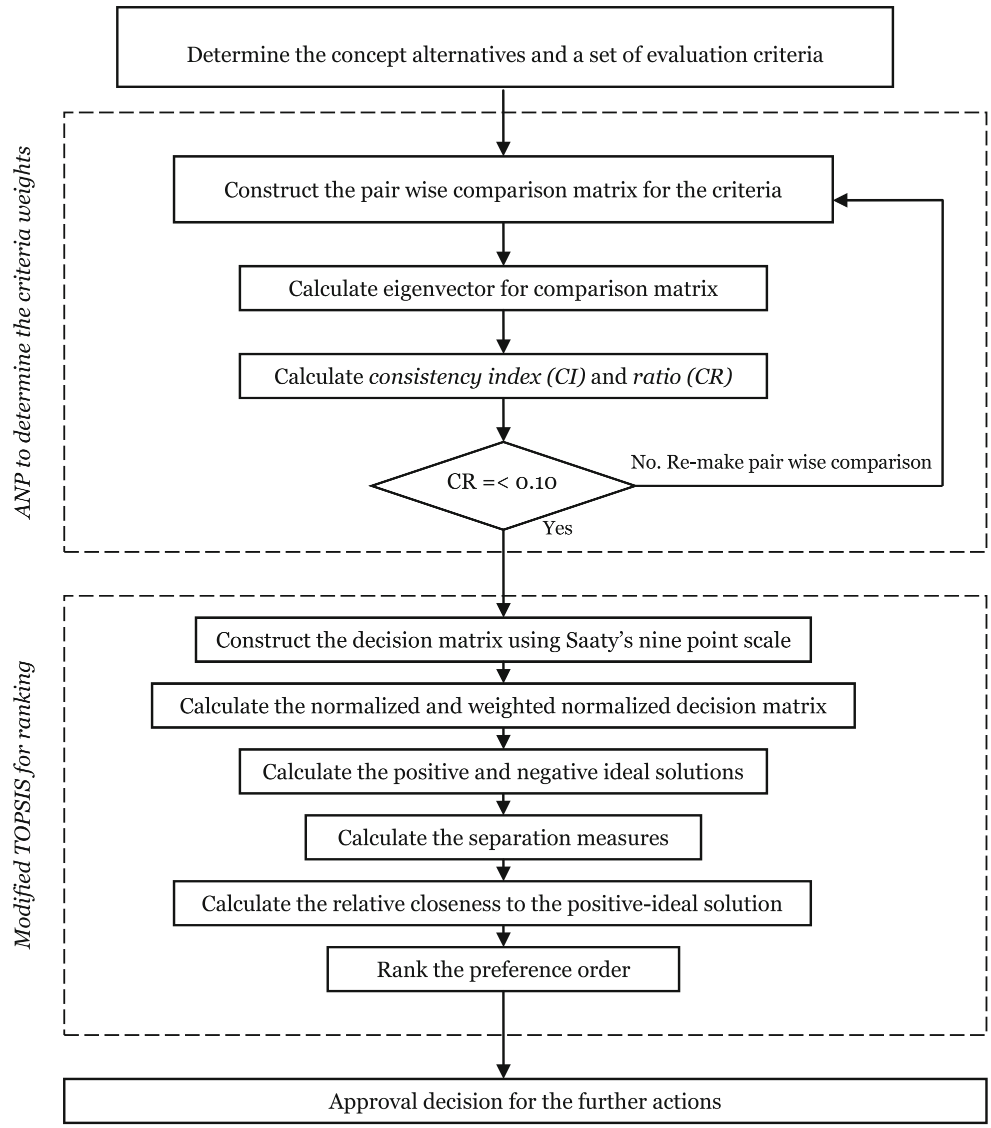

Fig. 2 Stepwise application of the proposed approach for concept selection problem

At the end of each phase a design review is held to approve the design and release it to the next level. In this study, as a phase of the NPD process (see Fig. 1), concept selection is taken into consideration because its aim is to select the most appropriate concept for further development activities, is conducted early in the process. As the development progresses on a selected concept, it becomes more difficult to make design changes due to cost and schedule implications, and thus, selecting *the best available concept is* very important. Therefore, to determine the best alternative among a set of conceptual design alternatives, in this study, as seen in Fig. 2, a stepwise approach through ANP and TOPSIS methods is proposed.

At the beginning, a cross-functional team consisting of the selected members from the departments (i.e. manufacturing, quality, and project or product engineering) of company should be set up for a NDP process. In addition to concept selection task, this team has also responsibility of realizing other product-related activities (i.e. identifying customer needs, establishing target specifications, concept generation, concept testing, and so on) in a NPD environment. Then, this team is also responsible of generating a number of the possible concept alternatives according to both the customer needs and the company's engineering specifications. After this, a set of evaluation criteria mainly expressing product characteristics is determined. If the number of alternatives is large (min.10), the proposed approach may not be effective for the problem because of a great deal of computational steps. In this case, through *Pareto optimality*, the number of the alternatives is reduced to a reasonable level by firstly comparing them in terms of each evaluation criterion and to eliminate extreme those. Pareto optimality is a kind of

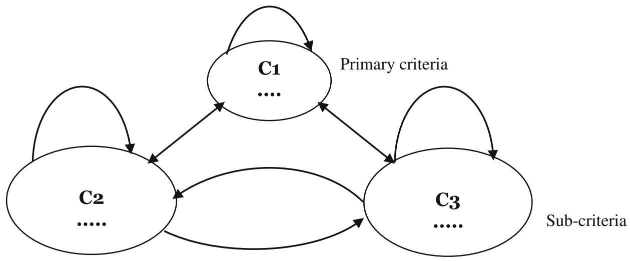

Fig. 3 Interdependence relationships among clusters and inside clusters

pre-screening process to eliminate extreme alternatives in terms of each criterion. For example: in a car selection problem, some of alternatives whose costs (cost as a criterion) are non-affordable can be eliminated at the beginning.

As seen in Fig. 2, the proposed approach has two modules, one of which is the ANP module that includes the steps of determining the relative weights of the evaluation criteria; another is the modified TOPSIS method to include the necessary steps to rank the competing alternatives to find out the best alternative. Later, the best concept alternative is presented to the company's management for approval, and then an implementation schedule is prepared for further development activities (i.e. concept testing, setting final specifications, pilot and serial manufacturing) in the NPD process.

Next the related modules of the proposed approach are defined more in detail. The approach modifies the TOPSIS method by using *weighted Euclidean distances* to ensure a meaningful interpretation of the comparison result.

Weighting of the evaluation criteria

In order to determine the weights of the evaluation criteria in a concept selection problem, an ANP-based framework is constructed to show the relationships among the criteria clusters, and inside clusters. The graphical representation of this framework and its decision environment is presented in Fig. 3. The clusters denoted as $C1$, $C2$ and $C3$ are used to determine the relative weights of the evaluation criteria.

The ANP method represents relationships hierarchically but does not require as strict a hierarchical structure and therefore allows for more complex interrelationships among the decision levels and attributes. After constructing flexible hierarchy, a decision-maker(s) (i.e. product or/and design engineer) is asked to compare the elements at a given level on a pair wise basis to estimate their relative importance in relation to the element at the immediate proceeding level. It also accommodates coupled decisions. In conventional ANP, the pair wise comparison is made by using a ratio scale. A frequently used scale is the nine-point scale developed by Saaty (1989) which shows the participants' judgments or preferences. Table 1 shows this fundamental nine-point scale.

Table 1 Nine-point fundamental scale used in pairwise comparisons (Saaty 1996)

Intensity of importance	Definition	Explanation
1	Equal importance	Two attributes contribute equally to the attribute to the objective
2	Weak	
3	Moderate importance	Experience and judgment slightly favor one attribute over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one attribute over another
6	Strong plus	
7	Very strong and demonstrated importance	An attribute is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one attribute over another is of the highest possible order of affirmation

Next, to understand the contribution of the ANP methodology to the proposed approach, firstly steps of the full ANP approach are given as follows (Gorener 2012);

Step 1: Model construction and problem structuring: The problem should be stated clearly and decomposed into a rational system like a network,

Step 2: Pairwise comparisons and priority vectors: In ANP, like AHP, pairs of decision elements at each cluster are compared with respect to their importance towards their control criteria. In addition, interdependencies among criteria of a cluster must also be examined pairwise; the influence of each element on other elements can be represented by an eigenvector. The relative importance values are determined with Saaty's scale,

Step 3: Supermatrix formation: The supermatrix concept is similar to the Markov chain process. To obtain global priorities in a system with interdependent influences, the local priority vectors are entered in the appropriate columns of a matrix. As a result, a supermatrix is actually a partitioned matrix, where each matrix segment represents a relationship between two clusters in a system.

Step 4: Synthesis of the criteria and alternatives' priorities and selection of the best alternatives: The priority weights of the criteria and alternatives can be found in the normalized supermatrix.

Secondly, more explanation on how the weights of the evaluation criteria are obtained is presented next: Only Steps 1–2 are used to calculate the weights of criteria as follows:

Without assuming the interdependence among the evaluation criteria, the decision-maker(s) are asked to make a series of pairwise comparison in order to construct a decision matrix, A, using nine-point scale (Table 1). When scoring is conducted for a pair, a reciprocal value is automatically assigned to the reverse comparison within the matrix. That is, if a_{ij} is a matrix value assigned to the relationship of component i to component j, then a_{ij} is equal to $1/a_{ij}$ or $a_{ji} = 1$. Once the pair wise comparisons are completed, the local priority vector w is computed as the unique solution to $Aw = \lambda_{\max} w$ where, $\lambda_{\max}$ is the largest eigenvalue of A. To check out consistency on the judgments of the decision-maker for the pair wise comparison matrix, A, the consistency ratio (CR) should be calculated. The deviations from consistency are calculated using the following formula (the measure of inconsistency is called the consistency index (CI));

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{1}$$

The CR is used to estimate directly the consistency of pair wise comparisons. The *CR* is computed by dividing the *CI* by a value obtained from a table of Random Consistency Index *(RI),* the average index for randomly generated weights (Saaty 1981) as follows. If the *CR* is equal or less than 0.10, the comparisons are acceptable, otherwise they are not.

$$CR = CI/RI \tag{2}$$

In comparison to the AHP, ANP is capable of handling interrelationships between the decision levels and attributes by obtaining the composite weights through the development of a "supermatrix". The supermatrix is a partitioned matrix, where each submatrix is composed of a set of relationships between two components or clusters in a connection network structure. Saaty (1996) explains the concept corresponding to the markov chain process. In this work, we utilized *the matrix manipulation* on the concept of Saaty and Takizawa (1986) instead of Saaty's original supermatrix, because of its ease of understanding. We also utilized the work of Shyur and Shih (2006) realized for vendor selection problem.

In order to reflect the interdependencies in the network, a set of pair wise comparison matrices are constructed for each criterion and their consistency ratios are calculated. These matrices are used to identify the relative impacts of the criteria interdependent relationships. The normalized principal eigenvectors for the matrices are calculated and shown as column component in the manipulated matrix, S, where zeroes are assigned in the matrix if there is no relationship between the related criteria. Finally, we can obtain the interdependence priorities of the criteria by synthesizing the results of previous calculations as follows;

$$w_{criteria} = S^{*} w^{T} \tag{3}$$

where, S is the manipulated matrix and w is the weight line vector of the criteria.

Ranking alternatives

In the previous section, the detailed explanation has been given on how to calculate the importance weights of the evaluation criteria using the ANP method. And now, it is time to apply the modified TOPSIS approach to rank the competing alternatives. The approach modifies the TOPSIS method by using *weighted Euclidean distances* (called the modified TOPSIS) to ensure a meaningful interpretation of the comparison result.

On the other hand, all four-steps of the full ANP would have been applied to rank the alternatives, if we have had a small number of criteria and alternatives (max. 9). But, in this study, to keep the number of pairwise comparisons made by decision-maker below a reasonable threshold, we only used the ANP to determine the relative weights of the evaluation criteria, and then the modified TOPSIS to achieve the final ranking result. For example, if there are n criteria and m alternatives, then to run a full ANP solution, there will be $n \times m \times (m-1)/2$ pairwise comparisons to be performed (Shyur and Shih 2006).

Next the steps of the modified TOPSIS technique is given (Triantaphyllou 2000);

Step 1: Construct the normalized decision matrix: The method evaluates the following decision matrix, D, which refers to m alternatives that are evaluated in terms of n criteria, where x_{ij} indicates the jugdment of the decision maker $(\mathrm{i} = 1, 2, 3, \ldots, \mathrm{n};\ \mathrm{j} = 1, 2, 3, \ldots, \mathrm{m})$

$$D = \begin{bmatrix} x_{11} & x_{12} & x_{13} & \cdot\cdot & x_{1n} \\ x_{21} & x_{22} & x_{23} & \cdot\cdot & x_{2n} \\ \cdot & \cdot & \cdot & \cdots & \\ \cdot & \cdot & \cdot & \cdots & \\ \cdot & \cdot & \cdot & \cdots & \\ x_{m1} & x_{m2} & x_{m3} & \cdot\cdot & x_{mn} \end{bmatrix}$$

Then, it converts the various criteria dimensions into non-dimensional criteria. An element r_{ij} of the normalized decision matrix, R is thus calculated as follows;

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}} \tag{4}$$

Step 2: Construct the weighted normalized decision matrix: A set of weights $W = (w_1, w_2, w_3, \ldots, w_n)$, where $\sum w_i = 1$ defined by the decision-maker is next used with the decision matrix to generate the weighted normalized matrix, V $(v_{ij} = w_j r_{ij})$ as follows:

$$V = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & w_3 r_{13} & \cdot\cdot & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & w_3 r_{23} & \cdot\cdot & w_n r_{2n} \\ \cdot & \cdot & \cdot & \cdots & \\ \cdot & \cdot & \cdot & \cdots & \\ \cdot & \cdot & \cdot & \cdots & \\ w_1 r_{m1} & w_2 r_{m2} & w_3 r_{m3} & \cdot\cdot & w_n r_{mn} \end{bmatrix}$$

where, $w_j r_{ij}$ is the weighted normalized matrix value obtained by multiplying decision matrix, x_{ij} by the weights of criteria w_j.

Step 3: Determine the positive- ideal and the negative-ideal solutions: The "positive-ideal" denoted as A^*, and the "negative-ideal" denoted as A^- alternatives (or solutions) are defined as follows;

$$A^* = \left\{ \left(\max_i v_{ij} \mid j \in J \right), \left(\min v_{ij} \left| j \in J^{/} \right. \right), i = 1, 2, 3, \ldots, m \right\}$$
$$A^* = \{v_{1^*}, v_{2^*}, \ldots, v_{n^*}\} \tag{5}$$
$$A^- = \left\{ \left(\min_i v_{ij} \mid j \in J \right), \left(\max v_{ij} \left| j \in J^{/} \right. \right), i = 1, 2, 3, \ldots, m \right\}$$
$$A^- = \{v_{1-}, v_{2-}, \ldots, v_{n-}\} \tag{6}$$

where, $J = \{j{=}1, 2, 3, \ldots, n\}$ and $J^{/}{=}\{j = 1, 2, 3, \ldots, n\}$

From the previous definitions, it follows that alternative A^* indicates the most preferable alternative or the positive-ideal solution. Similarly, alternative A^- indicates the least preferable alternative or the negative-ideal solution.

Step 4: Calculate the separation measure: The *n-dimensional Euclidean distance* method is next applied to measure the separation distances of each alternative from the positive-ideal solution and the negative-ideal solution. Thus, for the distances from the positive-ideal solution we have:

$$S_{i^*} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_{j^*}\right)^2} \quad \text{for } i = 1, 2, 3, \ldots, m \tag{7}$$

where S_{i^*} is the distance of each alternative from the positive-ideal solution.

$$S_{i-} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_{j-}\right)^2} \quad \text{for } i = 1, 2, 3, \ldots, m \tag{8}$$

where S_{i-} is the distance of each alternative from the negative-ideal solution.

Step 5: Calculate the relative closeness to the ideal solution: The relative closeness of an alternative A_i with respect to the ideal solution A^* is defined as follows:

$$C_{i^*}{=}\frac{S_{i-}}{S_{i^*}{+}S_{i-}}, \text{ where } 1 \geq C_{i^*} \geq 0, \text{ and } i{=}1, 2, 3, \ldots, m \tag{9}$$

Apparently, $C_{i^*} = 1$, if $A_i = A^*$, and $C_{i-} = 0$, if $A_i = A^-$

Step 6: Rank the preference order: The best alternative can be now decided according to the preference rank order of C_{i^*}. Therefore, the best alternative is the one that has the shortest distance to the ideal solution.

Case study

Above, an integrated approach using the modified TOPSIS and ANP has been proposed to carry out the following tasks: the ANP method is used determine the relative weights of a set of evaluation criteria, as the modified TOPSIS method is utilized to rank competing conceptual design alternatives in terms of their overall performance in order to reach to the best satisfying one. In this section, the work of Ayag and Ozdemir (2007) is re-analyzed again to prove this approach's applicability and validity on a real-life example. For more information of the case study please see the related paper of the authors.

But, to remember, we summarize it as follows: This case study was realized at the product engineering department of a leading hot runner system manufacturer in Ontario, CANADA. This company designs and manufactures three groups of hot runner systems that can be generally classified into standard (N), semi-custom (S), the products designed and manufactured using similar standard products, and custom (P), the products completely designed from sketch and manufactured first time. Due to the fact that tight competitive conditions in the market, the company's top management decided to develop a new kind of hot runner manifold and horizontal hot tip nozzle system (S-type) especially for fast-growing automotive industry, in order to keep their competitive advantage in the following years. Then, a cross-functional project team consisting of various departments in the company worked together and suggested 3 concept alternatives named; *Concept A1, A2* and *A3* respectively.

To generate the concepts, the team carried out the ways as follows: (1) Define the problem (general understanding of a new hot runner system design for automotive industry), (2) External sources (interview with lead mold-makers, consult suppliers for each critical system component, literature on technical documents (i.e. mold-making, hot runner system design) to find out existing solutions and more,

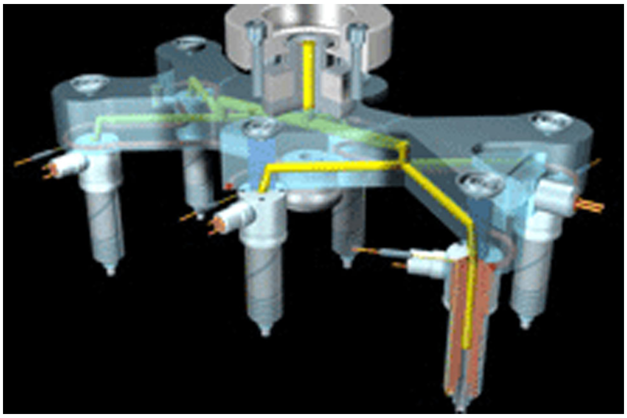

Fig. 4 Sample of a hot runner system

Fig. 5 Sample of a nozzle

benchmarking study of competitor products and patents for mold and hot runner system design), (3) Internal sources (the use of personal and team knowledge and creativity), (4) Organization of the possible set of the concepts was done by using a classification tree which divides the entire space of possible solutions into distinct classes which is facilitate comparison and pruning, (5) Final evaluation (first four steps were evaluated again to make sure that the entire space of concepts are fully-explored). Figure 4 shows the sample of a hot runner system, as Fig. 5 shows the sample of a nozzle.

The list of the primary criteria and their sub-criteria for concept selection problem is given in Table 2, as Fig. 6 shows the interdependence relationships among them.

In briefly explaining the table as follows: *Reducing cost* is only includes development cost and unit manufacturing cost of a product. *Having less development risk* can be categorized as follows: (1) *envisioning risk*: will a product with the targeted product attributes of the product vision create value for the customer and the company?, (2) *design risk*: does the product design embody the targeted product attributes of the product vision?, (3) *execution risk*: can the development team execute the conversion of the product design into a delivered product?, (4) *ability to meet scheduled delivery:* especially, the hot runner systems are used for mold-makers which has tight due dates of their injection molds for automotive industry. Delivering on time is quite critical. *Increasing customer satisfaction* or product performance on plastic products for automotive industry for customers (i.e. mold-

Table 2 List of primary criteria and their sub-criteria for concept selection problem

Primary criteria	Sub-criteria
Reducing cost	Development cost (DEC)
	Unit manufacturing cost (UMC)
Having less development risk	Envision risk (ENR)
	Design risk (DSR)
	Execution risk (EXR)
	Ability to meet scheduled delivery (AMS)
Increasing customer satisfaction	Improved part appearance and quality (IPQ)
	Faster cycle time (FCT)
	Quick color change (QCC)
	Precision temperature control and uniformity (PRU)
	Better wear resistance (BWR)
	More flexibility (i.e. gating options, various nozzle sizes) (MFL)
	High heat conductivity (HHC)
	More strength (MST)
	Better corrosion resistance (BCR)
	Availability of screw-in nozzles for molding large, deep-draw parts (ASD)
	Repeatability and reproducibility (RAR)
	Good performance for abrasive-filled compounds (GPA)

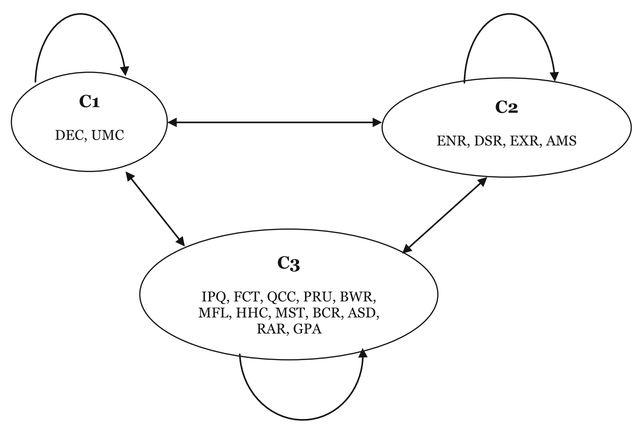

Fig. 6 Interdependence relationships among primary criteria and their sub-criteria for concept selection problem

makers) involves in the product specifications (i.e. improved part appearance and quality, faster cycle time and so on) defined by the mold-makers.

In applying the integrated approach, firstly, we should apply the first 2-steps of the full ANP to make the pairwise comparison of the evaluation sub-criteria using Saaty's nine-point scale (Table 1), and then calculate e-Vector denoted as w. Also, CI and CR are calculated by using Eqs. 1 and 2 to make sure that the judgments of decision maker(s) are consistent. If the CR value, 0.096 is less than 0.100, it is said that the all judgments are consistent. The pairwise comparisons of the evaluation sub-criteria are given in Table 3.

Then, the manipulated matrix is built, denoted as S for interdependent relations inside each cluster as given in Table 4.

Finally, using Eq. 3, the relative weights of the sub-criteria is calculated by multiplying the matrix S by the vector w in order to obtain, $w_{criteria}$ as follows:

$$w_{criteria} = \left\{ \begin{array}{l} 0.518, 0.518, 0.431, 0.330, 0.171, 0.084, 0.248, 0.185, 0.151, \\ 0.097, 0.069, 0.056, 0.048, 0.040, 0.033, 0.023, 0.026, 0024 \end{array} \right.$$

After determining the relative weights of the criteria, it is time to use the modified TOPSIS. In this method, we carried out its previously defined steps one-by-one as follows: first, we compared the concept alternatives in terms of each criterion using Saaty's nine-point scale [1/9, 9] to obtain the decision matrix shown in Table 5. Then, we normalized this matrix to get the normalized decision matrix, D, using Eq. 4 (Table 6).

Finally, we calculate the weighted normalized decision matrix, V, by multiplying the normalized decision matrix, D, by the column vector, $w_{criteria}$ as shown in Table 7.

We also calculated the positive and negative-ideal solution values for each sub-criterion using Eqs. 5 and 6, and marked them as seen in Table 7. These sets:

$$A^* = \left\{ \begin{array}{l} 1.554, 3.626, 2.586, 2.640, 1.539, 0.420, 1.240, 1.295, 1.359, \\ 0.388, 0.414, 0.504, 0.336, 0.360, 0.231, 0.138, 0.208, 0.168 \end{array} \right\}$$

$$A^- = \left\{ \begin{array}{l} 0.518, 2.072, 1.293, 0.990, 0.513, 0.084, 0.744, 0.370, 0.302, \\ 0.097, 0.207, 0.112, 0.048, 0.040, 0.066, 0.023, 0.078, 0.024 \end{array} \right\}$$

Next, we calculate both *the separation measures* using Eqs. 7 and 8, and *the relative closeness to the ideal solution* using Eq. 9 as shown in Table 8. As seen in the table, the alternative, *Concept A3* with the highest C_{i^*} value is selected as the best concept alternative among the others.

Finally, we can say: $Concept\,A3 \succ Concept\,A2 \succ Concept\,A1$

Conclusions

In this research, we proposed an integrated approach using ANP and the modified TOPSIS to carry out the following tasks: The ANP method was used to determine the relative weights of evaluation criteria, as the modified TOPSIS approach using a new *weighted Euclidean distance* was utilized to rank competing concept alternatives in terms of their overall performance in order to reach to the best concept.

Bringing these methods together considerably shortened the required computational steps (i.e. pairwise comparison) to reach final solution. Because the full ANP requires a great deal of computational steps as explained as follows: If the case study was realized using the full ANP method, the following steps would be done for 3 primary criteria and their 18 sub-criteria (Table 2);

(i) Calculating the weights of three primary criteria (*1 pairwise comparison matrix* constructed),
(ii) Calculating the weights of sub-criteria under each primary criteria (*three pairwise comparison matrix* constructed),
(iii) Constructing unweighted supermatrix (*18 pairwise comparison matrix* constructed), weighted and limit supermatrix,
(iv) Constructing pairwise comparison matrices of the concept alternatives for each sub-criterion) (*18 pairwise comparison matrix* constructed).

Finally, total of 40 pairwise comparison matrices with different sizes should have been constructed for the final result. If it is compared with other approaches, the proposed approach with less computational and easier steps provides better and reliable way to reach to the required solution.

On the other hand, in current literature, many CSMs have been proposed and implemented for concept selection problem; however, most of them have limitations relating to the following issues (Okudan and Shirwaiker 2012):

(i) functional decomposition and potential couplings among various functional areas (and hence generated concepts) are *not taken* into account,
(ii) despite rigor and increased computational complexity some solution methods do *not warrant* improved solutions,
(iii) most methods *do not incorporate* uncertainty to the concept selection process.

To overcome these limitations, in this study, an integrated approach using ANP and TOPSIS is proposed to concept selection problem. Use of ANP and TOPSIS on concept evaluation problem is a new approach in terms of the problem area, generally has outstanding advantages (i.e. making the

Table 3 Pairwise comparison of the evaluation sub-criteria (CR = 0.096)

Sub-criteria	DEC	UMC	ENR	DSR	EXR	AMS	IPQ	FCT	QCC	PRU	BWR	MFL	HHC	MST	BCR	ASD	RAR	GPA	e-Vector denoted as w
DEC	1.000	1.000	2.000	1.000	1.000	7.000	5.000	8.000	7.000	4.000	7.000	7.000	5.000	9.000	8.000	9.000	9.000	7.000	0.518
UMC	1.000	1.000	1.000	1.000	1.000	8.000	9.000	5.000	9.000	5.000	5.000	7.000	9.000	8.000	7.000	6.000	2.000	5.000	0.518
ENR	0.500	1.000	1.000	1.000	3.000	1.000	6.000	2.000	5.000	5.000	7.000	2.000	4.000	5.000	3.000	3.000	4.000	7.000	0.337
DSR	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	3.000	3.000	1.000	5.000	6.000	2.000	2.000	3.000	3.000	4.000	0.225
EXR	1.000	1.000	0.333	1.000	1.000	1.000	1.000	4.000	6.000	2.000	1.000	4.000	7.000	7.000	3.000	3.000	3.000	3.000	0.266
AMS	0.143	0.125	1.000	1.000	1.000	1.000	1.000	1.000	3.000	2.000	5.000	5.000	3.000	3.000	2.000	4.000	4.000	4.000	0.188
IPQ	0.200	0.111	0.167	1.000	1.000	1.000	1.000	1.000	2.000	1.000	4.000	6.000	3.000	2.000	1.000	3.000	3.000	3.000	0.151
FCT	0.125	0.200	0.500	1.000	0.250	1.000	1.000	1.000	1.000	1.000	1.000	2.000	2.000	2.000	4.000	6.000	6.000	3.000	0.129
QCC	0.143	0.111	0.200	0.333	0.167	0.333	0.500	1.000	1.000	1.000	1.000	3.000	1.000	5.000	3.000	6.000	6.000	2.000	0.107
PRU	0.250	0.200	0.200	0.333	0.500	0.500	1.000	1.000	1.000	1.000	1.000	1.000	1.000	2.000	1.000	1.000	1.000	1.000	0.083
BWR	0.143	0.200	0.143	1.000	1.000	0.200	0.250	1.000	1.000	1.000	1.000	1.000	3.000	3.000	2.000	3.000	3.000	5.000	0.109
MFL	0.143	0.143	0.500	0.200	0.250	0.200	0.167	0.500	0.333	1.000	1.000	1.000	1.000	1.000	1.000	5.000	5.000	4.000	0.078
HHC	0.200	0.111	0.250	0.167	0.143	0.333	0.333	0.500	1.000	1.000	0.333	1.000	1.000	1.000	3.000	1.000	1.000	3.000	0.067
MST	0.111	0.125	0.200	0.500	0.143	0.333	0.500	0.500	0.200	0.500	0.333	1.000	1.000	1.000	1.000	3.000	2.000	1.000	0.056
BCR	0.125	0.143	0.333	0.500	0.333	0.500	1.000	0.250	0.333	1.000	0.500	1.000	0.333	1.000	1.000	1.000	3.000	1.000	0.065
ASD	0.111	0.167	0.333	0.333	0.333	0.250	0.333	0.167	0.167	1.000	0.333	0.200	1.000	0.333	1.000	1.000	1.000	1.000	0.048
RAR	0.111	0.500	0.500	0.333	0.333	0.250	0.333	0.167	0.167	1.000	0.333	0.200	1.000	0.500	0.333	1.000	1.000	1.000	0.057
GPA	0.143	0.200	0.143	0.250	0.333	0.250	0.333	0.333	0.500	1.000	0.200	0.250	0.333	1.000	1.000	1.000	1.000	1.000	0.048
																			1.000

Table 4 Building the manipulated matrix, denoted as *S* for interdependent relations inside each cluster

Sub-criteria	DEC	UMC	ENR	DSR	EXR	AMS	IPQ	FCT	QCC	PRU	BWR	MFL	HHC	MST	BCR	ASD	RAR	GPA
DEC	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
UMC	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ENR	0.000	0.000	0.000	0.493	0.790	0.587	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DSR	0.000	0.000	0.693	0.000	0.133	0.324	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
EXR	0.000	0.000	0.211	0.368	0.000	0.089	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
AMS	0.000	0.000	0.096	0.139	0.077	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IPQ	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.255	0.280	0.320	0.331	0.317	0.310	0.273	0.277	0.293	0.303	0.267
FCT	0.000	0.000	0.000	0.000	0.000	0.000	0.296	0.000	0.222	0.194	0.192	0.205	0.200	0.188	0.188	0.177	0.191	0.167
QCC	0.000	0.000	0.000	0.000	0.000	0.000	0.246	0.245	0.000	0.118	0.130	0.127	0.146	0.148	0.140	0.142	0.127	0.156
PRU	0.000	0.000	0.000	0.000	0.000	0.000	0.109	0.115	0.113	0.000	0.085	0.084	0.096	0.124	0.119	0.123	0.106	0.088
BWR	0.000	0.000	0.000	0.000	0.000	0.000	0.079	0.086	0.085	0.078	0.000	0.067	0.064	0.069	0.071	0.064	0.085	0.092
MFL	0.000	0.000	0.000	0.000	0.000	0.000	0.043	0.064	0.073	0.074	0.065	0.000	0.054	0.064	0.073	0.061	0.043	0.049
HHC	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.059	0.057	0.060	0.053	0.052	0.000	0.042	0.042	0.043	0.038	0.055
MST	0.000	0.000	0.000	0.000	0.000	0.000	0.044	0.047	0.047	0.043	0.042	0.041	0.037	0.000	0.031	0.040	0.037	0.041
BCR	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.041	0.040	0.037	0.034	0.033	0.031	0.029	0.000	0.019	0.023	0.033
ASD	0.000	0.000	0.000	0.000	0.000	0.000	0.031	0.028	0.024	0.021	0.020	0.020	0.021	0.019	0.019	0.000	0.024	0.027
RAR	0.000	0.000	0.000	0.000	0.000	0.000	0.032	0.032	0.030	0.027	0.026	0.027	0.023	0.022	0.019	0.018	0.000	0.027
GPA	0.000	0.000	0.000	0.000	0.000	0.000	0.030	0.030	0.028	0.027	0.024	0.026	0.019	0.021	0.022	0.020	0.023	0.000

Table 5 Comparison concept alternatives in terms of each criterion using Saaty's nine-point scale [1/9, 9]

Sub-criteria alternatives	DEC	UMC	ENR	DSR	EXR	AMS	IPQ	FCT	QCC	PRU	BWR	MFL	HHC	MST	BCR	ASD	RAR	GPA
A1	1	7	3	5	3	5	3	7	2	3	5	9	5	1	7	1	8	5
A2	2	5	6	3	9	1	4	2	7	1	3	2	7	9	5	5	5	7
A3	3	4	5	8	5	2	5	4	9	4	6	3	1	3	2	6	3	1

Table 6 Normalized matrix, *D*

Sub-criteria alternatives	DEC	UMC	ENR	DSR	EXR	AMS	IPQ	FCT	QCC	PRU	BWR	MFL	HHC	MST	BCR	ASD	RAR	GPA
A1	0.267	0.738	0.359	0.505	0.280	0.913	0.424	0.843	0.173	0.588	0.598	0.928	0.577	0.105	0.793	0.127	0.808	0.577
A2	0.535	0.527	0.717	0.303	0.839	0.183	0.566	0.241	0.605	0.196	0.359	0.206	0.808	0.943	0.566	0.635	0.505	0.808
A3	0.802	0.422	0.598	0.808	0.466	0.365	0.707	0.482	0.777	0.784	0.717	0.309	0.115	0.314	0.226	0.762	0.303	0.115

evaluation process more reliable and faster, providing less computational steps than other CSM approaches). On the other hand, a case study is presented to indicate the feasibility of selecting the best concept in a NPD environment. Hence, the contributions are also original

We strongly believe that this proposed approach can be also easily used by a product or/and design engineer, a part of a cross-functional team in a company. For motivation of the team and its members, and the success of a study, the support of the top management of company, especially from the departments of product development, quality and manufacturing should be provided.

For future study, due to the vagueness and uncertainty on judgments of the decision-maker(s), the scales used in the conventional ANP and TOPSIS could be insufficient and imprecise to capture the right judgments of decision-maker(s). Therefore, a fuzzy logic can be integrated to this approach to get more satisfying results.

Table 7 Weighted normalized matrix, *V*

Sub-criteria alternatives	DEC	UMC	ENR	DSR	EXR	AMS	IPQ	FCT	QCC	PRU	BWR	MFL	HHC	MST	BCR	ASD	RAR	GPA
A1	0.518−	3.626*	1.293−	1.650	0.513−	0.420*	0.744−	1.295*	0.302−	0.291	0.345	0.504*	0.240	0.040−	0.231*	0.023−	0.208*	0.120
A2	1.036	2.590	2.586*	0.990−	1.539*	0.084−	0.992	0.370−	1.057	0.097−	0.207−	0.112−	0.336*	0.360*	0.165	0.115	0.130	0.168*
A3	1.554*	2.072−	2.155	2.640*	0.855	0.168	1.240*	0.740	1.359*	0.388*	0.414*	0.168	0.048−	0.120	0.066−	0.138*	0.078−	0.024−

* indicates the positive-ideal solution and − indicates the negative-ideal solution for related sub-criteria

Table 8 Final weights for the concept alternatives

Concept alternatives	S_{i^*}	S_{i-}	C_{i^*}	Ranking
A1	3.141	2.062	0.396	3
A2	2.739	2.052	0.428	2
A3	1.879	3.180	0.628	1

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