



A fuzzy group quality function deployment model for e-CRM framework assessment in agile manufacturing

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ARTICLE INFO

Article history:

Received 2 June 2010

Received in revised form 1 February 2011

Accepted 2 February 2011

Available online 9 March 2011

Keywords:

Electronic customer relationship management
Fuzzy quality function deployment
Agile manufacturing
Group fuzzy permutation
TOPSIS
Real options analysis

ABSTRACT

The rapid growth of the Internet and the expansion of electronic commerce applications in manufacturing have given rise to electronic customer relationship management (e-CRM) which enhances the overall customer satisfaction. However, when confronted by the range of e-CRM methods, manufacturing companies struggle to identify the one most appropriate to their needs. This paper presents a novel structured approach to evaluate and select the best agile e-CRM framework in a rapidly changing manufacturing environment. The e-CRM frameworks are evaluated with respect to their customer and financial oriented features to achieve manufacturing agility. Initially, the e-CRM frameworks are prioritized according to their financial oriented characteristics using a fuzzy group real options analysis (ROA) model. Next, the e-CRM frameworks are ranked according to their customer oriented characteristics using a hybrid fuzzy group permutation and a four-phase fuzzy quality function deployment (QFD) model with respect to three main perspectives of agile manufacturing (i.e., strategic, operational and functional abilities). Finally, the best agile e-CRM framework is selected using a technique for order preference by similarity to the ideal solution (TOPSIS) model. We also present a case study to demonstrate the applicability of the proposed approach and exhibit the efficacy of the procedures and algorithms.

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1. Introduction

Agile enterprise refers to an enterprise that can quickly, easily and inexpensively reconfigure itself to exploit opportunities and react to unpredictable internal and external changes. Agility is perhaps the most significant and, at the same time, the most difficult attribute to attain (Miller & Berger, 2001, p. 16). Agility in manufacturing requires a thorough decision to design flexibility, robustness, and adaptability into the very nature of the manufacturing processes in an enterprise. However, changing manufacturing processes is not a trivial proposition and requires a need for understanding and support by the leadership at the top. This need is more vital in a “new production enterprise” where Internet and e-business technologies have injected “velocity” into the business activities and enabled companies to shift their manufacturing operations from the traditional factory integration philosophy to an electronic manufacturing philosophy.

The rapid growth of the Internet and the expansion of electronic commerce applications in manufacturing has given rise to electronic customer relationship management (e-CRM) which enhances the overall customer satisfaction. Adeleye and Yusuf

(2006) and Devadasan et al. (2005) argue that the traditional companies do not adequately utilize electronic business and hence, fail to acquire agility in order to compete in the global market. For example, despite its phenomenal growth, the automobile industry has not been able to produce a vehicle to suit a customer's tastes within a short period of time (Holweg, 2005). Vinodh, Sundararaj, and Devadasan (2009) argue that the current need of agile manufacturing research is to concentrate on infusing agile manufacturing into a practical arena. For these reasons, a structured approach is becoming increasingly important to evaluate and select the best agile e-CRM framework in a rapidly changing manufacturing environment.

The contribution of the proposed approach is sixfold: (1) it addresses the gaps in the CRM literature on the effective and efficient assessment of the e-CRM frameworks; (2) it considers agility to quickly, easily and inexpensively reconfigure the manufacturing process to exploit opportunities and react to unpredictable internal and external changes; (3) it is grounded in the quality function deployment (QFD) model where the desires of the customer are translated into a final product through the various stages of product planning, engineering and manufacturing; (4) it uses real options analysis (ROA) to assess the risks associated with technology-based investment decisions by taking into consideration the changing nature of business strategies and organizational requirements; (5) it employs fuzzy sets and fuzzy logic to consider

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imprecise or vague judgments which lead to ambiguity in the decision process; and (6) it uses a technique for order preference by similarity to the ideal solution (TOPSIS) to aggregate both qualitative judgments and quantitative data.

We also present the results of a real-world case study to demonstrate the applicability of the proposed framework and exhibit the efficacy of the procedures and the algorithms. We show that the proposed approach can help a group of decision makers to think systematically by decomposing the e-CRM framework evaluation process into manageable steps and integrating the results to arrive at a solution consistent with managerial goals and objectives. The analysis of this case study allows for the articulation of a series of key factors that can be considered important in contributing to the successful implementation of the e-CRM framework. The first factor is building internal alliances. The second factor is getting the key people and the line managers on board. The third factor is the persistent and systematic process to evaluate the e-CRM success.

This paper is organized into six sections. In the next section, we review the relevant literature. In Section 3, we present the mathematical notations and definitions used in our method. Section 4 illustrates the details of the proposed method. In Section 5, we present a case study to demonstrate the applicability of this method and exhibit the efficacy of the procedures and algorithms. In Section 6, we sum up with our conclusions and future research directions.

2. Literature review

From mass production through flexible and lean manufacturing towards agile manufacturing philosophy, the craft manufacturing has undergone many evolutionary paradigm shifts (Esmail & Saggiu, 1996). Today, global competition and advanced manufacturing technology have dramatically increased the need for enterprises to produce high-quality and competitively priced products quickly and efficiently. Agile manufacturing can be defined as the “capability of surviving and prospering in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by ‘customer-defined’ products and services” (Cho, Jung, & Kim, 1996). The academic research has established a link between agility and enterprise competitiveness (Cao & Dowlatshahi, 2005; Ganguly, Nilchiani, & Farr, 2009; Giachetti, Martinez, Saenz, & Chen, 2003; Sharifi & Zhang, 2001; Vinodh et al., 2008; Vokurka, Zank, & Lund, 2002; Yusuf & Adeleye, 2002; Yusuf, Adeleye, & Sivayoganathan, 2003).

A study of a number of papers indicates that the coherent meaning of agile manufacturing is the capability of an organization to react quickly in response to the customers' dynamic demands (Brown & Bessant, 2003; Chen, Parker, & Lin, 2006; Christopher, 2000; Goh, 2006; Gupta, Messerschmidt, & Herath, 2006; Ho, Lau, Lee, & Ip, 2005; Mason-Jones & Towill, 1999; Nieminen & Takala, 2006; Yusuf & Adeleye, 2002). Jin-Hai, Anderson, and Harrison (2003), Cao and Dowlatshahi (2005) and Ramesh and Devadasan (2007) have enumerated the definitions of agile manufacturing given by various authors. Sharifi and Zhang (1999) identified a high rate of new product introduction and development as key properties of an agile manufacturing system. Sharifi and Zhang (2001) showed that agility is comprised of two main factors: responding to changes in proper ways and due time, exploiting changes and taking advantage of changes as opportunities. Tsourveloudis and Valavanis (2002) regarded the main capabilities of an agile manufacturing system as the ease with which the system can change between products, and the ability to introduce and develop new products. Hallgren and Olhager (2009) and Narasimhan et al. (2006) concluded that agile manufacturing has a significant impact on flexibility, delivery,

quality and ultimately customer satisfaction. Further studies in agile manufacturing focusing on flexibility, customer satisfaction and quick delivery includes: Brown and Bessant (2003), Chang, Yang, Cheng, and Sheu (2003), Jin-Hai et al. (2003), Ramasesh, Kulkarni, and Jayakumar (2001), Sharp, Irani, and Desai (1999), Sanchez and Nagi (2001), Sarkis (2001) and Steenhuis and Boer (2003).

With the emergence of Internet and e-business, the electronic manufacturing world is entering a new era. Electronic manufacturing is a system methodology that enables operations to successfully integrate with the functional objectives of enterprise. The Internet is used to monitor processes on the production floor and reduce geographical distances by allowing products to be manufactured and marketed on globally. Electronic customer relationship management (e-CRM) is a collection of concepts, tools, and processes that allows an enterprise to obtain the maximum value from their e-business investment (Mahdavi, Cho, Shirazi, & Sahebjamnia, 2008). E-CRM helps companies improve the effectiveness of their interaction with customers while at the same enhancing the agility of their manufacturing systems by customizing products, services, and prices (Ko, Kim, Kim, & Woo, 2008). Further studies in e-CRM includes: Ling and Yen (2001), Mitussis, O'Malley, and Patterson (2006), Ngai (2005), O'Leary, Rao, and Perry (2004), Swift (2001) and Xu et al. (2002).

Most early research studies have focused on the role of e-CRM as a customer satisfaction tool. More recently, research has shown that e-CRM plays a pivotal role in manufacturing (Chaston & Mangles, 2003; Forza & Salvador, 2008). Although, there is no dispute that e-CRM enhances the overall customer satisfaction in manufacturing, when confronted by the range of e-CRM methods, manufacturing companies struggle to identify the one most appropriate to their needs. This paper presents a novel structured approach to evaluate and select the best agile e-CRM framework in a rapidly changing manufacturing environment. The e-CRM frameworks are evaluated with respect to their customer and financial oriented features to achieve manufacturing agility. Initially, the e-CRM frameworks are prioritized according to their financial oriented characteristics using a fuzzy group ROA model. Next, the e-CRM frameworks are ranked according to their customer oriented characteristics using a hybrid fuzzy group permutation and a four-phase fuzzy QFD model with respect to three main perspectives of agile manufacturing (i.e., strategic, operational and functional abilities). Finally, the best agile e-CRM framework is selected using a TOPSIS model.

Several methods have been proposed for solving multi-attribute decision making problems. The TOPSIS is a well-known multi-attribute decision making method proposed by Hwang and Yoon (1981). TOPSIS has been used widely in manufacturing for evaluating flexible manufacturing systems (Rao, 2008), partner selection (Crispim & Pinho de Sousa, 2009), identifying investment opportunities for advanced manufacturing systems (Kim, Park, & Yoon, 1997) and performance measurement (Yurdakul & İc, 2005) among others.

A pitfall of the TOPSIS method is the need for precise measurement of the performance ratings and criteria weights (Yurdakul & Tansel, 2009). However, in many real-world problems, ratings and weights cannot be measured precisely as some decision makers may express their judgments using linguistic terms (Chen, 2000; Torabi & Hassini, 2009). Most measures in agility assessment are described subjectively by ill-defined and vague linguistic terms and the conventional assessment approaches cannot effectively handle such measurement. However, fuzzy logic provides a useful tool for dealing with agility assessment decisions in which the phenomena are imprecise and vague (Lin, Chiu, & Tseung, 2006). In recent years, several researchers have combined fuzzy sets theory with ROA for the quantification of risks and benefits. ROA has been used widely in manufacturing for project management (Boute,

Demeulemeester, & Herroelen, 2004) and capacity planning (Huang, Chang, & Chou, 2008) among others. Fuzzy logic and fuzzy sets can represent ambiguous, uncertain or imprecise information in ROA by formalizing inaccuracy in human decision making (Collan, Fullér, & Mezei, 2009). Fuzzy set algebra developed by Zadeh (1965) is the formal body of theory that allows the treatment of imprecise estimates in uncertain environments.

In this study, we use a four-phase fuzzy QFD model. QFD is a customer-driven approach that allows the needs of the customer to be communicated through the various stages of product planning, design, engineering, and manufacturing into a final product (Chen & Ko, 2008). The QFD model has been successfully used in many industries to improve design processes, customer satisfaction, and to create a competitive advantage (Hauser & Clausing, 1988). A manufacturing organization that correctly implements QFD can improve engineering knowledge, productivity and quality and reduce costs, product development time, and engineering changes (Besterfield, Besterfield-Michna, Besterfield, & Besterfield-Sacre, 2003). QFD is accomplished through a series of charts called “house of quality” (HoQ). A HoQ is a conceptual map providing information such as “what to do” (performance characteristics) or “how to do it” (engineering characteristics). Typically, a QFD system can be broken down into four inter-linked phases to fully deploy the customer needs phase by phase (Chan & Wu, 2005). A simplified form of the HoQ matrix as suggested by Lowe, Ridgway, and Atkinson (2000) was utilized in this study. The technical correlations and planning matrices were removed and only the prioritized requirements row was included at the base. Further studies in QFD includes: Bhattacharya, Sarkar, and Mukherjee (2005), Chen (2009), Chen and Ngai (2008), Chen, Fung, and Tang (2005), Delice and Güngör (2009), Han, Kim, and Choi (2004), Liu (2005), Karsak, Sozer, and Alptekin (2002), Liu and Wu (2008) and Matook and Indulska (2009). Chan and Wu (2002) and Carnevalli and Miguel (2008) present an extensive literature review of QFD and its extensive applications.

3. The mathematical notations and definitions

Let us introduce the following mathematical notations and definitions:

A_i	The i th e-CRM framework
n	The number of alternative e-CRM frameworks
c_j	The j th agile manufacturing criterion
p	The number of agile manufacturing criteria
k	The number of team members
$v_k(s)$	The voting power of the k th member of the strategic team
$w_i(s)$	The importance weight of the i th agile manufacturing strategic criterion
$m_1(s)$	The strategic team leader
$v_k(o)$	The voting power of the k th member of the operational team
$w_i(o)$	The importance weight of the i th agile manufacturing operational criterion
$m_1(o)$	The operational team leader
$v_k(a)$	The voting power of the k th member of the functional team
$w_i(a)$	The importance weight of the i th agile manufacturing functional criterion
$m_1(a)$	The functional team leader
$m_1(f)$	The financial team leader
C_{kl}	The concordance set that is the subset of all agility criteria for which $\tilde{r}_{kj} \geq \tilde{r}_{lj}$

D_{kl}	The discordance set that is the subset of all agility criteria for which $\tilde{r}_{kj} \leq \tilde{r}_{lj}$
$\tilde{r}_{ij}(s)$	The fuzzy weighted collective rank of the j th e-CRM framework with respect to the i th agile manufacturing strategic criterion
$\tilde{r}_{ij}(o)$	The fuzzy weighted collective rank of the j th e-CRM framework with respect to the i th agile manufacturing operational criterion
$\tilde{r}_{ij}(a)$	The fuzzy weighted collective rank of the j th e-CRM framework with respect to the i th agile manufacturing functional criterion
$\tilde{r}_{ij}[m_k(s)]$	The fuzzy ordinal rank of the j th e-CRM framework with respect to the i th agile manufacturing strategic criterion evaluated by the strategic team member $m_k(a)$
$\tilde{r}_{ij}[m_k(o)]$	The fuzzy ordinal rank of the j th e-CRM framework with respect to the i th agile manufacturing operational criterion evaluated by the operational team member $m_k(a)$
$\tilde{r}_{ij}[m_k(a)]$	The fuzzy ordinal rank of the j th e-CRM framework with respect to the i th agile manufacturing functional criterion evaluated by the functional team member $m_k(a)$
$r[A_j(s)]$	The assigned rank to the j th e-CRM framework with respect to the agile manufacturing strategic criteria
$r[A_j(o)]$	The assigned rank to the j th e-CRM framework with respect to the agile manufacturing operational criteria
$r[A_j(a)]$	The assigned rank to the j th e-CRM framework with respect to the agile manufacturing functional criteria
\tilde{s}_{i,t_j}	The weighted collective fuzzy present value of the expected payoffs for the i th e-CRM framework at time t_j
\tilde{x}_{i,t_j}	The weighted collective fuzzy present value of the expected cost for the i th e-CRM framework at time t_j
$\tilde{s}_{i,t_j}[m_k(f)]$	The individual fuzzy present value of the expected payoffs for the i th e-CRM framework at time t_j evaluated by the financial team member $m_k(f)$
$\tilde{x}_{i,t_j}[m_k(f)]$	The individual fuzzy present value of the expected cost for the i th e-CRM framework at time t_j evaluated by the financial team member $m_k(f)$
$E(\tilde{s}_{i,t_j})$	The possibilistic mean value of the weighted collective present value of the expected payoffs for the i th e-CRM framework at time t_j
$E(\tilde{x}_{i,t_j})$	The possibilistic mean value of the weighted collective expected costs for the i th e-CRM framework at time t_j
σ_{i,t_j}^2	The variance of the weighted collective fuzzy present value of the expected payoffs for the i th e-CRM framework at time t_j evaluated by the financial team member $m_k(f)$
δ_i	The value loss over the duration of the option
r_i	The risk-free interest rate
$n(d_{1i,t_j})$	The i th e-CRM framework cumulative normal probability for d_{1i,t_j}
$n(d_{2i,t_j})$	The i th e-CRM framework cumulative normal probability for d_{2i,t_j}
\tilde{ROV}_{i,t_j}	The fuzzy real option value of the i th e-CRM framework at time t_j

$\tilde{R}^f(K)$ The individual fuzzy real option matrix of the e-CRM frameworks evaluated by the financial team member $m_k(f)$

\tilde{R}^f The fuzzy weighted collective real option matrix

$V(f)$ The real option value vector of the e-CRM frameworks at time t_j

We also allow assigning different voting power weights to each financial team member:

$$V(f) = [v_1(f), v_2(f), \dots, v_l(f)] \tag{2}$$

Process 1.2: identification of the e-CRM frameworks

In this process, the team identifies the alternative e-CRM frameworks. Let us assume that the team has identified n e-CRM frameworks:

$$\underline{A} = [A_1, A_2, \dots, A_l, \dots, A_n] \tag{3}$$

Process 1.3: construction of the individual fuzzy real option matrices

In this process, the following individual real option matrices are given by each financial team member:

$$\tilde{R}^f(k) = \begin{matrix} A_1 & \begin{bmatrix} \tilde{s}_{1,t_j} & \tilde{x}_{1,t_j} \\ \tilde{s}_{2,t_j} & \tilde{x}_{2,t_j} \\ \vdots & \vdots \\ \tilde{s}_{n,t_j} & \tilde{x}_{n,t_j} \end{bmatrix} \\ A_2 & \\ \vdots & \\ A_n & \end{matrix} \quad (k = 1, 2, \dots, l) \tag{4}$$

4. The proposed method

The model depicted in Figs. 1 is proposed to select the agile e-CRM framework. The proposed approach consists of several processes, steps and procedures modularized into three phases.

4.1. Phase 1: prioritization of the e-CRM frameworks (financial oriented evaluation)

In this phase, we prioritize the e-CRM frameworks with respect to their financial value added perspectives.

Process 1.1: establishment of the financial team

Initially, we establish a team of financial analysts to consider and evaluate the financial aspects of the e-CRM frameworks. Let us assume that members of the financial team are as follows:

$$T(F) = [m_1(f), m_2(f), \dots, m_l(f)] \tag{1}$$

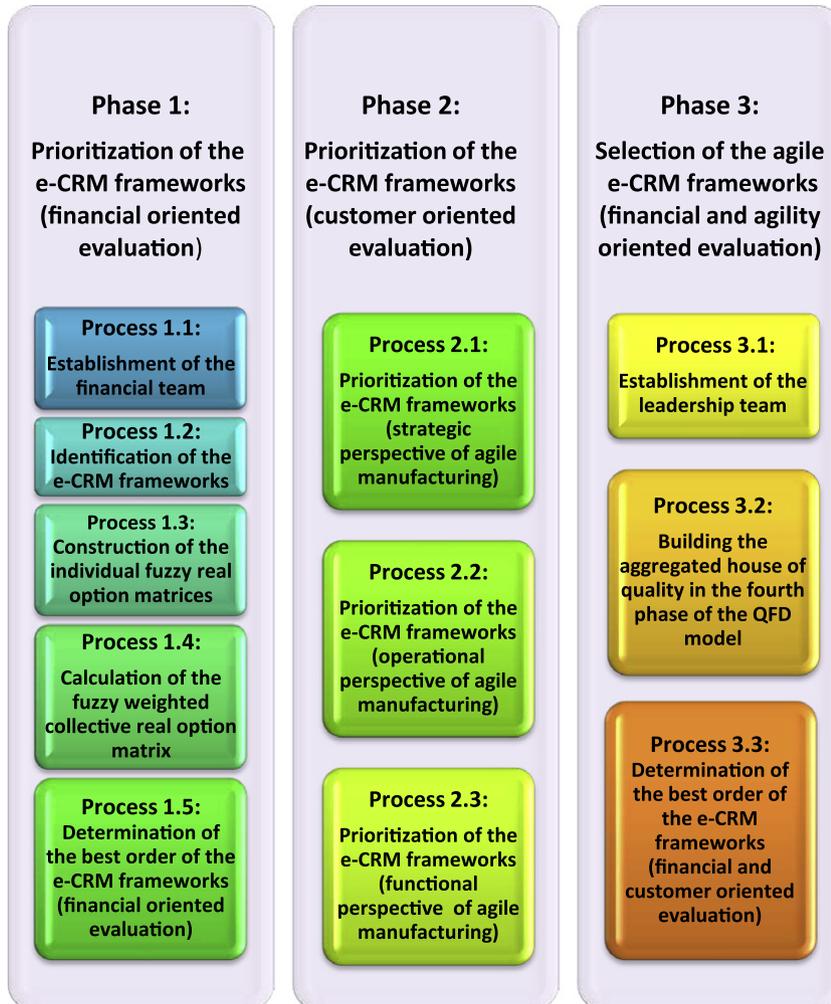


Fig. 1.1. The proposed framework (phases).



Fig. 1.2. The proposed framework (processes).

Process 1.4: calculation of the fuzzy weighted collective real option matrix

In this process, the individual fuzzy real option matrices will be aggregated by the voting powers to form a fuzzy weighted collective real option matrix as follows:

$$\tilde{R}^f = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_n \end{matrix} \begin{bmatrix} \tilde{s}_{i,t_j} & \tilde{x}_{i,t_j} \\ \tilde{s}_{1,t_j} & \tilde{x}_{1,t_j} \\ \tilde{s}_{2,t_j} & \tilde{x}_{2,t_j} \\ \vdots & \vdots \\ \tilde{s}_{n,t_j} & \tilde{x}_{n,t_j} \end{bmatrix} \quad (5)$$

where

$$\tilde{s}_{i,t_j} = \frac{\sum_{k=1}^l (v_k(f))(\tilde{s}_{i,t_j}[m_k(f)])}{\sum_{k=1}^l v_k(f)} \quad (6)$$

$$\tilde{x}_{i,t_j} = \frac{\sum_{k=1}^l (v_k(f))(\tilde{x}_{i,t_j}[m_k(f)])}{\sum_{k=1}^l v_k(f)} \quad (7)$$

Process 1.5: determination of the best order of the e-CRM frameworks (financial oriented evaluation)

In this process, the real options values of the e-CRM frameworks at time t_j are determined using the following vector:

$$V(f) = \begin{bmatrix} A_1 [E(ROV_{1,t_j})] \\ A_2 [E(ROV_{2,t_j})] \\ \vdots \\ A_n [E(ROV_{n,t_j})] \end{bmatrix} \quad (8)$$

The following trapezoidal fuzzy numbers are used to determine the real option value of the i th e-CRM framework at time t_j by the financial team member $m_k(f)$:

$$E(\tilde{ROV}_{i,t_j}) = \frac{(ROV_{i,t_j})^c + (ROV_{i,t_j})^d}{2} + \frac{(ROV_{i,t_j})^\beta - (ROV_{i,t_j})^\alpha}{6} \quad i = 1, 2, \dots, n \quad (9)$$

$$\tilde{ROV}_{i,t_j} = ((ROV_{i,t_j})^c, (ROV_{i,t_j})^d, (ROV_{i,t_j})^\alpha, (ROV_{i,t_j})^\beta) \quad i = 1, 2, \dots, n \quad (10)$$

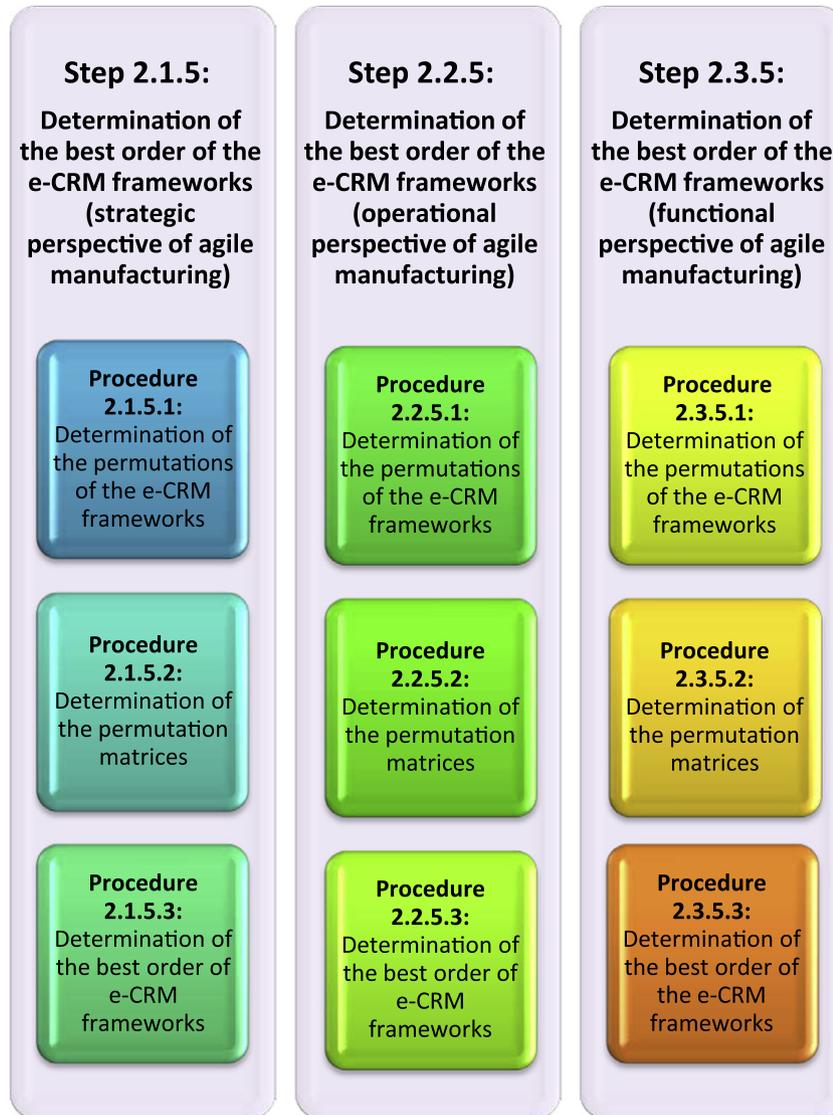


Fig. 1.3. The proposed framework (procedures).

$$\tilde{R}\tilde{O}V_{i,t_j} = \tilde{s}_{i,t_j} \cdot e^{-\delta \cdot t_j} \cdot n(d_{11,t_j}) - \tilde{x}_i, t_j \cdot e^{-r \cdot t_j} \cdot n(d_{21,t_j}) \quad (11)$$

where the e-CRM framework *i*th cumulative normal probability distribution for *d*₁ and *d*₂ are as follows:

$$N(f) = \begin{bmatrix} A_1 & n(d_{11,t_j}) & n(d_{21,t_j}) \\ A_2 & n(d_{12,t_j}) & n(d_{22,t_j}) \\ \vdots & \vdots & \vdots \\ A_n & n(d_{1n,t_j}) & n(d_{2n,t_j}) \end{bmatrix} \quad (12)$$

where

$$d_{1i,t_j} = \frac{\ln\left(\frac{E(\tilde{s}_{i,t_j})}{\tilde{x}_{i,t_j}}\right) + t_j \cdot \left(r_i - \delta_i + \frac{\sigma_{i,t_j}^2}{2}\right)}{\sigma_{i,t_j} \cdot \sqrt{t_j}} \quad (13)$$

$$d_{2i,t_j} = \frac{\ln\left(\frac{E(\tilde{s}_{i,t_j})}{\tilde{x}_{i,t_j}}\right) + t_j \cdot \left(r_i - \delta_i - \frac{\sigma_{i,t_j}^2}{2}\right)}{\sigma_{i,t_j} \cdot \sqrt{t_j}} \quad (14)$$

The following trapezoidal fuzzy numbers are used to determine the present value of the expected payoffs and cost of the *i*th e-CRM framework at time *t_j* by the financial team member *m_k*(*f*):

$$\begin{aligned} \tilde{s}_{i,t_j}^k &= \left((s_{i,t_j}^k)^c, (s_{i,t_j}^k)^d, (s_{i,t_j}^k)^\alpha, (s_{i,t_j}^k)^\beta \right) \\ \tilde{x}_{i,t_j}^k &= \left((x_{i,t_j}^k)^c, (x_{i,t_j}^k)^d, (x_{i,t_j}^k)^\alpha, (x_{i,t_j}^k)^\beta \right) \\ j &= 1, 2, \dots, m \end{aligned} \quad (15)$$

Since \tilde{S}_i and \tilde{X}_i are trapezoidal fuzzy numbers, we use the formulas proposed by Carlsson, Fuller, Heikkilä, and Majlender (2007) to find their expected value and variance:

$$\begin{aligned} E(\tilde{s}_{i,t_j}) &= \frac{(s_{i,t_j}^k)^c + (s_{i,t_j}^k)^d}{2} + \frac{(s_{i,t_j}^k)^\beta - (s_{i,t_j}^k)^\alpha}{6} \\ E(\tilde{x}_{i,t_j}) &= \frac{(x_{i,t_j}^k)^c + (x_{i,t_j}^k)^\alpha}{2} + \frac{(x_{i,t_j}^k)^\gamma - (x_{i,t_j}^k)^\beta}{6} \\ \sigma_{i,t_j}^2 &= \frac{\left((s_{i,t_j}^k)^d - (s_{i,t_j}^k)^c \right)^2}{4} + \frac{\left((s_{i,t_j}^k)^d - (s_{i,t_j}^k)^c \right) \left((s_{i,t_j}^k)^\alpha + (s_{i,t_j}^k)^\beta \right)}{6} \\ &\quad + \frac{\left((s_{i,t_j}^k)^\alpha + (s_{i,t_j}^k)^\beta \right)^2}{24} \end{aligned} \quad (16)$$

4.2. Phase 2: prioritization of the e-CRM frameworks (customer oriented evaluation)

In this phase, we use the QFD model and the fuzzy group Permutation method to prioritize the e-CRM frameworks according to their customer orientation with respect to the strategic, operational and functional perspectives suggested by Taylor (2007).

Process 2.1: prioritization of the e-CRM frameworks (strategic perspective of agile manufacturing)

In this process, the e-CRM frameworks are prioritized with respect to their agile manufacturing strategic perspective. This process is divided into the following five steps.

Step 2.1.1: establishment of the strategic agility team

Initially, we establish a strategic agility team to consider and evaluate the strategic agility aspects of the e-CRM frameworks. Let us assume that members of the strategic agility team are as follows:

$$T(s) = (m_1(s), m_2(s), \dots, m_k(s)) \tag{17}$$

We also allow assigning different voting power weights to each strategic agility team member:

$$V(s) = [v_1(s), v_2(s), \dots, v_k(s)] \tag{18}$$

Step 2.1.2: identification of the agile manufacturing strategic criteria

In this step, the strategic agility team identifies the relevant strategic criteria of agile manufacturing which should be consid-

ered in the evaluation process. Let us assume that the team has identified the following strategic criteria of agile manufacturing $x_1(s), x_2(s), \dots, x_p(s)$ with the following important weights:

$$W(s) = (w_1(s), w_2(s), \dots, w_p(s)) \tag{19}$$

Step 2.1.3: building the fuzzy individual houses of quality in the first phase of the QFD model

With regard to steps 2.1.1, 2.1.2 and process 1.2, each strategic team member constructs the fuzzy individual houses of quality presented in Fig. 2 based on each strategic criterion in the first phase of the QFD model.

Step 2.1.4: building the fuzzy weighted collective house of quality in the first phase of the QFD model

In this step, the weighted house of quality presented in Fig. 3 is built based on the obtained fuzzy individual houses of quality in step 2.1.3 in the first phase of the QFD model.

Step 2.1.5: determination of the best order of the e-CRM frameworks (strategic perspective of agile manufacturing)

In this step, we use the following three procedures to determine the best order of the e-CRM frameworks with respect to the strategic perspective of agile manufacturing.

Procedure 2.1.5.1: determination of the permutations of the e-CRM frameworks

There are $n!$ permutations of e-CRM frameworks which should be evaluated. Let us assume that the h th permutation of the e-CRM frameworks is:

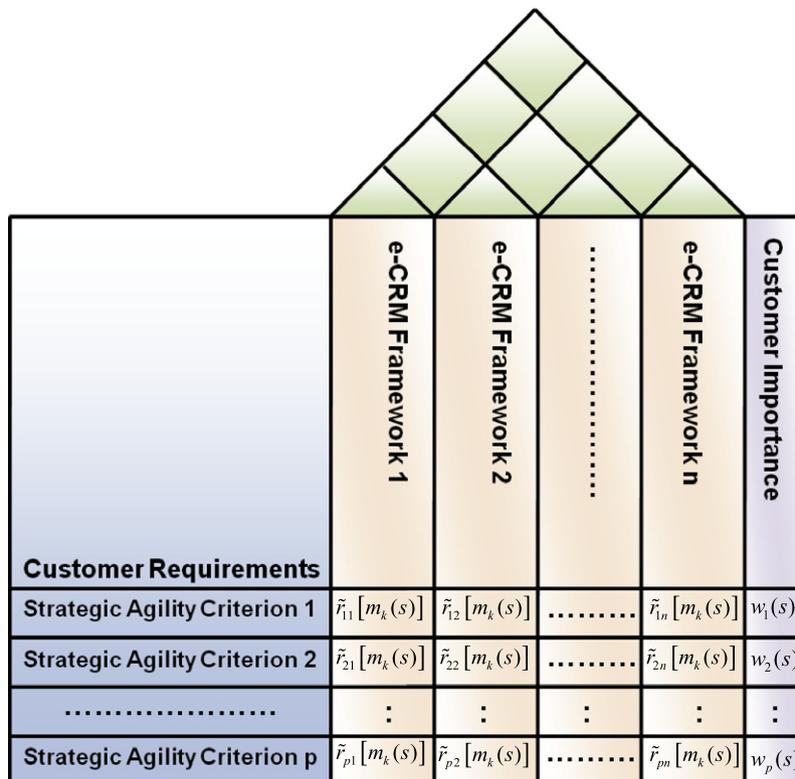


Fig. 2. The fuzzy individual house of quality in the first phase of the QFD model.

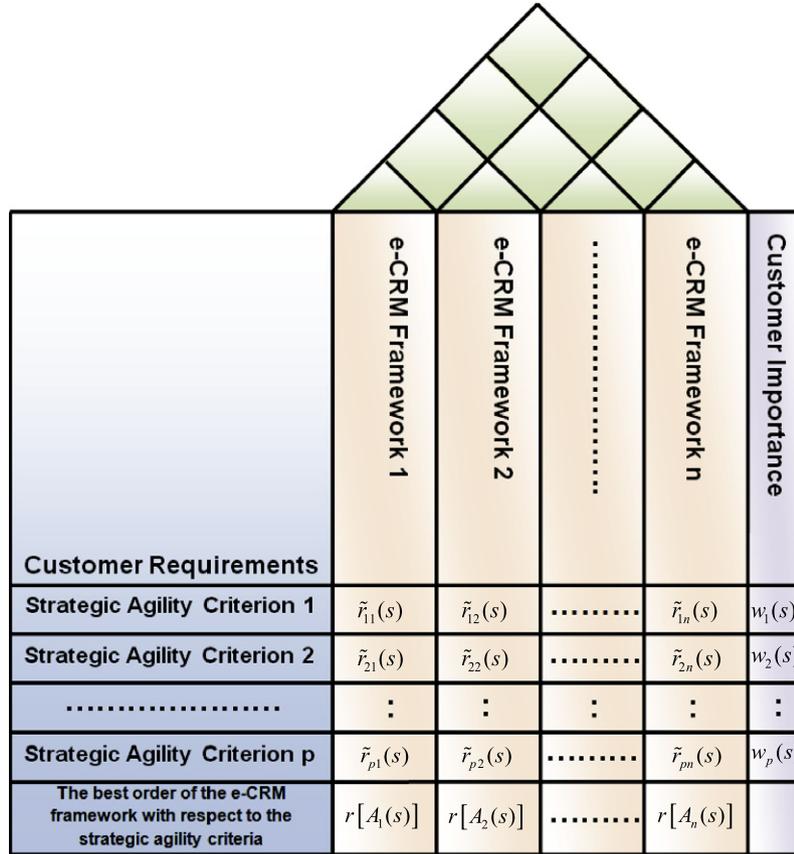


Fig. 3. The weighted collective houses of quality in the first phase of the QFD model.

$$p^{h(s)} = (A_1(h(s)), A_k(h(s)), \dots, A_l(h(s)), \dots, A_n(h(s)))$$

$$R^{h(s)} = \sum_{i=1}^n \sum_{j=1}^n p_{ij}^{h(s)}(C) - \sum_{i=1}^n \sum_{j=1}^n p_{ij}^{h(s)}(D) \tag{23}$$

Procedure 2.1.5.2: determination of the permutation matrices

For each permutation $p^{h(s)}$ of the e-CRM frameworks, we have:

$$p^{h(s)} = \begin{matrix} A_1(h(s)) & A_2(h(s)) & \dots & A_n(h(s)) \\ A_1(h(s)) & \begin{bmatrix} 0 & p_{12}^{h(s)}(C) & \dots & p_{1n}^{h(s)}(C) \\ p_{12}^{h(s)}(D) & 0 & \dots & p_{2n}^{h(s)}(C) \\ \vdots & \vdots & \dots & \vdots \\ p_{1n}^{h(s)}(D) & p_{2n}^{h(s)}(D) & \dots & 0 \end{bmatrix} \\ \vdots & & & \\ A_n(h(s)) & & & \end{matrix} \tag{20}$$

Let us further assume that the following vector represents the best order of the e-CRM frameworks with respect to the strategic perspective of agile manufacturing:

$$P(s) = \begin{bmatrix} r[A_1(s)] \\ r[A_2(s)] \\ \vdots \\ r[A_n(s)] \end{bmatrix} \tag{24}$$

where

$$p_{kl}^{h(s)}(C) = \sum_{j \in C_{kl}(s)} w_j(s) \tag{21}$$

$$p_{kl}^{h(s)}(D) = \sum_{j \in D_{kl}(s)} w_j(s) \tag{22}$$

The concordance set $C_{kl}(s)$ is a subset of all strategic criteria of agile manufacturing for which $E[\tilde{r}_{kj}(s)] \geq E[\tilde{r}_{ij}(s)]$, and the discordance set $D_{kl}(s)$ is a subset of all strategic criteria of agile manufacturing for which $E[\tilde{r}_{kj}(s)] \leq E[\tilde{r}_{ij}(s)]$.

Procedure 2.1.5.3: determination of the best order of e-CRM frameworks

The maximum value $R^{h(s)}$ is the best order of the e-CRM frameworks with respect to the strategic perspective of agile manufacturing:

Process 2.2: prioritization of the e-CRM frameworks (operational perspective of agile manufacturing)

In this process, the e-CRM frameworks are prioritized with respect to their agile manufacturing operational perspective. This process is divided into the following five steps.

Step 2.2.1: establishment of the operational agility team

Initially, we establish an operational agility team to consider and evaluate the operational agility aspects of the e-CRM frameworks. Let us assume that members of the operational agility team are as follows:

$$T(o) = (m_1(o), m_2(o), \dots, m_k(o)) \tag{25}$$

We also allow assigning different voting power weights to each operational agility team member:

$$V(o) = [v_1(o), v_2(o), \dots, v_k(o)] \tag{26}$$

Step 2.2.2: identification of the agile manufacturing operational criteria

In this step, the operational agility team identifies the relevant operational criteria of agile manufacturing which should be considered in the evaluation process. Let us assume that the team has identified the following operational criteria of agile manufacturing $x_1(o), x_2(o), \dots, x_p(o)$ with the following important weights:

$$W(o) = (w_1(o), w_2(o), \dots, w_p(o)) \tag{27}$$

Step 2.2.3: building the fuzzy individual houses of quality in the second phase of the QFD model

With regard to steps 2.2.1 and 2.2.2 and process 1.2, each operational team member constructs the fuzzy individual houses of quality presented in Fig. 4 based on each operational criterion in the second phase of the QFD model.

Step 2.2.4: building the fuzzy weighted collective house of quality in the second phase of the QFD model

In this step, the weighted house of quality presented in Fig. 5 is built based on the obtained fuzzy individual houses of quality in step 2.2.3 in the second phase of the QFD model.

Step 2.2.5: determination of the best order of the e-CRM frameworks (operational perspective of agile manufacturing)

In this step, we use the following three procedures to determine the best order of the e-CRM frameworks with respect to the operational perspective of agile manufacturing.

Procedure 2.2.5.1: determination of the permutations of the e-CRM frameworks

There are $n!$ permutations of e-CRM frameworks which should be evaluated. Let us assume that the h th permutation of the e-CRM frameworks is:

$$p^{h(o)} = (A_1(h(o)), A_k(h(o)), \dots, A_1(h(o)), \dots, A_n(h(o)))$$

Procedure 2.2.5.2: determination of the permutation matrices

For each permutation $p^{h(o)}$ of the e-CRM frameworks, we have:

$$p^{h(o)} = \begin{matrix} & A_1(h(o)) & A_2(h(o)) & \dots & A_n(h(o)) \\ \begin{matrix} A_1(h(a)) \\ A_2(h(a)) \\ \vdots \\ A_n(h(a)) \end{matrix} & \begin{bmatrix} 0 & p_{12}^{h(o)}(C) & \dots & p_{1n}^{h(o)}(\bar{C}) \\ p_{12}^{h(o)}(D) & 0 & \dots & p_{2n}^{h(o)}(C) \\ \vdots & \vdots & \ddots & \vdots \\ p_{1n}^{h(o)}(D) & p_{2n}^{h(o)}(D) & \dots & 0 \end{bmatrix} \end{matrix} \tag{28}$$

where

$$p_{kl}^{h(o)}(C) = \sum_{j \in C_{kl}(o)} w_j(o) \tag{29}$$

$$p_{kl}^{h(o)}(D) = \sum_{j \in D_{kl}(o)} w_j(o) \tag{30}$$

The concordance set $C_{kl}(o)$ is subset of all operational criteria of agile manufacturing for which $E[\tilde{r}_{kj}(o)] \geq E[\tilde{r}_{lj}(o)]$, and the discordance set $D_{kl}(o)$ is subset of all operational criteria of agile manufacturing for which $E[\tilde{r}_{kj}(o)] \leq E[\tilde{r}_{lj}(o)]$.

	e-CRM Framework 1	e-CRM Framework 2	...	e-CRM Framework n	Customer Importance
Customer Requirements					
Operational Agility Criterion 1	$\tilde{r}_{11}[m_k(o)]$	$\tilde{r}_{12}[m_k(o)]$	.....	$\tilde{r}_{1n}[m_k(o)]$	$w_1(o)$
Operational Agility Criterion 2	$\tilde{r}_{21}[m_k(o)]$	$\tilde{r}_{22}[m_k(o)]$	.....	$\tilde{r}_{2n}[m_k(o)]$	$w_2(o)$
.....	:	:	:	:	:
Operational Agility Criterion p	$\tilde{r}_{p1}[m_k(o)]$	$\tilde{r}_{p2}[m_k(o)]$	.....	$\tilde{r}_{pn}[m_k(o)]$	$w_p(o)$

Fig. 4. The fuzzy individual house of quality in the second phase of the QFD model.

	e-CRM Framework 1	e-CRM Framework 2	.....	e-CRM Framework n	Customer Importance
Customer Requirements					
Operational Agility Criterion 1	$\tilde{r}_{11}(o)$	$\tilde{r}_{12}(o)$	.....	$\tilde{r}_{1n}(o)$	$w_1(o)$
Operational Agility Criterion 2	$\tilde{r}_{21}(o)$	$\tilde{r}_{22}(o)$	.....	$\tilde{r}_{2n}(o)$	$w_2(o)$
.....	\vdots	\vdots	\vdots	\vdots	\vdots
Operational Agility Criterion p	$\tilde{r}_{p1}(o)$	$\tilde{r}_{p2}(o)$	.....	$\tilde{r}_{pn}(o)$	$w_p(o)$
The best order of the e-CRM framework with respect to the operational agility criteria	$r[A_1(o)]$	$r[A_2(o)]$	.....	$r[A_n(o)]$	

Fig. 5. The weighted collective houses of quality in the second phase of the QFD model.

Procedure 2.2.5.3: determination of the best order of e-CRM frameworks

The maximum value $R^{h(o)}$ is the best order of the e-CRM frameworks with respect to the operational perspective of agile manufacturing:

$$R^{h(o)} = \sum_{i=1}^n \sum_{j=1}^n P_{ij}^{h(o)}(C) - \sum_{i=1}^n \sum_{j=1}^n P_{ij}^{h(o)}(D) \tag{31}$$

Let us further assume that the following vector represents the best order of the e-CRM frameworks with respect to the operational perspective of agile manufacturing:

$$P(o) = \begin{bmatrix} r[A_1(o)] \\ r[A_2(o)] \\ \vdots \\ r[A_n(o)] \end{bmatrix} \tag{32}$$

Process 2.3: prioritization of the e-CRM frameworks (functional perspective of agile manufacturing)

In this process, the e-CRM frameworks are prioritized with respect to their agile manufacturing functional perspective. This process is divided into the following five steps.

Step 2.3.1: establishment of the functional agility team

Initially, we establish a functional agility team to consider and evaluate the functional agility aspects of the e-CRM frameworks.

Let us assume that members of the functional agility team are as follows:

$$T(a) = (m_1(a), m_2(a), \dots, m_k(a)) \tag{33}$$

We also allow assigning different voting power weights to each functional agility team member:

$$V(a) = [v_1(a), v_2(a), \dots, v_k(a)] \tag{34}$$

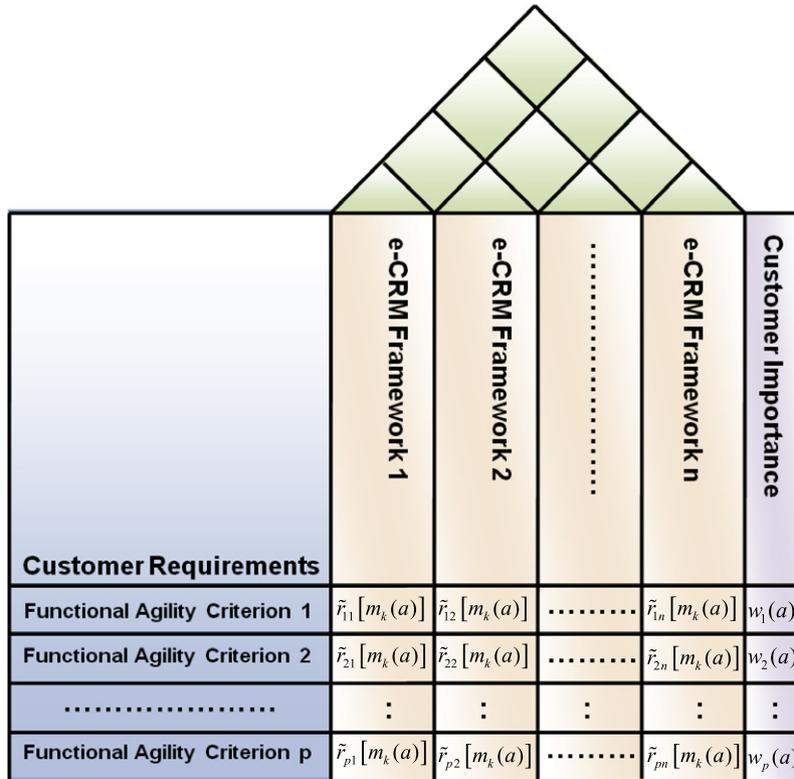
Step 2.3.2: identification of the agile manufacturing functional criteria

In this step, the functional agility team identifies the relevant functional criteria of agile manufacturing which should be considered in the evaluation process. Let us assume that the team has identified the following functional criteria of agile manufacturing $x_1(a), x_2(a), \dots, x_p(a)$ with the following important weights:

$$W(a) = (w_1(a), w_2(a), \dots, w_p(a)) \tag{35}$$

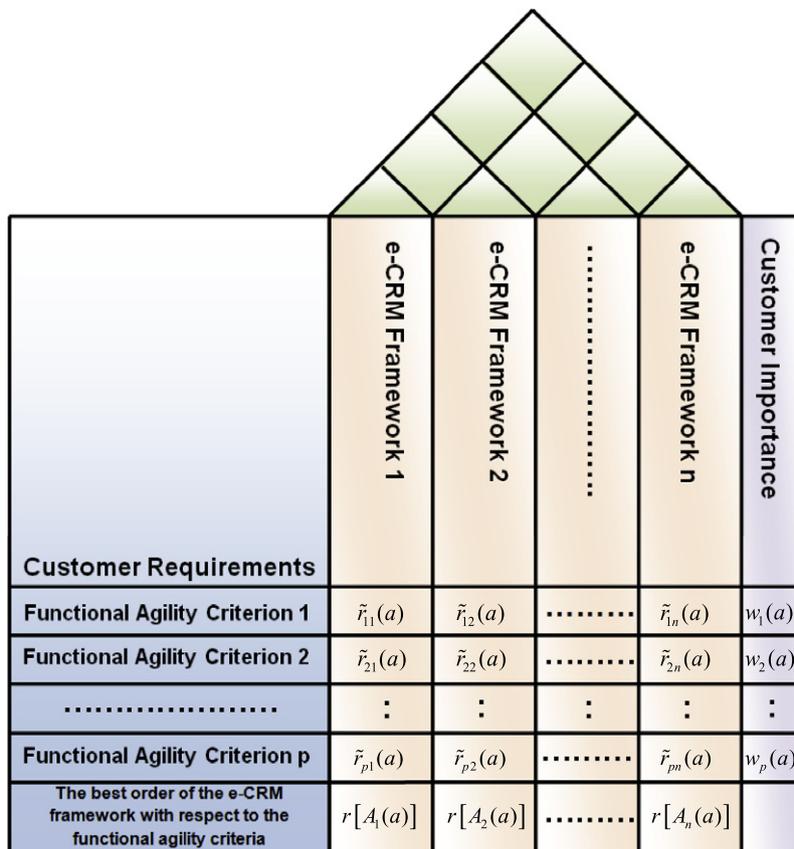
Step 2.3.3: building the fuzzy individual houses of quality in the third phase of the QFD model

With regard to steps 2.3.1 and 1.3.2 and process 1.2, each functional team member constructs the fuzzy individual houses of quality presented in Fig. 6 based on each functional criterion in the third phase of the QFD model.



	e-CRM Framework 1	e-CRM Framework 2	.....	e-CRM Framework n	Customer Importance
Customer Requirements					
Functional Agility Criterion 1	$\tilde{r}_{11}[m_k(a)]$	$\tilde{r}_{12}[m_k(a)]$	.....	$\tilde{r}_{1n}[m_k(a)]$	$w_1(a)$
Functional Agility Criterion 2	$\tilde{r}_{21}[m_k(a)]$	$\tilde{r}_{22}[m_k(a)]$	.....	$\tilde{r}_{2n}[m_k(a)]$	$w_2(a)$
.....	:	:	:	:	:
Functional Agility Criterion p	$\tilde{r}_{p1}[m_k(a)]$	$\tilde{r}_{p2}[m_k(a)]$	.....	$\tilde{r}_{pn}[m_k(a)]$	$w_p(a)$

Fig. 6. The fuzzy individual house of quality in the third phase of the QFD model.



	e-CRM Framework 1	e-CRM Framework 2	.....	e-CRM Framework n	Customer Importance
Customer Requirements					
Functional Agility Criterion 1	$\tilde{r}_{11}(a)$	$\tilde{r}_{12}(a)$	.....	$\tilde{r}_{1n}(a)$	$w_1(a)$
Functional Agility Criterion 2	$\tilde{r}_{21}(a)$	$\tilde{r}_{22}(a)$	.....	$\tilde{r}_{2n}(a)$	$w_2(a)$
.....	:	:	:	:	:
Functional Agility Criterion p	$\tilde{r}_{p1}(a)$	$\tilde{r}_{p2}(a)$	.....	$\tilde{r}_{pn}(a)$	$w_p(a)$
The best order of the e-CRM framework with respect to the functional agility criteria	$r[A_1(a)]$	$r[A_2(a)]$	.....	$r[A_n(a)]$	

Fig. 7. The weighted collective houses of quality in the third phase of the QFD model.

Step 2.3.4: building the fuzzy weighted collective house of quality in the third Phase of the QFD model

In this step, the weighted house of quality presented in Fig. 7 is built based on the obtained fuzzy individual houses of quality in step 2.3.3 in the third phase of the QFD model.

Step 2.3.5: determination of the best order of the e-CRM frameworks (functional perspective of agile manufacturing)

In this step, we use the following three procedures to determine the best order of the e-CRM frameworks with respect to the functional perspective of agile manufacturing.

Procedure 2.3.5.1: determination of the permutations of the e-CRM frameworks

There are $n!$ permutations of e-CRM frameworks which should be evaluated. Let us assume that the h th permutation of the e-CRM frameworks is:

$$p^{h(a)} = (A_1(h(a)), A_k(h(a)), \dots, A_l(h(a)), \dots, A_n(h(a)))$$

Procedure 2.3.5.2: determination of the permutation matrices

For each permutation $p^{h(a)}$ of the e-CRM frameworks, we have:

$$p^{h(a)} = \begin{matrix} & \begin{matrix} A_1(h(a)) & A_2(h(a)) & \cdots & A_n(h(a)) \end{matrix} \\ \begin{matrix} A_1(h(a)) \\ A_2(h(a)) \\ \vdots \\ A_n(h(a)) \end{matrix} & \begin{bmatrix} 0 & p_{12}^{h(a)}(C) & \cdots & p_{1n}^{h(a)}(C) \\ p_{12}^{h(a)}(D) & 0 & \cdots & p_{2n}^{h(a)}(C) \\ \vdots & \vdots & \ddots & \vdots \\ p_{1n}^{h(a)}(D) & p_{2n}^{h(a)}(D) & \cdots & 0 \end{bmatrix} \end{matrix} \quad (36)$$

where

$$p_{kl}^{h(a)}(C) = \sum_{j \in C_{kl}(a)} w_j(a) \quad (37)$$

$$p_{kl}^{h(a)}(D) = \sum_{j \in D_{kl}(a)} w_j(a) \quad (38)$$

The concordance set $C_{kl}(a)$ is a subset of all functional criteria of agile manufacturing for which $E[\tilde{r}_{kj}(a)] \geq E[\tilde{r}_{lj}(a)]$, and the discordance set $D_{kl}(a)$ is a subset of all operational criteria of agile manufacturing for which $E[\tilde{r}_{kj}(a)] \leq E[\tilde{r}_{lj}(a)]$.

Procedure 2.3.5.3: determination of the best order of the e-CRM frameworks

The maximum value $R^{h(a)}$ is the best order of the e-CRM frameworks with respect to the functional perspective of agile manufacturing:

$$R^{h(a)} = \sum_{i=1}^n \sum_{j=1}^n p_{ij}^{h(a)}(C) - \sum_{i=1}^n \sum_{j=1}^n p_{ij}^{h(a)}(D) \quad (39)$$

Let us further assume that the following vector represents the best order of the e-CRM frameworks with respect to the functional perspective of agile manufacturing:

$$P(a) = \begin{bmatrix} r[A_1(a)] \\ r[A_2(a)] \\ \vdots \\ r[A_n(a)] \end{bmatrix} \quad (40)$$

4.3. Phase 3: selection of the agile e-CRM framework (financial and agility oriented evaluations)

The TOPSIS approach is used in the fourth phase of the QFD model to determine an agile e-CRM framework by aggregating the results of the best order of the e-CRM frameworks with respect to the financial and customer oriented evaluations in phases 1 and 2. This phase is divided into the following three processes.

Process 3.1: establishment of the leadership team

Initially, we establish a leadership team to consider and evaluate the e-CRM frameworks. Let us assume that members of the leadership team are as follows:

$$T(l) = (m_1(s), m_1(o), m_1(a), m_1(f)) \quad (41)$$

We also allow assigning different voting power weights to each leadership team member:

$$V(l) = [v_1(s), v_1(o), v_1(a), v_1(f)] \quad (42)$$

We further assign the important weight of the criteria $x_1(s), x_2(s), \dots, x_p(s)$ as follows:

$$W(l) = [w(s), w(o), w(a), w(f)] \quad (43)$$

Process 3.2: building the aggregated house of quality in the fourth phase of the QFD model

In this process, the aggregated house of quality presented in Fig. 8 is built in the fourth phase of the QFD model based on the obtained best order of the e-CRM frameworks in the customer oriented evaluation (the fuzzy weighted collective house of quality in Phases 1–3 of the QFD model) and the financial oriented evaluation.

Process 3.3: determination of the best order of the e-CRM frameworks (financial and customer oriented evaluations)

In this process, the TOPSIS method is used to select the best agile e-CRM framework according to the financial and customer oriented evaluations. This process is comprised of the following two procedures.

Step 3.3.1: identification of the ideal and nadir agile e-CRM frameworks

Using this procedure, we identify the ideal (s^*) and the nadir (s^-) agile e-CRM frameworks as:

$$s^* = \{\max_i c_{i1}, \max_i c_{i2}, \max_i c_{i3}, \max_i c_{i4}\} = \{s_1^*, s_2^*, s_3^*, s_4^*\} \quad (44)$$

$$s^- = \{\min_i c_{i1}, \min_i c_{i2}, \min_i c_{i3}, \min_i c_{i4}\} = \{s_1^-, s_2^-, s_3^-, s_4^-\} \quad (45)$$

where

$$c_{i1} = \frac{r[A_i(s)]}{\sqrt{[r[A_1(s)]]^2 + \cdots + [r[A_n(s)]]^2}} \quad (46)$$

$$c_{i2} = \frac{r[A_i(o)]}{\sqrt{[r[A_1(o)]]^2 + \cdots + [r[A_n(o)]]^2}} \quad (47)$$

$$c_{i3} = \frac{r[A_i(a)]}{\sqrt{[r[A_1(a)]]^2 + \cdots + [r[A_n(a)]]^2}} \quad (48)$$

$$c_{i4} = \frac{E(ROV_{i,t_j})}{\sqrt{[E(ROV_{1,t_j})]^2 + \cdots + [E(ROV_{n,t_j})]^2}} \quad (49)$$

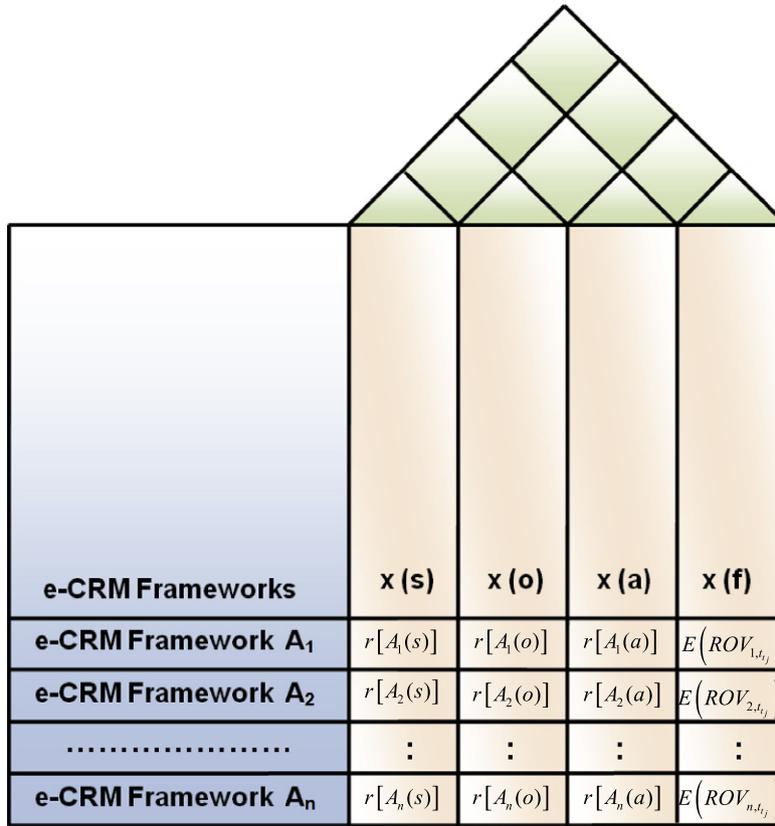


Fig. 8. The weighted collective houses of quality in the fourth phase of the QFD model.

Step 3.3.2: calculation of the relative closeness

The relative closeness to the ideal solution is defined as:

$$G_i = \frac{d_i^-}{d_i^* + d_i^-} \tag{50}$$

where

$$d_i^* = \sqrt{w(s)(c_{i1} - c_1^*)^2 + w(o)(c_{i2} - c_2^*)^2 + w(a)(c_{i3} - c_3^*)^2 + w(f)(c_{i4} - c_4^*)^2}$$

$$d_i^- = \sqrt{w(s)(c_{i1} - c_1^-)^2 + w(o)(c_{i2} - c_2^-)^2 + w(a)(c_{i3} - c_3^-)^2 + w(f)(c_{i4} - c_4^-)^2} \tag{51}$$

$(i = 1, 2, \dots, n)$

The e-CRM frameworks can now be ranked to the descending ordering of G_i . The e-CRM framework ranked first is selected as the best agile e-CRM framework. Next, we present a case study to demonstrate the applicability of this method and exhibit the efficacy of the procedures and algorithms.

5. The case study

¹The senior management at Semicon Technologies, the largest semiconductor manufacturer in Northern California, is concerned with the use of the Internet and e-business technologies in their semiconductor manufacturing operations. Semicon management plans to implement a new agile e-CRM framework to cover all aspects of their manufacturing operations (i.e. sales, marketing, customer service, new product development, procurement, supplier relationships, logistics, supply chain management, strategy development and so on).

¹ The name of the company is changed to protect their anonymity.

The senior management agreed to implement the approach proposed in this study to evaluate the agility of alternative e-CRM frameworks in their manufacturing operations. The following individuals were selected to participate in the evaluation process:

- The capital budgeting manager
- The e-quality manager
- The technical support manager
- The e-customer relations manager
- The e-marketing manager
- The research and development manager
- The manufacturing process manager
- The information technology manager
- The e-business process manager

5.1. Phase 1: prioritizing the e-CRM frameworks (financial oriented) evaluation

According to process 1.1, the financial team was established with the following members: $T(F) = (m_1(f), m_2(f), m_3(f))$; the capital budgeting manager, the e-quality manager and the technical support manager. Next, the financial team agreed to the following voting powers: $V(f) = (0.4, 0.3, 0.3)$ for the capital budgeting manager, the e-quality manager and the technical support manager, respectively.

According to process 1.2, the team identified the following three e-CRM frameworks for consideration and further evaluation:

- Finnegan and Currie (2009)
- Kotorov (2002)
- Romano and Fjermestad (2003)

Next, we used Eqs. (4)–(16) to determine the best order of the e-CRM frameworks presented below with respect to their financial orientation:

$$V(f) = \begin{bmatrix} A_2 \\ A_3 \\ A_1 \end{bmatrix}$$

5.2. Phase 2: prioritizing the e-CRM frameworks (customer oriented evaluation)

According to process 2.1, in step 2.1.1, the strategic team was established with the following members: $T(s) = (m_1(s), m_2(s), \dots, m_k(s))$; the e-customer relations manager, the e-marketing manager and the research and development manager. Next, the strategic team agreed to the following voting powers: $V(s) = (0.4, 0.4, 0.2)$ for the e-customer relations manager, the e-marketing manager and the research and development manager, respectively.

In step 2.1.2, the strategic team identified the following six strategic criteria of agile manufacturing:

- Improves strategic relationship with customers (Plonka, 1997)
- Increases customer satisfaction and loyalty (Buttle, 2004)
- Capability for re-configuration (Dyer & Shafer, 2003)
- Improves ability to find, obtain and keep customers (Jones, Stevens, & Chonko, 2005)
- Speed of acquiring customer needs change (Dyer & Shafer, 2003)
- Improves buyer–seller integration (Chen & Popovich, 2003)

In step 2.1.4, the weighted collective house of quality presented in Fig. 9 was built in the first phase of the QFD model based on the obtained fuzzy individual house of quality.

In step 2.1.5, we used procedures 2.1.5.1, 2.1.5.2 and 2.1.5.3 and Eqs. (20)–(24) to calculate the best order of the e-CRM frameworks presented below with respect to the strategic perspective of agile manufacturing:

$$P(s) = \begin{bmatrix} A_3 \\ A_2 \\ A_1 \end{bmatrix}$$

According to process 2.2, in step 2.2.1, an operational team was established with the following members: $T(o) = (m_1(o), m_2(o), m_3(o))$; the manufacturing process manager, the information technology manager and the technical support manager. Next, the operational team agreed to the following voting power: $V(s) = (0.4, 0.3, 0.3)$ for the manufacturing process manager, the information technology manager and the technical support manager, respectively.

In step 2.2.2, the operational team identified the following seven operational criteria of agile manufacturing:

- Continuous extraction of tacit knowledge related to customer's preferences (Sherehiy, Karwowski, & Layer, 2007)
- Easily reconfiguring or customizing for producing new products (Sarkis, 2001)
- Removing all activities that do not add value (Sarkis, 2001)
- Flexibility of the manufacturing process (Lin et al., 2006)
- manufacturing speed (Lin et al., 2006)

Strategic agility criteria	Customer Importance		
	e-CRM Framework 1	e-CRM Framework 2	e-CRM Framework 3
Improves strategic relationship with customers	(2.72, 3.25, 0.25, 0.25)	(1.72, 2.25, 0.25, 0.25)	(0.72, 1.25, 0.25, 0.25)
Increases customer satisfaction and loyalty	(2.72, 3.25, 0.25, 0.25)	(1.72, 2.25, 0.25, 0.25)	(0.72, 1.25, 0.25, 0.25)
Capability for re-configuration	(0.72, 1.25, 0.25, 0.25)	(2.72, 3.25, 0.25, 0.25)	(1.72, 2.25, 0.25, 0.25)
Improves ability to find, obtain and keep customers	(2.72, 3.25, 0.25, 0.25)	(0.72, 1.25, 0.25, 0.25)	(1.72, 2.25, 0.25, 0.25)
Speed of acquiring customer needs change	(2.72, 3.25, 0.25, 0.25)	(0.72, 1.25, 0.25, 0.25)	(1.72, 2.25, 0.25, 0.25)
Improves buyer–seller integration	(2.72, 3.25, 0.25, 0.25)	(1.72, 2.25, 0.25, 0.25)	(0.72, 1.25, 0.25, 0.25)

Fig. 9. The weighted collective houses of quality in the first phase of the QFD model for the case study.

- Allowing multi-channel integration (Wilson, Daniel, & McDonald, 2002)
- Increasing data sharing (Chen & Popovich, 2003)

In step 2.2.4, the weighted collective house of quality presented in Fig. 10 was built in the second phase of the QFD model based on the obtained fuzzy individual house of quality in step 2.2.3:

In the step 2.2.5, we used procedures 2.2.5.1, 2.2.5.2 and 2.2.5.3 and Eqs. (28)–(32) to calculate the best order of the e-CRM frameworks presented below with respect to the operational perspective of agile manufacturing:

$$P(o) = \begin{bmatrix} A_2 \\ A_1 \\ A_3 \end{bmatrix}$$

According to process 2.3, in step 2.3.1, the functional team was established with the following members: $T(a) = (m_1(a), m_2(a), m_3(a))$; the e-business process manager, the e-customer relations manager and the manufacturing process manager. Next, the functional team agreed to the following voting powers: $V(s) = (0.3, 0.4, 0.3)$ for the e-business process manager, the e-customer relations manager and the manufacturing process manager, respectively.

In step 2.3.2, the functional team identified the following five functional criteria of agile manufacturing:

- Improving knowledge sharing (Leigh & Tanner, 2004)

- Loose boundaries among function and units (Sherehiy et al., 2007)
- Enabling continuity across channels (Zikmund, McLeod, & Gilbert, 2003)
- Information management agility (Lin et al., 2006)
- Enhancing customer knowledge and feedback (The Sales Educators, 2006)

In step 2.3.4, the weighted collective house of quality presented in Fig. 11 was built in the third phase of the QFD model based on the obtained fuzzy individual house of quality in step 2.3.3.

In step 2.3.5, we used 2.3.5.1, 2.3.5.2 and 2.3.5.3 and Eqs. (36)–(40) to calculate the best order of the e-CRM frameworks presented below with respect to the functional perspective of agile manufacturing:

$$P(a) = \begin{bmatrix} A_2 \\ A_3 \\ A_1 \end{bmatrix}$$

5.3. Phase 3: selecting the agile e-CRM framework (financial and agility oriented evaluations)

According to process 3.1, the leadership team was established with the following members: $T(l) = (m_1(s), m_1(o), m_1(a), m_1(f))$; the capital budgeting manager, the e-customer relations manager,

Operational agility criteria	e-CRM Framework 1	e-CRM Framework 2	e-CRM Framework 3	Customer Importance
Continuous extraction of tacit knowledge related to customer's preferences	(2.9, 3.1, 0.1, 0.1)	(1.9, 2.1, 0.1, 0.1)	(0.9, 1.1, 0.1, 0.1)	0.15
Easily reconfiguring or customizing for producing new products	(1.9, 2.1, 0.1, 0.1)	(0.9, 1.1, 0.1, 0.1)	(2.9, 3.1, 0.1, 0.1)	0.15
Removing all activities that do not add value	(0.9, 1.1, 0.1, 0.1)	(1.9, 2.1, 0.1, 0.1)	(2.9, 3.1, 0.1, 0.1)	0.15
Flexibility of e-manufacturing process	(2.9, 3.1, 0.1, 0.1)	(1.9, 2.1, 0.1, 0.1)	(0.9, 1.1, 0.1, 0.1)	0.15
e-Manufacturing speed	(1.9, 2.1, 0.1, 0.1)	(0.9, 1.1, 0.1, 0.1)	(2.9, 3.1, 0.1, 0.1)	0.15
Allows multi-channel integration	(0.9, 1.1, 0.1, 0.1)	(1.9, 2.1, 0.1, 0.1)	(2.9, 3.1, 0.1, 0.1)	0.15
Increases data sharing	(0.9, 1.1, 0.1, 0.1)	(1.9, 2.1, 0.1, 0.1)	(2.9, 3.1, 0.1, 0.1)	0.10

Fig. 10. The weighted collective houses of quality in the second phase of the QFD model for the case study.

Functional agility criteria	e-CRM Frameworks			Customer Importance
	e-CRM Framework 1	e-CRM Framework 2	e-CRM Framework 3	
Improves knowledge sharing	(2.72, 3.25, 0.25, 0.25)	(1.72, 2.25, 0.25, 0.25)	(0.72, 1.25, 0.25, 0.25)	0.20
Loose boundaries among function and units	(2.72, 3.25, 0.25, 0.25)	(0.72, 1.25, 0.25, 0.25)	(1.72, 2.25, 0.25, 0.25)	0.20
Enables continuity across channels	(0.72, 1.25, 0.25, 0.25)	(1.72, 2.25, 0.25, 0.25)	(2.72, 3.25, 0.25, 0.25)	0.15
Information management agility	(1.72, 2.25, 0.25, 0.25)	(0.72, 1.25, 0.25, 0.25)	(2.72, 3.25, 0.25, 0.25)	0.25
Enhances customer knowledge and feedback	(2.72, 3.25, 0.25, 0.25)	(1.72, 2.25, 0.25, 0.25)	(0.72, 1.25, 0.25, 0.25)	0.20

Fig. 11. The weighted collective houses of quality in the third phase of the QFD model for the case study.

e-CRM Frameworks	X (s) X (o) X (a) X (f)			
	X (s)	X (o)	X (a)	X (f)
e-CRM Framework A ₁	3	2	3	3
e-CRM Framework A ₂	2	1	1	1
e-CRM Framework A ₃	1	3	2	2

Fig. 12. The weighted collective houses of quality in the fourth phase of the QFD model for the case study.

the manufacturing process manager and the e-business process manager. Next, the leadership team agreed to the following voting power: $V(I) = [0.3, 0.2, 0.2, 0.3]$ for the capital budgeting

manager, the e-customer relations manager, the manufacturing process manager and the e-business process manager, respectively.

According to process 3.2, the aggregated house of quality presented in Fig. 12 was built in the fourth phase of the QFD model based on the obtained best order of the e-CRM frameworks in Phases 1, 2 and 3 of the QFD model and financial oriented evaluation.

Finally according to process 3.3, the best order of the e-CRM frameworks was determined as: $[A_2, A_3, A_1]$. The senior management studied the recommendations of the leadership team and agreed to invest in the e-CRM Framework 2 as the agile e-CRM framework.

6. Conclusions and future research directions

Global competition and advanced manufacturing technology have dramatically increased the need for organizations to produce high-quality and competitively priced products quickly and efficiently. Agile manufacturing can help organizations prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets. Agility in manufacturing requires a thorough decision to design flexibility, robustness, and adaptability into the very nature of the manufacturing processes in an enterprise. However, changing manufacturing processes is not a trivial proposition and requires a need for understanding and support by the leadership at the top. This need is more pivotal in electronic manufacturing where the Internet is used to monitor processes on the production floor and reduce geographical distances by allowing products to be manufactured and marketed globally. E-CRM helps companies improve the effectiveness of their interaction with customers and at the same time enhance their manufacturing agility by customizing products, services and prices.

It is hard to say for sure which e-CRM framework is the best, but, the evaluation process could be made more comprehensive and systematic. The proposed approach was intended to enhance decision making and promote consensus. The nine managers who participated in the study to evaluate the agility of alternative e-CRM frameworks at Semicon were highly educated. To this end, a more logical and persuasive approach was necessary to gain their confidence and support. Upon completion of the e-CRM framework selection process, a meeting was held with the group to discuss the results and finalize the recommendations. The nine managers unanimously agreed that the proposed approach provided invaluable analysis aids and information processing support. They were convinced that the result was unbiased and consistent.

Armed with this feedback, the managers were confident that they could sell their recommendation to the top management. Nevertheless, the group was aware that the transformation of Semicon into an agile manufacturing plant is a gradual process and cannot be achieved overnight. They also knew that building internal alliances and establishing e-CRM as an activity that cuts across different manufacturing areas was a difficult task. They agreed to target various groups and key people at Semicon in order to gain their support. The group began building internal alliances with functional units and focused their efforts on getting other line managers on board. This process involved fostering collaboration and avoiding alienation of potential internal allies.

The internal alliance building process would not be complete without top management support. The group was adamant about the importance of gaining support from the top management. Gaining the top management support was easier than it may seem from the outside. The managers had already built internal alliances and the support of various key people and line managers. They discussed the overwhelming internal support and the tangible and intangible benefits of the selected e-CRM framework with the top management who in turn agreed to implement the proposed recommendation. The group was also required to develop a long-

term plan to measure the e-CRM success through qualitative measures (i.e., customer satisfaction) and quantitative measures (i.e., return on investment).

The analysis of this case study allows the articulation of a series of key factors that can be considered as important in contributing to the successful selection and implementation of e-CRM frameworks. The first factor is building internal alliances. The second factor is getting the key people and the line managers on board. The third factor is the persistent and systematic process in place to evaluate the e-CRM success.

Our approach helps the decision makers to think systematically about complex multi-attribute decision making problems and improves the quality of the decisions. We decompose the e-CRM framework evaluation and selection process into manageable steps and integrate the results to arrive at a solution consistent with managerial goals and objectives. This decomposition encourages decision makers to carefully consider the elements of uncertainty. The proposed structured framework does not imply a deterministic approach in multi-attribute decision making. While our approach enables decision makers to assimilate the information and organize their beliefs in a formal systematic approach, it should be used in conjunction with management experience and their gained knowledge that is often unable to be represented by and encapsulated with manufacturing data. Managerial judgment is an integral component of e-CRM framework evaluation and selection decisions; therefore, the effectiveness of the model relies heavily on the decision maker's cognitive capabilities.

Nevertheless, we stress that our contribution addresses yet a small part of the issues that are involved with e-CRM framework evaluation and selection in manufacturing. It is safe to say that the e-CRM assessment as a discipline is at its infancy. Therefore, we hope that the study presented here can inspire others to pursue further research in this area. Additional future research considering correlation coefficients between the risk and benefit factors is rather challenging but necessary to gain insight into this interaction influence in manufacturing agility and e-CRM framework selection decisions. Another possible future research direction is to investigate other drivers that influence the e-CRM framework evaluation decisions. These value drivers could also be incorporated into the model proposed in this study. It would be of interest to also consider in the proposed approach new practices that are currently being developed, such as virtual organizations or strategic alliances with competitors.

Acknowledgements

The authors would like to thank the anonymous reviewers and the editor for their insightful comments and suggestions.

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