Prioritizing User Requirements based on Analytic Hierarchy Process

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Abstract. As users have higher and higher requirements for products and competition in the product market becomes increasingly greater, how to use company resources more scientifically and quickly develop products that meet user needs becomes more and more important. Therefore, in this study, we apply the analytic hierarchy process for user requirement analysis, and clarify the advantages of the analytic hierarchy process compared with the existing commonly used models for prioritizing user needs and present the principles, methods, and results of the analytic hierarchy process in detail.

1. Introduction

The emergence of a product may stem from a certain idea or from a certain aspect of the company’s resources, but no matter what the reason is, a product that has just appeared is still far from a truly good product. The real user requirements are constantly discovered and satisfied while users using the product and users will always have new demands. It is also based on these two points that a good product is not a creation from scratch, but an iteration from emergence to excellent.

Users may pay attention to and use it because of a certain highlight of the product. But because the cost of abandonment is very low for users nowadays, as long as they think there is a better experience and a product that better meets his requirements, they are likely to switch to new products. In order for keeping users to stay or further recommend the product to others, it must rely on continuous iteration to continuously meet user demands and meet the company's strategic planning.

Therefore, the use of a more scientific and comprehensive decision-making prioritization method can help make the product serve users more perfectly and quickly.

In this study, we make the following contributions:

- Collect and compare decision priority models commonly used by product managers now.
- Introduce the application of analytic hierarchy process and analytic hierarchy process in other industries.
- Use analytic hierarchy process to prioritize product requirements.

2. Decision-Making Methods Currently Used

2.1. Kano model

Dr. Noriaki Kano, a professor of quality management at the Tokyo University of Science, created the Kano Model in 1984. Dr. Noriaki developed this framework while researching the factors that contributed to customer satisfaction and loyalty. (Kano, et al., 1984)

Product team can pull together a list of potential new features vying for development resources and space through KANO model. The team will then weigh these features according to two competing criteria:
1. Their potential to satisfy customers.
2. The investment needed to implement them.

In fact, you can also think of the Kano Model as the “Customer Delight vs. Implementation Investment” approach.

2.2. 2×2 prioritization matrix
2×2 Prioritization Matrix affords professional staff and teams a visual framework to identify which project to work on next. This method consists with a priority matrix grid with four quadrants. The vertical axis labelled “importance” and the horizontal axis labelled “effort”. Each quadrant in priority matrix grid will labelled as ①High value, high effort; ② Low value, high effort; ③Low value, low effort; ④ High value, low effort. The team will place the orders in appropriate spot of priority matrix grid according to the backlog project’s estimated value and the effort required to compete it. The team will have a clear view of what to focus on and what to do on next by checking this 2×2 Prioritization Matrix.

2.3. Value vs complexity model
Value vs. Complexity model is a framework to determine the priority. Product team can place backlog project in appropriate quadrant according how much value the project will bring and how difficult will it to be competed. This objective prioritization technique enables product teams to apply strategic and quantifiable reasoning to decisions about which initiatives to prioritize and which to shelve. The vertical axis labelled “value” and the horizontal axis labelled “effort”. The chart is then broken down into quadrants as follows: high value, low complexity; high value, high complexity; low value, low value, low complexity.
complexity; and low value, high complexity. The team will then evaluate each initiative and plot it on the graph, providing a visual representation of every initiative’s anticipated value and required effort.

Figure 3: Value vs. Complexity model

3. Introduction of Analytic Hierarchy Process

In the 1970s, Thomas L. Saaty developed the analytic hierarchy process (AHP) technique, which constructs a decision-making problem in various hierarchies as goal, criteria, sub-criteria, and decision alternatives. (Sipahi, S. & Timor, M. 2010) Now it has been widely integrated into the fields of economy, military, agriculture, education, medical treatment and environment.

3.1. AHP in manufactory

Lam and Chin (2005) examined the critical success factors of conflict management in collaborative new product development. By using AHP, they prioritized the importance of four categories of success factors, namely relationship management, conflict handling system, new product development, process management, and communication. They found that communication management, trust, and commitment to the collaboration are the most important factors.

3.2. AHP in transportation industry

Tsai and Su (2005) conducted a study of the political risk assessment process and designed a case study of business environment evaluations of five East Asian ports under political influences, including Hong Kong, Singapore, Busan, Kaohsiung, and Shanghai. This system approach consists of political risk factor identification, risk measurement, and assessment processes using the three methods of Delphi, AHP, and Ward's clustering. A total of 15 high-ranking managers from five leading global carriers presented their viewpoints for analysis. It was concluded that the residual risks resulting from port development and management policies were considered to be more significant than the risks from the integrated political and economic conditions.

3.3. AHP in health

Wu et al. (2007) used AHP for a hospital location, selection problem. The subjective factor was measured using AHP. Throughout the analysis, the various criteria and sub-criteria were identified while considering optimal selection of location to ensure a competitive advantage as a means of setting up hospitals. A detailed sensitivity analysis was performed to identify the variation in behaviour of the alternatives.
3.4. Advantage of AHP
(1) Systematic: It regards the research object as a system and makes decisions according to the thinking mode of decomposition, comparison, judgment and synthesis, and becomes an important tool for system analysis following mechanism analysis and statistical analysis.

(2) Practicality: It combines qualitative and quantitative methods, has a wide range of applications, and can handle many practical problems that cannot be tackled with traditional optimization techniques.

(3) Simplicity: The calculation is simple, and the results are clear, and most people can understand its basic principles and basic steps to master it. Analytic hierarchy process can provide a scientific and objective decision-making model.

4. Detailed Process of AHP
This section will show the specific process of using AHP to determine product demand priority.

4.1. Building a Hierarchical Model
It is divided into three layers: target layer, criterion layer, scheme layer. But in special cases, the criterion layer can have multiple layers. (1) Target level: priority of decision requirements; (2) Criterion layer: The factors of decision-making process and assigns weights to generate a matrix model; (3) Scheme layer: Arrange the priority of product demand through the calculation matrix.

Figure 4: Hierarchical model
To complete an excellent product, decision makers need to ensure that the product itself has perfect functions, has the potential to attract new customers, long-term development, and meet the company's strategic requirements. Therefore, when deciding on the priority of demand, decision makers need to consider three categories: product, marketing, and company.

1. Product: It is necessary to ensure that the product has complete functions and functional correctness
2. Marketing: It is necessary to ensure that the product can attract new users and retain old users, and has the potential for long-term development
3. Company: The product needs to meet the company's strategic needs and needs to be completed in the company budget

Now there are 3 product requirements that to fix bug, to develop new function and to upgrade user interface. Decision maker will use AHP to scientifically priority these requirements.

4.2. Constructing a pairwise comparison matrix
The pairwise comparison matrix is a comparison of the relative importance of all factors of this layer to a factor of the previous layer. The element $a_{ij}$ of the comparison matrix represents the comparison result of the i-th factor with respect to the j-th factor. This value is given by Santy's 1-9 scale method.
Scale meaning: “1” indicates that two factors are equally important; “3” indicates that compared to two factors, one factor is slightly more important than the other; “5” indicates that compared to two factors, one factor is obviously more important than the other; “7” indicates that compared to two factors, one factor is more important than the other; “9” indicates that compared to two factors, one factor is extremely important than the other; “2, 4, 6, 8” are the median of the above two adjacent judgments. According to the criterion level, a 6-dimensional matrix and 6 three-dimensional matrices are constructed from expert data.

4.2.1. The 6-dimensional matrix $A$ represents the relationship between $A1$, $A2$, $A$, $A4$, $A5$, and $A6$. $A1$, $A2$, $A$, $A4$, $A5$, and $A6$ respectively represent functionality correct, product structure, attract new customer, increase user stickiness, and involve the company's strategic planning, meet budget. Through the decision scale, compare the priorities of the 6 decision factors. Therefore, Matrix $A$ represents the relative priority among the 6 decision factors.

$$
A = \begin{bmatrix}
1 & 1 & 2 & 2 & 6/7 & 1 \\
1 & 1 & 2 & 2 & 6/7 & 1 \\
1/2 & 1/2 & 1 & 1 & 3/7 & 1/2 \\
1/2 & 1/2 & 1 & 1 & 3/7 & 1/2 \\
7/6 & 7/6 & 7/3 & 7/3 & 1 & 7/6 \\
1 & 1 & 2 & 2 & 6/7 & 1
\end{bmatrix}
$$

According to Matrix $A$, ① “correct functionality” is as important as a “completing functional architecture”; ② “Correcting functionality” is slightly more important than “attracting new customers”; ③ “correcting functionality” is slightly important than “increasing user stickiness”; ④ “involving the company’s strategic planning” is slightly important than “correcting functionality”; ⑤ “correcting functionality” is equally important as “meet budget”; ⑥ “product structure” is slightly more important than “attract new customers”; ⑦ “product structure” is slightly important than “increase user stickiness”; ⑧ “involving the company's strategic planning” is slightly important than “product structure”; ⑨ “product structure” is equally important as “meeting budget”.

Meanwhile, ① “involving the company's strategic planning” is more important than “attracting new customers”; ② “meeting budget” is slightly important than “attract new customers”; ③ “meeting budget” is slightly important than “increase user stickiness”; ④ “involving the company's strategic planning” is more important than “increase user stickiness”; ⑤ “involving the company's strategic planning” is slightly important than “meet budget”.

4.2.2. Six 3-dimensional matrices represent the relationship between the three requirements under each attribute

$B1$, $B2$, $B3$, $B4$, $B5$, and $B6$ respectively represent the functionality correct, product architecture, attract new customers, increase user stickiness, involve the company's strategic planning, meet budget. Under these 6 decision factors, the relative importance of the three demands that fix bug, develop new function, and upgrade the user interface.

$$
B1 = \begin{bmatrix}
1 & 9/5 & 3/2 \\
5/9 & 1 & 5/6 \\
2/3 & 6/5 & 1
\end{bmatrix}
$$

Matrix $B1$ represents the relative importance of the decision factor “correct functionality” to the three requirements. For “correct functionality”, “fix bug” is slightly important than “develop new function” and “upgrade user interface”.

$$
B2 = \begin{bmatrix}
1 & 7/5 & 7/4 \\
5/7 & 1 & 5/4 \\
4/7 & 4/5 & 1
\end{bmatrix}
$$
Matrix B2 represents the relative importance of the decision factor “product structure” to the three requirements. For “product structure”, “fix bug” is slightly important than “develop new function” and “upgrade user interface”.

\[
B_2 = \begin{bmatrix}
1 & 8/9 & 8/7 \\
9/8 & 1 & 9/7 \\
7/8 & 7/9 & 1
\end{bmatrix}
\]

Matrix B3 represents the relative importance of the decision factor “attract new users” to the three requirements. For “attract new users”, “develop new function” is slightly important than “fix bug” and “upgrade user interface”.

\[
B_3 = \begin{bmatrix}
1 & 4/3 & 8/7 \\
3/4 & 1 & 6/7 \\
7/8 & 7/6 & 1
\end{bmatrix}
\]

Matrix B4 represents the relative importance of the decision factor “increase user stickiness” to the three requirements. For “increase user stickiness”, “upgrade user interface” is slightly important than “fix bug” and “develop new function”.

\[
B_4 = \begin{bmatrix}
1 & 7/8 & 7/6 \\
8/7 & 1 & 4/3 \\
6/7 & 3/4 & 1
\end{bmatrix}
\]

Matrix B5 represents the relative importance of the decision factor “involve the company’s strategic planning” to the three requirements. For “involve the company's strategic planning”, “develop new function” is slightly important than “fix bug” and “upgrade user interface”.

\[
B_5 = \begin{bmatrix}
1 & 3/4 & 6/5 \\
4/3 & 1 & 8/5 \\
5/6 & 5/8 & 1
\end{bmatrix}
\]

Matrix B6 represents the relative importance of the decision factor “meet budget” to the three requirements. For “meet budget”, “develop new function” is slightly important than “fix bug” and “upgrade user interface”.

\[
B_6 = \begin{bmatrix}
1 & 8/9 & 8/7 \\
9/8 & 1 & 9/7 \\
7/8 & 7/9 & 1
\end{bmatrix}
\]

4.3. Calculating the eigenvectors and eigenvalues of all matrices separately

4.3.1. Characteristic values to verify consistency

Because it is usually difficult to construct a consistent matrix, but the deviation of the matrix must be within a certain range to have usable information. Therefore, the consistency of the matrix is a criterion to check whether the matrix with efficiency.

If the consistency check finds an error, you need to ask the expert again to get the correct value. The matrix eigenvalue means that if A is a n-dimension matrix, if there are a number m and a non-zero n-dimensional column vector x, so that Ax=λx holds, then λ is an eigenvalue of matrix A.

4.3.2. Defining the consistency criterion:

\[
CI = \frac{\lambda - n}{n - 1}
\]

When CI=0, there is complete consistency; when CI is close to 0, with satisfactory consistency; the larger the CI, the more serious the inconsistency. In order to measure the size of CI, the random consistency index RI is introduced. The method is to randomly construct 500 paired comparison matrices A1, A2..., A500, then the consistency index can be obtained CI1, CI2, ..., CI500.

\[
RI = \frac{CI_1, CI_2, ..., CI_{500}}{500} = \frac{\lambda_1 + \lambda_2 + ... + \lambda_{500}}{500} - \frac{n}{n - 1}
\]

Random consistency index RI value

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| RI | 0.05 | 0.08 | 0.11 | 0.14 | 0.17 | 0.20 | 0.23 | 0.26 | 0.29 |
4.3.3. Defining the consistency ratio:

\[ CR = \frac{CI}{RI} \]

Generally, when the consistency ratio \( CR = \frac{CI}{RI} < 0.1 \), it is considered that the inconsistency of A is within the allowable range, and there is satisfactory consistency. It can be normalized by the consistency test. The eigenvector is used as the weight vector, otherwise it is necessary to reconstruct the comparison matrix A to adjust \( a_{ij} \)

\[
A = \begin{bmatrix}
1 & 1 & 2 & 2 & \frac{6}{7} & 1 \\
1 & 1 & 2 & 2 & \frac{6}{7} & 1 \\
\frac{1}{2} & \frac{1}{2} & 1 & 1 & \frac{3}{7} & \frac{1}{2} \\
\frac{1}{2} & \frac{1}{2} & 1 & 1 & \frac{3}{7} & \frac{1}{2} \\
\frac{7}{6} & \frac{7}{6} & \frac{7}{3} & \frac{7}{3} & 1 & \frac{7}{6} \\
1 & 1 & 2 & 2 & \frac{6}{7} & 1 \\
\end{bmatrix}
\]

The maximum eigenvalue of the paired comparison matrix A is \( \lambda = 1 \). The normalized eigenvector corresponding to the eigenvalue \( \omega = \{1, 1, \frac{1}{2}, \frac{1}{2}, \frac{7}{6}, 1\} \). CI = (1-6)/(6-1)=-1. CR = -1/1.24 = -0.8<0.1. A passed the consistency test.

4.4. Verifying the consistency of all matrices

\[
B1 = \begin{bmatrix}
1 & 9/5 & \frac{3}{2} \\
\frac{5}{9} & 1 & \frac{5}{6} \\
\frac{2}{3} & \frac{6}{5} & 1 \\
\end{bmatrix}
\]

The maximum eigenvalue of the pairwise comparison matrix B1, \( \lambda = \sqrt{3} + 1 \). The normalized eigenvector corresponding to the eigenvalue \( \omega = \{\frac{3}{2}, \frac{5\sqrt{3} - 5}{6}, 1\} \). CI = (\( \sqrt{3} + 1 - 3 \)) /2 = -0.1. CR = -0.1/0.58=-0.1<0.1. B1 passed the consistency test.

\[
B2 = \begin{bmatrix}
1 & \frac{7}{5} & \frac{7}{4} \\
\frac{5}{7} & 1 & \frac{5}{4} \\
\frac{4}{7} & \frac{4}{5} & 1 \\
\end{bmatrix}
\]

The maximum eigenvalue of the pairwise comparison matrix B2 \( \lambda = 3 \). The normalized eigenvector corresponding to the eigenvalue \( \omega = \{\frac{7}{4}, \frac{5}{4}, 1\} \). CI = (3-3) /2 =0<0.1. CR=0/0.58=0<0.1. B2 passed the consistency test.

\[
B3 = \begin{bmatrix}
1 & 8/9 & \frac{8}{7} \\
\frac{9}{8} & 1 & \frac{9}{7} \\
\frac{7}{8} & \frac{7}{9} & 1 \\
\end{bmatrix}
\]

The maximum eigenvalue of the pairwise comparison matrix B3 \( \lambda = 3 \). The normalized eigenvector corresponding to the eigenvalue \( \omega = \{\frac{8}{7}, \frac{9}{7}, 1\} \). CI=(3-3)/2=0<0.1. CR=0.1/0.58=0<0.1. B3 passed the consistency test.

\[
B4 = \begin{bmatrix}
1 & \frac{4}{3} & \frac{8}{7} \\
\frac{3}{4} & 1 & \frac{6}{7} \\
\frac{7}{8} & \frac{7}{6} & 1 \\
\end{bmatrix}
\]

The maximum eigenvalue of the pairwise comparison matrix B4 \( \lambda = 3 \). The normalized eigenvector corresponding to the eigenvalue \( \omega = \{\frac{8}{7}, \frac{6}{7}, 1\} \). CI=(3-3)/2=0<0.1, CR=0.1/0.58=0<0.1. B4 passed the consistency test.

\[
B5 = \begin{bmatrix}
1 & \frac{7}{8} & \frac{7}{6} \\
\frac{8}{7} & 1 & \frac{4}{3} \\
\frac{6}{7} & \frac{3}{4} & 1 \\
\end{bmatrix}
\]
The maximum eigenvalue of the pairwise comparison matrix $B_5 \lambda=3$. The normalized eigenvector corresponding to the eigenvalue $\omega\{7/6,\ 4/3,\ 1\}$. CI=$(3-3)/2=0<0.1$, CR=$0.1/0.58=0<0.1$. $B_5$ passed the consistency test.

$B_6 = \begin{bmatrix} 1 & 3/4 & 6/5 \\ 4/3 & 1 & 8/5 \\ 5/6 & 5/8 & 1 \end{bmatrix}$

CI=$(3-3)/2=0<0.1$, CR=$0.1/0.58=0<0.1$. The maximum eigenvalue of the pairwise comparison matrix $B_6 \lambda=3$. The normalized eigenvector corresponding to the eigenvalue $\omega\{6/5,\ 8/5,\ 1\}$. $B_6$ passed the consistency test.

4.5. Synthesizing all matrix weights, and get $1 \times n$ matrix representing demand weight
Suppose that A matrix gets a characteristic matrix of $X = [a_1, a_2, a_3, a_4, a_5, a_6]$. And $B_1$ gets the characteristic matrix of $Y = [b_1, b_2, b_3]$. The weight value is $X \times Y$. The weight of $B_1$ to the overall goal: 6.3. $B_2$'s weight for the overall goal: 6.07. The weight of $B_3$ on the overall goal: 2.16.

$B_1 > B_2 > B_3$

And $B_1$, $B_2$, and $B_3$ respectively represent bug fixes, sign-in function development, and user interface upgrade. Therefore, the priority of the requirement is to fix bugs> develop sign-in functions> upgrade user interface.

5. Conclusion
Decision makers can use the analytic hierarchy process presented in this study to give the weight of each standard, the priority of each decision variable relative to each standard, quantify the decision variable, so as to provide a basis for decision-making, and can more systematically and scientifically decide the priority of user needs.

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