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Research Article

THE MOST SUITABLE MOBILE RFID READER SELECTION BY USING INTERVAL TYPE-2 FUZZY TOPSIS METHOD

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ABSTRACT

The novelties, innovations and ease of practical applications that the technology brings as it develops have become dispensable parts of our daily life. RFID technology, one of these novelties, forms the basis for new coding, storage and transmission systems; as well as helping businesses to solve the issues that they encounter in controlling data or the troubles faced due to lack of information. RFID applications in supply chain management insure several advantages; providing more accurate and faster communication, ensuring traceability on dealers networks and developing control mechanisms by ensuring real-time information transmission between logistics activities and supply chain management. RFID readers, one of the components of the RFID system, are the cores of RFID systems, and they all have unique and distinct properties that distinguish from each other. Prior to the creation of an RFID system, the selection of the suitable RFID readers that meet all the needs is the leading important issue.
In this study, the aim is to select the most suitable mobile RFID reader for a business that aims to organize warehouse transactions in supply chain management and reduce the errors in shipping operations. Since there are multiple criteria in selection of the RFID readers, the problem is considered as a multi-criteria decision making problem and the Interval Type-2 Fuzzy TOPSIS method, which uses type-2 fuzzy sets, is used for solution, as it is more effective in solving the uncertainties. After determining the effective criteria and alternatives in selection of mobile RFID reader, by adopting the steps of the method, "RFID Reader-2" which is superior to other alternatives in terms of "Memory", "Read Distance" and "Drop Spec.", has been chosen as the most suitable mobile RFID reader. Finally, the results that are obtained in the study are evaluated and suggestions for future studies are made.
Keywords: RFID, type-2 fuzzy sets, fuzzy TOPSIS, supply chain.

1. INTRODUCTION

The use of wireless technologies has become quite common in our daily lives. Basically, wireless communication uses many areas such as WiFi, Ultra Wideband (UWB), ISM BAND RADIO, Bluetooth, NFC, Infrared (IR) and ZigBee. This development of wireless systems has also been found in areas such as war technologies, applications requiring information confidentiality, production activities. RFID (Radio Frequency Identification) technology, which

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was develop ed for use in war technology in the mid-20th century, also took place in wireless systems. The rapid development of this technology, which was developed to describe physical objects, also made significant contributions to production activities. Today, RFID systems that are growing are preferred in terms of production activities and supply chain cost and production time. RFID systems can be used as an alternative to barcode systems [1].

The first work that could be counted as RFID milestones was published by Harry Stockman in October 1948 as "Communication By Means of Reflected Power" [2]. In Stockman's article, "Some basic problems of reflective power communication must be solved before research and development is done in this regard." After 1930's and 1940's radar and radio developments, a complete breakthrough was made for RFID in 1950's. With the use of RFID in aviation and applications to distinguish IFF (Identification Friend or Foe) aircraft, many technologies have begun to be discovered [3]. At the beginning of the 1970s, Sensormatic and Checkpoint companies presented their first commercial applications, specifically EAS (Electronic Article Surveillance), developed against anti-theft [4]. EAS systems, which are cheap and simple passive labels, especially for use in apparel stores and libraries for battery-free use, are the basis of today's RFID applications. In the 1980s, RFID applications spread to many areas. In Europe, animal tracking systems have become very popular, and in the case of countries such as Italy, France, Portugal and Norway, toll roads are equipped with RFID. The 1990s are a significant period for RFID. In Oklahoma, pay-per-ride system tools opened in 1991 introduced the possibility of a quick transition [5]. Developments continued until 1990, when RFID tags were reduced to a single integrated circuit size with the development of integrated circuits. However, inter-national standards have been established in frequency spectrum allocation [6]. In 2000, RFIDs began to be produced in miniature sizes. Shrinking RFIDs can be incorporated into many systems. The cost of RFID components has decreased. Custom switching and coding systems have been developed. Over the years, major retail chains and US government agencies such as the Department of Defense (DoD) have begun taking sanctions decisions to use RFID systems with their suppliers. As a result, the real adventure of RFID as a radar that started with the Second World War has come to a different point today and continues to develop and change today [7].

Factors such as the development of RFID systems, the facilities provided by life-saving systems, and the cost have increased the number of RFID applications. There are some common application areas. Airport baggage tracking [8], military applications [9], rapid packaging, ticket management, transportation and logistics management, security applications, waste management, postal services, electronic goods tracking (EAS), retail clothing sales, anti-theft protection, home monitoring and management, vehicle locking system, vehicle anti-theft protection [10], boxed / packaged food, pharmaceuticals and medical devices. applications made in RFID systems, devices, staffing, customer tracking, inventory tracking, paper record and forgery, hospitals and medical institutions, jewelery and antiques, libraries, parking systems, vehicle tracking systems, highway and bridge toll systems, live animal tracking systems a few examples [11].

One of the most important elements of the RFID system is the components in the system. The components used in RFID systems can be examined in three parts:

Label: The component, which is referred to as the label, is generally the part which carries the desired important data. This part typically consists of a microchip for storing data and a payload which is used to transmit the data to the reader via electromagnetic waves at radio frequency when desired. The microchip and antenna are stored in a common cover. This cover can be generally ceramic, plastic, epoxy or glass. The most basic features used in labeling tags are the source of power they use. According to this feature, labels are divided into three classes as active, passive and semi-active.

Database: In an RFID system, the reader and label as well as a reader-dependent database can be found. When the reader sends a sign to the tag for interrogation, the tag wakes up by receiving this signal and sends back its data back to the reader. The reader retrieves this answer, which is the tag's content, and sends it to the attached database. This data can be saved in the database or its existence can be queried in the database [12].

Reader: In an RFID system, the reader's task is to warn the tags using the antenna, read the data contained in the tags, and send that data to a server computer via a network [13]. Readers also have memory and can store data in this memory. From this point of view, the reader concept should not be misleading. The reader may be stable or mobile, depending on the application being performed. The channel from the reader to the ethics is called the "forward channel" and the channel from the tag to the reader is called the "backward channel" [14]. In the forward channel, the reader sends an electromagnetic signal to the label, waking it up first if the tag is inactive or in sleep mode. If the label is inactive, the data containing the contents of the label is sent back to the reader via back-scatter and the reader either saves the data either on its own or in the database of a computer running on its own background. If the label is active, it is possible to do some calculations (such as an encryption algorithm), and the generated data is sent back to the reader.

It has become critical for companies to have information about the current status of a product, its processes and the history of transactions in the process. A particular state of an item includes certain characteristics such as a specific identity, exact position, physical state, and so on. An effective and efficient information tracking system enables a decision maker to instantly intervene in targeted situations to reduce operational costs and increase productivity [15]. The most important elements of the RFID system are shown in Figure. 1.

a) RFID label **b) Fixed RFID reader** **c) Mobile RFID reader**

Figure 1. Most important elements of the RFID system

RFID technology can support real-time control of goods in the supply chain, work in process, and finished product. It can increase the degree of automation, reduce the likelihood of error, and improve the visibility of supply chain. Therefore, the RFID system can be used in the receiving and dispatching of goods, product assembly, personnel control, and stock management [16]. Figure 2 shows the general structure of the RFID system.

Reader is one of the key components of RFID systems. Therefore, it is necessary to be careful in selecting the most suitable components. The studies on the selection of RFID system in the literature are summarized below.

Büyüközkan et al. [17] proposed an integrated fuzzy MCDM approach to select RFID service provider. Owida et al. [18] Analytical Hierarchy Process (AHP) for selection of RFID system in retail supply chains and Vanany [19] proposed multi-staged approach that has three stages consisting of a brainstorming method, the "what's-how's" matrix and the AHP technique to select RFID for hospital and healthcare sectors. Cebeci and Kılınç [20] developed a fuzzy AHP method for selecting the most appropriate RFID system. Also, Özmen and Birgün [21] used the AHP method to select the most appropriate RFID system during the selection of an RFID system.

In this study, we aimed to select the most suitable mobile RFID reader for a company that wants to regulate warehouse operations in supply chain management and reduce the faults made in referral operations. Interval Type-2 Fuzzy TOPSIS method is used to select the most suitable mobile RFID reader. In the rest of the paper; in the second part, Interval Type-2 Fuzzy TOPSIS method is explained. In the third part, the application of the study is done and in the final part, the results and evaluation section of the study are given.

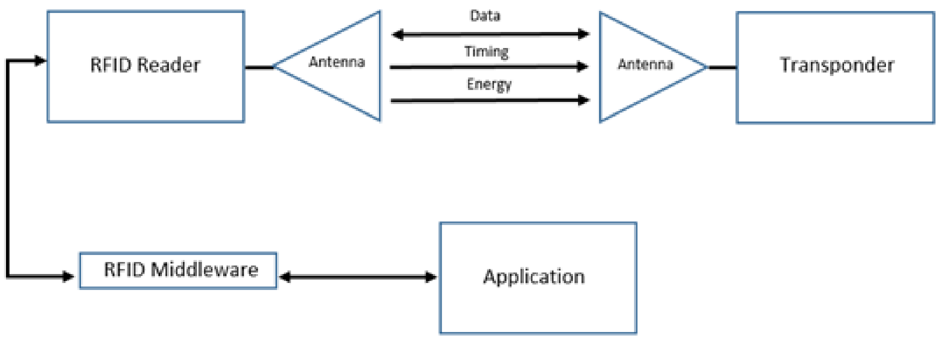

Figure 2. RFID System

2. INTERVAL TYPE-2 FUZZY TOPSIS METHOD

One of the most frequently used methods in multi-criteria decision making problems is the Fuzzy TOPSIS method which was developed by Hwang and Yoon [22, 23]. The main objective of the method is to select the alternative, which has the shortest distance to positive ideal solution and the farthest distance from the negative ideal solution. Many studies in the literature use this method to solve decision-making problems. However, Fuzzy TOPSIS may not always be suitable to represent uncertainties due to the use of type-1 fuzzy sets. The degree of membership in the type-1 fuzzy sets is an integer in [0, 1]. However, we often face situations where it is difficult to determine the full membership function of a fuzzy set, and it is not suitable to use type-1 fuzzy sets in these cases. Thus, Zadeh [24] has proposed type-2 fuzzy sets, which are extensions of type-1 fuzzy sets (Type-2 Fuzzy Sets-T2FS), in order to process the uncertainties. However, the use of T2FS, which was proposed by Zadeh, was difficult in real-life applications because of their complexity. Therefore, Liang and Mendel [25] developed a new concept of T2FS that makes calculations that are more useful. T2FS are defined by both primary and secondary membership in order to provide more degrees of freedom and flexibility, and these sets are three-dimensional. Thus, T2FS have more of the advantage of uncertainty modeling compared to type-1 fuzzy sets [26, 27]. Interval T2FS can be seen as a special case of generic T2FS in which all values of the secondary membership are equal to 1. Because of that, it simplifies calculation of uncertainty not only better than type-1 fuzzy sets, but also with T2FS [28]. In T2FS, the top and bottom fuzzy membership functions are derived from the type-1 fuzzy membership function, and the area between these two functions is an indication of the uncertainty used to characterize the T2FS [27]. In their study, Chen and Lee [29] have extended the classical TOPSIS method to develop a new method called “interval type-2 fuzzy TOPSIS”, in order to solve fuzzy multi-criteria decision-making problems with interval T2FS.

Interval T2FS widely uses comparative representations, such as vertical slice representations and wavy slice representations for downsizing, which are extremely useful for computational and theoretical work [30]. Interval type-2 fuzzy TOPSIS method provides smarter and more adaptable procedure to calculate the weights and values of the criterion since it uses T2FS to solve fuzzy multi-criteria decision-making problems. Below are the steps of the interval type-2 fuzzy TOPSIS method. Lee and Chen [31] presented the concept of ranking values of trapezoidal interval T2FS.

Let $\tilde{\tilde{A}}_i$ be an interval type-2 fuzzy set shown in Figure 3, where $\tilde{\tilde{A}}_i = \left(\tilde{A}_i^U . \tilde{A}_i^L\right) = ((a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U; H_1(\tilde{A}_i^U), H_2(\tilde{A}_i^L))).$

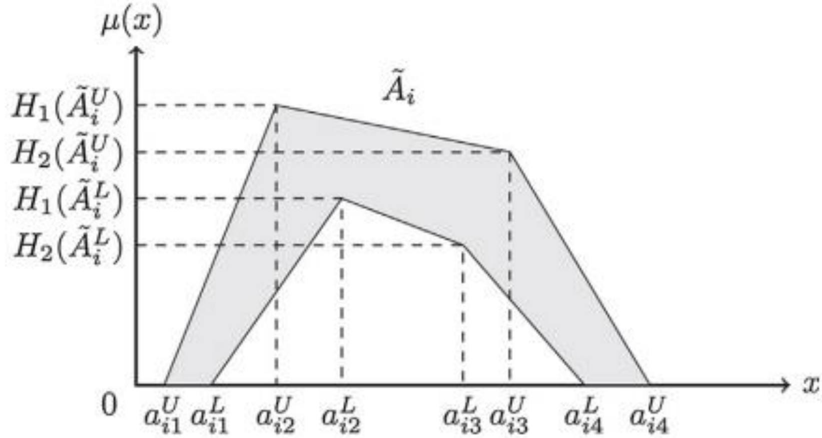

Figure 3. A trapezoidal interval type-2 fuzzy sets A [29]

The ranking value $Rank(\tilde{\tilde{A}}_i)$ of the trapezoidal interval type-2 fuzzy set $\tilde{\tilde{A}}_i$ is defined as follows [31];

$$\begin{aligned} Rank(\tilde{\tilde{A}}_i) = {} & M_1\left(\tilde{A}_i^U\right) + M_1\left(\tilde{A}_i^L\right) + M_2\left(\tilde{A}_i^U\right) + M_2\left(\tilde{A}_i^L\right) + M_3\left(\tilde{A}_i^U\right) + M_3\left(\tilde{A}_i^L\right) \\ & -\frac{1}{4}\left(S_1\left(\tilde{A}_i^U\right) + S_1\left(\tilde{A}_i^L\right) + S_2\left(\tilde{A}_i^U\right) + S_2\left(\tilde{A}_i^L\right) + S_3\left(\tilde{A}_i^U\right) + S_3\left(\tilde{A}_i^L\right) + S_4\left(\tilde{A}_i^U\right) + S_4\left(\tilde{A}_i^L\right)\right) + \\ & H_1\left(\tilde{A}_i^U\right) + H_1\left(\tilde{A}_i^L\right) + H_2\left(\tilde{A}_i^U\right) + H_2\left(\tilde{A}_i^L\right) \end{aligned} \tag{1}$$

where $M_p(\tilde{A}_i^j)$ indicates the average of the elements a_{ip}^j and $a_{i(p+1)}^j$, $M_p(\tilde{A}_i^j) = (a_{ip}^j + a_{i(p+1)}^j)/2,\ 1 \le p \le 3,$ $S_q(\tilde{A}_i^j)$ denotes the standard deviation of the elements a_{iq}^j and $a_{i(q+1)}^j$, $S_q(\tilde{A}_i^j) = \sqrt{\frac{1}{2}\sum_q^{q+1}\left(a_{ik}^j - \frac{1}{2}\sum_{k=q}^{q+1} a_{ik}^j\right)^2}$, $1 \le q \le 3,$ $S_4(\tilde{A}_i^j)$ denotes the standard deviation of the elements $a_{i1}^j, a_{i2}^j, a_{i3}^j, a_{i4}^j$, $S_4(\tilde{A}_i^j) = \sqrt{\frac{1}{4}\sum_{k=1}^{4}\left(a_{ik}^j - \frac{1}{4}\sum_{k=1}^{4} a_{ik}^j\right)^2}$, $H_p(\tilde{A}_i^j)$ indicates the membership value of the element $a_{i(p+1)}^j$ in the trapezoidal membership function $\tilde{A}_i^j$, $1 \le p \le 2,$ $j \in \{U, L\}$, and $1 \le i \le n.$

In Eq. (1), the summation of $M_1\left(\tilde{A}_i^U\right), M_1\left(\tilde{A}_i^L\right), M_2\left(\tilde{A}_i^U\right), M_2\left(\tilde{A}_i^L\right), M_3\left(\tilde{A}_i^U\right), M_3\left(\tilde{A}_i^L\right), H_1\left(\tilde{A}_i^U\right), H_1\left(\tilde{A}_i^L\right), H_2\left(\tilde{A}_i^U\right)$ and $H_2\left(\tilde{A}_i^L\right)$ is called the basic ranking score, where we decrease the average of

$S_1(\tilde{A}_i^U), S_1(\tilde{A}_i^L), S_2(\tilde{A}_i^U), S_2(\tilde{A}_i^L), S_3(\tilde{A}_i^U), S_3(\tilde{A}_i^L), S_4(\tilde{A}_i^U)$ *and* $S_4(\tilde{A}_i^L)$ from the basic ranking score to give the distributor interval type-2 fuzzy set a penalty, where $1 \le i \le n.$

In the following, TOPSIS method was extended to present a new method for handling fuzzy multi criteria group decision-making problems based on interval type-2 fuzzy sets. Assume that there is a set X of alternatives, where $X = \{x_1, x_2, \ldots, x_n\}$, and assume that there is a set F of attributes, where $F = \{f_1, f_2, \ldots, f_m\}$. Assume that there are k decision-makers $D_1, D_2, \ldots,$ and D_k. The set F of attributes can be divided into two sets F_1 and F_2, where F_1 denotes the set of benefit attributes, F_2 indicates the set of cost attributes, $F_1 \cap F_2 = \phi,$ and $F_1 \cup F_2 = F.$ The method is now presented as follows:

Step 1: Construct the decision matrix Y_p of the *pth* decision-maker and construct the average decision matrix $\overline{Y}$, respectively, shown as follows:

$$Y_p = (\tilde{f}_{ij}^{\,p})_{mxn} = \begin{array}{c} \\ f_1 \\ f_2 \\ \vdots \\ f_m \end{array} \overset{\begin{array}{cccc} x_1 & x_2 & \cdots & x_n \end{array}}{\begin{bmatrix} \approx{f}_{11}^{p} & \approx{f}_{12}^{p} & \cdots & \approx{f}_{13}^{p} \\ \approx{f}_{21}^{p} & \approx{f}_{22}^{p} & \cdots & \approx{f}_{23}^{p} \\ \vdots & \vdots & \vdots & \vdots \\ \approx{f}_{31}^{p} & \approx{f}_{m1}^{p} & \cdots & \approx{f}_{mn}^{p} \end{bmatrix}} \tag{2}$$

$$\overline{Y} = \left(\overset{\approx}{f}_{ij} \right)_{mxn}, \tag{3}$$

where, $(\overset{\approx}{f}_{ij}) = \left(\dfrac{\overset{\approx}{f}_{ij}^{1} \oplus \overset{\approx}{f}_{ij}^{2} \oplus \ldots . \oplus \overset{\approx}{f}_{ij}^{k}}{k} \right)$, $\overset{\approx}{f}_{ij}$ is an interval type-2 fuzzy set, $1 \le i \le m,$ $1 \le j \le n,$ $1 \le p \le k,$ and k indicates the number of decision-makers.

Step 2: Construct the weighting matrix W_p of the attributes of the pth decision-maker and construct the average weighting matrix $\overline{W}$, respectively, shown as follows:

$$W_p = (\overset{\approx}{w}_i^{p})_{1xm} = \begin{bmatrix} \overset{\approx}{w}_1^{p} & \overset{\approx}{w}_2^{p} & \cdots \overset{\approx}{w}_m^{p} \end{bmatrix}, \tag{4}$$

$$\overline{W} = (\overset{\approx}{w}_i)_{1xm}, \tag{5}$$

where $\overset{\approx}{w}_i = \left(\dfrac{\overset{\approx}{w}_i^{1} \oplus \overset{\approx}{w}_i^{2} \oplus \ldots . \oplus \overset{\approx}{w}_i^{k}}{k} \right)$, $\overset{\approx}{w}_i$ is an interval type-2 fuzzy set, $1 \le i \le m,$ $1 \le p \le k,$ and k indicates the number of decision-makers.

Step 3: Construct the weighted decision matrix $\overline{Y}_w$,

$$\overline{Y_w} = (\overset{\approx}{v}_{ij})_{mxn} = \begin{array}{c} \\ f_1 \\ f_2 \\ \vdots \\ f_m \end{array} \begin{array}{c} \begin{array}{cccc} x_1 & x_2 & \dots & x_n \end{array} \\ \begin{bmatrix} \overset{\approx}{v}_{11} & \overset{\approx}{v}_{12} & \cdots & \overset{\approx}{v}_{13} \\ \overset{\approx}{v}_{21} & \overset{\approx}{v}_{22} & \cdots & \overset{\approx}{v}_{23} \\ \vdots & \vdots & \vdots & \vdots \\ \overset{\approx}{v}_{m1} & \overset{\approx}{v}_{m2} & \cdots & \overset{\approx}{v}_{mn} \end{bmatrix} \end{array}, \tag{6}$$

where $\overset{\approx}{v}_{ij} = \overset{\approx}{w}_i \otimes \overset{\approx}{f}_{ij}$, $1 \le i \le m$, and $1 \le j \le n$.

Step 4: Based on Eq. (1), compute the ranking value $Rank(\overset{\approx}{v}_{ij})$ of the interval type-2 fuzzy set $\overset{\approx}{v}_{ij}$, where $1 \le j \le n$. Construct the ranking weighted decision matrix $\overline{Y}^*_w$,

$$\overline{Y^*_w} = \left(Rank(\overset{\approx}{v}_{11}) \right)_{mxn}, \tag{7}$$

where $1 \le i \le m$, and $1 \le j \le n$.

Step 5: Determine the positive ideal solution (PIS) $x^+ = (v_1^+, v_2^+, \dots\dots v_m^+)$ and the negative-ideal solution (NIS) $x^- = (v_1^-, v_2^-, \dots\dots v_m^-)$, where

$$v_i^+ = \begin{cases} \max\limits_{1 \le j \le n} \{rank(\overset{\approx}{v}_{ij})\}, & if \;\; f_i \in F_1 \\ \min\limits_{1 \le j \le n} \{rank(\overset{\approx}{v}_{ij})\}, & if \;\; f_i \in F_2 \end{cases} \tag{8}$$

and

$$v_i^- = \begin{cases} \min\limits_{1 \le j \le n} \{rank(\overset{\approx}{v}_{ij})\}, & if \;\; f_i \in F_1 \\ \max\limits_{1 \le j \le n} \{rank(\overset{\approx}{v}_{ij})\}, & if \;\; f_i \in F_2 \end{cases} \tag{9}$$

where F_1 indicates the set of benefit attributes, F_2 denotes the set of cost attributes, and $1 \le i \le m$

Step 6: Compute the distance $d^+(x_j)$ between each alternative x_j and the positive ideal solution x^+, shown as follows:

$$d^+(x_j) = \sqrt{\sum_{i=1}^{m} (Rank(\overset{\approx}{v}_{ij}) - v_i^+)^2} \tag{10}$$

where $1 \leq j \leq n$. Calculate the distance $d^-(x_j)$ between each alternative x_j and the negative-ideal solution x^-, shown as follows:

$$d^-(x_j) = \sqrt{\sum_{i=1}^{m} (Rank\,(\tilde{\tilde{v}}_{ij}) - v_i^+)^2} \tag{11}$$

where $1 \leq j \leq n$.

Step 7: Calculate the relative degree of closeness $C(x_j)$ of x_j with respect to the positive ideal solution x^+, shown as follows:

$$C(x_j) = \frac{d^-(x_j)}{d^-(x_j) + d^+(x_j)}, \tag{12}$$

where $1 \leq j \leq n$.

Step 8: Sort by the values of $C(x_j)$ in a descending sequence, where $1 \leq j \leq n$. The higher the value of $C(x_j)$, the higher the preference of the alternative x_j, where $1 \leq j \leq n$.

3. SELECTION OF MOBILE RFID READER

In this study, for RFID system that will use in warehouse process in supply chain management of a company operating in the manufacturing sector in Turkey, interval type-2 fuzzy TOPSIS method was used for the selection of the most suitable mobile RFID reader. The significant criteria in the selection of RFID readers are determined by literature review and the alternative mobile RFID readers are specified by three experts (Industrial engineer, quality manager and electrical-electronics engineer). Once the criteria and alternatives are identified, the best mobile RFID reader selection model is established and given in Figure 4.

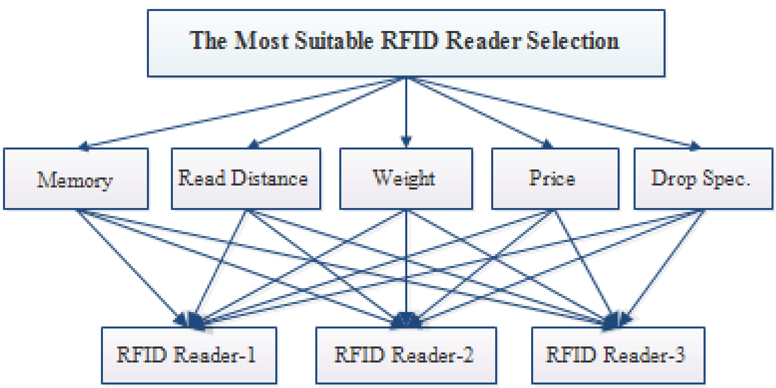

Figure 4. The Most suitable mobile RFID reader selection model

Then, according to the determined criteria, the data of alternative mobile RFID readers are specified from web sites and these values are given in Table 1.

Table 1. Criteria values for alternative RFID readers

Mobile RFID Readers	Criteria				
	Memory	Read Distance	Weight	Price	Drop Spec.
RFID Reader-1	512MB RAM /512MB ROM	7 m	250 g	2584 $	1.5 m
RFID Reader-2	512MB RAM/2GB Flash	13.72 m	765 g	2056 $	1,8 m
RFID Reader-3	256MB RAM/512MB ROM	7 m	290.3 g	2600 $	1,5 m

After the selection model has been established and the criterion values have been determined, the steps described above for the interval type-2 fuzzy TOPSIS method are followed in order to find out the best mobile RFID reader.

Step 1: The criterion values given in Table 1 were normalized and the decision matrix was formed by converting Table 2 into the linguistic expressions. This decision matrix is given in Table 3.

Table 2. Linguistic terms and interval type-2 fuzzy sets

Linguistic terms	Interval type-2 fuzzy sets
Very Low (VL)	((0, 0, 0, 0.1; 1, 1), (0, 0, 0, 0.05; 0.9, 0.9))
Low (L)	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))
Medium Low (ML)	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))
Medium (M)	((0.3, 0.5, 0.5, 0.7; 1, 1), (0.4, 0.5, 0.5, 0.6; 0.9, 0.9))
Medium High (MH)	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))
High (H)	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
Very High (VH)	((0.9, 1, 1, 1; 1, 1), (0.95, 1, 1, 1; 0.9, 0.9))

Table 3. Linguistic evaluation of alternative mobile RFID readers

Criteria	Alternatives Mobile RFID Readers		
	RFID Reader-1	RFID Reader-2	RFID Reader-3
Memory	MH	H	M
Read Distance	M	VH	M
Weight	VH	ML	H
Price	ML	ML	L
Drop Spec.	MH	H	MH

After the decision matrix was formed, the fuzzy decision matrix was formed by linguistic expressions into interval type-2 trapezoidal numbers. In this step, the values are obtained with the help of equation (3) and they are given in Table 4.

Step 2: The selection criteria are evaluated in accordance with the linguistic variables given in

Table 2 and equation (3) by the consensus of three decision makers, and the obtained weight matrix is given in Table 5.

Table 4. Fuzzy decision matrix

Criteria	Alternatives Mobile RFID Readers		
	RFID Reader-1	RFID Reader-2	RFID Reader-3
Memory	(0.5,0.7,0.7,0.9,1,1) (0.6,0.7,0.7,0.8,0.9,0.9)	(0.7,0.9,0.9,1,1,1) (0.8,0.9,0.9,0.95,0.9,0.9)	(0.3,0.5,0.5,0.7,1,1) (0.4,0.5,0.5,0.6,0.9,0.9)
Read Distance	(0.3,0.5,0.5,0.7,1,1) (0.4,0.5,0.5,0.6,0.9,0.9)	(0.9,1,1,1,1,1) (0.95,1,1,1,0.9,0.9)	(0.3,0.5,0.5,0.7,1,1) (0.4,0.5,0.5,0.6,0.9,0.9)
Weight	(0.9,1,1,1,1,1) (0.95,1,1,1,0.9,0.9)	(0.1,0.3,0.3,0.5,1,1) (0.2,0.3,0.3,0.4,0.9,0.9)	(0.7,0.9,0.9,1,1,1) (0.8,0.9,0.9,0.95,0.9,0.9)
Price	(0.1,0.3,0.3,0.5,1,1) (0.2,0.3,0.3,0.4,0.9,0.9)	(0.1,0.3,0.3,0.5,1,1) (0.2,0.3,0.3,0.4,0.9,0.9)	(0,0.1,0.1,0.3,1,1) (0.05,0.1,0.1,0.2,0.9,0.9)
Drop Spec.	(0.5,0.7,0.7,0.9,1,1) (0.6,0.7,0.7,0.8,0.9,0.9)	(0.7,0.9,0.9,1,1,1) (0.8,0.9,0.9,0.95,0.9,0.9)	(0.5,0.7,0.7,0.9,1,1) (0.6,0.7,0.7,0.8,0.9,0.9)

Table 5. Linguistic evaluation of selection criteria and weight matrix

Criteria	Linguistic assessment	Interval Type-2 Fuzzy Sets	
Memory	H	(0.7,0.9,0.9,1,1,1)	(0.8,0.9,0.9,0.95,0.9,0.9)
Read Distance	MH	(0.5,0.7,0.7,0.9,1,1)	(0.6,0.7,0.7,0.8,0.9,0.9)
Weight	M	(0.3,0.5,0.5,0.7,1,1)	(0.4,0.5,0.5,0.6,0.9,0.9)
Price	VH	(0.9,1,1,1,1,1)	(0.95,1,1,1,0.9,0.9)
Drop Spec.	M	(0.3,0.5,0.5,0.7,1,1)	(0.4,0.5,0.5,0.6,0.9,0.9)

Step 3: The weighted fuzzy decision matrix is then obtained by the using equation (6) and given in Table 6.

Table 6. Weighted fuzzy decision matrix

Criteria	Alternatives Mobile RFID Readers		
	RFID Reader-1	RFID Reader-2	RFID Reader-3
Memory	(0.35,0.63,0.63,0.9,1,1) (0.48,0.63,0.63,0.76,0.9,0.9)	(0.49,0.81,0.81,1,1,1) (0.64,0.81,0.81,0.9,0.9,0.9)	(0.21,0.45,0.45,0.7,1,1) (0.32,0.45,0.45,0.57,0.9,0.9)
Read Distance	(0.15,0.35,0.35,0.63,1,1) (0.24,0.35,0.35,0.48,0.9,0.9)	(0.45,0.7,0.7,0.9,1,1) (0.57,0.7,0.7,0.8,0.9,0.9)	(0.15,0.35,0.35,0.63,1,1) (0.24,0.35,0.35,0.48,0.9,0.9)
Weight	(0.27,0.5,0.5,0.7,1,1) (0.38,0.5,0.5,0.6,0.9,0.9)	(0.03,0.15,0.15,0.35,1,1) (0.08,0.15,0.15,0.24,0.9,0.9)	(0.21,0.45,0.45,0.7,1,1) (0.32,0.45,0.45,0.57,0.9,0.9)
Price	(0.09,0.3,0.3,0.5,1,1) (0.19,0.3,0.3,0.4,0.9,0.9)	(0.09,0.3,0.3,0.5,1,1) (0.19,0.3,0.3,0.4,0.9,0.9)	(0,0.1,0.1,0.3,1,1) (0.05,0.1,0.1,0.2,0.9,0.9)
Drop Spec.	(0.15,0.35,0.35,0.63,1,1) (0.24,0.35,0.35,0.48,0.9,0.9)	(0.21,0.45,0.45,0.7,1,1) (0.32,0.45,0.45,0.57,0.9,0.9)	(0.15,0.35,0.35,0.63,1,1) (0.24,0.35,0.35,0.48,0.9,0.9)

Step 4: The ranking weighted decision matrix is obtained with the help of the equation (1) as shown in Table 7.

Step 5: The positive and negative ideal solutions given in Table 8 calculated based on the equations (8) and (9).

Step 6: The distances of each alternative from the positive ideal solution (d^+) and the negative ideal solution (d^-) are calculated with the help of equations (10) and (11) and they are given in Table 9.

Table 7. Ranking weighted decision

Criteria	Alternatives Mobile RFID Readers		
	RFID Reader-1	RFID Reader-2	RFID Reader-3
Memory	7,39	8,39	6,34
Read Distance	5,80	7,81	5,80
Weight	6,64	4,65	6,34
Price	5,46	5,46	4,38
Drop Spec.	5,80	6,34	5,80

Table 8. Positive and negative ideal solutions

Criteria	Positive ideal solution x^+	Negative ideal solution x^-
Memory	7,39	8,39
Read Distance	5,80	7,81
Weight	6,64	4,65
Price	5,46	5,46
Drop Spec.	5,80	6,34

Table 9. The distances of each alternative from positive and negative ideal solution

	RFID Reader-1	RFID Reader-2	RFID Reader-3
d^+	3,06	0,00	3,55
d^-	1,50	3,70	0,29

Step 7: The proximity coefficient of each alternative is calculated with equation (12) and they are given in Table 10.

Table 10. Closeness coefficient of each alternative

	RFID Reader-1	RFID Reader-2	RFID Reader-3
$C(x_j)$	0,330	1,000	0,076
Sıralama	2	1	3

The order of alternative mobile RFID readers according to the obtained closeness coefficients is RFID Reader-2> RFID Reader-1> RFID Reader-3. According to this ranking, the best mobile RFID reader is "RFID Reader-2" which has the highest closeness coefficient.

4. CONCLUSION AND DISCUSSION

Many innovations have been parts of our lives in order to facilitate business processes and reduce costs parallel to the technological developments. RFID, one of these innovations, is a substantial element of an information system that is used in a variety of business fields, from supermarkets to warehouses in factories, where dynamic data may be or is required to be used to make easy, rapid, error-free data entry, storage and transmission. RFID reduces labor costs as well as dependence on human power significantly in many business areas including the supply chain management by its accurate and rapid applications. RFID applications in supply chain management has several benefits such as; reduction of repetitive tasks, reduction of errors and labor costs due to increased automation of processes that were previously done by workers, capability to respond to changes in the supply chain immediately, and consequently the establishment of supply chain management and control. Therefore, the selection of the most suitable RFID systems to be used in managing business processes is of great importance. It is more suitable to apply the multi-criteria decision-making methods in solving the selection problem, because there are many criteria affecting the purchase of RFID systems.

In this study, Interval Type-2 Fuzzy TOPSIS method is used to select the most suitable mobile RFID reader to be used in the supply chain management of a production factory. For the application, firstly, the effective criteria for the purchase of mobile RFID reader are determined and then alternative mobile RFID readers are specified. After the criteria values of the identified alternative RFID readers were determined from the web addresses, Interval Type-2 Fuzzy TOPSIS method steps are followed in order to select the most suitable mobile RFID reader for the company. According to closeness coefficients that are obtained from the analysis, purchasing of "RFID Reader-2" is identified as the most suitable reader. Although the value of weight criterion of this reader is higher than other alternatives which is a disadvantage, the values of read distance, memory and drop spec. are also high which are advantageous for the reader. The high values of these criteria were effective in the analysis. If the firm chooses this reader, it will have the advantages of recording more objects, perceiving objects from further distances and better drop performance (it will not to be damaged easily) which are very important in RFID systems.

This study is the first study that uses Type-2 fuzzy sets in the selection procedure of RFID systems in the literature. In the following studies, the most suitable RFID tags and printers may be selected and the most suitable RFID system may also be selected as a whole. The results may be compared with the other methods using Type-2 fuzzy sets in these applications.

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