Management and Production Engineering Review
Volume 7 • Number 4 • December 2016 • pp. 16–26
DOI: 10.1515/mper-2016-0032

BRINGING KANO'S PERSPECTIVE TO AHP: THE 2D-AHP DECISION MODEL

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Received: 1 July 2016
Accepted: 28 July 2016

Abstract

AHP and the Kano model are such prevalent TQM tools that it may be surprising that a true hybrid decision-making model has so far eluded researchers. The quest for a hybrid approach is complicated by the differing output perspective of each model, namely discrete ranking (AHP) versus a multi-dimensional picture (Kano). This paper presents a hybrid model of AHP and Kano model, so called two-dimension AHP (2D-AHP).

This paper first compares the two approaches and justifies a hybrid model based on a simple conceit drawn from the Kano perspective: given a decision hierarchy, child and parent elements can exhibit multi-dimension relationships under different circumstances. Based on this premise, the authors construct a hybrid two-dimension AHP model whereby a functional-dysfunctional question-pair technique is incorporated into a traditional AHP framework.

Using the proposed hybrid model, this paper provides a practical test case of its implementation. The 2D-AHP approach revealed important evaluation variances obscured through AHP, while a survey study confirmed that the 2D-AHP approach is both feasible and preferred in some respects by respondents.

Although there have been rich research efforts to combine AHP and Kano model, most of them is simply about a series of individual usage of each methodology. On the other hand, the type of hybridization between AHP and Kano model in this paper is quite unique in terms of the two dimensional perspective. The model provides a general approach with application possibilities far beyond the scope of the test case and its problem structure, and so calls for application and validation in new cases.

Keywords

analytic hierarchy process, Kano model, hybrid model, multi-criteria decision-making, two-dimension perspective.

Introduction

With the convincing business benefits of employing Total Quality Management (TQM) strategies [1, 2], TQM implementation has remained a top agenda item for contemporary businesses decision makers across a wide spectrum of industries. Enacting TQM relies heavily on consistent, rational decision making throughout the organization, as well as attention to customer satisfaction. Academics and practitioners alike have turned their attention to the question of how best to introduce and implement TQM. What analytical processes produce the most effective decisions regarding TQM deployment? Which theoretical models lead to the greatest performance increases from TQM with the least wastage? While previous studies have suggested various methods for TQM introduction and implementation [3, 4], a throng of TQM professionals and researchers have chosen to employ analytic hierarchy processes (AHP) to deconstruct and analyze decision criteria and alternatives, while others have applied the Kano model (also called the 'Theory of Attractive Quality') to develop the organization's customer focus through their products and services.

As Wang et al. [5] identify, AHP continues to gain popularity as a particularly effective analytical tool. In one such case of TQM implementation, Chin et al. [6] used an AHP approach to identify critical factors and sub-factors for implementing TQM in Chinese organizations with the help of two evaluator groups. The resulting sophisticated hierarchical model allows Chinese companies to best compare and formulate their own TQM implementation strategies. In another case, Bayazit and Karpak [7] developed an analytic network process-based framework, or ANP framework (an extended version of AHP) to identify the degree of impact of different factors on TQM implementation and to assess the readiness of Turkish manufacturers in adopting TQM practices.

At the same time, others have made use of the Kano model for its emphasis on customer satisfaction as a critical factor in TQM decision-making. The question-pairs of the Kano questionnaire allow researchers to tease apart the relative impact on customer satisfaction (satisfied or dissatisfied) of product attributes along two dimensions (sufficiency and insufficiency) rather than just one (sufficiency), thus resulting in a four-quadrant relationship possibility field [8]. This technique reveals import information for decision makers regarding trade-offs between different product/service attributes and suggests the appropriate areas for and limits to investment for specific attributes. Numerous studies have employed the Kano model, particularly in the field of TQM, where Kano classifications have been used to adjust improvement ratios in quality-function deployment [9–11]. To improve the original methodology, several authors have modified the wording of the questions and/or the answers [12, 13]. Others have modified the original Kano attribute categories to suit their particular needs [14].

Comparing the two approaches, AHP delivers rational problem analysis and discretely ranks alternatives, eliminating subjectivity in the quantification of impact relationships even in multi-layered, seemingly interdependent decision scenarios. The Kano model's "two dimension" perspective does not point to one definitive "best" alternative, but instead allows respondents to entertain the possibility of different relationships between consequent and antecedent under varying conditions: more like a mixing board than a switch. The Kano approach teases apart the product or service attributes' qualities with respect to customer satisfaction, leading to a clearer picture of each attribute's role in achieving the goal.

Not surprisingly, there have been numerous attempts to combine the strengths of AHP and the Kano model for decision-making purposes [15–20]. For example, in [16], authors attempted to integrate AHP, Kano and QFD methods in library services. First, a focus group study is held to find out the requirements of university students for the university library that are then classified using the Kano model. The requirement categories are ranked with respect to their relative importance using analytical hierarchy process (AHP). In [17], authors prioritized factors affecting bank customers using Kano model and AHP. They first identify 24 important factors for bank customers then classify them into Kano's quality attributes. Applying AHP into factors without Kano's quality attributes, authors show that the importance weight ranks of factors in the must-be quality attribute is comparably high. Lee et al. [20] proposed a service requirements identification method using Kano model and AHP for superior medical tourism service system design. Through their method, they calculate the priority of requirements using AHP in each group which is created through the Kano model excluding the reverse quality attribute. Yet these studies do not achieve a true combined analytical stratagem, but instead serially apply one process, then another. To our best knowledge, there has not been any genuine attempt to create a "hybridized" analytical process model, merging the two-dimension attribute quality modeling of the Kano approach with the direct parent-child/weighted computational ranking of AHP.

This paper then attempts to deliver a refined and more flexible analytical process for decision-making: the two-dimension AHP (2D-AHP) model. In the proposed model, the original AHP is decomposed into two sub-processes derived from the two-dimension Kano question stratagem with respect to the AHP goal: functional AHP and dysfunctional AHP. The results of each of these processes are combined to yield a set of relative weights of the decision criteria/alternatives. This paper applies the 2D-AHP model to a preliminary feasibility study (PFS) conducted on a national R&D program in Korea, comparing the original AHP results and implementation to that encountered by survey respondents using the 2D-AHP approach. Using the proposed hybrid approach, we embrace a more flexible and conditional understanding of the impact relationship between parent and child elements, in our case project feasibility criteria.

The rest of this study is organized as follows: in Sec. 2, a general background of AHP and the Kano model is reviewed including a schematic comparison between them. The proposed approach is provided in Sec. 3, and illustrated with the aforementioned case study in Sec. 4. Discussions and conclusions are derived accordingly in Sec. 5.

Background

The AHP approach, introduced by Saaty [21], decomposes general decision problems into a multilevel hierarchy of goals, criteria, sub criteria, and alternatives. It uses a pairwise comparison technique to derive the relative importance (or weight) of each criterion with respect to its parent throughout the hierarchy. Pairwise comparison helps decision makers simplify a complex problem by focusing their interest on the comparison of just two criteria, improving their judgment consistency across the decision process [21–24].

Underpinning the Kano model are the two related assertions that customers express satisfaction around a product or service by comparing its various attributes' performances to their expectations, and that customer satisfaction is indicative of product/service quality. Therefore it is important to identify not only which product criteria or attributes create more satisfaction than others, but also at what point does attribute performance have diminishing returns on customer satisfaction. Kano et al. [8] developed a two-dimension model to explain the different relationship between customer satisfaction and product attribute performance: satisfaction through dissatisfaction measured under conditions of functional attribute performance (sufficiency) and dysfunctional attribute performance (insufficiency).

AHP and the Kano model both employ a hierarchical structure in approaching decision-making, but differ in their perspectives, methods and outputs, and analytical tools. Thus their strengths and weaknesses differ, as identified in Table 1.

As seen in Table 1, structurally, they both use a hierarchical decision process predicated on singular goals and layered decision criteria. For AHP, the goal and the criteria are decision-maker defined throughout the hierarchy, decomposed in parent-child fashion, with singular and exclusive alternatives. For the Kano model, the goal is customer satisfaction evaluated under sufficiency and insufficiency conditions, with the alternatives classified according to Kano qualities (A, O, M, I, R). In Kano, alternatives are not ranked but can be viewed multi-dimensionally, and therefore given different parameters (e.g. limited resources, limited time, etc.) could yield different decisions (e.g. invest, redesign, do nothing, etc.). Still, generically these can both be viewed as hierarchical decision-making processes, with a goal at the top, alternatives at the bottom, and a structured evaluative process in between.

Table 1
Comparison of AHP and Kano model.

Characteristics		AHP	Kano model
Hierarchical Structure	Upper level	Goal: Decision-maker (user) defined	Goal: Customer satisfaction
	Lower level	Alternatives (criteria): User defined	Alternatives: product/service features
Method		– Assign importance weight to elements – Check judgment consistency	– Survey sufficiency/insufficiency scenarios for feature satisfaction – Apply Kano evaluation table, perform frequency analysis
Output		Quantifiably ranked alternatives	Classification of features
Evaluation perspective		Direct/one-dimension (more or less important)	Two dimensions (satisfaction and performance sufficiency)
Technical tools		– Eigenvector decomposition – Pairwise comparison	– Functional/dysfunctional questionnaire – Kano evaluation table
Strengths and Weaknesses	Strengths	– Quantifiably determines relative importance of decision elements – Ability to verify the consistency of respondents' judgments – Good for making single rational selection from alternatives	– Demonstrates impact of selective features' performance on customer satisfaction in multiple dimensions – Good for seeing possible trade-offs amongst many alternatives
	Weaknesses	– Considers one dimension/quality only (more or less important) – Defines a linear parent-child relationship	– Difficulty prioritizing alternatives post evaluation – Relies on customer survey data quality

The method and output of each approach differs: the AHP approach asks evaluators to assign relative importance weights to elements and alternatives in order to definitively rank alternatives according to judgment, whereas the Kano model approach uses customer survey data to qualify the relationship between customer satisfaction and a selected attribute's performance sufficiency and then insufficiency, in order to identify the qualities of a selected attribute. The perspective of each approach is therefore different, with AHP 'importance' weighted on a direct, one-dimension scale (more or less important), whereas Kano 'attribute quality' is categorized and charted according to a two-dimensional relationship (satisfaction and performance sufficiency). The key technical tools of each approach also differ. AHP uses the pairwise comparison technique and eigenvector decomposition to obtain the relative importance weights.

The Kano model utilizes a functional/dysfunctional questionnaire and Kano evaluation table to categorize the relationship between customer satisfaction and attribute performance. The strengths and weaknesses of each approach derive largely from those of these methods and tools. Focusing on their strengths, AHP allows decision-makers to obtain clear and unambiguous relative importance weights of their decision criteria, which can be quantitatively adjusted as circumstances change. Importantly, AHP also provides consistency checking of the evaluator judgments using its tools. Alternatives are clearly ranked as output. On the other hand, the Kano model affords a multi-dimensional view of the impact of select attributes on the goal (satisfaction). While Kano does not rank alternatives, it does make trade-offs more apparent.

Research framework

Concept

This paper contends that, logically, child elements can display different relationship traits with respect to their parents under different conditions, so reducing the choice to a one-dimensional, more or less comparison may lead to dissatisfaction from decision makers. Just like in life, what parent can easily choose one child over another? While AHP promotes judgment consistency, it does not promote judgment flexibility. The aim of this paper, then, is quite simple: to analytically embrace the possibility that the parent-child relationship can be multi-dimensional. In creating a new, hybrid AHP model that utilizes the strengths of Kano methods and outputs (multiple dimension relationships derived through a double questionnaire method) with those of the AHP model (quantifiably ranked alternatives derived from quantified judgments), we intend to bring about a more satisfactory and sustainable decision-making model for respondents. Yet as previously mentioned, simply applying pairwise comparison à la the AHP method to attributes with differing qualities (of which the Kano classification is representative) is problematically reductive, compounding the weaknesses of each model rather than combining their strengths. Therefore, this study proposes a different kind of hybrid approach – the 'two-dimension AHP model' (2D-AHP) – whereby we adapt the double questionnaire functional/dysfunctional technique of Kano to the pairwise comparison method of AHP to beget a multiple-dimension perspective on parent-child decision level relationships. For this brief explanation, we will refer to parent and child elements generally as goal (parent element) and criteria (child) in a decision-making process.

Process

Two approaches to questioning respondents are apparent once we consider establishing the separate functional and dysfunctional AHP structure: a scheme where you conduct pairwise comparison twice ('2D-AHP Double Pairwise Comparison') and one where instead you twice employ a fundamental scale to simplify comparison ('2D-AHP Absolute Evaluation').

In the case of '2D-AHP Double Pairwise Comparison' approach, there is no huge obstacle in procedural complexity in actual application of this scheme, as it maintains the merits of a traditional AHP approach. However, asking respondents to make pairwise comparisons twice (once in the positive perspective and again in the negative perspective) might lead to fatigue and confusion, especially as making pairwise judgments is in itself cognitively taxing. Pairwise comparison in the traditional AHP requires $n(n-1)/2$ decisions when there are n elements; the 2D-AHP Double Pairwise comparison scheme requires $n(n-1)$ decisions. Hence, there might be a high possibility that the two question modes are unable to tease apart quality differences in the parent-child relationship as intended. Therefore, this study discusses only the latter '2D-AHP Absolute Evaluation'. In this section, we assume there is an AHP type decision-making problem as modeled Fig. 1.

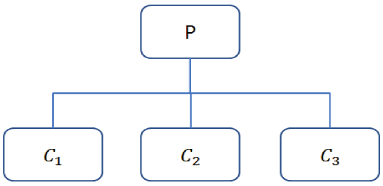

Fig. 1. An example of an AHP-type decision-making problem.

An alternative way to reduce the cognitive burden on respondents is to incorporate the absolute rating using a fundamental scale concept from AHP. From the positive and negative perspective scenarios, simple absolute evaluation is carried out instead of pairwise comparison. This scheme looks like as following:

Step 1: Respondents are asked which perspective is a more important outcome in consideration of the target problem's characteristic between 'positive' and 'negative' perspectives. A relative ratio is established using the common pairwise comparison technique. Therefore, we obtain W_P and W_N, which are the relative weights from the positive and negative perspectives respectively.

Step 2: As in the traditional AHP absolute evaluation technique, we calculate each evaluation level's relative weight through pairwise comparison between evaluation levels as below (also see Table 2).

- (Question for assessing the element levels' relative weights) Assuming the four levels of rating (Low Importance, Medium Importance, High Importance, Very high Importance) can be expressed with quantitative numbers, please express how many times bigger the intensity of the importance is for level A compared to level B. (c.f. Level A and B are from the four levels of rating. An expression of '1' times bigger means that the two levels' intensities are equal in your view).

Step 3: Next, the relationship of parent to child is explained to the respondents (for example, as in Fig. 1), and two questions are provided to the respondents as below. The respondents are requested to check ('V') one of the four levels in the evaluation table shown in Table 3 and 4 as appropriate.

- (Question in positive perspective) When we consider only that the parent element P improves (positively changes), how much importance on that outcome do you attribute to a sufficiency increase in each of the child elements (Ci) in their evaluation level? (rate using the prescribed levels: low, medium, high, very high).
- (Question in negative perspective) When we consider only that the parent element P declines (negatively changes), how much importance on that outcome do you attribute to an insufficiency increase in each of the child elements (Ci) in their evaluation level? (rate using the prescribed levels: low, medium, high, very high).

Step 4: We obtain the weights of elements from each of the positive and negative perspectives in Step 2. From these responses we construct our 'functional AHP' (positive perspective), and 'dysfunctional AHP' (negative perspective) absolute weights ('Abs').

Step 5: We normalize the weights of each element in the table in typical fashion. After this process is carried out regarding each of the positive and negative perspectives (functional and dysfunctional AHPs), the relative normalized weights ('Norm') of the child elements in each of the positive and negative perspectives are calculated respectively. Therefore, we obtain $\mathrm{Norm_P}$ and $\mathrm{Norm_N}$ are the normalized weight values from the positive and negative perspectives respectively (see Table 3 and Table 4).

Step 6: Finally, we synthesize the results from functional and dysfunctional AHPs by incorporating the relative positive to negative ratio decided in Step 1, and calculate the final weight of elements: Relative weight of criterion $= \mathrm{W_P} \times \mathrm{Norm_P} + \mathrm{W_N} \times \mathrm{Norm_N}$.

Table 2
An example of the pairwise comparison table for assessing evaluation levels' relative weights.

Level B Level A	Very high importance	High importance	Medium importance	Low importance	Relative Weight
Very high importance	1	2	4	8	0.533
High importance		1	2	4	0.267
Medium importance			1	2	0.133
Low importance				1	0.067
CR = 0.0					

Table 3
example of child elements' evaluation levels in positive perspective for 2D-AHP Absolute Evaluation.

Child elements in one level	Low Importance	Medium Importance	High Importance	Very high Importance	Assigned weight	Normalized weight ('Norm_P')
C1			V		0.267	0.572
C2	V				0.067	0.143
C3		V			0.133	0.285
					0.467	1.000

Table 4
An example of child elements' evaluation levels in negative perspective for 2D-AHP Absolute Evaluation.

Child elements in one level	Low Importance	Medium Importance	High Importance	Very high Importance	Assigned weight	Normalized weight ('Norm_N')
C1	V				0.067	0.091
C2				V	0.533	0.727
C3			V		0.133	0.181
					0.733	1.000

The 2D-AHP Absolute Evaluation scheme as above has the following benefits: First, it is easier for respondents to grasp and fulfill, given that it only requires n decisions whereas pairwise comparison requires $n(n-1)/2$ decisions when we have n elements. Second, although fewer decisions are required, we are still able to tease apart the element qualities in multiple dimensions using the two-dimension perspective. On the downside, judgment consistency checking is no longer possible due to the fact that no pairwise comparison is conducted. It can be thought of as the price of making fewer decisions in this context. For our purposes, we propose using a 2D-AHP Absolute Evaluation scheme as our fundamental 2D-AHP model.

Test case: Preliminary feasibility studies on proposed R&D programs in Korea

The preliminary feasibility studies (PFS) conducted by the Korean government on its proposed national R&D programs provide great material upon which to test the feasibility and performance of our proposed 2D-AHP Absolute Evaluation model (henceforth simply 2D-AHP model). As part of its effort to increase economic growth on behalf of its citizens, the Korean government is actively investing in large-scale national R&D programs. As it increases investment, pressure mounts to demonstrate the efficiency and effectiveness of its spending; the cost of failure in large scale national R&D programs is huge. The budget for such programs exceeds KRW 50bn (USD 46m), including more than KRW 30bn (USD 28m) in government subsidies. Therefore, a PFS system was adopted in 1999 so as to prevent budget waste and increase the efficiency of financial investments in their preliminary stages. The PFS process requires evaluating R&D programs according to technological, political, and economic feasibility according to various qualitative and quantitative criteria measures. For this reason, PFS evaluators employ primarily multi-criteria decision making analysis (MCDM) approaches, especially AHP. The PFS context therefore well suits our purpose: to compare the criteria weights assigned by evaluators using traditional AHP analysis compared to those assigned through 2D-AHP, and to see if the two-dimension questioning technique reveals variation.

The simple version of criteria used in a typical Korean R&D Program PFA is shown in Table 5. The hierarchy is fairly straightforward in this case, and we will focus our analysis on two levels: Level 1 – Technology feasibility, Policy feasibility, and Economic feasibility; Level 2 – sub criteria. Unlike technology and policy feasibility, economic feasibility is not segmented into child/sub-criteria; it is instead assessed by a quantified cost-benefit analysis.

Table 5
Decision/criteria hierarchy structure for Korea's National R&D PFA.

Level 1	Level 2
Technology feasibility (L1-T)	Plan adequacy of technology development (L2-T1)
	Success possibility of technology development (L2-T2)
	Similarity/duplicity with an existing program (L2-T3)
Policy feasibility (L1-P)	Policy consistency and promotion system (L2-P1)
	Risks of promoting the program system (L2-P2)
Economic feasibility (L1-E)	–

Note 1: Parentheses represent the evaluation items tested in this case study

Note 2: To make the question presentation clear, the following represent the sufficiency/insufficiency of the Level 2 criteria: L2-T1: adequate/inadequate; L2-T2: possible/not possible; L2-T3: unique/redundant; L2-P1: consistent, present/inconsistent, absent; L2-P2: surety/risk

Limitations of classical AHP in PFS viewed from the Kano model's perspective

Such an AHP-style hierarchy as that in Table 5 is based on the premise that a parent element and child element have a one-dimensional relationship. Namely, if the child element increases in sufficiency, the parent element improves, and if the child element increases in insufficiency, the parent element declines likewise. Based on this premise, AHP evaluators make a pairwise judgment on the relative importance weight of one child compared to another. This limited perspective raises serious issues for consideration in the PFS system. Illustrations of this issues follow:

- National R&D programs often include public health and safety-oriented programs. For example, if a certain R&D program fulfills a very important role for people's safety such as public health, the relation between policy feasibility in level 1 (L1-P) and risk factor of program promotion in level 2 (L2-P2) is hardly one-dimensional. It might very well be characterized as a 'must-be' initiative, with high risk of decline in feasibility from a negative viewpoint (high risk deteriorates the feasibility greatly), yet only present moderate gains from the positive perspective (low policy feasibility despite low program risk) context. This does not mean that it should not be pursued in the name of public health and safety, even if in comparison to other programs it does not have the same feasibility payoff. Of course, it depends on the characteristics of the R&D program theme.
- Another issue may apply to technological feasibility. Viewed from Kano's two-dimension perspective, someone may conceive that technology feasibility (L1-T) has a 'must-be' relationship with the duplicity with existing programs criteria L2-T3: as redundancy with respect to existing programs increases, feasibility declines, whereas uniqueness may have little impact on feasibility. On the other hand, the relation between technology feasibility (L1-T) and success possibility of technology development in level 2 (L2-T2) may be perceived as an 'attractive' attribute: as success possibility increases so does feasibility, but as success possibility decreases, after a certain point it has no additional bearing on feasibility. In such a case, it may be unreasonable and difficult to compare L2-T2 and L2-T3 in pairwise comparison mode.

Depending on the various themes of R&D programs addressed in the PFS, flexibility in judgment is necessary given that the relation between parent and child elements in a hierarchy can be variable under different conditions. As an alternative to overcome the issues pointed out above, this study applied the following 2D-AHP approach to the PFS test case.

Hypothetical R&D program scenarios for comparison of AHP and 2D-AHP

To verify the effectiveness of the 2D-AHP model presented in this study, we hypothesized two different R&D program scenarios targeted for PFS, and observed how the respondents evaluated each program's criteria weights using AHP compared to 2D-AHP. The themes and program characteristics of these two hypothetical programs are shown in Table 6.

Table 6
Hypothetical R&D programs.

	Title/Details
Program A	Title: Luxury Auto Part Development Program Details: Replace existing technology by developing high value-added auto parts for the luxury car market; create new overseas markets
Program B	Title: Medical Imaging Analysis Equipment Center Program Details: Install, operate, and promote joint use of cutting-edge medical imaging research infrastructure through which new drug mark discovery and candidate material development can occur

We intentionally use hypothetical programs with different characteristics in order to test the model's robustness through different scenarios. Program A is characterized by economic benefit creation through engineering technology development, whereas Program B is characterized as enhancing the health and safety of the public through scientific advancement, in addition to economic benefits. This study is to examine how respondent's evaluation weightings of criteria elements change when using AHP versus 2D-AHP against these two different programs as described above.

Questionnaire respondents represented university professors and doctoral degree holders in the fields of engineering, science, management, and economy, who are also qualified with expertise in PFS evaluation. Since there are typically six experts that comprise a PFS committee, this study also selected six respondents for evaluation. While the number of respondents was somewhat small, it is thought to be a good initial test of our model in anticipation of more rigorous future research.

Comparison results

Table 7 shows the weights derived from our 2D-AHP model for Programs A and B. Each respondent provides an absolute evaluation of each criterion following a fundamental evaluation scale (1 = Low; 2 = Medium; 3 = High; 4 = Very high), from the positive and negative perspective in turn. 'Abs' represents the average value of the six respondents' absolute evaluation responses for the corresponding criterion. 'Norm' represents the normalized weight value by synthesizing each respondent's evaluation record and the evaluation level's weights assigned by each respondent. As clearly shown in Table 7, the positive and negative perspectives on a common criterion result in different relative weights and ranks. For example, for program A, the evaluation criterion L2-T2 (Success possibility of technology development) has the highest rank with relative weight 0.387 from the positive perspective, but second rank with 0.364 from the negative perspective. Moreover, the range (difference between the largest and smallest) of relative weights that some evaluation criteria produced vary considerably compared between the positive and negative perspectives. For instance, for program A, three criteria in level 1 (containing L1-T, L1-P, and L1-E) in the positive perspective have a range of 0.258 (0.438 to 0.180) while those criteria in the negative perspective have a range of only 0.041 (0.354 to 0.313). These results suggest that the positive and negative perspective question-pair approach could be valuable in the evaluation of criteria's relative weights as well.

The test also demonstrated significant differences in the element weighting resulting from AHP and 2D-AHP analysis (Table 8). AHP weights are derived following the traditional process of pairwise comparison, while those derived from our 2D-AHP model are a synthesis of the Norm and Weight values from each of the perspectives teased apart in Table 7. For example, in the Program A scenario, the relative weight of L1-T by 2D- AHP is calculated as follows; Relative

Table 7
Positive and negative perspective criteria weights according to 2D-AHP for Program A and B.

Evaluation criteria		Program A scenario				Program B scenario			
		Positive perspective		Negative perspective		Positive perspective		Negative perspective	
		Abs	$Norm_P$	Abs	$Norm_N$	Abs	$Norm_P$	Abs	$Norm_N$
Level 1	L1-T	2.333	0.438	1.833	0.354	1.833	0.355	2.333	0.410
	L1-P	0.667	0.180	1.333	0.313	1.500	0.316	2.000	0.347
	L1-E	2.000	0.382	1.833	0.333	1.667	0.328	1.167	0.243
	Sum	–	1.000	–	1.000	–	1.000	–	1.000
Level 2	L2-T1	1.667	0.370	1.833	0.368	2.000	0.367	2.000	0.367
	L2-T2	1.667	0.387	1.667	0.364	1.833	0.360	1.667	0.334
	L2-T3	0.833	0.243	1.167	0.268	1.500	0.273	1.667	0.300
	Sum	–	1.000	–	1.000	–	1.000	–	1.000
	L2-P1	2.000	0.609	2.000	0.573	2.333	0.628	1.833	0.574
	L2-P2	1.167	0.391	1.500	0.427	1.333	0.372	1.167	0.426
	Sum	–	1.000	–	1.000	–	1.000	–	1.000
Weight of perspectives		0.456		0.544		0.500		0.500	

('Abs': Average of absolute evaluation (0(low) 3(very high); 'Norm': Normalized weight applying the evaluation level's respective weights as assigned by each respondent; L1-T: Technology feasibility; L1-P: Policy feasibility; L1-E: Economy feasibility; L2-T1: Plan adequacy of technology development; L2-T2: Success possibility of technology development; L2-T3: Similarity/duplicity with the existing program; L2-P1: Policy consistency and promoting system; L2-P2: Risk of promoting the program).

Table 8
Resulting criteria weights by AHP and 2D-AHP for program A and B scenarios.

		Program A scenario		Program B scenario	
Level	Comparison items	AHP	2D-AHP	AHP	2D-AHP
Level 1	L1-T	0.342	**0.392**	0.342	**0.383**
	L1-P	0.208	0.252	0.275	0.332
	L1-E	**0.450**	0.355	**0.383**	0.286
	Sum	1.000	1.000	1.000	1.000
Level 2	L2-T1	0.310	0.369	**0.545**	**0.367**
	L2-T2	**0.543**	**0.375**	0.265	0.347
	L2-T3	0.147	0.256	0.191	0.287
	Sum	1.000	1.000	1.000	1.000
	L2-P1	0.378	**0.590**	0.191	**0.601**
	L2-P2	**0.662**	0.410	**0.809**	0.399
	Sum	1.000	1.000	1.000	1.000

weight of L1-T $= \mathrm{W_P} \times \mathrm{Norm_P} + \mathrm{W_N} \times \mathrm{Norm_N} = 0.456 \times 0.438 + 0.544 \times 0.354 = 0.392$ where $\mathrm{W_P}$ and $\mathrm{W_N}$ are the relative weights from the positive and negative perspectives respectively, and $\mathrm{Norm_P}$ and $\mathrm{Norm_N}$ are the normalized weight values (Norm) from the positive and negative perspectives respectively in Table 7. Although the judgment on which weight is right is not to be decided through the value itself, the significant difference of weights is revelatory. For example, among the items in level 1 for program A and B scenarios, the greatest weight is assigned to 'Economy feasibility (L1-E)' from AHP whereas 'Technology feasibility (L1-T)' is weighted greatest from 2D-AHP. Among the items in level 2 of 'Policy feasibility' for program A and B scenarios, 'Risk of promoting the program (L2-P2)' has a bigger weight than 'Policy consistency and promoting system (L2-P1)' from AHP. But, 2D-AHP results in the opposite.

After conducting our analysis using AHP and 2D-AHP, this study conducted a survey on the evaluator's preferences for questionnaire mode. The purpose of this questionnaire was to identify which method the respondents preferred by asking their feelings with respect to the questionnaires provided using the traditional AHP compared to 2D-AHP. The questionnaire was carried out with the following four different topics:

- the need for separately considering positive and negative perspectives,
- the cognitive burden experienced in following each process,
- the accuracy of expression afforded by each process,
- the relative preference for AHP or 2D-AHP.

Respondents answered two to three questions on each topic, and the study obtained the answer's mean value with a 95% confidence interval (C.I.). The result is summarized in Table 9. The survey results concerning methodological preference from Q1∼Q9 in Table 9 is summarized as follows:

- The respondents generally felt that separately considering positive and negative perspectives for target R&D program PFS was appropriate (Q1, Q2).
- There was no statistically significant difference in the feeling of cognitive burden (Q3, Q4), however, some respondents seemed to feel that 2D-AHP was more burdensome than AHP in interviews.
- The 2D-AHP approach was more accurate in terms of respondent's judgment (Q5, Q6), and respondents felt that the two-dimension perspective might yield more precise results
- From the ease, convenience, and simplicity aspect (Q7), there was no big difference between the two methods. Although 2D-AHP was initially expected to make the respondents feel a greater cognitive burden, there was no big difference in ease of either approach, but 2D-AHP performs more accurately compared to AHP (Q8) according to respondents. Therefore, as long as enough time is provided to the respondents, working with 2D-AHP is still valid.
- Consequently, most respondents preferred the 2D-AHP model approach as a more appropriate method of PFS (Q9).

Table 9
Survey results on the preference for AHP and 2D-AHP.

Survey Topic		Question	Mean	95% C.I.
Need of considering two dimensional perspective (−3(Not at all)∼3 (Extremely agree))	Q1	Do you think the positive and negative perspectives should be considered separately in deciding the feasibility of R&D projects?	**2.167**	(1.738, 2.595)
	Q2	Do you think proper judgment can be made with synthesized vision without separating the positive and negative perspectives in deciding R&D project feasibility?	**−1.500**	(−2.601, −0.399)
Cognitive burden (−3(Not at all)∼3 (Extremely agree))	Q3	Did you feel a cognitive burden in deciding the importance of feasibility evaluation items in the AHP method?	−0.667	(−2.621, 1.287)
	Q4	Did you feel a cognitive burden in deciding the importance of feasibility evaluation items in the 2D-AHP method?	1.167	(−0.515, 2.848)
Accuracy of opinion expression (−3(Not at all)∼3 (Extremely agree))	Q5	Did you feel your thinking was accurately reflected in deciding the importance of feasibility evaluation items in the AHP method?	**0.833**	(0.405, 1.262)
	Q6	Did you feel your thinking was accurately reflected in deciding the importance of feasibility evaluation items in the 2D-AHP method?	**1.833**	(0.289, 3.378)
Preference (−3(AHP)∼3 (2D-AHP))	Q7	Which method was easier (more convenient or simpler) to express your opinion in deciding R&D program feasibility?	0.333	(−1.730, 2.397)
	Q8	Which method do you think more accurately reflects your opinion in deciding R&D program feasibility?	**1.667**	(0.583, 2.751)
	Q9	Which method is more appropriate for your opinion expression in deciding R&D program feasibility?	**1.667**	(1.125, 2.209)

Conclusion

This study proposes the use of a 2D-AHP model, a hybrid of the traditional AHP approach and the Kano model's application of a two-dimension perspective. The Korean PFS test case illustrates that the 2D-AHP hybrid approach can effectively account for the variety of relationships between parent and child criteria in a multi-level hierarchical decision-making context. Furthermore, respondents preferred the proposed approach to the traditional AHP for its perceived accuracy in replicating their judgments, as well as its ease and convenience. The paper provides value to practitioners by providing a generic model to use in multi-criteria decision-making, and to researchers by demonstrating a new and novel direction for further development of the AHP approach.

While we believe that the approach presented is meant to be a generic model applicable across different MCDM environments in quality management, it is acknowledged that the decision-making structure would be different depending on the quality issues involved. Actually, this is one of the strengths of the concept behind 2D-AHP: the applicability of a general methodology to a specific situation. Depending on the decision environment, more complicated quality structures with additional factors and criteria could be added. Thus, the modification of the proposed approach for more complicated problem structures will be a promising area for future research. For example, the proposed approach only reflects two-dimension relationships between parent and child levels in a decision hierarchy; there may be more decision structures such as decision networks that could employ this general model. As another example, incorporating the Kano model's attribute qualities in the ANP model could produce more realistic results as well. And fuzzy set theory may prove effective in reducing the vagueness associated with a decision maker's perception via pairwise comparisons and absolute evaluations.

As far as validation of the 2D-AHP model is concerned, proof that its results match the judgments of thoughtful people rests on application of the model and review of results in future research cases: 2D-AHP admittedly precludes judgment consistency checks. As a counterweight to this deficiency, decision makers could consider discussion and critique regarding an individual's judgments in order to consider facts that may have been forgotten or point out judgments that may be clouded. The 2D-AHP model makes it possible for people to debate and combine their judgments in order to draw a reasonable group decision. It opens the door for taking anyone's suggestion and including it in consideration, giving it a high or a low weight in the end. Exploiting these avenues in future research will increase the value of the 2D-AHP approach presented in this paper to the decision-making community.

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