Global Journal of Flexible Systems Management (June 2021) 22(2):113–126
https://doi.org/10.1007/s40171-021-00258-w

ORIGINAL ARTICLE

A Time-Dependent Sustainable–Flexible Supplier Selection Considering Uncertainty and TODIM Method in Iranian Dairy Industries

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Received: 12 September 2020 / Accepted: 8 January 2021 / Published online: 16 March 2021
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Abstract *Nowadays, by increasing awareness on environmental and social responsibilities, stakeholders and people put more pressure on the enterprises and companies to respect these issues. Owing to the fact that suppliers as the upstream of the supply chain play an important role in success and prosperity, the sustainability of suppliers would be a must and enterprises need to create and utilize an integrated assessment model based on related criteria in every specific industry. However, these sustainability and environmental criteria especially would be critical in the cold chain and dairy industries; to our knowledge, there are not enough surveys related to this category. Interval triangular fuzzy numbers have been utilized to overcome uncertainty of the linguistic notions of the experts in this area. As criterion's weight and even its matter would be changed during the time horizon, fuzzy time function would be applied to illustrate these modifications during the time. For solving our integrated sustainable–flexible multi-criteria model, we take advantage of TODIM, a discrete multi-criteria method based on prospect theory in uncertainty which includes gain and loss of decision simultaneously. Finally, managerial insight and associated sensitivity analysis of the ability and robustness of the proposed decision framework have been illustrated in the small- and medium-scale dairy industries in Iran.*

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Keywords Dairy industry · Fuzzy time function · Interval TFN · Supplier selection · Sustainability · TODIM

Introduction

There would be several definitions of sustainability in supply chain management and one of the clear expressions for that could be presented by the World Commission on Environment and Development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Dubey et al., 2017). In recent times, by increasing the knowledge of end-users and passed lows by the governments, industries have been forced to achieve sustainability in their process of manufacturing and related supply chain (Luthra et al., 2017; Trollman and Colwill, 2020). As sustainable evaluation includes environmental, social and economic aspects, in order to have appropriate collaboration in sustainability aspects, organizations should have close coordination with all the supply chain aspects (Amindoust et al., 2012; Lu et al., 2018; Zahraee et al., 2018). Suppliers are crucial upstream SC partners which contribute significantly to the sustainable objectives of the enterprises (Luthra et al., 2017). Zhu et al. believed environmental aspects which could be considered by the suppliers enhance the whole supply chain performance (Zhu & Sarkis, 2006). Hence, sustainable supplier selection would be a strategic point in our sustainability plan. Owing to the widespread criteria in three aspects of economic, environmental and social, decision-makers are facing a lot of qualitative and quantitative criteria and some experts who have their opinions with vagueness and uncertainty. Under these circumstances, as mentioned in the literature, scholars took the advantage of fuzzy MCDM techniques

(Chai et al., 2013; Govindan et al., 2015; Kaur et al., 2016; Shojaie et al., 2018; Mittal, 2019). MCDM is an optimization process that specifies the best alternative thanks to the comparisons of all the alternatives under several criteria. In particular, in our survey in the dairy industries, we are facing variations and vagueness and uncertainties. It would be irrational for the DMs to illustrate their preferences by precise values, here the difference between criteria will be distinguished by taking advantage of linguistic numbers. In this case, interval TFN has been applied for better comprehension and finding complete perception of the experts' notions and decreasing uncertainty. Nowadays, one of the challenges for the companies and SCs as well would be prompt changes, and here, in our problem, this pace will emerge in many aspects of the supply chain and the most prestigious would be market-driven and customer-related specifications. Under these circumstances, adaptation to the market values would be worthwhile. Here, we consider fuzzy time functions that make our decisions based on the necessities, fluctuations and variations of the criteria's priority during the time and criteria weights in time horizon in such a way that our a sustainable supplier would be determined clearly and reasonably. Our proposed MCDM method to find the final ranking of the dairy suppliers would be TODIM (an acronym in Portuguese for Interactive Multi-Criteria Decision Making), which is a behavioral decision-making method based on prospect theory and can prescribe the bounded rational behavior of DM. Considering both loss and gain of every decision should be an extra advantage of the proposed method to the other MCDM. Shukla et al. (2010) depicted flexibility and sustainability in two dimensions and illustrated enterprises which have both sustainability and flexibility as a whole, "Trendsetter" companies that aim to improve both of them at the same time (Shukla et al., 2010; Shukla et al., 2019). In our survey in dairy industries in Iran, both types of criteria for flexibility and sustainability have been considered. The dairy supply chain is a crucial and economic part of the agri-food supply chain with international attention to it and is highly regulated and accordingly, several environmental legislations and standards have been released during the last years from both sides of European and international directives. The dairy industry also received highly environmental-related attention regarding Methane emission. These several legislations and standards obligate the dairy companies to observe control and specify all the environmental actions (Yu & Huatuco, 2016). To the best of our knowledge, only a few studies have been accomplished on sustainable suppliers related to dairy industries. Michael Bourlakis surveyed sustainability performance in the supply chain regarding the Greek dairy sector (Bourlakis et al., 2014). An investigation for social responsibility adaptation in supplier development by institutional theory has been conducted by Sadaat Ali Yawar in the dairy supply chain in India (Yawar & Kauppi, 2018) and an investigation on green supplier selection through fuzzy group decision making has been accomplished on agri-food industries (Banaeian et al., 2018).

The rest of our paper is organized as follows: In "Literature review" section, a literature review on sustainable supplier selection in dairy industries and fuzzy sustainable supplier selection will be reviewed. In part 3, a survey on fuzzy numbers, fuzzy time function and TODIM and interval TFN will be illustrated. Our real case study in the dairy industry will be explained in section four. Managerial insight and sensitivity analysis will be addressed in part 5. Finally, the conclusion will be presented in "Conclusion" section.

Literature Review

In this part, a brief summary has been presented with a focus on sustainable supplier selection criteria and fuzzy sustainable supplier selection models in dairy industries.

Sustainability of the Suppliers in the Dairy Industries

One of the significant issues in the procurement department is supplier selection and assessment. These days, people are really observant about health, information related to it, processing and finally distribution of them all around the world (Van Kleef et al., 2006). Nowadays, people notice quality, safety and environmental aspects in their purchasing decisions. Managerial insights in the dairy and food companies investigate these customers' requirements through a special concern on Environmental aspects (Wognum et al. 2011). Most of the papers prepare a discrete structure and different numbers of criteria and subcriteria related to their case study. Bai and Sarkis (2010) prepared a framework considering three aspects of economic, environmental and social issues. The economic criteria are related to common business aspects such as cost, flexibility, innovativeness, time and quality, organizational criteria as culture, technology and relationships. The environmental dimension consists of control of pollution, prevention of pollution, management of the environmental system, usage of resources and created pollutant material. The social aspects consist of participation in employment, safety and health, and the penetration of local communities and participants (Bai & Sarkis, 2010; Anbarasan and Sushil, 2018).

Zimmer et al. (2016) also constructed the same three-dimensional criteria in their survey: business, environmental and social-related aspects. In their business part, management, organization, external perception, financial capabilities and performance have been compromised. The

social aspects comprise internal, external social practices and social performance (Zimmer et al., 2016). Awasthi et al. (2018) proposed two different aspects to the previous issues as risks: environmental, social, and global risk and the quality of the relationship. In the economic section, they considered innovativeness, quality, flexibility and cost. In the quality of relationships, effectiveness of communication, EDI and trust has been compromised. Their environmental criteria consist of biodiversity, water, material, energy, emissions, waste and environmental factors. Social criteria consist of labor practices, responsibility of the product, social procedure for supplier selection, human rights. In the end, global risk factors in their survey consist of currency risk, disruption risk for political instability, cultural incompatibility and terrorism (Awasthi et al., 2018).

Luthra et al. (2017) summarized all the previous studies according to sustainable supplier selection in 22 separable criteria. In the economic criteria, they addressed quality of good, cost, flexibility, dispatching, technical capability, production, service, location and position, market, finance, organizational management, communication and attitude. The culmination for the environmental aspect of sustainable supplier selection would have been management for environmental system, pollution control, resource utilization, pollution production, reduction and recycling, ecodesign and green proficiency. Finally, the social aspect for sustainable supplier selection mentioned as internal aspect with the attention and rights of staff, health and security, supportive activities, and the external aspects consisted of local districts impact, stakeholder impacts, and Information disclosure (Luthra et al., 2017).

Yawar and Kauppi (2018) conducted a study on the adaptation of socially responsible supplier development in the dairy industry in India. They surveyed the similarity of social responsibility enhancement activities in private and public dairy manufacturers in India. In their definition, private scale meant those farmers who owned small land and had restricted livestock to support their families on a daily basis. Bourlakis et al. (2014) examined sustainability performance in the supply chain for Greek dairy sector. They investigated sustainability assessment criteria associated with relevant comprehension of experts and finalized them in: Product quality, flexibility, efficiency and responsiveness. Finally, they evaluate suppliers in dairy products in Greece regarding the mentioned factors. The main sustainability factors which have been considered by dairy companies in Greece were efficient and flexibility in six sub-criteria: Raw material and manufacturing cost, net and gross profit, warehousing cost, dispense and delivery cost, waste cost, economic costs, respectively. They also illustrated responsiveness in three sub-criteria as the ability of replyıng ın lead time, capability of responsiveness in delivering to the specific point, the capability of dispensing a multitude of goods. Finally, product quality was mentioned in their survey in detail by grade of raw material, grade of company's product, product maintenance duration, consistency in the traceability of an order, warehouse, and delivery condition, quality of firm's products packaging.

Fuzzy Sustainability for Supplier Assessment

Luthra et al. (2017) conducted a survey of sustainability in supplier selection. They mentioned that the majority of the papers in this issue were MCDM based (Luthra et al., 2017). Furthermore, the fuzzy set theory could be an appropriate tool when quantifying is not clear and brings ambiguity and also in the cases when we want finally crisp outputs as a solution for decision-makers (Ghadimi et al., 2017). In sustainability aspect, scholars have accompanied by the fuzzy set theory with other MCDM techniques such as TOPSIS, DEA and AHP. Here, we reviewed some of the sustainability works which have been done during recent years. Azadnia et al. (2015) proposed sustainability in their supplier selection and order allocation model which combined with multi-period multi-product lot-sizing problems. In their mathematical model fuzzy AHP has been accompanied with multi-objective mathematical programming (Azadnia et al., 2015). Ghadimi et al. (2017) evaluated and selected the most sustainable suppliers in the automotive spare part industry. They considered economic, environmental and social aspects both with the audition checklist and FIS system (Ghadimi et al., 2017). Mavi et al. (2017) investigated the sustainability of the third party (3pl) logistics provider through fuzzy SWARA and MOORA techniques. Their research which was conducted in the plastic industry completely considered triple sustainability factors (Mavi et al., 2017). Rao et al. (2017) developed a linguistic fuzzy type 2 with grey correlation degree for their assessment of the sustainability in the proposed supplier selection problem. Fallahpour et al. (2017) proposed a sustainable supplier selection model under uncertainty for textile. Singh et al. (2016) developed a system for evaluation of sustainability in the small and medium manufacturing companies by taking advantage of the fuzzy inference system.

Awasthi et al. (2018) utilized fuzzy AHP-VIKOR for sustainable assessment of suppliers considering global risks. Banaeian et al. (2018) conducted a comparison between three uncertain methods as fuzzy TOSIS, fuzzy VIKOR and GRA for the agri-food industries through

economic and environmental aspects. The results illustrated similarity in both three mentioned methods, where the GRA method had less complexity in calculation. Hendiani and Bagherpour (2019) applied fuzzy logic to determine the importance of every social index in supplier selection. Finally, they applied their proposed method for finding social barriers against the supplier selection in construction projects. Rashidi and Cullinane (2019) used two different means for supplier selection as fuzzy DEA and fuzzy TOPSIS and compared them in the complexity of calculation and sensitivity to the magnitude of the number of suppliers. Ahmed Mohammed et al. (2019) illustrated an integrated MCDM and FMOO method for sustainable assessment of the suppliers and order allocation. Owing to the ranking of suppliers, they suggested a hybrid fuzzy AHP-TOPSIS method (Mohammed et al., 2019). Najafi et al. (2020) developed an integrated sustainable and flexible supplier evaluation model under uncertainty applying game theory and subjective/objective data and they applied their proposed model in the Iranian casting industry. Tseng et al. (2012) utilized a combination of TODIM and TFNs to select green suppliers in the supply chain. Tosun and Akyüz (2015) illustrated a TODIM based fuzzy model for supplier assessment and they utilized their model in a case study on a furniture manufacturing company. Qin et al.(2017) proposed an extended TODIM behavior decision method to green supplier selection. Li et al. (2018) explored a novel assessment model for sustainability by taking advantage of the extended TODIM method. Liang et al. (2019) extended an improved multi-granularity interval 2-tuple TODIM approach and utilized it for assessment of the greenness in the suppliers.

Methodology of the Research

In our proposed method, we taking advantage of fuzzy decision making, fuzzy time function, TODIM method and interval-value triangular fuzzy numbers which are illustrated here in detail as follows.

A Brief Review on Fuzzy Numbers

Fuzzy set theory has been presented by Zadeh (1965) as an extension to the set theory where every element has a degree of membership for the nominated set whereas in classic set theory belonging to an element to a specific set was bivalent (Liou et al., 2008; Zadeh, 1965).

For a fuzzy number $\tilde{A}$, the membership function on R depicted by $\mu_{\tilde{A}}(X) : \rightarrow [0,\ 1]$ is equal to following Eq. (1):

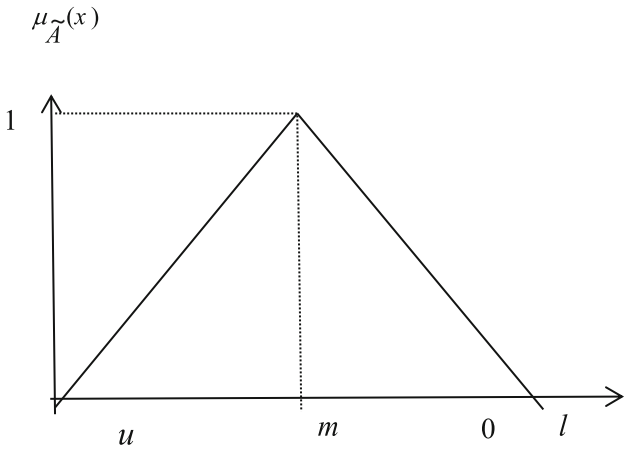


Fig. 1 Triangular fuzzy number membership function

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

where $\tilde{A}$ is triangular fuzzy number (TFN). In Eq. (1), l, u represent the lower and upper bound of the fuzzy number $\tilde{A}$, and m is the modal value for $\tilde{A}$, (as Fig. 1). So TFN could be presented by $\tilde{A} = (l,\ m,\ u)$.

The operational laws of TFN $\tilde{A}_1 = (l_1,\ m_1,\ u_1)$ and $\tilde{A}_2 = (l_2,\ m_2,\ u_2)$ are displayed as follows: Eqs. (2)–(3).

Addition of the fuzzy number $\oplus$

$$\begin{aligned} \tilde{A}_1 \oplus \tilde{A}_2 &= (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) \\ &= (l_1 + l_2, m_1 + m_2, u_1 + u_2) \end{aligned}. \tag{2}$$

For subtraction of two fuzzy numbers by symbol Θ, we have:

$$\begin{aligned} \tilde{A}_1 \Theta \tilde{A}_2 &= (l_1, m_1, u_1) \Theta (l_2, m_2, u_2) \\ &= (l_1 - u_2, m_1 - m_2, u_1 - l_2). \end{aligned} \tag{3}$$

Fuzzy Time Function (FTF)

Owing to the fact that some of the criteria will be changed during the time and according to many political, social, and scientific limitations and obligations, we need to reconsider our criteria, and some of the older may be deleted and part of them get stronger for the future. Under these circumstances, we have to consider dynamic decisions through time observation. If executives would not accompany these changes, companies have to pay extra costs, penalties, or even lose the market. Under these circumstances, using a fuzzy time function will be an appropriate tool for foretelling future changes and a company with future changes. De Figueiredo et al. (1997) applied fuzzy time function in fault and timing analysis (Perkusich & De Figueiredo, 1997). Yoneyama (2007) applied the uncertain Takagi–Sugeno fuzzy model for the time-delay system (Yoneyama,

2007). Here, a new aspect of fuzzy time function accompanied by triangular fuzzy numbers (TFN) will be presented. A fuzzy time function will be explained in three non-cross-parts as optimistic, normal and pessimistic related to time. Here, all are depicted in blue, red and green lines, respectively (Fig. 2). By using the FTF definition we could consider variation in strength and weakness of criteria regarding experts' opinions during the time horizon.

According to the aforementioned description, the FTF for every criterion is as:

$$F = \begin{cases} F1 & for\ Optimistic \\ F2 & for\ Normal \\ F3 & for\ Pesimistic \end{cases} \quad (4)$$

Equation (4) describes the triangular fuzzy number during the time as:

$$\tilde{A} = (a1, a2, a3) \rightarrow F(F1, F2, F3). \quad (5)$$

Here, for computing the FTF, we taking advantage of the mean slope of our lines related to the time horizons which are gathered from the experts opinions. For accumulation of the related expert's notions, fuzzy linguistic priorities will be extracted based on Table 1 for the importance of all the criteria.

In summary, here we will have these steps, respectively.

According to the experts' opinion, the importance of every criterion is determined based on the optimistic, average and pessimistic opinions.
Regarding part a, average for all opinions are calculated
Based on the demanded horizons, a linear forecasting equation is calculated
By taking advantage of center of gravity method which turns a fuzzy number as a(l,*m*,*u*) to a defuzzified number as: a crisp = $l + [(m - l) + (u - l)]/3$, final ranking of the criteria for different horizons are clarified.

TODIM Method

The TODIM method is a discrete multi-criteria method based on the prospect theory. TODIM is an experimental method that expands based on the treatment of people in risky conditions. In this method, pairwise comparisons associated with the elimination of occasional inconsistency will be regarded. Thanks to the hierarchy of criteria, interdependence relationship among the alternatives, verbal value judgments will be formed. TODIM function shape is identical to the prospect theory's gain and loss function. The shape and the value function are depicted in Fig. 3 and Eq. (6), respectively.

Table 1 Linguistic variable in triangular fuzzy numbers

Linguistic terms	Fuzzy scores
Very poor (VP)	(0, 0, 1)
Poor (P)	(0,1,3)
Medium poor (MP)	(1,3,5)
Fair (F)	(3,5,7)
Medium good (MG)	(5,7,9)
Good (G)	(7,9,10)
Very good (VG)	(9,10,10)

$$v(x) = \begin{pmatrix} x^{\alpha} & \text{if } x > 0 \\ -\theta(x)^{\beta} & \text{if } x < 0 \end{pmatrix}. \quad (6)$$

In Eq. (6), α and β are parameters related to gain and loss, respectively. The parameter θ shows the risk factor which must be greater than 1. As obvious in Fig. 3, the prospect value function is concave and S shape. According to Gomes et al (2009), there could be *n* alternatives which would be evaluated based on the qualitative or quantitative criteria. In this model, we fix one of these criteria as a reference. Steps of the TODIM method are as follows:

In order to evaluate the alternatives based on the criteria, the experts are asked to assess the contribution of each alternative *I* for the qualitative criterion *c*.
The matrix of the evaluation will be prepared after all the alternatives have been assessed regarding the criteria.
To get the normalized and standard comparison, the qualitative criteria evaluated on a verbal scale are transformed into a cardinal scale based on the Gomes method (Gomes et al., 2009). This normalization procedure would be performed by the division of the value for every alternative by the sum of all alternatives. Finally, a matrix will be extracted, which would present normalized alternatives' scores related to the criteria.
$P = [Pnm]$, where *n* indicates the number of alternatives and *m* referred to the number of criteria. A schematic figure is depicted in Table 2.
Calculating the partial dominance matrices.
The decision-makers must specify a specific criterion r as the reference one, for the calculations according to the relative importance assigned to each criterion. Normally, the highest priority criterion would be selected as the reference. Thus, w_{rc} is the weight of criterion c divided by the weight of the reference criterion r.
Calculating the final dominance matrices
Calculating the final dominance of each alternative *Ai* over alternative *Aj*, now incorporated to prospect theory, is illustrated by Eq. (7). That measurement is given by a sum of relative gain and loss.

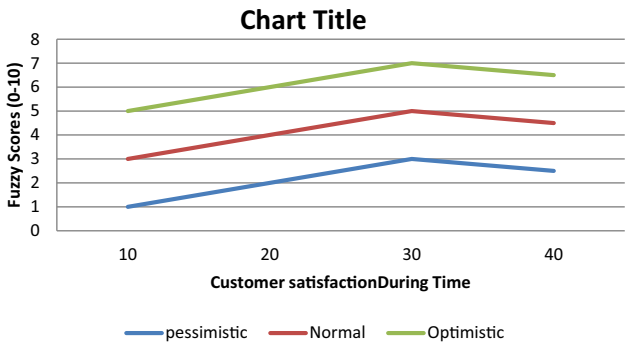


Fig. 2 Fuzzy time function (FTF)

Depicting the gain and the loss part of the value function by Eq. (8), where $\delta(A_i, A_j)$ defines the dominance of Ai over Aj

$$\delta(A_i, A_j) = \sum_{c=1}^{m} \phi_c(A_i, A_j), \quad \forall i, j \tag{7}$$

$$\phi_c = \begin{pmatrix} \sqrt{w_{rc}(P_{ic} - P_{jc}) / \sum_{c=1}^{m} w_{rc}}, & \text{if } P_{ic} > P_{jc} \\ 0 & \text{if } P_{ic} = P_{jc} \\ (-1/\theta)\sqrt{\left(\sum_{c=1}^{m} w_{rc}\right)(P_{ic} - P_{jc})/w_{rc}}, & \text{if } P_{ic} < P_{jc} \end{pmatrix}. \tag{8}$$

Here, m shows the number of criteria and c is every criterion. For $c = 1,\ldots,m$, w_{rs} refers to division of w_c by w_r, where r is the reference criterion; P_{ic} and P_{jc} illustrate the performance of alternative A_i, A_j related to c; θ is the attenuation index of the losses. $\phi_c(A_i, A_j)$ illustrates the contribution of the criterion c in the function $\delta(A_i, A_j)$.
In a comparison of alternative i with alternative j, if $(P_{ic} - P_{jc}) > 0$, the gain function will be the first part of Eq. (8). And if $(P_{ic} - P_{jc}) = 0$, there is no loss or gain and elsewhere there would be a specific loss which is illustrated in the last part of Eq. (8). Taking advantage of the function $\phi_c(A_i, A_j)$ actually gives an adjustment of the data to the value function in the prospect theory. After calculating the diverse partial matrices of dominance, the final dominance matrix of the general element $\delta(A_i, A_j)$ is obtained by the sum of the elements of the diverse matrices.

Table 2 Normalized alternatives' scores against criteria

	*C*1	*C*2	…	*Cm*
*A*1	*P*11	*P*12	…	*P*1*m*
*A*2	*P*21	*P*22	…	*P*2*m*
…	…	…	…	…
An	*An*1	*An*2	…	*Anm*

Preparing the final rank of the alternatives:

At the end, Eq. (9) determines the final rank of the alternatives.

$$\xi_i = \frac{\sum_{j=1}^{n} \delta(A_i, A_j) - \min \sum_{j=1}^{n} \delta(A_i, A_j)}{\max \sum_{j=1}^{n} \delta(A_i, A_j) - \min \sum_{j=1}^{n} \delta(A_i, A_j)}. \tag{9}$$

Interval-Value Triangular Fuzzy Numbers

In the fuzzy set theory, we often encounter triangular or trapezoidal fuzzy numbers. The TFN is based on a three-value judgment: the minimum, the mean and the maximum possible values a_1, a_2, a_3, respectively. But by the ordinary fuzzy number, some of the linguistic terms and uncertainty in the linguistic notions would not be covered clearly. To overcome these necessities and adding uncertainty in the fuzzy sets. Interval-valued fuzzy sets were suggested for the first time by Türkşen & Bilgiç (1996). The interval TFN values which will be applied in our research contain five parameters; on the other hand, these are two TFN numbers that have the same middle point. In this survey, all the experts will be asked about the advantage of the alternatives in comparison to each other, which brings more vagueness and inconsistency in their notions. By using this type of TFN as interval TFN (ITFN) this concern will be eliminated. Table 3 illustrates all the linguistic terms related to interval TFN.

$$c_{ij} \text{ expressed as an interval - value TFN where } C_{ij} = \left[(a_1, a_1'), a_2, (a_3, a_3')\right] \tag{10}$$

and normalized performance rating is:

$$\widetilde{r}_{ij} = \left[\left(\frac{\overline{a_{ij}}}{d_j^+}, \frac{\overline{a'_{ij}}}{d_j^+}\right), \frac{b_{ij}}{d_j^+}, \left(\frac{\overline{a'_{ij}}}{d_j^+}, \frac{\overline{a_{ij}}}{d_j^+}\right)\right], \quad i = 1, 2, \ldots m, \; j = 1, 2, \ldots, n$$
$$\widetilde{r}_{ij} = \left[\left(\frac{\overline{a_j}}{d_{ij}}, \frac{\overline{a_j}}{d'_{ij}}\right), \frac{\overline{a_j}}{b_{ij}}, \left(\frac{\overline{a_j}}{a'_{ij}}, \frac{\overline{a_j}}{a_{ij}}\right)\right], \quad i = 1, 2, \ldots m, \; j = 1, 2, \ldots, n \tag{11}$$

$$d_j^+ = \max\{c_{ij}, i = 1, 2, \ldots m\} \text{ and } a_j^- = \min\{a_{ij}, \quad i = 1, 2, \ldots, m\})$$
$$\text{where} \quad r_{ij} = \left[\left(l_{ij}, l'_{ij}\right); m_{ij}; \left(u_{ij}, u'_{ij}\right)\right], R = [r_{ij}]_{m \times n}$$
$$R_0 = (r_{01}, r_{02}, \ldots, r_{on}) = [(1,1); 1; (1,1)][(1,1); 1; (1,1)]....[(1,1); 1; (1,1)] \tag{12}$$

The distance between the reference value and each comparison value, here in the case of interval fuzzy triangular numbers would be expressed as follows:

Table 3 Corresponding I-TFNS for linguistic preferences

Linguistic terms	Fuzzy scores
Very poor (VP)	[(0, 0), 0, (1, 1.5)]
Poor (P)	[(0, 0.5), 1, (2.5, 3.5)]
Medium poor (MP)	[(0, 1.5), 3, (4.5, 5.5)]
Fair (F)	[(2.5, 3.5), 5, (6.5, 7.5)]
Medium good (MG)	[(4.5, 5.5), 7, (8, 9.5)]
Good (G)	[(5.5, 7.5), 9, (9.5, 10)]
Very good (VG)	[(8.5, 9.5), 10, (10, 10)]

$$\begin{aligned}\delta_{ij}^{(1)} &= \sqrt{(1/3)\left[\left(l'_{ij}-1\right)^2+\left(m_{ij}-1\right)^2+\left(u'_{ij}-1\right)^2\right]}\\ \delta_{ij}^{(2)} &= \sqrt{(1/3)\left[\left(l_{ij}-1\right)^2+\left(m_{ij}-1\right)^2+\left(u_{ij}-1\right)^2\right]}\end{aligned} \tag{13}$$

By taking the advantage of the above distance, the difference between reference values and a specific value would be specified. Therefore, a new interval TFN for every TFN will be illustrated as $\delta ij = [\delta^{(1)}ij, \delta^{(2)}ij]$.The forthcoming process by Zhang et al. (2011) will illustrate the weight of the alternatives in comparison with the specific criteria:

$$\begin{aligned}\xi_{ij}^{(1)} &= \frac{\delta_{\min}^{(1)}+\zeta\delta_{\max}^{(1)}}{\delta_{ij}^{(1)}+\zeta\delta_{\max}^{(1)}}\\ \xi_{ij}^{(2)} &= \frac{\delta_{\min}^{(2)}+\zeta\delta_{\max}^{(2)}}{\delta_{ij}^{(2)}+\zeta\delta_{\max}^{(2)}}\end{aligned} \tag{14}$$

$$\begin{aligned}&\delta_{\max}^{(1)} = \max_{ij}\delta_{ij}^{(1)},\ \delta_{\max}^{(2)} = \max_{ij}\delta_{ij}^{(2)}\\ &\delta_{\min}^{(1)} = \min_{ij}\delta_{ij}^{(1)},\ \delta_{\min}^{(2)} = \min_{ij}\delta_{ij}^{(2)}\\ &\xi = 0.5\end{aligned} \tag{15}$$

finally

$$w_{ij} = \frac{\xi_{ij}^{(1)}+\xi_{ij}^{(2)}}{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\xi_{ij}^{(1)}+\xi_{ij}^{(2)}\right)} \tag{16}$$

which would be the importance of the alternative i in comparison with criterion j.

Problem Solving Method

Regarding the above-mentioned sections, here we summarized our steps to find sustainable suppliers in dairy industries as follows:

Step 1 An appropriate survey on the criteria and subjects related to sustainability and special topics related to dairy in literature review accompanied with getting experts' opinions and finding the most significant criteria.

Step 2 Collect the DM opinions with linguistic variables and define FTF for each important criterion based on the specific horizon times.

Step 3 According to fuzzy time function, prepare the appropriate fuzzy timeline for forecasting horizons.

Step 4 Applying defuzzification methods such as the center of gravity, and normalization weights for the criteria during the specified time, the horizon will be done.

Step 5 Gather expert opinions on alternatives regarding criteria by taking advantage of interval TFN, normalization.

Step 6 Based on the weight vector for the criteria on step 3 and changing the linguistic interval triangular fuzzy numbers in step 4, here TODIM method would be applied to find the final weights of the alternatives. According to more than a weight vector which is created on step 3 based on the fuzzy time function (FTF), here we would have more than one priority set for alternatives.

Illustrative Example

Here, in this section, we discuss a real case study in the private and limited dairy industries in Iran. Here, we encounter four dairy companies which will be mentioned as A1 to A4 in the forthcoming part. All the information about the previous survey in the literature which are completely illustrated in "Sustainability of the Suppliers in the Dairy Industries" section as sustainability of the suppliers in the dairy industries by Bourlakis et al. (2014), Luthra et al. (2017) and Yawar and Kauppi (2018) have been presented for the experts and managers and some of the senior engineers in these companies. After a survey on literature review, summarizing managerial attitudes and experts' opinions by dispensing questionnaires and even some direct sessions, these nine criteria have been concluded as the first level. Major specifications for *sustainable–flexible* supplier selection are illustrated in Table 4.

Step 1

Table 4.

Step 2

In this stage, we accumulate all the experts' opinions and get their vague notions and attitudes by TFN for the specific time horizons and summarize them in Table 5.

Table 4 A summary of sustainable–flexible criteria

Target	Sub-criteria	Detailed criteria
Sustainability–flexibility	Economic	Total profit (*C*1)
		Quality (*C*2)-quality of production/warehousing/packaging/delivering and cold transit system
		Flexibility: The supplier must be flexible enough to withstand market changes (*C*3)
	Environmental	Environmental management system (*C*4)
		Pollution reduction (*C*5)
		Green footprint (*C*6)
	Social	Information disclosure (*C*7)
		Internal supportive activities/health and safety of HR (*C*8)
		Local community impact (*C*9)

Table 5 Experts attitudes on criteria through time horizon

Criteria	Short term (6 months)	Mid-term (18 months)	Long term (30 months)
*C*1	VG,G,G,F	F,F,G,MG	MG,MG,MG,F
*C*2	VG,MG,F,F	G,F,G,MG	VG,VG,MG,G
*C*3	MG,MP,VP,MG	P,F,VP,MG	MG,MG,MG,F
*C*4	MG,P,P,P	MP,P,F,MG	MG,MG,MG,G
*C*5	VP,P,P,P	MP,P,P,G	MG,G,F,G
*C*6	VP,VP,VP,VP	F,MP,MP,P	G,VG,F,G
*C*7	VP,P,VP,MP	F,MP,F,VP	G,G,G,VG
*C*8	F,MP,G,F	G,F,MP,G	MG,G,G,VG
*C*9	MP,MP,P,F	F,F,G,VG	MG,G,G,VG

In our data gathering system, we used 4 experts' notions so, in every cell of Table 5, four different fuzzy terms are presented. Here, we aim to predict and establish our appropriate weights for the criteria during these time horizons (milestones) to sign the contract with the suppliers. According to the increasing attention to the environmental and social responsibilities, the weights of the criteria would be changed. By means of fuzzy time function, the capability of having fluctuation and variation in the criteria' weights during the time for different periods will be cleared. Therefore, we get opinions based on Table 5. During the FTF calculation, we define our time functions and finally, we will have a Table 6 for the median fuzzy opinions of our experts.

Step 3

Based on the data in Table 6, here we can create our linear equations related to them every time horizons discreetly. Here, for the first criterion, two linear equations should address our experts treatments during every specific timeline from 6 months up to 18 months and 18 months up

Table 6 Summary of the experts results in TFN

	SHORT $T = 6$			MIDDLE $T = 18$			LONG $T = 30$		
*C*1	6.5	8.25	9.25	4.5	6.5	8.25	4.5	6.5	8.5
*C*2	5	6.75	8.25	5.5	7.5	9	7.5	9	9.75
*C*3	2.75	4.25	6	2	3.25	5	7.5	9	9.75
*C*4	1.25	2.5	4.5	2.25	4	6	5.5	7.5	9.25
*C*5	0	0.75	2.5	2	3.5	5.25	5.5	7.5	9
*C*6	0	0	1	1.25	3	5	6.5	8.25	9.25
*C*7	0.25	1	2.5	1.75	3.25	5	7.5	9	10
*C*8	3.5	5.5	7.25	4.5	6.5	8	7	8.5	9.75
*C*9	1.25	3	5	5.5	7.25	8.5	7	8.75	9.75

Table 7 Triangular fuzzy numbers based on FTF

	$T = 12$			$T = 24$		
*C*1	5.5	7.375	8.75	4.5	6.5	8.375
*C*2	5.25	7.125	8.625	6.5	8.25	9.375
*C*3	2.375	3.75	5.5	4.75	6.125	7.375
*C*4	1.75	3.25	5.25	3.875	5.75	7.625
*C*5	1	2.125	3.875	3.75	5.5	7.125
*C*6	0.625	1.5	3	3.875	5.625	7.125
*C*7	1	2.125	3.75	4.625	6.125	7.5
*C*8	4	6	7.625	5.75	7.5	8.875
*C*9	3.375	5.125	6.75	6.25	8	9.125

Table 8 Final ranks of criteria for different horizons

	$T = 12$			$T = 24$		
	def.weight	Nor.weight	Rank	def.weight	Nor.weight	Rank
*C*1	7.21	0.19	1	6.46	0.11	4
*C*2	7	0.18	2	8.04	0.14	1
*C*3	3.88	0.1	5	6.08	0.1	5
*C*4	3.42	0.09	6	5.75	0.1	5
*C*5	2.33	0.06	7	5.46	0.09	8
*C*6	1.71	0.04	9	5.54	0.09	8
*C*7	2.29	0.06	7	6.08	0.1	5
*C*8	5.88	0.15	3	7.38	0.13	2
*C*9	5.08	0.13	4	7.79	0.13	2

Table 9 Final crisp weights for interval TFN values

	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9
*A*1	0.02458	0.026	0.02677	0.03495	0.03556	0.03325	0.02283	0.02258	0.03467
*A*2	0.02617	0.0228	0.026	0.026	0.03391	0.02179	0.02347	0.02354	0.01821
*A*3	0.02412	0.02155	0.02364	0.02617	0.0242	0.02333	0.02051	0.03304	0.03467
*A*4	0.0242	0.03495	0.0373	0.03	0.03	0.02637	0.03603	0.03391	0.03295

to 30 months, respectively. Here, for the first part, we encounter two pints (6, 6.5) and (18, 4.5), respectively, which brings us the lower(pessimistic) fuzzy part of our triangular fuzzy number for month 12 based on the linear equation between these two points as 5.5. In the same way, we can calculate all the rows and columns for the pessimistic, average and optimistic for all the C1 up to C9. All the data are depicted in Table 7 for time horizons, 12 and 24 months.

Step 4

Hereby applying defuzzification method and normalization, we finalized our weights for the criteria regarding time horizons = 12, 24, respectively, in Table 8.

We took advantage of the center of gravity method which turns a fuzzy number as: a(l,*m*,*u*) to a defuzzified number as: $a_{\text{crisp}} = l + [(m - l) + (u - l)]/3$.

As it is obvious here, regarding the changes in experts' notions, in Tables 5 and 6 for different time horizons and applying the fuzzy time function we encounter some changes in the priority of the criteria.

Step 5

In this step according to the interval triangular fuzzy numbers method which is illustrated with Zhang, we got experts' opinions according to the status of the alternative company regarding every criterion (c1–c9).

Here, you will find in Tables 9, 14 and 15 (see "Appendix" for Tables 14, 15), interval triangular fuzzy

Table 10 Normalized comparison table regarding criteria

	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9
*A*1	0.248	0.247	0.235	0.298	0.288	0.317	0.222	0.2	0.288
*A*2	0.264	0.217	0.229	0.222	0.274	0.208	0.228	0.208	0.151
*A*3	0.243	0.205	0.208	0.223	0.196	0.223	0.199	0.292	0.288
*A*4	0.244	0.332	0.328	0.256	0.243	0.252	0.35	0.3	0.273

Table 11 Detail data related to $\delta(A_i, A_j)$ for $T = 12$

$T = 12$	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9
Fi(*A*1,*A*2)	− 0.2901861	0.0734715	0.02448792	0.0827331	0.02899285	0.06610553	− 0.3161177	− 0.231006	0.13343558
Fi(*A*1, *A*3)	0.03082253	0.08693266	0.05194671	0.082187	0.07432258	0.0613887	0.03716129	− 0.7833793	0
FI(*A*1,*A*4)	0.06164506	− 0.6873076	− 0.96464	0.06150312	0.05197962	0.05104829	− 1.460085	− 0.8167294	0.04415267
FI(*A*2,*A*3)	0.06316739	0.04646746	0.04581269	− 0.1053726	0.06843435	− 0.6116755	0.04172784	− 0.7485448	− 1.0267127
FI(*A*2,*A*4)	0.06164506	− 0.7994487	− 0.9952711	− 0.6144223	0.04314274	− 1.0476152	− 1.4254535	− 0.7833793	− 0.9688768
FI(*A*2,*A*1)	0.05513702	− 0.4083216	− 0.2450188	− 0.9186166	− 0.4828777	− 1.6488787	0.01898027	0.03463114	− 1.0267127
FI(*A*3,*A*4)	− 0.0725465	− 0.8401243	− 1.0957575	− 0.6053192	− 0.8847531	− 0.8505003	− 1.5858482	− 0.231006	0.04415267
FI(*A*3,*A*1)	− 0.162219	− 0.4831326	− 0.5197634	− 0.9125531	− 1.2378473	− 1.5312263	− 0.6189236	0.11743992	0
FI(*A*3,*A*2)	− 0.33245	− 0.2582452	− 0.4583882	0.00949014	− 1.1397785	0.02452281	− 0.6949797	0.11221772	0.13343558
FI(*A*4,*A*1)	− 0.1450931	0.12367097	0.09640902	− 0.6828922	− 0.8657239	− 1.2733041	0.08766613	0.12243958	− 0.3397303
FI(*A*4,*A*2)	− 0.324438	0.14384913	0.09947038	0.05533653	− 0.718545	0.04200015	0.0855868	0.11743992	0.125919
FI(*A*4,*A*3)	0.01378426	0.1511681	0.10951329	0.05451669	0.05312217	0.03409758	0.09521718	0.03463114	− 0.3397303

Table 12 Detail data related to $\delta(A_i, A_j)$ for T = 24

$T = 24$	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9
Fi(*A*1,*A*2)	− 0.37942	0.0651313	0.0246124	0.0875961	0.0356778	0.0995515	− 0.24378	− 0.246779	0.134152
Fi(*A*1,*A*3)	0.0235736	0.0770643	0.0522107	0.0870179	0.0914594	0.0924482	0.0481883	− 0.836868	0
FI(*A*1,*A*4)	0.0210848	− 0.775319	− 0.959762	0.0651182	0.0639647	0.076876	− 1.12597	− 0.872496	0.0443897
FI(*A*2,*A*3)	0.0483114	0.0411926	0.0460455	− 0.099523	0.0842135	− 0.406173	0.0541099	− 0.799655	− 1.02123
FI(*A*2,*A*4)	0.0471471	− 0.90182	− 0.990238	− 0.580312	0.0530903	− 0.695652	− 1.099264	− 0.836868	− 0.963703
FI(*A*2,*A*1)	0.0421697	− 0.460608	− 0.24378	− 0.867619	− 0.392401	− 1.094911	0.0246124	0.0324177	− 1.02123
FI(*A*3,*A*4)	− 0.094855	− 0.947705	− 1.090216	− 0.571714	− 0.718976	− 0.564761	− 1.222955	− 0.246779	0.0443897
FI(*A*3,*A*1)	− 0.212102	− 0.544999	− 0.517135	− 0.861892	− 1.005911	− 1.016786	− 0.477294	0.1099336	0
FI(*A*3,*A*2)	− 0.43468	− 0.291314	− 0.45607	0.010048	− 0.926217	0.0369301	− 0.535946	0.1050452	0.134152
FI(*A*4,*A*1)	− 0.18971	0.1096323	0.096899	− 0.644981	− 0.703513	− 0.845517	0.1136797	0.1146138	− 0.337916
FI(*A*4,*A*2)	− 0.424204	0.1275199	0.099976	0.0585892	− 0.583911	0.06325	0.1109834	0.1099336	0.126595
FI(*A*4,*A*3)	0.0105424	0.134008	0.1100699	0.0577211	0.0653707	0.0513492	0.1234714	0.0324177	− 0.337916

numbers, normal data regarding I-TFN, and the final crisp weights based on Eq. (16), respectively.

Step 6

In this step, Table 10 illustrates all the normalized data regarding criteria c1…c9.

Regarding Eqs. (7) and (8), we have Tables 11 and 12 for $T = 12$, $T = 24$, respectively.

According to Eq. (9). All the ξ_i related to two separate $T = 12$ and $T = 24$ will be calculated and is summarized in Table 13.

Table 13 Alternative ranking based on the criteria and different time horizons

Alternative	ξ_i		Normalized weight and Rank, $T = 12$		Normalized weight and Rank, $T = 24$	
	T = 12	T = 24	Weight (%)	Rank	Weight (%)	Rank
*A*1	− 0.2384	− 0.254	18	2	9	2
*A*2	− 1.5915	− 1.541	3	3	1	3
*A*3	− 2.607	− 2.253	2	4	1	3
*A*4	− 0.542	− 0.025	78	1	89	1

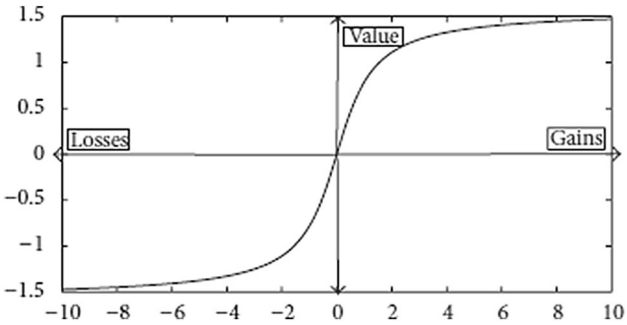


Fig. 3 TODIM value function

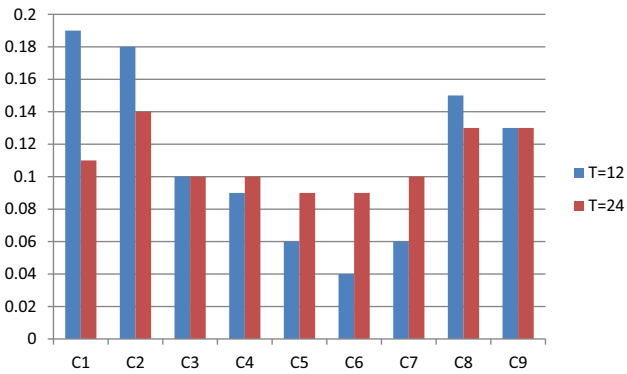


Fig. 4 Variation of the criteria importance during the time horizon (T = 12,24)

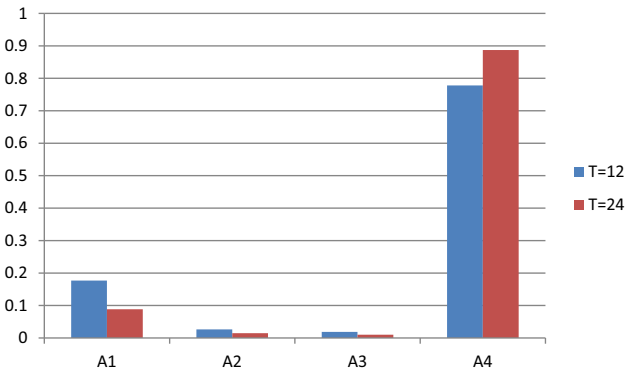


Fig. 5 Status of the companies during the time

Sensitivity Analysis and Managerial Insight

Up to now, we surveyed experts opinions on criteria and expert notions on alternatives by interval TFN. By utilization of Eqs. 10–14, our expert's notions are expressed in Table 15. Furthermore through Eqs. 15–16, our final ranking for alternatives has been clarified separately for time horizons as, T = 12, T = 24.

In this section, some more detail according to the final solution and managerial insight will be clarified as follows:

Two completely separate weights have been calculated for the criteria, which could be utilized for future decision making and contracts with the suppliers.

These distinctive weighting for the criteria which have been performed based on the TFN accompanied with FTF, would be appropriate for the managers to find the best investment priorities for the organizations and assessment of suppliers in the coming years

Even though in our real case problem, the final ranking of the suppliers have not been modified, but as it is integrally obvious from our future weights that, investment and even having a closer partnership with the *A*4, would be recommended as its grade will empower in the next year according to the changes in the criteria weights and some new significant topics in the future. These merits for company 4(*A*4) will come through the advantageous of the social responsibility and related criteria in this issue and social responsibilities of the companies.

In the following plot, the modifications and the status for the T = 12, T = 24 will be depicted (Fig. 4).

As it is clear from Fig. 5, the status of the *A*4 will be empowered in the coming years and also the status of the *A*1, *A*2, *A*3 will be decreased, which means that working with *A*2, *A*3 will not be reasonable even for T = 12.

Conclusion

Sustainability plays an important role in the prosperity of enterprises, companies and plants. One of the critical points through this line of success would be suppliers. Here, in

this study, we focus on the sustainability factors in the dairy industries in Iran for the small and medium companies. Here, we practiced to find the vital criteria in the coming years and in comparison with today during literature review and expert notions. In this survey, we finalized our mentioned criteria as total profit, quality which consist of the quality of production, warehousing, cold transfer, flexibility, in environmental criteria, environmental management system, pollution reduction, green footprint, and in social section, information disclosure, internal supportive activities/health and safety of human resources and local community impact.

According to these criteria and applying the fuzzy time function, different weights regarding two-time horizons ($T = 12$, $T = 24$) have been prepared for the criteria which acquire worthwhile information for the executives of the companies. As receiving opinions in linguistic, verbal and qualitative factors increase uncertainty, we took the advantage of the interval triangular fuzzy (I-TFN) numbers and record all the experts opinions for comparisons of four selected dairy suppliers on finalized criteria. Finally, as TODIM is a helpful means in multi-criteria decision making particularly by taking advantage of the prospect theory and utilization of loss and gain function in its process, the final priorities of the suppliers have been clarified. This model will demonstrate a mathematical structure for the companies to prioritize their plans and programs for the assessment, qualification, promotion and auditing and signing contracts/renew contracts with the suppliers based on their future status. This status will be addressed by the ranking of the suppliers in the future according to the value and importance of every criterion in the future.

Acknowledgements I would like to thank the esteemed reviewers for their valuable and unique contribution by providing critical feedback and comments to improve the manuscript. I would like to thank the editors and editor-in-chief for their encouragement and framework for keeping the paper in shape.

Declarations

Conflict of interest The author declares that he has no conflict of interest.

Appendix

See Tables 14 and 15.

Table 14 Interval TFN for alternatives based on criteria

	*C*1					*C*2					*C*3					*C*4					*C*5				
*A*1	4.5	5.5	6	6.5	7.5	5.5	6	6	6.5	7.5	5.5	6	6.5	6.5	7.5	6.5	7	8	8.5	9	7	7.7	7.5	8	8.5
*A*2	4.5	5.5	7	7	7.5	4.5	5	5.5	6	6.5	5.5	6	6	6.5	7.5	5.5	6	6	6.5	7.5	6.5	7	7.7	8	8.5
*A*3	4	5.5	6	6.5	7.5	3.5	4.5	5	6.5	7	4.5	5	5.5	7	7.5	4.5	5.5	7	7	7.5	4.5	5	6	7	7
*A*4	3.5	5	6.5	7	8	6.5	7	8	8.5	9	7	7.5	8	8.5	9	6	6.5	7	7.5	8	6	6.5	7	7.5	8

	*C*6					*C*7					*C*8					*C*9				
*A*1	6.5	7	8	8.5	9	3.5	5	6.5	7	8	3.5	5	6.5	7	8	7	7.5	8	8.5	9
*A*2	5.5	6	6	6.5	7.5	5.5	6	6	6.5	7.5	5.5	6	6	6.5	7.5	4.5	5	5.5	6	6.5
*A*3	4.5	5.5	7	7	7.5	4.5	5	5.5	6	6.5	7	7.7	7.5	8	8.5	7	7.5	8	8.5	9
*A*4	6	6.5	7	7.5	8	7	7.5	8	8.5	9	6.5	7	8	8.5	9	6.5	7	8	8.5	9

Table 15 Normalized data

	*C*1					*C*2					*C*3					*C*4					*C*5				
*A*1	0.5	0.6	0.7	0.7	0.8	0.6	0.7	0.7	0.7	0.8	0.6	0.7	0.7	0.7	0.8	0.7	0.8	0.9	0.9	1	0.8	0.9	0.8	0.9	0.9
*A*2	0.5	0.6	0.8	0.8	0.8	0.5	0.6	0.6	0.7	0.7	0.6	0.7	0.7	0.7	0.8	0.6	0.7	0.7	0.7	0.8	0.7	0.8	0.9	0.9	0.9
*A*3	0.4	0.6	0.7	0.7	0.8	0.4	0.5	0.6	0.7	0.8	0.5	0.6	0.6	0.8	0.8	0.5	0.6	0.8	0.8	0.8	0.5	0.6	0.7	0.8	0.8
*A*4	0.4	0.6	0.7	0.8	0.9	0.7	0.8	0.9	0.9	1	0.8	0.8	0.9	0.9	1	0.7	0.7	0.8	0.8	0.9	0.7	0.7	0.8	0.8	0.9

	*C*6					*C*7					*C*8					*C*9				
*A*1	0.7	0.8	0.9	0.9	1	0.4	0.6	0.7	0.8	0.9	0.4	0.6	0.7	0.8	0.9	0.8	0.8	0.9	0.9	1
*A*2	0.6	0.7	0.7	0.7	0.8	0.6	0.7	0.7	0.7	0.8	0.6	0.7	0.7	0.7	0.8	0.5	0.6	0.6	0.7	0.7
*A*3	0.5	0.6	0.8	0.8	0.8	0.5	0.6	0.6	0.7	0.7	0.8	0.9	0.8	0.9	0.9	0.8	0.8	0.9	0.9	1
*A*4	0.7	0.7	0.8	0.8	0.9	0.8	0.8	0.9	0.9	1	0.7	0.8	0.9	0.9	1	0.7	0.8	0.9	0.9	1

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Key Questions

1. What would be the advantages of a time-dependent system in supplier selection?
2. What would be the aggregation of flexibility and sustainability in the supplier selection system in Dairy industries?



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