Towards the analysis of e-CRM practices using an integrated fuzzy approach

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Abstract: Nowadays, organisations are extensively looking for ways and methods to interact and communicate efficiently with customers in order to influence them. Internet technology enables organisations to catch new customers, track their online behaviour and performance, and makes the communications, products, services and prices unique. The main purpose of this study is to prioritise electronic customer relationship management (e-CRM) implementation practices based on an integrated fuzzy approach. To achieve this goal, after identifying criteria influencing on e-CRM using expert opinions and literature review, these criteria were analysed using the fuzzy decision-making trial and evaluation laboratory (F-DEMATEL) technique. Eventually, these practices were prioritised using the fuzzy technique for order of preference by similarity to ideal solution (F-TOPSIS) technique. The results indicated that practices named: 'online and electronically transaction and communication with the customer (P7)', 'integrate the data and information and tools needed to catch more customers (P10)' and 'technology development across the organisation (P9)' are respectively in the first to third order.

Keywords: electronic customer relationship management; e-CRM; F-TOPSIS; F-DEMATEL.

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1 Introduction

The results of studies and related research illustrate that the growth in products' demand is not commensurate with the growth in the number of producers and manufacturers. In other words, increasing the number of manufacturers of a product will not lead to increased sales and demand. Customers have different choices in purchase processes and do not easily show their loyalty to an organisation (Zablah et al., 2004). The business world is moving away from the concept of 'production-oriented' to 'customer-oriented' and 'service-oriented'; consequently, in the era of competition, success is those organisations and companies that can attract many customers and sustain their satisfaction for future purchases (Dussart, 2001).

In today's global economy and competitive world, customer orientation and customer retention are considered as a competitive advantage. Customers are considered as a key and vital factor of any organisation; then, customer satisfaction is becoming the main goal of organisations and managers are aware that achieving the sustainable competitive advantage depends on customer satisfaction (Liu et al., 2012).

Nowadays, companies are widely looking for ways to interact and communicate with customers to influence them (Javadi and Azmoon, 2011). Customer relationship management (CRM) is defined as an approach that involves identifying, attracting, developing, and maintaining customer relationships over time to increase profitable customer loyalty (Bradshaw and Brash, 2001). If CRM system is well designed and implemented, it will lead to a complete and comprehensive knowledge about the customers. Implementing CRM in many organisations increases competitiveness, increases revenue and reduces operating costs (Kevork and Vrechopoulos, 2006).

Internet and web and electronic services as an information centre facilitate the transfer and share data and information (Souri and Navimipour, 2014). Currently, internet have a perfect impact on society and creating a new revolution in the 21st century (Industry 4.0), and is playing an important role in making everything online (Navimipour and Zareie, 2015; Nguyen and Simkin, 2013). New technologies based on the internet, World Wide Web and wireless communications have changed the world of the 21st century. These changes require new challenges, communication approaches and creative behaviours. Major internet connection and information exchange through it is known as e-commerce. E-commerce offers many opportunities for businesses that operate even in the short-term. Hence, managers must create and present new ways and systems in order to adapt to the vast changes in technology (Kirakosyan and Dănăiaţă, 2014; Mokhtarzadeh et al., 2021).

Electronic customer relationship management (e-CRM) emphasises on meeting personal customers' need and increasing the value of both customers and the company (Yu et al., 2015). e-CRM enables organisations and companies to take full advantage of the data collected and transfer it to useful and valuable information for customers (Chen, 2013). Furthermore, e-CRM improves and enhances the relationship between the organisation and its customers through digital technologies (Perzon, 2008).

The related literature review has shown some challenges. First, numerous criteria affect the e-CRM that all organisations, including manufacturing and services, have forced special and fundamental attention to these criteria and ultimately improve and promote them to achieve the sustainable competitive advantage and increase customer satisfaction. Since number of criteria affecting the e-CRM is high and also no action has been taken to eliminate trivial criteria in previous researches. The second challenge relates to the choice of the appropriate MADM method. According to the literature, the use of hybrid MADM methods may lead to different results (Antucheviciene et al., 2011), which makes the selection of the appropriate MADM method in the process of evaluation an attractive problem for researchers (Akhavan et al., 2015). Researchers have shown that the simultaneous use of MADM methods enhances the efficiency, transparency, and rationale of the decision making process, and improves the quality of decisions. Accordingly, various studies have been conducted with the approach of combining MADM methods to make the final decision (Favardin et al., 2002; Yazdi and Barazandeh, 2016).

The purpose of this study is to prioritise e-CRM practices using a combination of the MADM approaches that can overcome the aforementioned challenges. In this regard, a relatively comprehensive list of criteria and practices in e-CRM is first extracted from the literature. Due to the high number of criteria identified, the fuzzy decision making trial and evaluation laboratory (F-DEMATEL) technique was used to decrease this criteria list. Then, he identified practices are then ranked using fuzzy technique for order of preference by similarity to ideal solution (F-TOPSIS) method.

The rest of this paper is structured as follows. Section 2 describes the thematic and conceptual literature of e-CRM and presents the list of identified criteria and practices. The research methodology is illustrated in Section 3. Section 4 presents the findings and results of the research based on the research framework. To end, conclusions and suggestion for future researchers are presented in Section 5.

2 Literature review

2.1 Customer relationship management

CRM is considered as one of the most fundamental and especially profitable strategies for customer retention. In recent years, CRM has attracted the attention of a number of different trends, including marketing and information technology (Plakoyiannaki, 2005). In fact, CRM is a system that focuses on the customers with the aim of predicting, understanding and responding to the needs of current and future customers (Erdil and Öztürk, 2016). Many researchers have come up with different elaborations for CRM concept which are gathered in Table 1.

Table 1 Definitions for CRM

Row	*Definition*	*References*
1	"CRM is technology-based and organizations need to change in the face of extensive changes in technology and move from production-oriented strategies to customer-oriented strategies."	Alshawi et al. (2011)
2	"The process of building and sustaining beneficial customers' interaction by creating excellent value to customers and satisfaction increasing."	Kotler and Armstrong (2010)
3	"CRM is the process of identifying, attracting, differentiating, and retaining an organization's potential customers. In other words, CRM integrates each step of the value chain of organizations in order to value creation for customers as the organization's heart."	Hassan et al. (2015)

2.2 Electronic customer relationship management

When all the activities and tasks of CRM system, such as customer interactions and finding ways to improve these interactions, are done through the internet, e-CRM makes sense (Liz et al., 2003; Sigala, 2011). Concept of e-CRM is a critical factor in determining the success of CRM (Bull, 2003). e-CRM is a set of concepts, tools and processes which allow organisations to get the most value of e-business. e-CRM also helps organisations to increase and improve the effectiveness of customer interactions (Mahdavi et al., 2011; Babgohari et al., 2021). Characteristics and features of e-CRM are presented in Table 2.

Now, a critical question is: what are points of distinction between CRM and e-CRM? Or in what aspects, they are different? Table 3 answers this question.

Table 2 e-CRM features

• Part of CRM	• Online marketing
• Increase and improve CRM	• Automated processes and automation
• Equipped with technology	• Personalisation
• Use of electronic channels	• Smart search engine
• Use of digital channels	• Data analysis
• Electronic business context	• Buy and sell online
• Network connection point	• Television
• Mobile	• Internet

Source: Sivaraks et al. (2011)

Table 3 Differences between CRM and e-CRM

Dimension	*CRM*	*e-CRM*
Customer relationship	Outdated devices such as fax, telephone, etc.	Internet, e-mail, mobile, Industry 4.0 applications
Customer services	Time and place restrictions	Anytime, anywhere
Information customisation	Customisation not possible: customisation needs significant changes to organisation	Personalisation of information is easy for each person
System focus	Products, tasks and job instructions	Customer needs

Source: Alhaiou et al. (2009)

The issue of e-CRM has become increasingly important for the success of CRM implementation (Wu and Hung, 2009). Therefore, the increasing importance of e-CRM has led to this which many researchers investigate this concept and the factors affecting it. For example, Wolfinbarger and Gilly (2003) identified e-CRM criteria that included website design, reliability, security and customer service. However, they did not identify the relationships of identified criteria and also any practices or solutions have been proposed. Hence, in our work, we are try to identify the relationships among all identified criteria and after computing the importance of criteria, some solutions of e-CRM will be prioritised by their impact on multiple criteria.

Sivaraks et al. (2011) proved that the implementation of e-CRM' solutions have a significant and direct relationship with customer-based services. But they have no analysis on their decision making about solutions. While, we will use a MADM technique in this paper to prioritise the identified solutions. In addition, both mentioned works, have not been implemented in an uncertainty environment like Fuzzy; which one of the contributions in this paper is that we implemented a hybrid MADM techniques in fuzzy environment.

2.2.1 e-CRM criteria

The multiple criteria to implementing a MADM technique have made this difficult for many industries to achieve (Dahooie et al., 2020). The many statistical methods available for setting and grouping different analytical criteria do not include ways to reduce the number of criteria in MADM decision making processes. As many criteria affect e-CRM, which are identified based on literature review and similar works shown in Table 4.

Table 4 e-CRM criteria

Code	*Criteria*	*Reference*
C1	Teamwork culture	Kim et al. (2010)
C2	Variability culture	Bohling et al. (2006), Ocker and Mudambi (2003)
C3	Data sharing culture	Kim et al. (2010), Ocker and Mudambi (2003)
C4	Learning culture	Kim et al. (2010)
C5	Integration with other systems	Chen and Chen (2004), Mendoza et al. (2007)
C6	Data integration	Chen and Chen (2004), Kim et al. (2010)
C7	System compliance	Sophonthummapharn (2009)
C8	Operational integration	Kim et al. (2010), Ocker and Mudambi (2003)
C9	Support, commitment and learning of senior managers	Chen and Chen (2004), Mendoza et al. (2007)
C10	Allocation of financial resources	Chou and Lee (2009), Ocker and Mudambi (2003)
C11	Personnel tendency to customer-oriented	Chou and Lee (2009), Ocker and Mudambi (2003)
C12	Existence of technical, communication infrastructures	Ocker and Mudambi (2003)
C13	Selection an effective CRM software	Chen and Chen (2004)
C14	Customer lifecycle support	Chen (2013)
C15	Customer acquisition	Bohling et al. (2006), Chen (2013)
C16	Customer sustaining	Chen (2013), Kim et al. (2010)
C17	Customer development	Chen (2013), Kim et al. (2010)
C18	Customer value	Chen (2013), Kim et al. (2010)

2.2.2 e-CRM practices

To drive e-CRM criteria, organisations need to recognise the most proper plans and practices to apply in order to ensure more specific e-CRM system. Many industries have thus endeavoured to adopt a variety of practices from the field of customer relationship. Researchers have proposed various practices, which are presented in Table 5 (Aiassi et al., 2020; Sen and Sinha, 2011).

2.3 Fuzzy logic

In order to consider the qualitative information of experts in researches, fuzzy approach has been implemented in this research, too. As the first outline by Zadeh et al. (1996), fuzzy logic has been widely adopted in practices and papers, particularly for decision making problems which can be applied in MCDM techniques (Vats et al., 2014; Wang et al., 2009). The views of qualified experts have particular significance, and fuzzy logic approaches in uncertainty environment allow for their contributions to be weighted accordingly. Hence, triangular fuzzy numbers should be produced during process. Due to its simplicity (straight lines) and productivity (fast calculations), triangular membership function (MF) is broadly used with these problems (Sadollah, 2018). Along with Zhou et al. (2011), triangular MF is better to another MFs. Triangular MF is a common and broadly used MF that can be represented as $\tilde{A} = (l, m, u)$ where l, m and u denote lower, medium and upper numbers of the fuzzy sets. A triangular fuzzy number can be expressed as equation (1) (Zhou et al., 2018).

$$\mu_{\tilde{A}} = \begin{cases} 0 & x < 1 \\ (x-l)/(m-l) & l \le x \le m \\ (u-x)/(u-m) & m \le x \le u \\ 0 & x \ge u \end{cases} \tag{1}$$

Table 5 e-CRM practices to drive criteria

Code	*Practice*
P1	Identify goods, services or interactions which have the most valuable to customers.
P2	Increase the level of integration and customers' information sharing among all stakeholders.
P3	Utilisation data and information to develop products and processes to retain customers.
P4	Gain deep and new insights and understandings on customer engagement.
P5	Analysing big data to provide effective customer services.
P6	Development and optimisation of website and search engine for more effective communication with customers.
P7	Transaction and communication with the customer completely through perfect online platform.
P8	Making data and information available to internal stakeholders (i.e., operators) and external stakeholders (i.e., customers and suppliers).
P9	Development of technology throughout the organisation.
P10	Integrate the data and tools needed to achieve more customers.

Triangular MF is presented in Figure 1 with respect to the expressed concepts. Table 6 shows the connection between the linguistic terms and triangular fuzzy numbers in F-DEMATEL. In addition, the triangular fuzzy numbers used to prioritise e-CRM practices by F-TOPSIS are presented in Table 7. However, it is considered that an ordinal scale (linguistic variables) is much more appropriate to elaborate preferences, specifically when the number of alternatives and criteria are numerous (Raj and Kumar, 1999). Hence, Figure 2 reveals the fuzzy rating and MF. The mathematical calculation of each two triangular fuzzy numbers $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$ can be described as follow equations:

- the sum of triangular fuzzy numbers as equation (2):

$$\tilde{A}_1 + \tilde{A}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{2}$$

- the subtraction of the triangular fuzzy numbers as equation (3):

$$\tilde{A}_1 - \tilde{A}_2 = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \quad (3)$$

- the multiplication of the triangular fuzzy numbers as equation (4):

$$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1 \otimes u_2, m_1 \otimes m_2, u_1 \otimes l_2) \quad (4)$$

- the arithmetic triangular fuzzy numbers as equations (5) and (6):

$$k \otimes \tilde{A}_1 = (k \otimes l_1, k \otimes m_1, k \otimes u_2) \quad k > 0 \quad (5)$$

$$\frac{\tilde{A}_1}{k} = \frac{l_1}{k}, \frac{m_1}{k}, \frac{u_1}{k} \quad (6)$$

Figure 1 Triangular fuzzy number (see online version for colours)

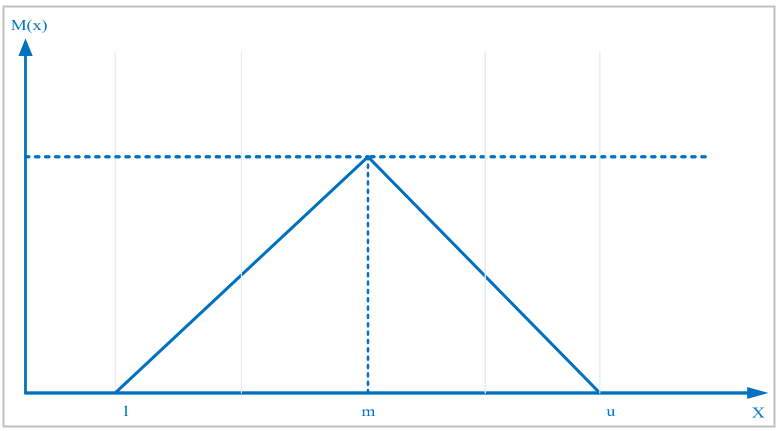


Table 6 Triangular fuzzy numbers for F-DEMATEL in present study

Linguistic terms	*Score*	*Triangular fuzzy numbers*
No impact	0	(0.00, 0.00, 0.25)
Very low impact	1	(0.00, 0.25, 0.50)
Low impact	2	(0.25, 0.50, 0.75)
High impact	3	(0.50, 0.75, 1.00)
Very high impact	4	(0.75, 1.00, 1.00)

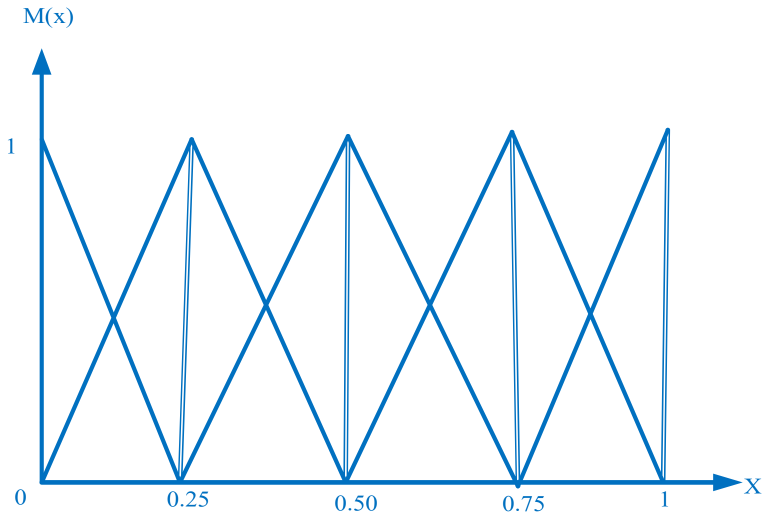
Source: Chang et al. (2011)

Table 7 Linguistic scale for prioritising e-CRM practices

Linguistic terms	*Score*	*Triangular fuzzy numbers*
Very poor (VP)	1	(1, 1, 3)
Poor (P)	2	(1, 3, 5)
Medium (M)	3	(3, 5, 7)
Good (G)	4	(7, 5, 9)
Very good (VG)	5	(7, 9, 11)

Source: Patil and Kant (2014)

Figure 2 The fuzzy rating and MF (see online version for colours)



3 Research methodology

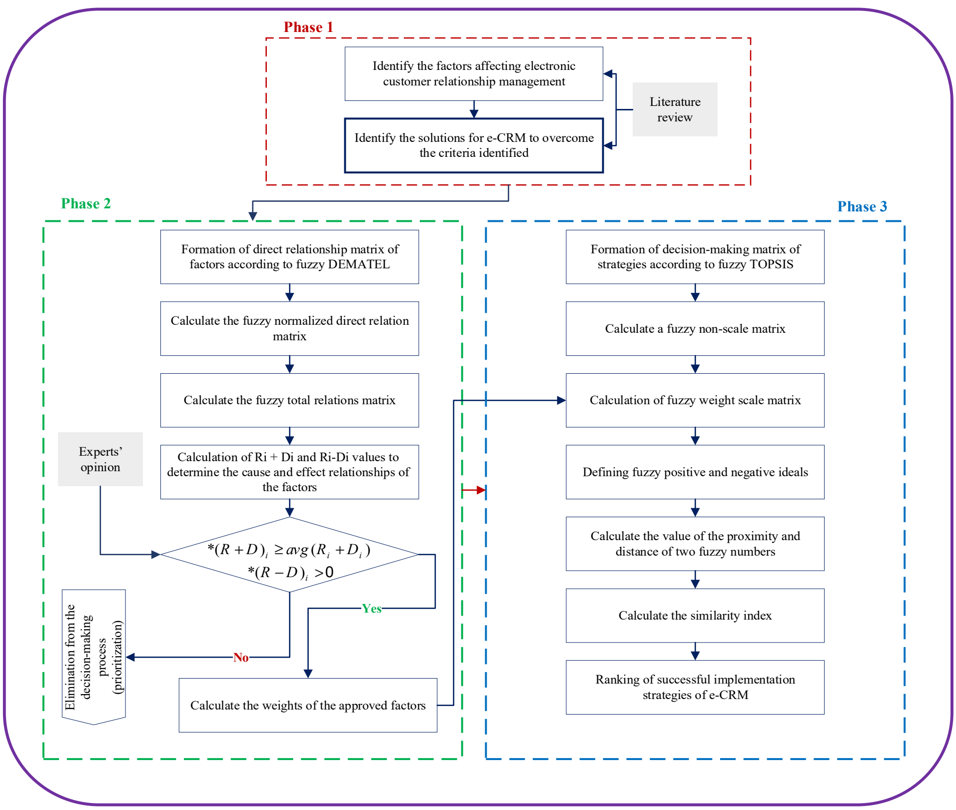
As mentioned previously, the present study's main purpose was to provide an assessment framework to prioritise e-CRM practices by which ones most effectively overcome relevant criteria. Choosing practices to deal with these barriers is highly challenging given the multiple barriers to achieving e-CRM, as well as their interdependence and importance and the need to pay attention simultaneously to their impacts. MADM techniques have been used to solve problems with similar features, so researchers have sought to apply these methods to rank and select appropriate e-CRM practices. The current research focused specifically on overcoming various criteria in implementing MADM techniques by using appropriately integrated approach.

As shown in Figure 3, the research path was divided into three main phases. In the first phase, a literature review was conducted, and related research in this field was examined, after which 18 criteria and the ten practices were identified. The results are presented in Tables 4 and 5, respectively. The multiple criteria previously reported by researchers have presented a challenge to decision making processes because weighting of criteria based on committee members' opinions means that only a limited number of criteria can be used to ensure sufficient confidence in decisions and their results (Jolai et al., 2010; Babgohari et al., 2021)

It is noticeable that the required data for this research is gathered based on opinions of five experts through two questionnaires. In this regard, five academic experts on CRM were selected as the number of samples to collect the required data in our research process. It should be noted that the final decision makers are the five mentioned experts who are scholars in the subject of CRM and also e-CRM.

Decision making based on multiple criteria is a massive data MADM problem that has been previously dealt with in limited ways (Liu et al., 2017). This challenge becomes even more pronounced when the assumption of independence between criteria is invalid because of interrelationships (Gölcük and Baykasoğlu, 2016). Different methods such as rough set theory (Liu et al., 2015, 2017) and criteria clustering have been used in previous studies. Therefore, in the current research's second phase (i.e., criteria reduction), an attempt was made to eliminate less significant factors by applying the F-DEMATEL method. The results were a final list of seven major barriers. In addition, in the last section of this phase, the identified criteria' relative importance was determined using equation (7) in order to prioritise e-CRM solutions, and a decision-support table was created with the help of experts in this field. Finally, in the third phase of current research, the solution identified of e-CRM which shown in Table 5, were prioritised based on F-TOPSIS method.

Figure 3 Research framework (see online version for colours)

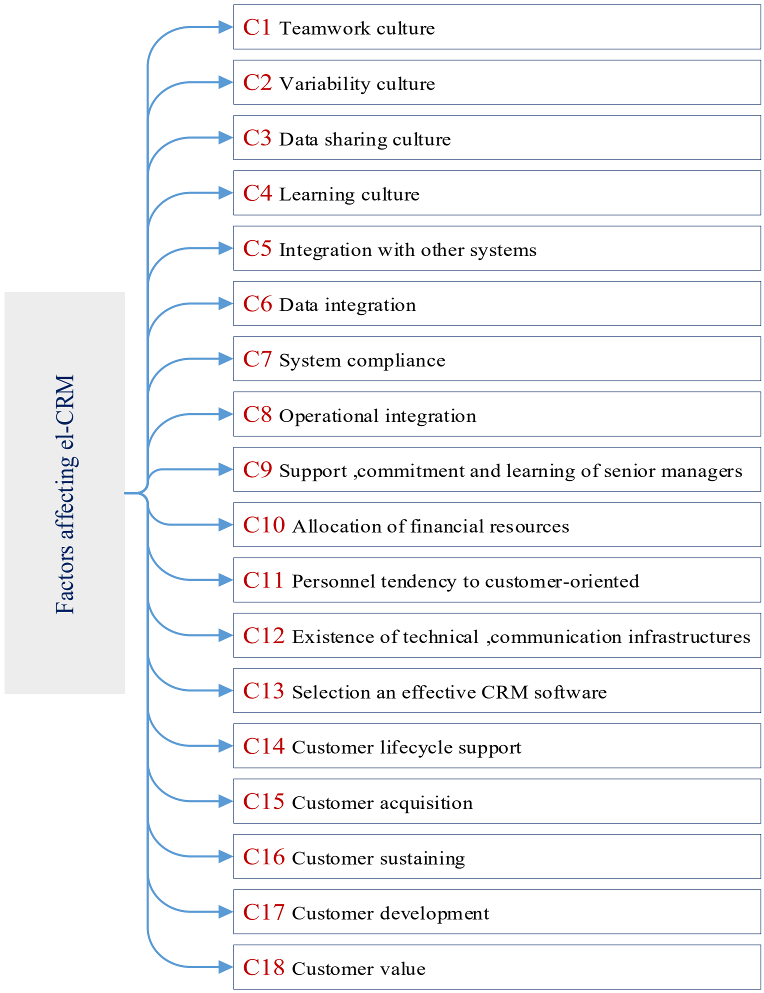


4 Data analysis

4.1 Phase 1: identifying the criteria affecting e-CRM

In this phase, a list of practices for implementing e-CRM was first identified and determined based on expert opinions as well as review of previous literature. These practices are shown in Table 5. Then, the criteria affecting the e-CRM were recognised through similar research literature and expert opinions, which are shown in Figure 4.

Figure 4 Hierarchical diagram of criteria affecting e-CRM (see online version for colours)



4.2 Phase 2: using the F-DEMATEL method to determine the importance of the criteria identified for selecting high importance criteria

In this phase, by distribution of DEMATEL questionnaire to five experts and specialists in the field of e-CRM, the relevant data were collected to determine the cause and effect relationships between the identified criteria and to calculate criteria weights. The F-DEMATEL method is elaborated in Appendix A. Furthermore, after implementing the F-DEMATEL method and by using triangular fuzzy numbers presented in Table 6, values of $\tilde{D}_i - \tilde{R}_i$ and $\tilde{D}_i + \tilde{R}_i$ are presented in Table 8.

Equation (16) is used to defuzzy the values of $\tilde{D}_i - \tilde{R}_i$ and $\tilde{D}_i + \tilde{R}_i$ which presented in Table 8. Results of defuzzification are shown in Table 9.

Table 8 Values $\tilde{D}_i - \tilde{R}_i$ and $\tilde{D}_i + \tilde{R}_i$ of each criteria

Criteria	$\tilde{D}_i - \tilde{R}_i$	$\tilde{D}_i + \tilde{R}_i$
C1	(–18.22, –0.02, 18.01)	(1.83, 5.25, 38.06)
C2	(–17.46, –0.04, 17.39)	(1.70, 4.98, 36.55)
C3	(–18.03, –0.06, 17.80)	(1.81, 5.22, 37.63)
C4	(–18.01, 0.09, 18.43)	(1.84, 5.28, 38.28)
C5	(–18.03, 0.16, 18.91)	(1.92, 5.42, 38.85)
C6	(–18.60, –0.05, 18.44)	(1.93, 5.43, 38.97)
C7	(–18.12, –0.16, 17.41)	(1.78, 5.13, 37.31)
C8	(–17.37, 0.18, 18.39)	(1.77, 5.16, 37.53)
C9	(–18.78, –0.05, 18.32)	(1.92, 5.45, 39.03)
C10	(–17.31, 0.11, 17.85)	(1.71, 5.00, 36.86)
C11	(–18.03, –0.08, 17.64)	(1.82, 5.19, 37.49)
C12	(–19.16, –0.23, 17.64)	(1.88, 5.35, 38.67)
C13	(–17.21, 0.07, 17.55)	(1.64, 4.87, 36.40)
C14	(–17.08, 0.31, 18.84)	(1.81, 5.22, 37.73)
C15	(–17.92, –0.15, 17.14)	(1.68, 4.97, 36.74)
C16	(–19.33, –0.13, 18.82)	(2.07, 5.71, 40.22)
C17	(–18.23, –0.10, 17.53)	(1.78, 5.15, 37.54)
C18	(–17.90, 0.17, 18.66)	(1.86, 5.31, 38.43)

Table 9 Defuzzy values $\tilde{D}_i - \tilde{R}_i$ and $\tilde{D}_i + \tilde{R}_i$

Criteria	$(\tilde{D}_i - \tilde{R}_i)^{def}$	$(\tilde{D}_i + \tilde{R}_i)^{def}$	*Criteria*	$(\tilde{D}_i - \tilde{R}_i)^{def}$	$(\tilde{D}_i + \tilde{R}_i)^{def}$
C1	–0.06	12.60	C10	0.19	12.14
C2	–0.04	12.05	C11	–0.14	12.42
C3	–0.09	12.47	C12	0.49	12.81
C4	0.15	12.67	C13	0.12	11.94
C5	0.30	12.90	C14	0.59	12.59
C6	0.07	12.94	C15	–0.27	12.09
C7	–0.26	12.34	C16	0.19	13.43
C8	0.34	12.41	C17	–0.22	12.40
C9	0.14	12.96	C18	0.28	12.73

The final list of criteria was determined based on two conditions. Condition 1 is that the value of the normalised $(\tilde{D}_i + \tilde{R}_i)^{def}$ for that criteria is larger than or equal to this index's average values, that is, $[Normalised(\tilde{D}_i + \tilde{R}_i)_i^{def}] \geq [Average(Normalised(\tilde{D}_i + \tilde{R}_i)_i^{def})]$. The threshold value for the normalised $(\tilde{D}_i + \tilde{R}_i)^{def}$ and be adjusted to reflect the relevant experts' opinions. The current study's threshold value was 0.49 based on the committee members' judgement, which was calculated according to the values of the normalised $(\tilde{D}_i + \tilde{R}_i)^{def}$ shown in Table 10.

Table 10 Values of normalised $(\tilde{D}_i + \tilde{R}_i)^{def}$ and normalised $(\tilde{D}_i - \tilde{R}_i)^{def}$ (see online version for colours)

Criteria	*Normalised* $(\tilde{D}_i + \tilde{R}_i)^{def}$	*Normalised* $(\tilde{D}_i - \tilde{R}_i)^{def}$
C1	0.513	0.764
C2	0.234	1.000
C3	0.000	0.345
C4	0.664	0.978
C5	0.678	0.431
C6	0.716	0.657
C7	0.256	0.187
C8	0.400	0.549
C9	0.878	0.960
C10	0.000	0.543
C11	0.309	0.675
C12	0.699	0.930
C13	0.654	0.000
C14	1.000	0.431
C15	0.125	0.987
C16	0.716	0.704
C17	1.000	0.342
C18	0.577	0.844

Condition 2 is that the value of the normalised $(\tilde{D}_i - \tilde{R}_i)^{def}$ for each criteria is larger than or equal to the index's average values, namely, $[Normalised(\tilde{D}\tilde{R})_i^{def}] \geq [Average(Normalised(\tilde{D}_i - \tilde{R}_i)_i^{def})]$. The threshold value for the normalised $(\tilde{D}_i - \tilde{R}_i)^{def}$ can be adjusted to match the relevant experts' opinions. The current research's threshold value was 0.61 based on the committee members' estimations, which were calculated according to the values of the normalised $(\tilde{D}_i - \tilde{R}_i)^{def}$ presented in Table 10.

The criteria that met both these conditions are shown in Figure 5. These criteria were used as the next section of Phase 2 (i.e., weighting) input. To represent the data in Figure 4 more clearly, the values in Table 10 were normalised using a fuzzy normalisation method with the interval [0, 1]. After reducing the number of criteria by applying the F-DEMATEL method, seven criteria were identified to finally rank the ten identified practices in the next phases. Figure 6 shows the decision hierarchy for this study.

Figure 5 Final barriers selected by F-DEMATEL method (see online version for colours)

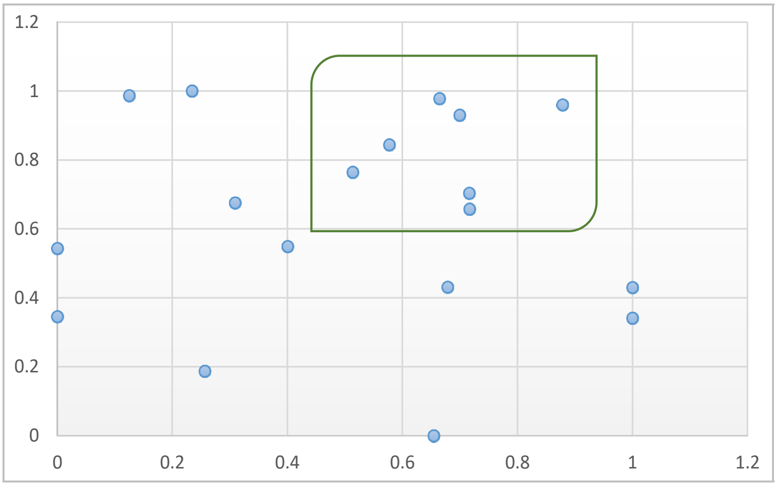
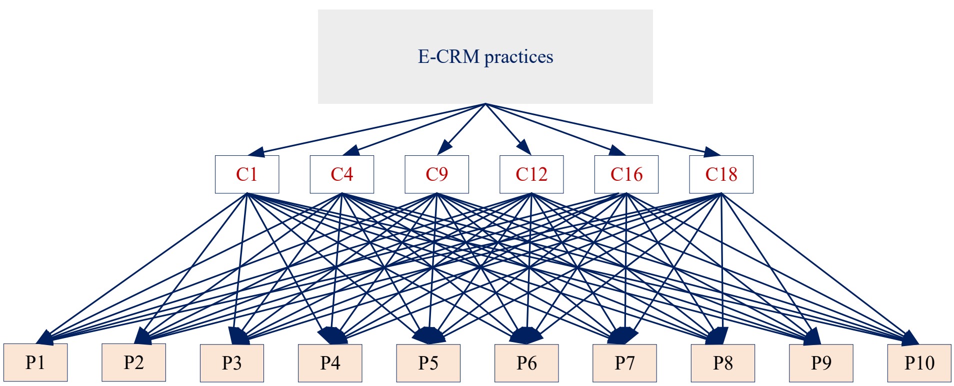


Figure 6 Final research model based on selected criteria and e-CRM implementation practices (see online version for colours)



Then, before entering the third phase of the research, first, weight of the selected criteria from the second phase will be calculated using equation (1) and then normalisation of calculated weights will be done based on equation (8). The results of these calculations are provided in Table 11.

$$\omega_i = \left[\left\{ \left(\tilde{D}_i + \tilde{R}_i \right)^{def} \right\}^2 + \left\{ \left(\tilde{D}_i - \tilde{R}_i \right)^{def} \right\}^2 \right]^{\frac{1}{2}} \tag{7}$$

$$W_i = \frac{\omega_i}{\sum_{i=1}^{n} \omega_i} \tag{8}$$

Table 11 Weight of selected criteria

Criteria	*Calculations*	ω_i	$\omega_i^{Normalised}$
C16	$\sqrt{(13.43)^2+(0.19)^2}$	13.43134	0.14897318
C9	$\sqrt{(12.96)^2+(0.14)^2}$	12.96076	0.143753761
C6	$\sqrt{(12.94)^2+(0.07)^2}$	12.94019	0.143525609
C12	$\sqrt{(12.81)^2+(0.49)^2}$	12.81937	0.142185539
C18	$\sqrt{(12.73)^2+(0.28)^2}$	12.73308	0.141228457
C4	$\sqrt{(12.67)^2+(0.15)^2}$	12.67089	0.140538679
C1	$\sqrt{(12.58)^2+(0.59)^2}$	12.60382	0.139794775
	Sum	90.15945	1

4.3 Phase 3: applying F-TOPSIS method to prioritise the e-CRM practices

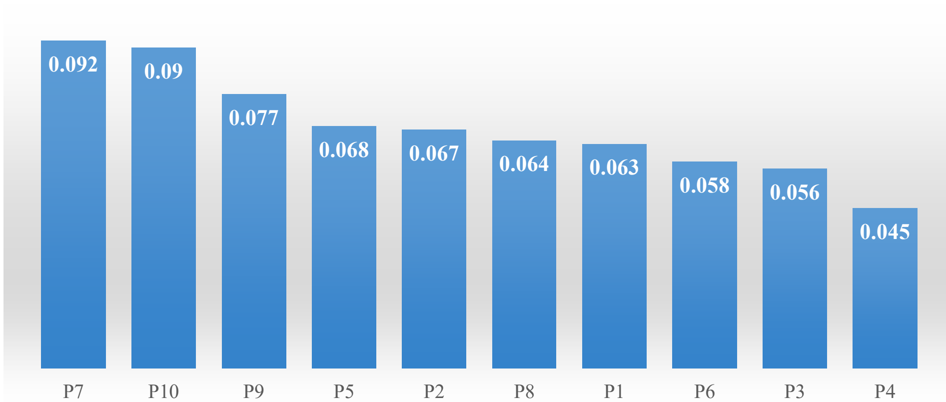
TOPSIS is a classic MCDM developed by Hwang and Yoon (1981). This approach is based on the concept that the chosen alternative should be the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS) (Aydogan, 2011; Baykasoğlu et al., 2013). In this phase, the implementation practices of e-CRM, which are provided based on the opinions of experts and literature review, will be prioritised using the F-TOPSIS technique and based on selected criteria in the second phase. Final hierarchical structure of the selected criteria and implementation practices of e-CRM (final research model) are shown in Figure 6. The present results obtained with the F-TOPSIS are shown in Table 12. In addition, the process of applying this method as recommended by Patil and Kant (2014) is shown in Appendix B.

Table 12 Results of F-TOPSIS method

Practice	d^+	d^-	CC_i	*Rank*
P1	6.594	0.442	0.063	7
P2	6.564	0.474	0.067	5
P3	6.642	0.397	0.056	9
P4	6.736	0.314	0.045	10
P5	6.557	0.480	0.068	4
P6	6.631	0.411	0.058	8
P7	6.381	0.645	0.092	1
P8	6.591	0.448	0.064	6
P9	6.492	0.539	0.077	3
P10	6.391	0.635	0.090	2

The results of Table 12 indicate that the seventh practice (P7), 'transaction and communication with the customer completely through perfect online platform' has the first priority given its highest CC_i value. In addition, the fourth practice (P4), 'gain deep and new insights and understandings on customer engagement' has the last priority given its lowest CC_i value. Diagram of prioritisation of implementation practice of e-CRM (according to CC_i values) is shown in Figure 7.

Figure 7 Ranking of e-CRM practices (see online version for colours)



5 Conclusions and future works

Today, customers are very smart, powerful and informed, and the principle of attention to CRM is to get closer and deeper effective relationships with them. The desire and ability to change a customer's behaviour is based on what the customer tells you and everything you know about the customer. In other words, e-CRM is defined as an integrated customer strategy for effective customer management by improving product and service and increasing customer lifespan in the organisation (Wu and Hung, 2009). Purpose of e-CRM is to improve and modify the services provided, to establish and maintain desirable and appropriate communication with customers, to improve productivity.

Due to the ability of MADM methods to deal with similar situations, some previous researches have tried to use these methods in selecting the best e-CRM practices. The present study's purpose was to propose an appropriate MADM framework to address the shortcomings identified in previous researches. F-DEMATEL method is used to face the criteria of a large number of criteria and reduce the number of identified criteria. Also, DEMATEL method can calculate the weight of each criterion (barrier's importance), while considering the relationships between these criteria. The use of fuzzy numbers to perform assessments by experts can reduce the uncertainty in the decision making process and increase the accuracy of the final results. Finally, we use F-TOPSIS method for ranking identified e-CRM practices.

The proposed framework was implemented in the context of e-CRM. Results show that 'customer sustaining' (C16) and 'support, commitment and learning of senior managers' (C9) are the most important criteria in this company. On the other hand, 'transaction and communication with the customer completely through perfect online platform' (P7) and 'integrate the data and tools needed to achieve more customers' (P10) were selected as the most important e-CRM practices. Findings of this study present several learning insights for organisations. In the first place, because many companies pay less attention to electronic relationships with customers as the most valuable capital, this study can motivate companies to implement e-CRM. Also, the results could encourage the companies to adopt the e-CRM practices which are the most important to competitive advantage (Dahooie et al., 2020). On the other hand, this study identifies a verity of key criteria to implement e-CRM by reviewing the literature. Although different organisations may have similar criteria, it makes more sense that their decision-makers have unlike views on the criteria to achieve competitive advantage.

Despite the theoretical and practical contributions stated above, it is essential to acknowledge the limitations of our study that might provide opportunities for future researches. First of all, our proposed framework is largely depends on the experts' opinions. So, it is recommended that experts' opinions should be collected carefully or we replace our subjective methods with objective and data-driven methods. This article was written to present a new decision making framework. Future research can use statistical approaches or structural equation modelling (SEM) to complete or modify the list of criteria in other fields, as well as to examine the possibility of generalising the results. Finally, it should be emphasised that the issue of reducing the number of criteria is a concern that has not been addressed sufficiently, and therefore more research can be done in this area.

Furthermore, the proposed methodology-based hybrid decision making methods and model may also be extended to different industry sectors, which are particularly known for having a substantial impact on the customers' relations.

More practices can be considered for similar analysis. We considered only ten practices in this research, although in reality additional practices exist. This research investigated the most dominant practices based on related researches. Such a proposed model may be applied in future research to other developing countries such as China and the USA, with marginal modifications.

References

Aiassi, R., Sajadi, S.M., Hadji-Molana, S.M. and Zamani-Babgohari, A. (2020) 'Designing a stochastic multi-objective simulation-based optimization model for sales and operations planning in built-to-order environment with uncertain distant outsourcing', *Simulation Modelling Practice and Theory*, Vol. 104, No. 7, p.102103.

Akhavan, P., Barak, S., Maghsoudlou, H. and Antuchevičienė, J. (2015) 'FQSPM-SWOT for strategic alliance planning and partner selection; case study in a holding car manufacturer company', *Technological and Economic Development of Economy*, Vol. 21, No. 2, pp.165–185 [online] https://doi.org/10.3846/20294913.2014.965240.

Alhaiou, T., Irani, Z. and Ali, M. (2009) 'The relationship between ecrm implementation and eloyalty at different adoption stages of transaction cycle: a conceptual framework and hypothesis', *Proceedings of the European and Mediterranean Conference on Information Systems*, Izmir, Turkey, 13–14 July.

Alshawi, S., Missi, F. and Irani, Z. (2011) 'Organisational, technical and data quality factors in CRM adoption – SMEs perspective', *Industrial Marketing Management*, Vol. 40, No. 3, pp.376–383 [online] https://doi.org/https://doi.org/10.1016/j.indmarman.2010.08.006.

Antucheviciene, J., Zakarevicius, A. and Zavadskas, E.K. (2011) 'Measuring congruence of ranking results applying particular MCDM methods', *Informatica*, Vol. 22, No. 3, pp.319–338 [online] https://www.scopus.com/inward/record.uri?eid=2-s2.0-80055081895&partnerID=40&md5=ec4bf150aed9cc3d80abe1c2dd669cc8.

Aydogan, E.K. (2011) 'Performance measurement model for Turkish aviation firms using the rough-AHP and TOPSIS methods under fuzzy environment', *Expert Systems with Applications*, Vol. 38, No. 4, pp.3992–3998.

Babgohari, A.Z., Taghizadeh-Yazdi, M.R., Hatami-Marbini, A. and Sajadi, S.M. (2021) 'Efficiency analysis in steel manufacturing with undesirable outputs', *Third International Conference at the Institute of Energy and Sustainable Development*, De Montfort University, Leicester (UK), July.

Baykasoğlu, A., Kaplanoğlu, V., Durmuşoğlu, Z.D. and Şahin, C. (2013) 'Integrating fuzzy DEMATEL and fuzzy hierarchical TOPSIS methods for truck selection', *Expert Systems with Applications*, Vol. 40, No. 3, pp.899–907.

Bohling, T., Bowman, D., LaValle, S., Mittal, V., Narayandas, D., Ramani, G. and Varadarajan, R. (2006) 'CRM implementation: effectiveness issues and insights', *Journal of Service Research*, Vol. 9, No. 2, pp.184–194 [online] https://doi.org/10.1177/1094670506293573.

Bradshaw, D. and Brash, C. (2001) 'Managing customer relationships in the e-business world: how to personalise computer relationships for increased profitability', *International Journal of Retail & Distribution Management*, Vol. 29, No. 12, pp.520–530.

Bull, C. (2003) 'Strategic issues in customer relationship management (CRM) implementation', *Business Process Management Journal*, Vol. 9, No. 5, pp.592–602.

Chang, B., Chang, C-W. and Wu, C-H. (2011) 'Fuzzy DEMATEL method for developing supplier selection criteria', *Expert Systems with Applications*, Vol. 38, No. 3, pp.1850–1858.

Chen, Q. and Chen, H-M. (2004) 'Exploring the success factors of eCRM strategies in practice', *Journal of Database Marketing & Customer Strategy Management*, Vol. 11, No. 4, pp.333–343 [online] https://doi.org/10.1057/palgrave.dbm.3240232.

Chen, T-L. (2013) 'Exploring e-learning effectiveness perceptions of local government staff based on the diffusion of innovations model', *Administration & Society*, Vol. 46, No. 4, pp.450–466 [online] https://doi.org/10.1177/0095399713482313.

Chou, T.C. and Lee, A.S. (2009) 'A process model for customer relational assets creation: a case study of online securities trading platform', *Information Management & Computer Security*, Vol. 17, No. 3, pp.218–233 [online] https://doi.org/10.1108/09685220910978095.

Dahooie, J.H., Babgohari, A.Z., Meidutė-Kavaliauskienė, I. and Govindan, K. (2020) 'Prioritising sustainable supply chain management practices by their impact on multiple interacting barriers', *International Journal of Sustainable Development & World Ecology*, pp.1–24 [online] https://doi.org/10.1080/13504509.2020.1795004.

Dussart, C. (2001) 'Transformative power of e-business over consumer brands', *European Management Journal*, Vol. 19, No. 6, pp.629–637 [online] https://doi.org/https://doi.org/10.1016/S0263-2373(01)00088-3.

Erdil, A. and Öztürk, A. (2016) 'Improvement a quality oriented model for customer relationship management: a case study for shipment industry in Turkey', *Procedia – Social Behavioral Sciences*, Vol. 229, No. 19, pp.346–353.

Favardin, P., Lepelley, D. and Serais, J. (2002) 'Borda rule, Copeland method and strategic manipulation', *Review of Economic Design*, Vol. 7, No. 2, pp.213–228 [online] https://doi.org/10.1007/s100580200073.

Gölcük, İ. and Baykasoğlu, A. (2016) 'An analysis of DEMATEL approaches for criteria interaction handling within ANP', *Expert Systems with Applications*, Vol. 46, No. 4, pp.346–366.

Hassan, R.S., Nawaz, A., Lashari, M.N. and Zafar, F. (2015) 'Effect of customer relationship management on customer satisfaction', *Procedia Economics Finance India*, Vol. 23, No. 12, pp.563–567.

Hwang, C. and Yoon, K. (1981) *Multiple Attributes Decision Making Methods and Applications*, Springer, New York.

Javadi, M.H.M. and Azmoon, Z. (2011) 'Ranking branches of system group company in terms of acceptance preparation of electronic customer relationship management using AHP method', *Procedia Computer Science*, Vol. 3, pp.1243–1248 [online] https://doi.org/https://doi.org/10.1016/j.procs.2010.12.199.

Jolai, F., Asadzadeh, S. and Taghizadeh, M. (2010) ‘A preemptive discrete-time priority buffer system with partial buffer sharing’, *Applied Mathematical Modelling*, Vol. 34, No. 8, pp.2148–2165.

Kevork, E. and Vrechopoulos, A. (2006) ‘Defining, manipulating and measuring customer relationship management’, *European Marketing Academy Conference*,

Kim, H-S., Kim, Y-G. and Park, C-W. (2010) ‘Integration of firm’s resource and capability to implement enterprise CRM: a case study of a retail bank in Korea’, *Decision Support Systems*, Vol. 48, No. 2, pp.313–322 [online] https://doi.org/https://doi.org/10.1016/j.dss.2009.07.006.

Kirakosyan, K. and Dănăiaţă, D. (2014) ‘Communication management in electronic banking. Better communication for better relationship’, *Procedia – Social Behavioral Sciences*, Vol. 124, No. 124, pp.361–370.

Kotler, P. and Armstrong, G. (2010) *Principles of Marketing*, Pearson Education, London, UK.

Liu, C-C., Chuang, L-m. and Huang, C-M. (2012) ‘A study of the impact of the e-CRM perspective on customer satisfaction and customer loyalty-exemplified by Bank Sinopac’, *Journal of Economics and Behavioral Studies*, Vol. 4, No. 8 [online] https://doi.org/10.22610/jebs.v4i8.348.

Liu, J., Liu, P., Liu, S.F., Zhou, X.Z. and Zhang, T. (2015) ‘A study of decision process in MCDM problems with large number of criteria’, *International Transactions in Operational Research*, Vol. 22, No. 2, pp.237–264.

Liu, J., Zhao, H-K., Li, Z-B. and Liu, S-F. (2017) ‘Decision process in MCDM with large number of criteria and heterogeneous risk preferences’, *Operations Research Perspectives*, Vol. 4, No. 1, pp.106–112.

Liz, L-K., David, G. and Robin, M. (2003) ‘How e-CRM can enhance customer loyalty’, *Marketing Intelligence Planning Review*, Vol. 21, No. 4, pp.239–248.

Mahdavi, I., Movahednejad, M. and Adbesh, F. (2011) ‘Designing customer-oriented catalogs in e-CRM using an effective self-adaptive genetic algorithm’, *Expert Systems with Applications*, Vol. 38, No. 1, pp.631–639 [online] https://doi.org/https://doi.org/10.1016/j.eswa.2010.07.013.

Mendoza, L.E., Marius, A., Pérez, M. and Grimán, A.C. (2007) ‘Critical success factors for a customer relationship management strategy’, *Information and Software Technology*, Vol. 49, No. 8, pp.913–945 [online] https://doi.org/https://doi.org/10.1016/j.infsof.2006.10.003.

Mokhtarzadeh, N.G., Jafarpanah, I. and Babgohari, A.Z. (2021). The impact of international networking capability on international performance: the mediating role of dynamic entrepreneurship capabilities’, in Jafari-Sadeghi, V., Amoozad Mahdiraji, H. and Dana, LP. (Eds.): *Empirical International Entrepreneurship. Contributions to Management Science. A Handbook of Methods, Approaches, and Applications*, pp.307–336, Springer, Cham, https://doi.org/10.1007/978-3-030-68972-8_16.

Navimipour, N.J. and Zareie, B. (2015) ‘A model for assessing the impact of e-learning systems on employees’ satisfaction’, *Computers in Human Behavior*, Vol. 53, pp.475–485 [online] https://doi.org/https://doi.org/10.1016/j.chb.2015.07.026.

Nguyen, B. and Simkin, L. (2013) ‘The dark side of CRM: advantaged and disadvantaged customers’, *Journal of Consumer Marketing*, Vol. 30, No. 1, pp.17–30 [online] https://doi.org/10.1108/07363761311290812.

Ocker, R.J. and Mudambi, S. (2003) ‘Assessing the readiness of firms for CRM: a literature review and research model’, *Proceedings of the 36th Annual Hawaii International Conference on System Sciences, 2003*, 6–9 January.

Patil, S.K. and Kant, R. (2014) ‘A fuzzy AHP-TOPSIS framework for ranking the solutions of knowledge management adoption in supply chain to overcome its barriers’, *Expert Systems with Applications*, Vol. 41, No. 2, pp.679–693.

Perzon, H. (2008) *Assessing the Readiness for Implementing e-CRM in B2B Markets*, Master thesis, Lulea University of Technology.

Plakoyiannaki, E. (2005) 'How do organisational members perceive CRM? Evidence from a U.K. service firm', *Journal of Marketing Management*, Vol. 21, Nos. 3–4, pp.363–392 [online] https://doi.org/10.1362/0267257053779136.

Raj, P.A. and Kumar, D.N. (1999) 'Ranking alternatives with fuzzy weights using maximizing set and minimizing set', *Fuzzy Sets and Systems*, Vol. 105, No. 3, pp.365–375 [online] https://doi.org/https://doi.org/10.1016/S0165-0114(97)00243-1.

Sadollah, A. (2018) 'Introductory chapter: which membership function is appropriate in fuzzy system?', in *Fuzzy Logic Based in Optimization Methods and Control Systems and its Applications*, IntechOpen, London, UK.

Sen, A. and Sinha, A.P. (2011) 'IT alignment strategies for customer relationship management', *Decision Support Systems*, Vol. 51, No. 3, pp.609–619 [online] https://doi.org/https://doi.org/10.1016/j.dss.2010.12.014.

Sigala, M. (2011) 'eCRM 2.0 applications and trends: the use and perceptions of Greek tourism firms of social networks and intelligence', *Computers in Human Behavior*, Vol. 27, No. 2, pp.655–661 [online] https://doi.org/https://doi.org/10.1016/j.chb.2010.03.007.

Sivaraks, P., Krairit, D. and Tang, J.C.S. (2011) 'Effects of e-CRM on customer-bank relationship quality and outcomes: the case of Thailand', *The Journal of High Technology Management Research*, Vol. 22, No. 2, pp.141–157 [online] https://doi.org/https://doi.org/10.1016/j.hitech.2011.09.006.

Sophonthummapharn, K. (2009) 'The adoption of techno-relationship innovations: a framework for electronic customer relationship management', *Marketing Intelligence Planning Review*, Vol. 27, No. 3, pp.380–412.

Souri, A. and Navimipour, N.J. (2014) 'Behavioral modeling and formal verification of a resource discovery approach in grid computing', *Expert Systems with Applications*, Vol. 41, No. 8, pp.3831–3849 [online] https://doi.org/https://doi.org/10.1016/j.eswa.2013.11.042.

Vats, S., Vats, G., Vaish, R. and Kumar, V. (2014) 'Selection of optimal electronic toll collection system for India: a subjective-fuzzy decision making approach', *Applied Soft Computing*, Vol. 21, No. 10, pp.444–452.

Wang, Y-M., Chin, K-S., Poon, G.K.K. and Yang, J-B. (2009) 'Risk evaluation in failure mode and effects analysis using fuzzy weighted geometric mean', *Expert Systems with Applications*, Vol. 36, No. 2, pp.1195–1207.

Wolfinbarger, M. and Gilly, M.C. (2003) 'eTailQ: dimensionalizing, measuring and predicting etail quality', *Journal of Retailing*, Vol. 79, No. 3, pp.183–198 [online] https://doi.org/https://doi.org/10.1016/S0022-4359(03)00034-4.

Wu, I-L. and Hung, C-Y. (2009) 'A strategy-based process for effectively determining system requirements in eCRM development', *Information and Software Technology*, Vol. 51, No. 9, pp.1308–1318 [online] https://doi.org/https://doi.org/10.1016/j.infsof.2009.03.004.

Yazdi, M.R.T. and Barazandeh, H. (2016) 'Identifying and ranking health tourism development barriers in Iran using fuzzy VIKOR method', *Asian Social Science*, Vol. 12, No. 5, pp.54–63.

Yu, X., Nguyen, B., Han, S.H., Chen, C-H.S. and Li, F. (2015) 'Electronic CRM and perceptions of unfairness', *Information Technology and Management*, Vol. 16, No. 4, pp.351–362 [online] https://doi.org/10.1007/s10799-014-0210-4.

Zablah, A., Bellenger, D.N. and Johnston, W.J. (2004) 'An evaluation of divergent perspectives on customer relationship management: towards a common understanding of an emerging phenomenon', *Industrial Marketing Management*, Vol. 33, No. 6, pp.475–489, https://doi.org/10.1016/j.indmarman.2004.01.006.

Zadeh, L.A., Klir, G.J. and Yuan, B. (1996) *Fuzzy Sets, Fuzzy Logic, and Fuzzy Systems: Selected Papers*, Vol. 6, World Scientific, Singapore.

Zhou, F., Wang, X., Lim, M.K., He, Y. and Li, L. (2018) 'Sustainable recycling partner selection using fuzzy DEMATEL-AEW-FVIKOR: a case study in small-and-medium enterprises (SMEs)', *Journal of Cleaner Production*, Vol. 196, No. 27, pp.489–504.

Zhou, Q., Huang, W. and Zhang, Y. (2011) 'Identifying critical success factors in emergency management using a fuzzy DEMATEL method', *Safety Science*, Vol. 49, No. 2, pp.243–252 [online] https://doi.org/https://doi.org/10.1016/j.ssci.2010.08.005.

Appendix A

Process of fuzzy DEMATEL method

Step 1 The modified DEMATEL method starts with the two direct-relation fuzzy matrices X_{ij} $\forall$ $k = 1, \ldots, p$, where X_{ij} is $(n \times n)$ matrix, n represents the number of criteria (barriers) and p is the number of surveyed experts in the group, which $p = 2$.

Step 2 Calculate the average direct relation matrices based on equation (9).

$$\tilde{x}_{ij} = \frac{\sum_{k=1}^{p} \tilde{x}_{ij}^{(k)}}{p} \tag{9}$$

Step 3 Normalise the average direct relation matrices based on equations (10), (11) and (12).

$$\tilde{x}_{ij}^{(k)} = \frac{\tilde{z}\tilde{x}_{ij}^{(k)}}{\tilde{R}^{(k)}} = \left(\frac{\tilde{z}_{ij}^{(k)}, \ell}{r_\ell^{(k)}}, \frac{\tilde{z}_{ij}^{(k)}, m}{r_m^{(k)}}, \frac{\tilde{z}_{ij}^{(k)}, u}{r_u^{(k)}} \right) \tag{10}$$

$$\tilde{R}^{(k)} = \left(r_\ell^{(k)}, r_m^{(k)}, r_u^{(k)} \right), k = 1, \ldots, p \tag{11}$$

and

$$r_s^{(k)} = \max \left(\sum_{\substack{j=1 \\ 1 \le i \le n}}^{n} z_{ij,s}^{(k)} \right) \forall s = \ell, m, u \tag{12}$$

Step 4 Calculate the total-relation fuzzy matrix $\tilde{T}$ can be acquired by calculating equation (13).

$$\tilde{T} = \lim_{w \to \infty} \left(\tilde{X} + \tilde{X}^2 + \ldots + \tilde{X}^w \right) = \tilde{X} \left(I - \tilde{X} \right)^{-1} \tag{13}$$

Step 5 The sum of rows and the sum of columns of the sub-matrices T_ℓ, T_m, T_u denoted by the fuzzy numbers $\tilde{D}_i$ and $\tilde{R}_i$, respectively, can be obtained through equations (14) and (15).

$$\tilde{D}_i = \sum_{j=1}^{n} \tilde{t}_{ij} \quad (i = 1, 2, \ldots, n) \tag{14}$$

$$\tilde{R}_i = \sum_{i=1}^{n} \tilde{t}_{ij} \quad (j = 1, 2, \ldots, n) \tag{15}$$

Step 6 Deffuzzification of $\tilde{D}_i$ and $\tilde{R}_i$ using equation (16).

$$Deffuzification\ point = \begin{cases} u - \sqrt{(u-\ell)(u-m)/2} & u - m > m - \ell \\ \sqrt{(u-\ell)(u-m)/2} - \ell & u - m < m - \ell \\ m & \text{otherwise} \end{cases} \tag{16}$$

Appendix B

Process of fuzzy TOPSIS method

Step 1 Construct the fuzzy decision matrix.

Step 2 Calculate the normalise fuzzy decision matrix based on equation (17).

$$\tilde{r}_{ij} = \left(\frac{\ell_{ij}}{c_j^*}, \frac{m_{ij}}{c_j^*}, \frac{u_{ij}}{c_j^*} \right) \text{ and } c_j^* = \max_i c_{ij} \tag{17}$$

Step 3 Construct the weighted normalised matrix through equation (18).

$$\tilde{V}_{ij} = \left[\tilde{v}_{ij} \right]_{m \times n} \ i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n \text{ where } \tilde{v}_{ij} = \tilde{r}_{ij} \otimes w_j \tag{18}$$

Step 4 Determine the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) as equations (19) and (20).

$$A^* = \left(\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^* \right) \text{ where } \tilde{v}_j^* = \left(\tilde{c}_j^*, \tilde{c}_j^*, \tilde{c}_j^* \right) \text{ and } \tilde{c}_j^* = \max_i \left\{ \tilde{c}_{ij} \right\} \tag{19}$$

$$A^- = \left(\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^- \right) \text{ where } \tilde{v}_j^- = \left(\tilde{a}_j^-, \tilde{a}_j^-, \tilde{a}_j^- \right) \text{ and } \tilde{a}_j^- = \min_i \left\{ a_j^- \right\} \tag{20}$$

Step 5 Calculate the distance of each alternative from FPIS and FNIS as equations (21) and (22).

$$d_i^+ = \sum_{j=1}^{n} dv\left(\tilde{v}_{ij}, v_j^* \right), \quad i = 1, 2, \ldots, m \tag{21}$$

$$d_i^- = \sum_{j=1}^{n} dv\left(\tilde{v}_{ij}, v_j^- \right), \quad i = 1, 2, \ldots, m \tag{22}$$

Step 6 Calculate the closeness coefficient (CC_i) of each alternative using equation (23).

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+} \tag{23}$$

Step 7 Rank the alternatives.