

A Simple Multi-Criteria Selection Model to Set Boundary Sample for Auto Parts

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Abstract—When faced with several alternatives, decision making is not simple. At an automobile manufacturer, the review boundary sample activity for reducing cost and maintaining the best quality for customers is complex; it requires criteria-based judgments, e.g., defect ratio, claimed history of customers' parts, and customer complaint history data. We propose a decision support system for this multiple criteria selection problem by applying the Analytic Hierarchy Process (AHP) technique. Quality control engineers were surveyed to determine weights for criteria. With this system, the automobile manufacturer can use collected data to select alternatives. Even an inexperienced engineer can objectively identify the best selection.

Index Terms—Analytic Hierarchy Process (AHP), Boundary Sample, Multiple-Criteria Decision Making, Supplier Selection.

I. INTRODUCTION

Because an automobile manufacturer needs to maintain a goal of "Customers Come First," it must ensure that its suppliers provide products with the highest quality. However, the auto maker does not have explicit knowledge of suppliers' capability; some of them cannot control the quality of parts or defect outflow to the auto maker. They sometimes choose to scrap and repair parts in order to deliver them in conditions acceptable to the auto maker; this scrapping results in higher costs to suppliers themselves, even though the parts may not be unacceptably defective.

Boundary Sample is defined as the defective limit of a vehicle's parts specified by the auto maker to ensure that suppliers make proper judgments on the quality of their parts, when screening parts are consigned to the auto maker. However, the boundary samples are not set for every part. Three conditions for setting the boundary sample are (1) when suppliers have been unable to control their production process; (2) when a defective part is identified and declared as clearly not meeting the standard, and (3) when the parts are in areas visible to customers.

In light of customer satisfaction, the auto maker always sets stricter boundary samples than required. There are three main standards for quality control: The *Complete Vehicle Inspection Standard (CVIS)* is used to control vehicle quality at the auto maker, by reference to the Japanese fitting standards; the *Shipping Quality Audit (SQA)* controls vehicle quality, by reference to customer satisfaction. Generally, the CVIS exercises stricter control than the SQA. Finally, the *Approval Inspection Standard (ATIS)* specifies parts quality for suppliers, by reference to engineering drawings. If a part is shown in the CVIS or on a drawing, the auto maker would not set a boundary sample; else, the company would set

boundary samples based on a stricter SQA, to ensure the quality for customers.

Suppliers negotiate with the auto maker of defects of parts and price. The Quality Control (QC) department needs to make judgments on whether to accept or reject these proposals (the process called *boundary sample review*) by considering multiple criteria, e.g., defect ratio, benefit-cost analysis, supplier's history, extent of defects, and acceptable defects based on the SQA. Generally, QC engineers approve suppliers' proposals regarding the extent of defects by referring to the SQA; however, few engineers have sufficient understandings to judge the acceptable extent of defects in the SQA.

As a result, a decision support system (DSS) is needed to enable correct judgment in minimum time and with limited skill and experience. Ideally, judgments should be objective and take into account several selections or alternatives to provide the best selection. Suppliers' data and the SQA's constraints are integrated into this system through the Analytic Hierarchy Process (AHP) framework. We have implemented our software prototype in Microsoft Excel because of its user friendliness and widespread presence. This DSS is ideal for efficient judgment of boundary samples by engineers with limited skills or experience.

II. LITERATURE SURVEY

Dickson [1] studies the vendor selection decisions. He identifies at least 50 distinct meaningful factors in vendor selection (i.e., characteristics of vendor performance) from the purchasing literature. Dickson summarizes the importance of these criteria for vendor selection.

Ragsdale [2] and Bhutta and Huq [3] suggest AHP as a structured approach for determining the scores and weights for the multi-criteria scoring model, which is a simple procedure for scoring (or rating) each alternative in a decision making process. First, the decision maker specifies weights, w_i that indicate the relative importance of each criterion. These weights must sum to 1. The score for alternative j on criterion i is denoted by S_{ij} . For each alternative j , we compute its weighted score as $\sum w_i S_{ij}$. Then, the alternative with the largest score is selected.

Sometimes, a decision maker finds it difficult to subjectively determine the criterion scores and weights needed in the multi-criteria scoring model, especially when subjective and/or intuitive considerations have to be incorporated. AHP standardizes criterion weights and scores so that they can be compared and used for making decisions. Narasimhan [4] applies AHP to the supplier selection activity because it offers a methodology to rank alternative courses of

action based on the decision maker’s judgments concerning the importance of the criteria, and the extent to which they are met by each alternative.

In Lee, Ha, and Kim [5], the supplier selection and management system (SSMS) relies on the AHP model to calculate the weights of both tangible and intangible criteria for supplier selection and to rank the suppliers’ performance. The weights of these criteria are applied to select the key factors for reinforcing the quality of each part.

III. SURVEY RESULTS

To determine the AHP weights, w_i , we use three sets of questionnaire surveys: the criteria ranking (Section IIIA), extent of defects (Section IIIB), and other criteria (Section IIIC). Section IIID describes the AHP scoring for criterion weights for pair-wise comparisons.

A. The Criteria Ranking

The five quality criteria considered are the extent of defect, defect ratio, benefits, claimed history data and customer complaint history data. The extent of defect questionnaire is designed to find acceptable extents smaller than the standard of SQA. We find that the extent of defect criteria is difficult to establish because it requires respondents’ experience. The questionnaires for other quality criteria include acceptable defect ratios, sufficient benefits, the acceptable number of customer complaint cases, and the acceptable number of claimed part cases when we accept the extent of defect presented by suppliers. Because the extent of defect criterion requires judgments from work experience, we assign weights relative to job positions (the more senior the positions, the higher the weights), e.g., 1 for engineers, 1.5 for chief engineers, and 2 for positions higher than assistant managers.

B. Design of Extent-of-Defect Questionnaire

Initially, we designed the extent-of-defect questionnaire for one part at a time, but we found it impractical for respondents to answer every question from suppliers’ proposal. The questionnaire was then redesigned and distributed to eighteen qualified engineers in the QC Department for setting the grade of suppliers who present the extent of defect for establishing boundary samples. Usually, AHP scales are from 1 to 9, but we deem it too fine; thus we use only the grades of A, B, C, D, and E to represent *surely accept* (to consider the proposal for a *boundary sample review*), *accept*, *may accept*, *need supports from leaders* and *not accept* (i.e., refuse to consider the proposal) opinions, respectively. The questionnaire asks only for the minimum and maximum extent of defect (*surely accept* and *not accept* grades); the remaining grades are interpolated from the minimum to maximum values.

Both types of questionnaires have 44 questions with 6 multiple choices. For each part item, the *surely accept* questionnaire asks “What is the worst extent of defect that you find acceptable?” and the *not accept* questionnaire asks “What is the beginning extent of defect that you find not acceptable?”

Questions are classified by the zones of defect (e.g., Zone A is area which can be seen while sitting on the front seat)

and the type of auto parts (e.g., interior and exterior, or paint), following the SQA. Each choice is assigned according to the extent of defect in the SQA. For example, if the SQA specifies that the scratch mark of Item 1 in Zone A should be no more than 5 mm. in diameter, then the choices for the *surely accept* questionnaires are set as a) 0.1-1.0, b) 1.1-2.0, c) 2.1-3.0, d) 3.1-4.0, e) 4.1-5.0 and f) Unacceptable, whereas the choices for the *not accept* questionnaire are similarly set as above, but the last choice is “More than the standard.” The complete questionnaires can be found in [6].

The empirical results of minimum and maximum extent of defect questionnaire are shown in Fig. 1 and 2. The horizontal axis is the item number, and the vertical axis is the fraction of respondents selecting each choice (shown in different colors). The results from the *surely accept* survey show that most respondents do not accept any defects although some engineers did provide meaningful upper bounds. The *not accept* results in Fig. 2 are more informative in that it provides the lower bound of defect size, beyond which parts are certainly rejected. We see that maximum extent of defect depends on the zone and part types; some zones and part types are more critical and visible that small extent of defect is required.

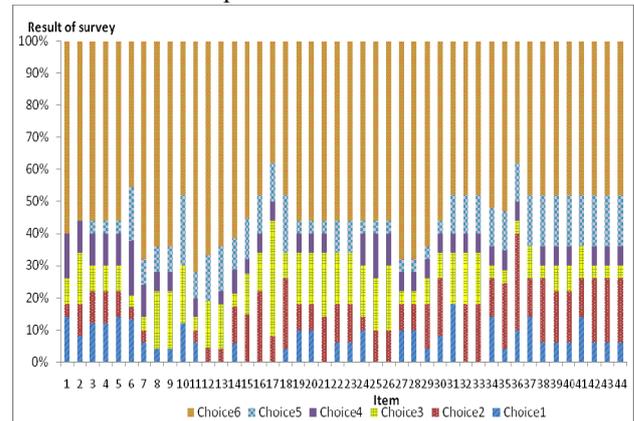


Fig. 1. The survey results in *surely accept* questionnaire (minimum extent of defect).

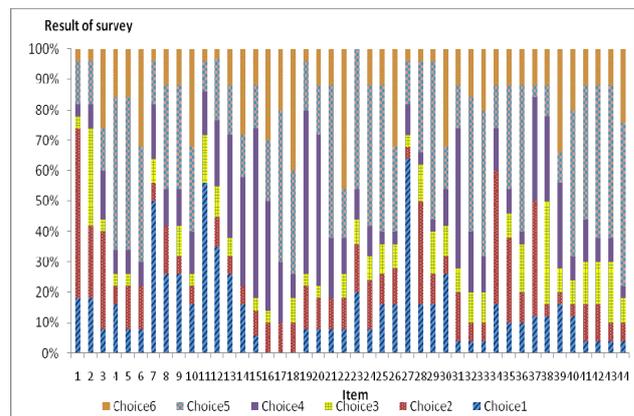


Fig. 2. The survey results in *not accept* questionnaire (maximum extent of defect).

C. The Other-Criteria Questionnaire Design

The rest of the questionnaires are on benefits, defect ratio, claimed history, and customer complaint history. Twenty-eight QC engineers are asked about their preferences on the supplier’s proposals on the scales of A to E, similar to the extent-of-defect questionnaire. Grade A (*surely accept*) is

assigned when respondents can accept a proposal for a *boundary sample review* by themselves; Grade B (*accept*) is when respondents can decide after requesting one more piece of information (e.g., process capability ratio, C_p); Grade C (*may accept*) is when respondents can make a decision after getting more than one piece of information; Grade D (*need support from leaders*) is when respondents need support from leaders; and Grade E (*not accept*) is when respondents can reject a proposal by themselves. For example, on Grade A of the cost benefit criteria, respondents are asked “What fraction of cost reduction that you are willing to immediately accept the proposal for boundary sample review?” and to choose one out of nine choices.

TABLE 1. THE RESULT OF SURVEYS ON THE BENEFIT CRITERION

Grade	Benefits (%)	Fraction of respondents
A	80% and up	71%
B	51% – 60%	46%
C	41% – 50%	39%
D	21% – 30%	46%
E	0% – 10%	71%

TABLE 2. THE RESULT OF SURVEYS ON THE DEFECT RATIO CRITERION

Grade	Defect Ratio	Fraction of respondents
A	80% and up	64%
B	31% – 40%	46%
C	21% - 30%	46%
D	11% - 20%	54%
E	0% – 10%	89%

TABLE 3. THE RESULTS OF CUSTOMER COMPLAINT CASES IN 8 MONTHS

Grade	# of customer complaint cases	Fraction of respondents
A	0	82%
B	1	54%
C	2-3	64%
D	4-5	36%
E	More than 7 cases	68%

TABLE 4. THE RESULT OF SURVEY OF PART CLAIMED CASES IN 8 MONTHS

Grade	# of part claimed cases	Fraction of respondents
A	1 – 10	54%
B	11 - 20	57%
C	21 - 30	39%
D	31 - 40	43%
E	More than 80	61%

The survey results are shown in Tables 1-4. The selected choices are ones which win the majority votes. Benefits are in terms of fraction of yearly target of cost reduction. Grade

A of benefits criteria should reduce cost by more than 80% of the yearly target, i.e., if supplier presents cost reduction of more than 80%, almost all engineers will accept this proposal by themselves. The survey results of defect ratio (Table 2) indicate that the QC engineers want to do a boundary sample review if the supplier’s defects are high; on the other hand, when the defect ratio is low, suppliers are left to solve their problem by themselves. Grade C of customer complaint criteria is 2 to 3 cases (Table 3); if customer complaint history of this supplier is 2 to 3 cases in 8 months, almost all of engineers will accept the supplier’s proposal after requesting more than one item of information. Grade E on part claimed criteria are 80 cases and higher; if part claimed history of the suppliers is more than 80 cases in 8 months, almost all engineers will not accept the supplier’s proposal with support from leaders.

D. The Criterion Weights for AHP scoring

The pair-wise criterion weight is designed to find weight scores on each criterion by using the AHP framework. The questionnaire consists of twenty questions, which are answered by twenty-eight QC engineers. The pair-wise comparison questions are of the following nature: “How much do you prefer criteria 1 over criteria 2 for approval of boundary samples?” The preference scales are from 1 to 9, ranging from “Equally Preferred” (1) to “Extremely Preferred” (9). Let the preference of criterion i over criterion j be P_{ij} ; then the preference of j over i is simply $P_{ji} = 1/P_{ij}$. To compute the criterion weights, we first calculate the column sums, $S_j, j = 1, 2, \dots, 5$, then the normalized preference of criterion i over criterion j is P_{ij} / S_j . The weight of criterion i is simply

$$w_i = \frac{1}{5} \sum_{j=1}^5 \frac{P_{ij}}{S_j}$$

See [2] for more details. The empirical result and the criterion weights for pair-wise comparisons are shown in Table 5. As expected, the quality-related criteria receive most of the weights; i.e., the extent-of-defect weight is 48.8% whereas the defect-ratio weight is 24.9%.

IV. AHP SCORING PROCESS

The grades of alternatives are determined by pair-wise comparison scales (Table 6) together with differences of alternatives’ grade (Table 7). The AHP pair-wise comparison uses scales of 1, 3, 5, 7 and 9, representing “equally preferred” when two proposals are given the same grade; “moderately preferred” represents the difference of 1 grade, “strongly preferred” 2 grades, “very strongly preferred” 3 grades and “extremely preferred” 4 grades (Table 7). For example, the supplier S_1 presents the extent of defects and results in grade A, whereas the supplier S_2 presents his and receives grade E. Therefore, the AHP score is “9” because they differ by 4 grades.

When a supplier submits his proposal, the part item is identified by the zone of defect and part types, and the proposal’s grade is determined by using pair-wise comparison scales (Table 6) together with difference of alternatives’ grade (Table 7). Once the criterion scores are determined, they are multiplied by the weights shown in

Table 5. The proposal with the largest total score is selected.

TABLE 5. THE SURVEY RESULTS ON THE CRITERION PREFERENCES

	Extent of defects	Benefits	Defect Ratio	# of customer complaints	# of claimed parts
Extent of defects	1	5	5	5	5
Benefits	0.2	1	0.17	0.25	0.25
Defect Ratio	0.2	6	1	3	5
# of customer complaints	0.2	4	0.33	1	2
# of claimed parts	0.2	4	0.2	0.5	1
Criterion Weight	0.488	0.046	0.249	0.123	0.094

TABLE 6. PREFERENCE SCORES.

Value	Preference
1	Equally Preferred
3	Moderately Preferred
5	Strongly Preferred
7	Very Strongly Preferred
9	Extremely Preferred

TABLE 7. GRADE DIFFERENCES AND PREFERENCE SCORES.

	A	B	C	D	E
A	1	3	5	7	9
B	-	1	3	5	7
C	-	-	1	3	5
D	-	-	-	1	3
E	-	-	-	-	1

V. EXCEL-BASED PROTOTYPE SOFTWARE

We implement our AHP framework on Excel because it is convenient to collect, manipulate, and display data. Users specify supplier' name, the values for extent of defect, benefits, and defect ratio in the Excel template. The steps in using our software are described as follows:

A. Input the extent of defect

A user specifies the extent of defect on a blank form that corresponds to the item's zone of defect and type of part. The input value is checked with the maximum thresholds that are already stored in the Excel worksheet. If the proposed extent of defect is less than the acceptable value, the software will continue to set a grade based on the extent of defects and to determine AHP scores by pair-wise comparisons. On the other hand, if the extent of defect is larger than the allowable limits, the proposal will not be approved, and the reviewing process is stopped.

B. Input a supplier's name

A user provides a supplier's name to check its record: the customer complained record and the claimed record which are already stored in the Excel program. It generates a grade of an alternative for these criteria. Then a pair-wise

comparison is done to translate a grade of an alternative to an AHP scores.

C. Input a defect ratio

A user inputs the defect ratio that a supplier presents for the approval of a boundary sample. The software generates a grade of alternative and an AHP score.

D. Input benefits

The suppliers always present benefits in term of cost reduction per year, and our Excel template translates it to a fraction of target of cost reduction per year (250,000 Baht) and generates a grade of an alternative in benefits criteria and an AHP score.

E. The decision-making process

We select the proposal with the largest AHP scores.

VI. CONCLUSION AND FUTURE WORK

We have developed an Excel-based template for users to select the best proposal based on the AHP framework. Initial satisfaction surveys reveal that our software can reduce time and produce objective selections; even a new or an inexperienced engineer can use our system to identify the best selection. We plan to make it more user-friendly and cover other auto parts.

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