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Combining the Analytic Hierarchy Process and Quality Function Deployment for a Location Decision from a Requirement Perspective

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This paper combines analytic hierarchy process (AHP) and quality function deployment (QFD) techniques to support a facility location decision from a requirement perspective. The proposed approach begins by identifying location requirements, followed by the derivation of location evaluating criteria. Then, a central relationship matrix is established to display the degree of relationship between each pair of location requirement and location criterion for the QFD process. The AHP is used to measure the relative importance weighting for each location requirement. The importance degree and the normalised importance degree of each location criterion are then computed using the QFD transformation for constructing the facility location model. The AHP is used to assess the evaluating score for each candidate location for each particular location criterion. Finally, an overall score for each of the candidate locations is computed for the decision-maker to select the optimal location. An example is given to demonstrate how the proposed approach works.

Keywords: Analytic hierarchy process; House of quality; Location decision; Quality function deployment

1. Introduction

A facility location decision is a long-term business strategic planning matter for a firm [1] to satisfy multiple objectives by considering both quantitative and qualitative criteria. An appropriate facility location is an important link between upstream suppliers and downstream customers in the supply chain. The advantage of selecting an optimal facility location is not only to reduce the transportation cost and increase the relationships between a firm and its customers and suppliers, but also to improve business performance and increase the competitiveness and profitability of the firm.

To assist the facility location decision, most of the existing literature adopted mathematical programming or a networking approach to construct an evaluation model. For constructing a mathematical programming model, Klincewicz [2] developed an efficient heuristic for a complex single-period facility location. Tombak [3] proposed a cost-minimisation objective function for a facility location model, which caters for a local market. Ghosh and Craig [4] presented a competitive equilibrium model based on the cumulative profits generated from all of the facility sites to formulate a strategic location plan in a dynamic environment. Aiken [5] reviewed eight categories of mathematical programming models that were proposed by other workers and have significant contributions for distribution facility location problems. Holmberg et al. [6] and Ronnqvist [7] proposed a primal heuristic, which incorporates a repeated matching algorithm into the Lagrangian heuristic, for single-source capacitated facility location problems. Holmberg [8] developed a branch-and-bound method based on a dual ascent and adjustment procedure to generate the exact solution methods for uncapacitated facility location problems. In the area of networking approach, Chen et al. [9] proposed a network programming approach for a facility location decision in multisource Weber and conditional Weber problems. Su and Wang [10] adopted a Tabu search algorithm to develop a heuristic for the location-routeing problem for physical distribution. For the network analysis of the facility location problem, Swink and Speier [11] presented the geographic-information-system (GIS) as a decision-supporting tool for the visual display of data in the form of maps.

The evaluating criteria considered in the above work generally focus on quantitative factors such as the construction costs of facility hardware and software, the transportation cost, the operating cost, and the supply capacity. However, the selection of a facility location should always satisfy multiple objectives by considering both the quantitative (economical) factors and the qualitative factors. The quantitative factors include the costs of land and buildings, the inbound and outbound transportation costs, and the raw materials supply quantity. The qualitative

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factors include the closeness to suppliers and retailers, the government policies, the environment factors, the quality of life, the availability of required technical labour and the availability of utilities.

Ross and Soland [12] provided a multicriteria approach for siting the location of a public facility. Current et al. [13] reviewed the broad and multidisciplinary literature of location analysis to summarise the scope of research that has examined the multi-objective aspect of the facility location problem. To resolve the uncertainties encountered in multi-objective location analysis, Eiselt and Laporte [14] studied the major components of four different types of location model, in which facilities enter the market in a sequential fashion. A sensitivity analysis was performed for each basic model to identify the changes of location decision that may happen when assumptions are dropped or replaced by others. Current et al. [15] developed a dynamic model for multi-objective facility location analysis that has considerable uncertainty regarding the way in which relevant parameters in the location decision will change over time. Drezner and Guyse [16] used decision theory rules to solve the location problem with future uncertainty that may happen in the location evaluating criteria. Badri [17] proposed an analytic hierarchy process and multi-objective goal-programming methodology as aids in making location-allocation decisions to solve the volatile and complex global facility location problem.

The evaluating criteria of the location decision model considered in those papers are determined from the viewpoint of the firm. Nevertheless, a facility location model should be constructed from the perspective of those who are concerned about where the location site is and generate requirements from the facility location. That is, the evaluating criteria for a location model must be established from the viewpoints of the firm's customers, suppliers, and employees to satisfy their multiple location requirements.

Quality function deployment (QFD) is a method for structured product planning and development that enables a development team to specify clearly the customer's wants and needs, and then evaluates each proposed product systematically in terms of its impact on meeting those needs [18,19]. It is used to ensure that the voice of the customer is heard throughout the product planning and design stage [20]. In the QFD process, a matrix called the house-of-quality (HOQ) is used to display the relationship between the voice of customers (WHATs) and the quality characteristics (HOWs). During the QFD transformation, the HOQ is then developed to demonstrate how the quality characteristics satisfy the customer requirements.

Though QFD has been proved to be a successful tool to support a product design project, the application of QFD to the location decision was rarely found in the literature. The traditional QFD approach uses absolute importance to identify the degree of importance for each customer requirement. This assumes that accurate and representative data in an absolute scale is available. However, customers tend to rate almost everything as being important. Whereas everything is important to the customer, the development team is still forced to make trade-offs, because of constrained resources. Thus, if customers can differentiate the importance of those customer requirements, the QFD process can help the developer translate those differences into prioritised technical responses. If the absolute weighting data tend to be bunched near the highest possible scores, it does not contribute much to helping developers to prioritise technical responses [21]. An alternative to avoid this problem is to adopt the analytic hierarchy process (AHP) approach, developed by Saaty [22]. The AHP can be used to measure the relative degree of importance of each customer requirement by comparing each pair of customer requirements to indicate how much more important one member of each pair is than the other. In addition, AHP is a powerful tool that can be used to make decisions in situations involving multiple objectives [23]. Thus, it would be a useful tool to assist the location planning process to make an optimal location decision by assessing the relative suitability among candidate alternatives.

This paper proposes combining the AHP and the QFD techniques for a location decision that satisfies multiple location criteria from a requirement perspective. In the proposed approach, the WHATs in the HOQ represent the location requirements, whereas the HOWs represent the location evaluating criteria. AHP is used to measure the relative degree of importance for each location requirement in the QFD process. Then, after the transformation of QFD to determine the location evaluating criteria, the AHP is again used to assess how good a particular candidate location is compared to the others to help the location planning process in making an optimal selection.

2. QFD Process for Location Criteria

A basic framework of the QFD process for developing the evaluating criteria of a facility location model is shown in Fig. 1. As shown in the figure, a typical QFD contains the following five sections:

1. A structured list of the location requirements, which are the quality requirements in the traditional QFD for product design, to represent the needs of a firm's customers, suppliers, and employees for the facility location.

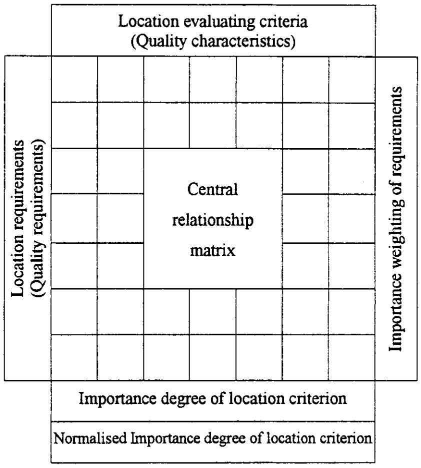

Fig. 1. A framework of the QFD process for location criteria.

2. A column vector called the importance weighting of the requirement to represent the relative degree of importance for each location requirement by using the AHP technique.
3. The location evaluating criteria, which are the quality characteristics in the traditional QFD for product design, to represent the evaluating criteria that should be considered to satisfy the location requirements.
4. A central relationship matrix to link the relationship between the location requirements and the location evaluating criteria. The central relationship matrix displays the degree by which each evaluating criteria satisfies the corresponding location requirement.
5. A row vector called the importance degree of the location criterion to identify the degree by which each evaluating criterion satisfies the overall location requirements and a row vector called the normalised importance degree of the location criterion to represent the relative importance and to prioritise the location criteria. The normalised importance degree of each criterion is finally used as the evaluating weight in the facility location model.

3. The AHP Technique for the Proposed Approach

When multiple objectives are important to a decision-maker, it may be difficult to choose between alternatives. In this case, the AHP technique is a powerful tool for solving complicated problems that may have interactions and correlations among objectives. It is a systematic decision approach first developed by Saaty in 1971. In this section, the AHP technique will be discussed to show how it helps the location decision. Suppose that there are m objectives, the AHP technique performs the multi-objective decision by the following steps.

1. Complete the following pairwise comparison matrix **A** for m objectives.

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix} \tag{1}$$

   Where, a_{ij} indicates how much more important the ith location requirement is than the jth location requirement for constructing the column vector of importance weighting of location requirements.

a_{ij} indicates how much more satisfactory the ith candidate location is than the jth candidate location for a particular location criterion for making the optimal location decision.

For all i and j, it is necessary that $a_{ii} = 1$ and $a_{ij} = 1/a_{ji}$. The possible assessment value of a_{ij} with the corresponding interpretation is shown in Table 1.

2. Divide each entry in column i of **A** by the sum of the entries in column i. This yields a new matrix $\mathbf{A}_w$, in which the sum of the entries in each column is 1.

Table 1. The assessment of a_{ij}.

Value of a_{ij}	Interpretation
1	Objective i and j are of equal importance
3	Objective i is weakly more important than objective j
5	Objective i is strongly more important than objective j
7	Objective i is very strongly more important than objective j
9	Objective i is absolutely more important than objective j
2,4,6,8	Intermediate values

$$\mathbf{A}_w = \begin{bmatrix} \dfrac{a_{11}}{\sum_{i=1}^{m} a_{i1}} & \dfrac{a_{12}}{\sum_{i=1}^{m} a_{i2}} & \cdots\cdots & \dfrac{a_{1m}}{\sum_{i=1}^{m} a_{im}} \\ \vdots & \vdots & \cdots\cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ \dfrac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} & \dfrac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} & \cdots\cdots & \dfrac{a_{mm}}{\sum_{i=1}^{m} a_{im}} \end{bmatrix} \tag{2}$$

3. Compute c_i as the average of the entries in row i of $\mathbf{A}_w$ to yield column vector **C**.

$$\mathbf{C} = \begin{bmatrix} c_1 \\ \vdots \\ \vdots \\ \vdots \\ c_m \end{bmatrix} = \begin{bmatrix} \dfrac{\dfrac{a_{11}}{\sum_{i=1}^{m} a_{i1}} + \dfrac{a_{12}}{\sum_{i=1}^{m} a_{i2}} + \ldots + \dfrac{a_{1m}}{\sum_{i=1}^{m} a_{im}}}{m} \\ \vdots \\ \vdots \\ \vdots \\ \dfrac{\dfrac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} + \dfrac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} + \ldots + \dfrac{a_{mm}}{\sum_{i=1}^{m} a_{im}}}{m} \end{bmatrix} \tag{3}$$

   Where, c_i represents the relative degree of importance for the ith location requirement in the column vector of importance weighting of location requirement.

c_i represents the evaluating score that the ith candidate location is assessed for a particular location criterion for making the optimal location decision.

4. To check for consistency in a pairwise comparison matrix, the substeps are performed as follows.
   (i) Compute $\mathbf{A}\cdot\mathbf{C}$:

$$\mathbf{A}\cdot\mathbf{C} = \begin{bmatrix} a_{11} & a_{12} & \vdots & a_{1m} \\ a_{21} & \ddots & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & \cdots & \cdots & a_{mm} \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_m \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_m \end{bmatrix} \tag{4}$$

(ii) Compute δ:

$$\delta = \frac{1}{m}\sum_{i=1}^{m}\frac{i\text{th entry in } \mathbf{A}\cdot\mathbf{C}}{i\text{th entry in } \mathbf{C}} = \frac{1}{m}\sum_{i=1}^{m}\frac{x_i}{c_i} \tag{5}$$

(iii) Compute the consistency index (*CI*) as follows:

$$CI = \frac{\delta - m}{m - 1} \tag{6}$$

(iv) Compare *CI* to the random index (*RI*) for the appropriate value of *m* to determine if the degree of consistency is satisfactory. If *CI* is sufficiently small, the decision-maker's comparisons are probably consistent enough to give useful estimates of the weights for the objective function. If $CI/RI < 0.10$, the degree of consistency is satisfactory, but if $CI/RI > 0.10$, serious inconsistencies may exist, and the AHP may not yield meaningful results. The reference values of the *RI* for different numbers of *m* [23] are shown below.

m	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

4. Procedure for the Location Decision

The planning procedure of combining the AHP and QFD techniques for a location decision to satisfy multiple location requirements is step by step as follows:

1. The planning procedure begins by identifying the location requirements. This paper suggests that the location planning team investigates the voices of the firm's customers, suppliers, and employees about their requirements for the facility location. Information is collected on potential requirements from a sampling survey of those who have requirements for the facility location. Their opinion is asked on whether each particular requirement should exist. The confirmed requirements are identified as the location requirements in the QFD process to ensure that the location decision is requirement-driven.
2. In the second step, the location evaluating criteria are developed by the location planning team. The evaluating criteria are derived directly from the location requirements for what criteria should be considered in order that the facility location satisfies the location requirements. The location evaluating criterion is a term used as the internal and technical language of a firm and is placed at the top of the QFD framework.
3. A central relationship matrix is established to display the degree of relationship between each location requirement and the corresponding location evaluating criterion. This matrix should be constructed by integrating the cross-functional expert knowledge of the location planning team. In the central relationship matrix, a symbol representing a strong, moderate, or weak relationship in each cell reflects the extent to which the location evaluating criterion contributes to meeting the corresponding location requirement. During the transformation, quantified scales, such as 1–2-4 or 1–3-9, are used to denote a weak–moderate–strong relationship for the QFD computation.
4. The column vector of the importance weighting of location requirements is the place to record the relative degree of importance for each location requirement. This paper proposes using the AHP process to perform this task. In this stage, the facility location planning team make pairwise comparisons of the customer requirements to indicate how much more important one member of each pair is than the other. The pairwise comparison data is further analysed by the AHP approach to construct the column vector of the importance weighting of requirements.
5. The degree of importance of each location criterion is computed from the weighted column sum of the importance weighting of each requirement multiplied by the quantified relationship value of the corresponding location evaluating criterion in the central relationship matrix. That is, if *n* location evaluating criteria are considered for the purpose of satisfying *m* location requirements, the degree of importance of each location criterion is computed by Eq. (7).

$$w_j = \sum_{i=1}^{m} R_{ij}\, c_i \tag{7}$$

Where,

w_j = importance degree of the *j*th location criterion ($j = 1,2,\ldots,n$)

R_{ij} = quantified relationship value between the *i*th location requirement and the *j*th location evaluating criterion in the central relationship matrix

c_i = importance weighting of the *i*th requirement ($i = 1, 2, \ldots, m$)

The degree of importance of each criterion is then normalised to a total of 100 to represent the weight of each location criterion in the facility location model. The normalised process for each location criterion is shown below.

$$Normalised\ w_j = \frac{w_j}{\sum_{j=1}^{n} w_j} \times 100 \tag{8}$$

6. A facility location model is constructed by listing the location criteria with the corresponding evaluating weight, which is the normalised degree of importance from Eq. (8).
7. For each location criterion, the facility location planning team uses the AHP technique to make pairwise comparisons of the candidate locations to indicate how much more satisfactory one member of each pair is than the other. The pairwise comparison data is further analysed by the AHP to compute the evaluating score for each candidate location for each of the location criteria.
8. Finally, the overall score for each candidate location is computed by Eq. (9) for the purpose of selecting the optimal location decision. The higher the overall score, the better is the location. That is, a higher overall score for a candidate location means that it would be more satisfactory for the

overall location criteria, which in turn contributes to satisfying the overall location requirements.

$$S_j = \sum_{i=1}^{n} w_i e_{ij} \qquad (9)$$

Where,

S_j = overall score for the jth candidate location ($j = 1,2,\ldots$)
w_i = evaluating weight of the ith location criterion ($i = 1,2,\ldots,n$)
= normalised importance degree of the ith location criterion from Eq. (8).
e_{ij} = evaluating score of the jth candidate location on the ith location criterion computed by the AHP process

5. Demonstration Example

An example is given of how a firm applies the proposed approach to make the location decision among three candidate locations.

5.1 Constructing a Facility Location Model

To construct a facility location model, first, ten location requirements are identified from surveying the firm's customers, suppliers, and employees, and nine location criteria are derived to satisfy the overall location requirements. The central relationship matrix that displays the degree of relationship between each location requirement and the corresponding location criterion is shown in Fig. 2.

To measure the relative degree of importance for each location requirement, a pairwise comparison matrix for the location requirements is completed:

$$\mathbf{A} = \begin{bmatrix} 1 & 5 & 4 & 7 & 3 & 3 & 6 & 8 & 9 & 2 \\ \frac{1}{5} & 1 & \frac{1}{2} & 3 & \frac{1}{3} & \frac{1}{3} & 2 & 4 & 5 & \frac{1}{4} \\ \frac{1}{4} & 2 & 1 & 4 & \frac{1}{2} & \frac{1}{2} & 3 & 5 & 6 & \frac{1}{3} \\ \frac{1}{7} & \frac{1}{3} & \frac{1}{4} & 1 & \frac{1}{5} & \frac{1}{5} & \frac{1}{2} & 2 & 3 & \frac{1}{6} \\ \frac{1}{3} & 3 & 2 & 5 & 1 & 1 & 4 & 6 & 7 & \frac{1}{2} \\ \frac{1}{3} & 3 & 2 & 5 & 1 & 1 & 4 & 6 & 7 & \frac{1}{2} \\ \frac{1}{6} & \frac{1}{2} & \frac{1}{3} & 2 & \frac{1}{4} & \frac{1}{4} & 1 & 3 & 4 & \frac{1}{5} \\ \frac{1}{8} & \frac{1}{4} & \frac{1}{5} & \frac{1}{2} & \frac{1}{6} & \frac{1}{6} & \frac{1}{3} & 1 & 2 & \frac{1}{7} \\ \frac{1}{9} & \frac{1}{5} & \frac{1}{6} & \frac{1}{3} & \frac{1}{7} & \frac{1}{7} & \frac{1}{4} & \frac{1}{2} & 1 & \frac{1}{8} \\ \frac{1}{2} & 4 & 3 & 6 & 2 & 2 & 5 & 7 & 8 & 1 \end{bmatrix}$$

and

$$\mathbf{A}_w = \begin{bmatrix} 0.316 & 0.259 & 0.297 & 0.207 & 0.349 & 0.349 & 0.230 & 0.188 & 0.173 & 0.383 \\ 0.063 & 0.052 & 0.037 & 0.089 & 0.039 & 0.039 & 0.077 & 0.094 & 0.096 & 0.048 \\ 0.079 & 0.104 & 0.074 & 0.118 & 0.058 & 0.058 & 0.115 & 0.118 & 0.115 & 0.064 \\ 0.045 & 0.017 & 0.019 & 0.030 & 0.023 & 0.023 & 0.019 & 0.047 & 0.058 & 0.032 \\ 0.105 & 0.156 & 0.149 & 0.148 & 0.116 & 0.116 & 0.153 & 0.141 & 0.135 & 0.096 \\ 0.105 & 0.156 & 0.149 & 0.148 & 0.116 & 0.116 & 0.153 & 0.141 & 0.135 & 0.096 \\ 0.053 & 0.026 & 0.025 & 0.059 & 0.029 & 0.029 & 0.038 & 0.071 & 0.077 & 0.038 \\ 0.040 & 0.013 & 0.015 & 0.015 & 0.019 & 0.019 & 0.013 & 0.024 & 0.038 & 0.027 \\ 0.035 & 0.010 & 0.012 & 0.010 & 0.017 & 0.017 & 0.010 & 0.012 & 0.019 & 0.024 \\ 0.158 & 0.207 & 0.223 & 0.177 & 0.233 & 0.233 & 0.192 & 0.165 & 0.154 & 0.192 \end{bmatrix}$$

Then, the column vector (**C**) of the importance weighting of location requirement can be computed.

$$C^T = [0.275\ 0.063\ 0.090\ 0.031\ 0.132\ 0.132\ 0.045\ 0.022\ 0.017\ 0.193]$$

where C^T is the transpose of column vector **C**.

Furthermore, to check for consistency in the pairwise comparison matrix, the **A**·**C**, δ, *CI*, and *CI*/*RI* are computed as follows.

$$(\mathbf{A}\cdot\mathbf{C})^T = [2.944\ 0.655\ 0.952\ 0.316\ 1.407\ 1.407\ 0.453\ 0.226\ 0.170\ 2.082]$$

where $(\mathbf{A}\cdot\mathbf{C})^T$ is the transpose of $(\mathbf{A}\cdot\mathbf{C})$

$$\delta = \frac{1}{10}\left(\frac{2.944}{0.275} + \frac{0.655}{0.063} + \frac{0.952}{0.090} + \frac{0.316}{0.031} + \frac{1.407}{0.132} + \frac{1.407}{0.132} + \frac{0.453}{0.045} + \frac{0.226}{0.022} + \frac{0.170}{0.017} + \frac{2.082}{0.193}\right) = 10.432$$

$$CI = \frac{10.432 - 10}{10 - 1} = 0.048$$

$$\frac{CI}{RI} = \frac{0.048}{1.51} = 0.03 < 0.10$$

Since $CI/RI < 0.10$, the degree of consistency is satisfactory. Therefore, the column vector (**C**) of the importance weighting for location requirements can be given for the QFD transformation as shown in Fig. 3.

By using Eqs (7) and (8), the degree of importance and the normalised importance degree for each location criterion can be computed. The computed results are shown on the bottom two rows of Fig. 3. The normalised degree of importance for each location criterion is then used as the evaluating weight in the firm's facility location model. Figure 3 also shows that the resource allocation priority of the location evaluating criteria follows the sequence: initial and operating costs ≫ transportation conditions ≫ information technology conditions ≫ closeness to suppliers and retailers ≫ political regulation and law ≫ labour conditions ≫ land features ≫ energy/utilities ≫ community and working environment ("≫" means "more important than"). This can provide a company with advice on the resource allocation policy to improve the conditions of those criteria that are more important in order to satisfy the overall location requirements better.

		Location evaluating criteria									
		Land features	Initial and operating costs	Transportation conditions	Closeness to suppliers and customers	Political regulation and Law	Community and working environment	Labor conditions	Energy / utilities	Information technology conditions	**Importance weighting of requirements**
Location requirements	1.Fast/precise distribution ability	○	●	●	⊙	●		●	⊙	●	
	2.Convenient transportation	●	●	●	⊙	⊙	⊙	⊙		⊙	
	3.Adequate land space	●	●		⊙	●	⊙				
	4.Appropriate site location	●	●	⊙	⊙						
	5.Low transportation cost		●	●	⊙					⊙	
	6.Smooth inbound/outbound Transportation	●	⊙	●	⊙	○					
	7.Available labor supply		⊙	●	⊙	⊙	⊙	●			
	8.Available public facilities		⊙		⊙	●	●	⊙			
	9.Stable utilities supply		●			○			●		
	10.Quick response to requirements		●	⊙	●		⊙		●	●	

(Quantified value of relationship: strong : ● = 9 ; moderate : ⊙ = 3 ; weak : ○ = 1 ; no relationship: blank=0)

Fig. 2. The central relationship matrix.

		Location evaluating criteria									
		Land features	Initial and operating costs	Transportation conditions	Closeness to suppliers and customers	Political regulation and Law	Community and working environment	Labor conditions	Energy / utilities	Information technology conditions	**Importance weighting of requirements**
Location requirements	1.Fast/precise distribution ability	○	●	●	⊙	●		●	⊙	●	0.275
	2.Convenient transportation	●	●	●	⊙	⊙	⊙	⊙		⊙	0.063
	3.Adequate land space	●	●		⊙	●	⊙				0.090
	4.Appropriate site location	●	●	⊙	⊙						0.031
	5.Low transportation cost		●	●	⊙					⊙	0.132
	6.Smooth inbound/outbound Transportation	●	⊙	●	⊙	○					0.132
	7.Available labor supply		⊙	●	⊙	⊙	⊙	●			0.045
	8.Available public facilities		⊙		⊙	●	●	⊙			0.022
	9.Stable utilities supply		●			○			●		0.017
	10.Quick response to requirements		●	⊙	●		⊙		●	●	0.193
	Importance degree of location criteria	3.119	7.806	6.495	4.107	3.956	1.371	3.135	2.715	4.797	
	Normalized Importance degree	8.3	20.8	17.3	11.0	10.5	3.7	8.4	7.2	12.8	

(Quantified value of relationship: strong : ● = 9 ; moderate : ⊙ = 3 ; weak : ○ = 1 ; no relationship: blank=0)

Fig. 3. The QFD process for the example.

5.2 Location Assessment and Decision

To select the optimal location, the AHP process is used to assess the evaluating score for each candidate location for each particular location criterion. The pairwise comparison matrix of the candidate locations on each of the nine location criteria is completed. Each entry in the pairwise comparison matrix indicates how much more satisfactory one member of each pair of candidate locations is than the other for a particular location criterion. The pairwise comparison matrix for each of the nine location criteria is shown below.

1. For "land feature" criterion

$$A = \begin{array}{c} \\ \end{array}\begin{array}{cccc} & X & Y & Z \\ X & 1 & 1 & \frac{1}{3} \\ Y & 1 & 1 & \frac{1}{2} \\ Z & 3 & 2 & 1 \end{array}$$

2. For "initial and operating costs" criterion

$$A = \begin{bmatrix} 1 & 1 & 3 \\ 1 & 1 & 3 \\ \frac{1}{3} & \frac{1}{3} & 1 \end{bmatrix}$$

3. For "transportation conditions" criterion

$$A = \begin{bmatrix} 1 & 3 & 4 \\ \frac{1}{3} & 1 & 1 \\ \frac{1}{4} & 1 & 1 \end{bmatrix}$$

4. For "closeness to suppliers and customers" criterion

$$A = \begin{bmatrix} 1 & \frac{1}{5} & 2 \\ 5 & 1 & 9 \\ \frac{1}{2} & \frac{1}{9} & 1 \end{bmatrix}$$

5. For "political regulation and law" criterion

$$A = \begin{bmatrix} 1 & \frac{1}{2} & 3 \\ 2 & 1 & 5 \\ \frac{1}{3} & \frac{1}{5} & 1 \end{bmatrix}$$

6. For "community and working environment" criterion

$$A = \begin{bmatrix} 1 & \frac{1}{5} & \frac{1}{5} \\ 5 & 1 & 1 \\ 5 & 1 & 1 \end{bmatrix}$$

7. For "labour conditions" criterion

$$A = \begin{bmatrix} 1 & 2 & 5 \\ \frac{1}{2} & 1 & 3 \\ \frac{1}{5} & \frac{1}{3} & 1 \end{bmatrix}$$

8. For "energy/utilities" criterion

$$A = \begin{bmatrix} 1 & \frac{1}{5} & \frac{1}{5} \\ 5 & 1 & 1 \\ 5 & 1 & 1 \end{bmatrix}$$

Table 2. Location evaluating scores for the example.

Location criterion	Evaluating weight	Evaluating score for candidate location			CI	$\frac{CI}{RI}$	Consistency
		X	Y	Z			
Land feature	8.3	0.211	0.241	0.549	0.0095	0.016	*
Initial and operating costs	20.8	0.429	0.429	0.143	0	0	**
Transportation conditions	17.3	0.633	0.193	0.175	0.0045	0.008	*
Closeness to suppliers and customers	11.0	0.158	0.761	0.082	0.0015	0.0026	*
Political regulation and law	10.5	0.309	0.582	0.110	0.001	0.0017	*
Community and working evironment	3.7	0.091	0.455	0.455	0	0	**
Labour conditions	8.4	0.582	0.309	0.110	0.001	0.0017	*
Energy/utilities	7.2	0.091	0.455	0.455	0	0	**
Information technology conditions	12.8	0.732	0.130	0.138	0.0015	0.0026	*
Overall score		41.86	37.96	20.27			

*Consistency
**Perfect consistency

9. For "information technology conditions" criterion

$$A = \begin{bmatrix} 1 & 6 & 5 \\ \frac{1}{6} & 1 & 1 \\ \frac{1}{5} & 1 & 1 \end{bmatrix}$$

By using Eqs (2) to (6), the evaluating score for each candidate location for each of the location criteria along with the corresponding *CI* and *CI*/*RI* values are computed and listed in Table 2. The overall score for each candidate location is also computed by using Eq. (9) and is shown on the bottom row of Table 2. From the table, candidate location *X* has the highest overall score, so the facility location decision would choose it as the optimal alternative.

6. Conclusion

A facility location decision should be made from a requirement perspective to satisfy the overall requirements of those who are concerned about where the location site is. This paper proposes an approach that combines the AHP and QFD techniques to help the location planning decision to select an optimal location. The QFD technique is applied to develop the location criteria with corresponding evaluating weights for constructing the facility location model. The AHP process is used in two cases. First, it was used to measure the relative importance weighting for each of the location requirements to avoid the problems that may occur in traditional QFD applications. Secondly, it is used to assess the evaluating score for each of the candidate locations for each particular location criterion. The proposed approach can provide a firm with an objective method for making an optimal location decision to satisfy the overall location requirements.

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