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Omega 37 (2009) 711–723
omega
The International Journal of Management Science
www.elsevier.com/locate/omega

Incorporating cost and environmental factors in quality function deployment using data envelopment analysis☆

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Received 14 May 2007; accepted 17 December 2007
Available online 23 December 2007

Abstract

Quality function deployment (QFD) is an important tool available to organizations for efficient product design and development. Traditionally, QFD rates the design requirements (DRs) with respect to customer needs, and aggregates the ratings to get relative importance scores of DRs. An increasing number of studies stress on the need to incorporate additional factors, such as cost and environmental impact, while calculating the relative importance of DRs. However, there is a paucity of methodologies for deriving the relative importance of DRs when several additional factors are considered. In this paper, data envelopment analysis (DEA) is suggested for the purpose. It is proved that the relative importance values computed by DEA coincide with traditional QFD calculations when only the ratings of DRs with respect to customer needs are considered, and when only one additional factor, namely cost, is considered. DEA provides a general framework facilitating QFD computations when more factors need to be considered. The calculations are explained using a step-by-step procedure and illustrations. The proposed QFD–DEA methodology is applied to the design of security fasteners for a Chinese company. Though traditional QFD calculations consider the ratings as cardinal numbers, DEA has the flexibility to treat the ratings as qualitative variables. This aspect is illustrated in a separate section.

Keywords: DEA; Quality function deployment; Qualitative and quantitative factors; Design of security fasteners

1. Introduction

Organizations that pay attention to quality and customer requirements (CRs) stay ahead of competition and survive in the modern competitive market place. A variety of tools are available to organizations in order to help them achieve this goal. Quality function deployment (QFD) is one such extremely important quality management tool that is useful in product design and development and for benchmarking.

When QFD is used for designing a product, the expectations of customers are related to the main design characteristics of the product through a matrix generally known as the "house of quality" (HOQ). The HOQ matrix contains many numerical entries, including the importance of CRs, the relationships between CRs and design requirements (DRs) and the correlations between different DRs. Some of them are elicited using a semantic scale, which are later converted to numerical values. Normally, a simple weighted arithmetic

☆ This paper was processed by Associate Editor J. Zhu.

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doi:10.1016/j.omega.2007.12.003

aggregation procedure is employed to aggregate the ratings of DRs with respect to CRs. The resulting weights of DRs can be interpreted as in the proportion of their importance in meeting the CRs.

The above QFD process does not explicitly incorporate cost and financial factors [1–4]. These factors are normally incorporated in further analysis. For example, a limited budget may be allocated for the development of DRs on the basis of their relative importance [5]. Given the green considerations in developing QFD matrices [6], DRs resulting in adverse environmental impacts could be discouraged. Some studies have considered the level of difficulty of implementing DRs for adjusting the relative importances of DRs [7]. However, in general, studies have considered only one extra factor in their analysis [2,4,7]. In this paper, the data envelopment analysis (DEA) [8,9] is proposed to obtain the relative importance of DRs when several factors have to be considered simultaneously.

Since DEA and QFD are not new to the field of operations management, this paper provides only a brief description of these techniques in the next section. Interested readers are referred to some prominent articles. The use of DEA in computing an aggregate weighted score of DRs is explained in Section 3. It is proved that the relative importance of DRs calculated by DEA agrees with traditional methods of aggregation employed in QFD when no factors have been considered or when only one factor is considered. Use of DEA when many additional factors are considered is illustrated using a numerical example. Finally, the proposed QFD–DEA procedure is applied for the design of security fasteners for a Chinese company in Section 4.

2. The tools—QFD and DEA

2.1. Quality function deployment

QFD has been described by Sullivan [10] as "a system to assure that customer needs drive the product design and production process". It was originally developed in 1972 at Mitsubishi's Kobe shipyard site [11,12] as a tool to identify and quantify customer needs, and translate these needs into technical and design requirements during the design and manufacture of products and services. Over the last few decades, QFD has found a number of applications in the operations and quality management literature [3,13,14]. QFD is briefly described here and more detailed descriptions are available elsewhere [12,15–19]. Costa et al. [20] and Chan and Wu [21] review recent developments in QFD.

Though QFD is a very popular tool and has found a variety of applications, the terminologies used by different authors in QFD literature vary widely [17]. In this note, customer needs are called CRs (also called WHATs in the literature) and the technical characteristics of the product as DRs (also called HOWs). A matrix called the HOQ with CRs as its rows and DRs as its columns is developed in the QFD process.

In general, a typical HOQ comprises six main parts (Matrices A–F) as shown in Fig. 1[17]. The needs of customers are identified and their relative importance as perceived by the customers estimated in Matrix A. The relative importance may be obtained using simple methods such as direct rating, or more complex ones such as the swing method [3], the analytic hierarchy process (AHP) [22] or the analytic network process [14].

The DRs are listed in Matrix B, and the degree of relationship between CRs and DRs are measured in Matrix C. The relationship is usually captured using four levels—no relationship, weak/possible relationship, medium/moderate relationship, and strong relationship—and is usually captured using symbols similar to the ones described in the legend of Fig. 1. The symbols are converted into numbers using a measurement scale (0,1,3,9) though (0,1,3,5) is also used in the QFD literature.

The technical correlation Matrix D is needed because some of the DRs are interrelated. The degree of the interrelations are captured using a symbolic scale, similar to the one used for Matrix C.

When there is significant interrelations between the DRs as shown by entries of Matrix D, this information should be used to normalize the entries of Matrix C. The following normalization procedure suggested by Wasserman [5] is usually employed for this purpose.

$$R_{ij}^{\text{norm}} = \frac{\sum_{k=1}^{N} R_{ik}\gamma_{kj}}{\sum_{j=1}^{N}\sum_{k=1}^{N} R_{ik}\gamma_{kj}},\quad i = 1, 2, \ldots, K, \quad j = 1, 2, \ldots, N, \tag{1}$$

where R_{ik} is an element of the Matrix C representing the relationship between CR_i and DR_k,, γ_{kj} is an element of the technical correlation Matrix D representing the interrelation between DR_k and DR_j, K is the number of CRs, and N is the number of DRs [3]. R_{ij}^{norm} form the entries of the normalized Matrix C, which can be denoted as C^{norm}. Note that C^{norm} needs to be calculated only when there are significant interrelations among DRs; otherwise Matrix C can be directly used.

The absolute and relative importances of DRs are calculated in Matrix E. Matrix F is used for benchmarking.