ANKARA YILDIRIM BEYAZIT UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

VENDOR SELECTION IN IT INDUSTRY USING HYBRID MODELS OF MCDM AND FUZZY METHODOLOGIES

M.Sc. Thesis by

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February, 2022 **Aylin TAN**

VENDOR SELECTION IN IT INDUSTRY USING HYBRID MODELS OF MCDM AND FUZZY METHODOLOGIES

ABSTRACT

In modern times, products are becoming more and more complex due to the increasing complexity of real-world problems. Because of this, when developing a product or service, organizations should collaborate to combine different technologies. Moreover, working with the best supplier for a company is important to develop products or services more agile, competitive, and cost-friendly. In this research, suppliers are compared considering quality, cost, maintenance, and flexibility criteria with twelve underlying sub-criteria. A combined approach of VIKOR and IF on MCDM problems is proposed and the methodology is applied to select the speech recognition supplier for a product used in the call center industry. The decision matrix is determined with intuitionistic fuzzy due to existing subjectivity and uncertainty, and the problem is solved by VIKOR to find the best alternative for the group utility. A real-life case study is conducted to demonstrate the efficiency of the combined model.

Keywords: MCDM, VIKOR, Intuitionistic fuzzy, speech recognition, supplier selection

ÇOK KRİTERLİ KARAK VERME VE BULANIK METODOLOJİLERİNİN HİBRİT MODELLERİNİ KULLANARAK BT ENDÜSTRİSİNDE SATICI SEÇİMİ

ÖZ

Günümüz dünyasında, gerçek yaşam problemlerinin karmaşıklaşması sebebi ile ürünler de karmaşıklaşmaktadır. Bu sebeple, organizasyonlar ürün ve servisler yaratırken farklı tedarikçilerin birbiri ile entegre çalışabilen farklı teknolojilerini biraraya getirmelidir. Aynı zamanda, en uygun tedarikçi ile çalışmak esnek, rekabetçi ve karlı ürünler yapmak için çok önemlidir. Bu çalışmada, tedarikçiler katile, maliyeti, bakım ve esneklik kriterleri göz önüne alınarak değerlendirilmiştir. Bilgi teknolojisi projelerinde tedarikçi seçimi süreci için VIKOR ve Sezgisel Bulanık yaklaşımları hibrit olarak kullanılmıştır. Karar verme matrisi, belirsiz veriler nedeniyle sezgisel bulanık yöntemi ile oluşturulmuş ve grup faydası göz önüne alınarak en iyi alternatifi bulmak için problem çözümünde VIKOR yaklaşımı kullanılmıştır.

Anahtar Kelimeler: Çok Kriterli Karar Verme, VIKOR, Sezgisel Bulanık, Konuşma Tanıma, Tedarikçi Seçimi

CONTENTS

NOMENCLATURE

Acronyms

AHP	Analytical Hierarchy
ANP	Analytical Network Process
IF	Intuitionistic Fuzzy
MCDM	Multi-criteria decision-making
NLU	Natural Language Understanding
Orch.	Orchestrator
SR	Speech Recognition
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TTS	Text to Speech
WER	Word Error Rate
VIKOR	Vise Kriterijumska Optimizacija I Kompromisno Resenje

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CHAPTER 1

INTRODUCTION

Technology is changing pretty faster day by day and it makes people's live easier and better. Especially, after neural network algorithms were getting more popular for researchers, new methodologies were appeared in all fields. Computer science and information technologies are most affected fields from new approaches, because they provide new solutions for real-life problems in their industries. Based on Internet World Stats's reports number of internet users are increased exponentially every year. While 0.4% of world population were internet user in 1995, 65.6% of world population have internet access. This report shows that internet and information technology is located many steps in people's lives. Also, according to Gartner report in 2025, 75% of companies will lose their customers because cost of customer loyalty will be more than having new customers. Bots and IVRs assist companies for raising customer satisfaction and loyalty and reducing functional expenses while running contact center operations. Today, chatbots, IVR's and virtual assistants are utilized like never before to accomplish a more effective client experience in pretty much every area, like medical services, banking, government, protection. In banking industry, banks have smart assistants to run transactions of customers and to give right and fast information to customers when they need without going any branch office or even ATM. This is an opportunity for banking companies to reduce their operational cos and human resource while increasing customer experience and loyalty. Making transactions remotely has got more importance with COVID-19, because people want to decrease their works in person to keep out from disease. Also, branch offices were worked more remotely in almost all countries when number of active cases were at top. All these contact center operations and software need core software to apply their processes. Therefore, Speech to text is one of the ttechnology that converts speech to readable format, so a bot, IVR system, or virtual assistant can recognize what the user wants to do while using them. The technology is very important in the robust conversational services with its success. Choosing the most appropriate Speech recognition supplier for businesses is crucial due to

providing an enhanced and easy-to-implement conversational system that is the key to a successful customer experience. Furthermore, using appropriate speech-to-text engine can assist control devices to users easily. It gives effectiveness not exclusively to individual clients yet additionally for associations to translate enormous assignments like medical services, protection, or banking. Before, providers were analyzed in light of just quantitative information of their precision levels.

1.1 Supplier Selection

Vendor/supplier selection is a decision-making process for organizations to define, evaluate and deal with other organizations [1]. This process includes many parameters for reducing risk and cost, maximizing competitiveness, profit, and quality to achieve the organization's supply chain management. Especially, in uncertain environments, working with the most appropriate supplier provides agility to organizations. There are many methodologies for supplier selection in literature according to criteria, alternatives, and other constraints. The high-level supplier selection process is shown in Figure 1.1.

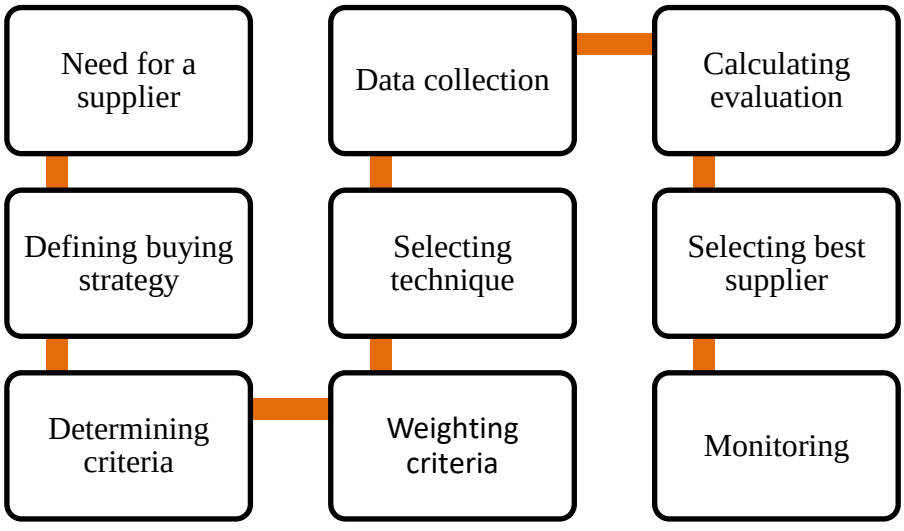

Figure 1.1 General overview for supplier selection process

Criteria have importance to select the best supplier selection methodology. Criteria

can be both quantitative and qualitative according to the application area. In literature, the most popular criteria that are used in supplier selection problems are cost, quality, and safety, delivery, social responsibility, convenience, long-term relationships, financial stability, responsiveness, risk management, and flexibility.

The purchasing cost is quite an important criterion due to its direct effect to profit maximization. Quality is another important criterion in the supplier selection process because it affects the overall quality and performance of the organizations. Delivery also has importance for supplier selection because it affects the success of project management and lead time. People give importance to sustainability, charity, human rights, etc., when buying or using something more than past. Therefore, nowadays, many organizations care about social responsibility activities because of new laws of the countries and marketing or branding management. Convenience is also essential for some industries because integration costs may rise dramatically if the product is not easy to use. Long-term relationships constitute the main parts of creating sustainable and high stable products because changing supplier frequently causes new integration efforts, quality risks, and higher lead times for organizations. Due to long-term relationship effects, the financial stability of suppliers is important. If a supplier does not have financial stability, organizations may face problems similar to changing suppliers. Responsiveness is another significant criterion in the supplier selection process because, in case of any defect, damage, or other problems of products used from a supplier can be solved only by the supplier. Therefore, fast action or quick reply and support from the supplier has importance for supplier selection. Risk management is another criterion in selecting the best supplier because it indirectly affects all key performance indicators in case of crisis. Lastly, flexibility is used as a criterion for finding the most appropriate supplier due to the uncertain environment and demand.

1.2 Multi-criteria Decision Making

Multi-criteria decision making evaluates insufficient criteria for improvement as a sub-discipline of operational research. Decision making for supplier selection processes is significant topic because of it’s effect on general organizational success. For

example, sustainability, quality and profit are most important criteria for all organizations, but success for these criteria is depended on the success of suppliers of the organizations.

The multi-criteria decision-making process starts with the need for change and problem definition. The steps of MCDM are explained below.

1. The latest goal is defined.

2. Problem is formulated, and a model is created based on formulation. In this step, the aim of the problem and level of measurements are defined. Also, sub-goals and sub-criteria, constraints and environment of the problem are defined.

3. Analysis and evaluation step. In this step, each alternative is evaluated based on rules. Then, according to the evaluation result, the decision is made.

4. Decisions are interpreted and evaluated. In literature, there are many methodologies for supplier selection according to constraints and parameters of the decision-making problem.

When alternatives are finite and have more than one criterion, which is quantitative and qualitative, the most common methodologies called multi-criteria decision-making methodologies are applied [2]. Multi-criteria decision making (MCDM) problems have more than one criterion and goal. Also, criteria have a trade-off between them and values which cannot be measured with the same unit in MCDM. Some decision-makers have responsibility and authority, alternatives set of prospects or candidates, goals, criteria, value and judgement system, and decision rules. Therefore, many studies have been published for supplier selection problems in different areas.

1.2.1 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process approach is found by Thomas L. Saaty in 1977. In AHP, first criteria and sub-criteria are defined, and hierarchy is established. A goal is defined, and these criteria are selected based on this goal. Also, there are more than one, but limited number of alternatives are defined. Main property of AHP is keeping

simple the solution by dividing problem into sub-pieces.

Analytical Hierarchy Process consists of six steps defined below.

Step 1: Problem definition

Problem definition is first step for all decision-making problems. In this step, problem should be clarified very clearly.

Step 2: Definition of alternatives and criteria

Second step of AHP is defining criteria and alternatives. In this step, literature and expert opinions are considered. N criteria, and m alternatives are defined as one-side hierarchy.

Step 3: Comparison matrix creation

Pairwise comparison matrices are created based on importance scale which is shown in Table 1.1.

Table 1.1 Importance Scale for AHP

1	Equal importance
3	Moderate importance
5	Strong importance
7	Very Strong importance
9	Extreme importance
2,4,6,8	Intermediate values

Step 4: Calculation of priority of criteria and alternatives

In step 4, weights of criteria are calculated by some methodologies. To do this, columns elements of pairwise comparison matrix are added up. Then, these elements are normalized based the summation. Lastly, priority is found as average of row

elements.

Step 5: Determination of consistency index of the decision matrix

Firstly, weighted summation vector is calculated by multiplying elements with column elements of pairwise comparison matrix. Then, elements of weighted summation vector are divided by weight values of them. Finally, average values of previous step are found as λ_{max}. Being closer to the n for λ_{max} means that pairwise comparison matrix is more consistent.

Step 6: Decision-making

Final step for AHP is making decision. The alternative which has highest importance value is selected as best alternative in the frame of main goal.

AHP method is quite useful methodology when

- A hierarchy is existing between alternative criteria and goals and benefits,
- Criteria are mostly qualitative rather than quantitative and they are defined mostly by subjectivity of decision makers,
- Variants are fully comparable.

1.2.2 Analytical Network Process (ANP)

Analytical network process is an approach which is expended form AHP. ANP process provides relationship between criteria and decision-making levels. Therefore, pairwise comparison between criteria should be done to create a super matrix. The comparison defines how important the criteria from the other one based on decision maker's opinion. Like AHP, ANP also uses 1-9 importance scale to define the comparison numerically [35].

Analytical Network Process consists of four steps defined below.

Step 1: Problem definition and network model creation

Like all multi-criteria decision-making problems, alternatives, criteria and sub-

criteria are clearly defined in first step. Also, in ANP internal and external dependencies between them are analyzed to create network model. Network model consists of decision units and their elements. Therefore, while internal dependencies are showing that effect of elements on the other elements in same unit, external dependencies are representing effect on the different units.

Step 2: Pairwise comparison matrix creation and definition of weights

Pairwise comparison matrices are created based on decision-makers' opinions by using importance scale of Saaty in Table 1.1 [35]. If x_i criteria is more important than x_j, the number which is left side of 1 is marked. If x is more important than x_i , the number which is right side of 1 is marked. When both criteria have same importance 1 is marked.

After that, consistency rate (CR) is calculated. If CR is less than or equal to 0.1, this means comparison matrix is consistent. Next, importance weights are calculated by AHP methodology.

Table 1.2 Importance Scale for ANP

	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	
x_i	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	x_j

Step 3: Creation of super matrix and limit super matrix

In step three, super matrix which is a block matrix represents relationship between two unit is created.

Step 4: Selection of best alternative

Columns with a summation greater than 1 are normalized to create weighted super matrix. It provides importance rate for each element. The 2k+1 power of the weighted super matrix is taken to ensure that the importance weights equate at some point. This step gives the limit super matrix for decision-makers and the alternative with highest importance value is found as best alternative.

AHP method is quite useful methodology when not only qualitative but also quantitative data are existing, because it can provides with feedback and interdependence between all situations.

1.2.3 Technique for Order of Preference by Similarity to Ideal Solution

Technique for order of preference by similarity to ideal solution approach is found by Chen and Hwang in 1992. They referenced studies of Hwang and Yoon 1987 [36]. Logic in TOPSIS approach choosing the best alternative which has shortest geometric distance from the positive ideal solution and longest geometric distance to negative one. Technique is included in distance-based approach in multi-alternative decision matrix approaches.

TOPSIS consists of seven steps defined below.

Step 1: Evaluation matrix creation

First step of TOPSIS is defining alternatives and criteria to define problem and goal clearly. Then, matrix which includes intersection of each alternative and criteria.

Step 2: Creation of normalized decision matrix

Normalized decision matrix is calculated by taking square root of the summation of the squares of the scores or features belonging to the criteria in the decision matrix.

Step 3: Definition of relative importance of criteria

Chen and Hwang(1992) developed 10-point scale which is shown below.

Table 1.3 10-point scale

Criteria Evaluation	Value
Most unimportant	0
Very little important	1
Little important	3

Averagely important	5
Important	7
Very important	9
Most important	10

Step 4: Creation of weighted normalized decision matrix

In fourth step, weighted normalized decision matrix is created by multiplying elements of matrix and weight points of criteria. Decision-maker's opinion is considered while weights are defining.

Step 5: Determining positive and negative ideal solutions

Ideal solutions are determined in fifth step. Positive ideal solution is maximum value in weighted normalized decision matrix while negative ideal solution is minimum one. Note that biggest value is ideal for-profit criteria when smallest value is ideal for cost criteria in positive ideal solution. In negative ideal solution opposite is true.

Step 6: Calculation of distance between alternatives and solutions

Distances of alternatives to the positive ideal solution are calculated by taking square root of summation of square difference between criteria in weighted normalized decision matrix and positive ideal. Moreover, distance of alternatives to the negative ideal solution are calculated by taking square root of summation of square difference between criteria in weighted normalized decision matrix and negative ideal.

Step 7: Calculating ranking points based on distances

In final step, the ranking score is found by dividing the alternative's distance from the negative solution by the sum of the alternative's distance from the negative solution and the alternative's distance from the positive solution.

TOPSIS approach is quite useful methodology when a need to rank alternatives based on being closest to positive ideal solution is existing.

CHAPTER 2

CONVERSATIONAL SOLUTIONS

2.1 Definition of Conversational Solutions

Conversational technology is a way to entertain, transact and get information from computers for people. Conversational solutions can be agents, analytics tools, virtual assistants, etc. Conversational solutions are critical for not only organizations but also people who use them because they reduce operational costs, maximize efficiency, increase automation, and provide a service to more people. These solutions can run on many device-like smartphones, mobile, cloud or other devices, making them easy to reach. Also, these systems provide communication to people written and oral naturally [3]. A general topology view example is given in Figure 2.1 to explain pieces of conversational solutions clearly.

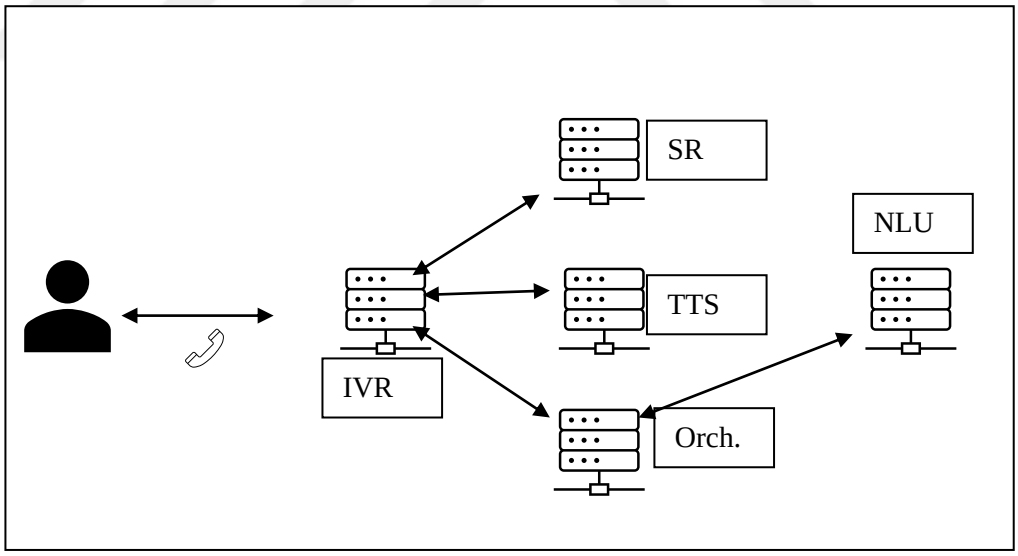

Figure 2.1 Example for conversational solution topology

At this point, the speech part of the conversational solutions is getting more important because understanding user's speak constitutes one of the biggest parts of conversational agents. Moreover, it has great importance to reach successful

conversational solutions because it provides an understanding of users ’speech [4].

2.1.1 Conversational IVR

Conversational IVR provides an opportunity that users can speak with their own words to machines. Due to the complexity of non-conversational IVRs, customers or users cannot deal with them, resulting in either losing customers or degrading the quality of customer experience. However, as conversational IVR has the ability to understand users' words, it provides an intuitive self-service experience. Moreover, people need different communication channels and automation to handle their problems and requests. On the other hand, businesses have difficulty providing consistent support to their customers and corresponding customers' requests 7/24 and quickly. In this case, conversational IVRs provide them with a smooth and consistent customer experience with less cost. The main features of conversational IVRs are listed below [5].

- Humanlike conversations
- Intent Understanding
- Custom service
- Omnichannel experience
- Flexibility and powerful reporting.

2.1.2 Virtual Assistant

A virtual assistant is a smart interface that provides business understanding and responds to their customer’s requests.

Thanks to virtual assistant technology, businesses can meet customer demands quickly as being available 7/24 like conversational IVRs. Here, there is an interface rather than a navigation menu. Customers can speak their problems or demands directly to virtual assistants anytime they need. Just like IVRs, virtual assistants decrease operational costs thanks to automation rather than human resources. Also, it

has many advantages like conversational IVR [6].

2.2 Definition of Speech Recognition

Speech recognition is a technology that transforms voice into words. It processes the speech signals in a multidisciplinary manner. It was first developed in Bell Labs in 1952. He proposed an automatic digit recognizer that transcribes speech by software machine into ten-digit numbers from zero to nine when a speaker speaks to the microphone. Then, IBM creates Shoebox, which recognizes 16 words that are ten-digits and six arithmetical command words in the 1960s. Speech recognition of IBM works like dividing voice into speech units like tiny phonetic units, which are units of sound that can separate a word into small pieces. Also, phonetics can be defined as a unit of speech sounds of words or languages. After, in the 1970s, more robust algorithms were developed. These algorithms can recognize thousands of words, whereas their counterparts used in the 1960s could recognize only sixteen words. The speech recognition algorithms become even more successful with the Hidden Markov Model. It is a mathematical system algorithm that works with chains and probabilities of becoming phonemes together with each other's. In 1987, the first commercial large-vocabulary speech recognition was found by Ray Kurzweil. Later, speech recognition evolved to continuous speech recognition software in the 90s by the Nuance company, which produces speech recognition products. Finally, after the 00s, neural network algorithms using deep learning and artificial intelligence have appeared. A neural network works like the human brain, with one hundred billion neurons, approximately seven thousand synapses, and from twenty thousand to seventy thousand different inputs and data. Deep learning changed the speech recognition world with huge improvements on speech recognition engines [7].

Speech recognition spreads to different areas and industries with recent improvements. It falls into many parts of our daily lives. For instance, we could use only pre-defined sentences while using our voice biometry in the past, but nowadays, we can define our own security sentences. Also, recently we tell our identity, the birth date or other information instead of using digits [8]. The technologies spreading in different industries surfaces new constraints. Research topics are occurred because

of different constraints of speech recognition systems. There are many research directions related to speech recognition technology, such as digital signal processing, artificial intelligence, pattern recognition, acoustic processing, linguistics, etc. Also, research requirements may be changed based on language, speaker properties and continuous systems [8]. For example, research topics can be changed based on the specific or non-specific speaker. Also, vocabulary for speech recognition systems can be small, medium, large, and even infinite.

2.3 Benefits of Speech Recognition

Speech recognition technology brings many benefits to our lives like other artificial intelligence technologies. It provides automation and decreased costs and provides many advantages to people in health, education, special needs, etc. In the past, speech recognition technology was used with a combination of geographic information systems, global positioning systems and remote sensing to improve land consolidation [9]. Also, in the health industry, speech recognition is used to spend less time for documentation so that more time can be spared for patient care [10]. Moreover, scientists developed a wearable speech to text system for people who are deaf. It made their life significantly easier with turning speech to text with 95% accuracy [11].

Furthermore, the benefit of speech recognition for children with hearing loss was studied. The study shows that speech recognition with noise training can help children who have hearing loss [12]. These examples from many different fields can be multiplied. Besides all that, speech recognition provides many benefits being behind many conversational technologies.

As mentioned in the previous section, people need fast responses and always available solutions to their demands and problems. At this point, speech-to-text advances customer experience with a low word error rate. Also, since speech recognition transforms speech into words correctly, it increases the automation in call centers and facilitates conversational solutions. Transforming speech into words also provides to create analytics for call center businesses. For example, all conversations between agent and customer in call for any business are recorded. If speech

recognition is not applied to the analysis process, these recordings are controlled and analyzed by a supervisor of agents. Controlling each call is impossible for supervisors, so instead of listening and controlling each call, they can select a few of them that can cause missing more important and urgent calls.

However, thanks to speech recognition technology, all calls can be written as words and analyzed. This provides increasing quality for call centers while decreasing operational work and cost [13].

For this reason, the round about economy works with the change to a feasible future by isolating interest from natural substance interest due to being viewed as the answer for the world's expanding asset utilization issue [26]. The round economy model, which is quickly acquiring energy around the world, is viewed as a way to deal with defeat supportability challenges for a world that requires monetary development, ecological assurance, and social government assistance.

CHAPTER 3

FUZZY SET AND MCDM

3.1 Fuzzy Sets

Problems may have information which are incomplete or imprecise n many different fields. These made it very difficult to solve the problems. Therefore, fuzzy set is introduced by Zadeh first time in 1965 [37]. The approach is applied many different industry and study area usefully. In fuzzy set theory, members are classified in two way which is belonging in a set or not belonging in a set.

3.2 Intuitionistic Fuzzy

By the time of progress, Atanassov is extended the fuzzy set theory as IF set [38]. Difference between intuitionistic and classical fuzzy set theory is that IF theory provides to make assessment gradually for being member of elements in a set. It allows that gradual evaluation of the being member of elements in a set. It means that intuitionistic fuzzy theory has a membership function which has unit interval between 0 to 1. Fuzzy sets provide ranking membership with grading scores from zero to one. Based on the study of basic concepts of IF set is defined as

$$A= \{(r , \mu_A(r) , \nu(r)) : r \in R\} \quad \textbf{(3.1)}$$

while $\mu_A(r)$ is member of function, $v_A(r)$ is not member [14].

However, by the law of the nature, there are many subjectivity and assumptions in real cases. Therefore, intuitionistic fuzzy set approach is introduced to literature.

In fuzzy set, summary of these functions should greater or equal to 0 and less than equal to 1. Also, $\pi_A(r)$ is the intuitionistic fuzzy index of belogging to A.

$$\pi_A(r) = 1- \mu_A(r) + v_A(r) \quad \textbf{(3.2)}$$

As equation 1 where $\pi_A(r)$ is hesitancy of r to A for every $r \in R$,

$$0 \leq \pi_A(r) \leq 1,\ \pi_A(r) \quad \textbf{(3.3)}$$

defines the degree of uncertainty. Having more knowledge of r, the number should be smaller.

$$\mu_A(r) = 1 - v_A(r) \quad \textbf{(3.4)}$$

Intuitionistic fuzzy theory is used in many different fields because uncertainty and lack of information are existing in these fields. Real life problems are mostly very complex, and environment is generally uncertain. This situation causes to make solve these problems impossible or hard to solve. Therefore, forecasts, subjectivity and assumptions are included the solution to solve the problems. At this point, fuzzy and intuitionistic fuzzy sets are applied in solutions of many different kind of problems at various fields.

3.3 VIKOR

Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) is introduced by Opricovic in 1998 [39]. VIKOR aimed to produce compromise solutions to decision problems. There are group utility and individual regret criteria in this approach to evaluate alternatives for decision-making. Also, VIKOR aims to identify if the best alternative is the only one or more than one. Complicated decision-making problems consist of more than one and contradictory criteria in same time. Therefore, multi-criteria decision-making approach are very useful to solve these problems. VIKOR stand up for selecting best alternative which has highest group utility while it has lowest individual regret. Although VIKOR can not give the optimal solution for the problem, it gives the closer solution to the ideal. VIKOR is applied in many fields and industries in the literature. The approach is used for selecting best silent Genset with WASPAS-Entropy method. Study includes different kind of criteria like power consumption, fuel tank capacity, fuel consumption, etc. [40]. Moreover, VIKOR and CRITIC are combined and applied as MCDM technique for financial decision-making process to increase quality of selection [41]. Furthermore, impediments in front of adopting industry 4.0 technologies for Indian manufacturers are prioritized by VIKOR. Study shows that lack of skilled workers, internal resistance to change, concern for IT security and lack of consultancy from outside of the organizations are

biggest impediments for industry 4.0 re-evaluation in Indian [42]. Also, VIKOR is selected as MCDM technique to select best supplier in Chinese nuclear power problem. Method is aimed to help eliminating uncertainty with using quantitative and scientific approach [43]. As a result, usage area of VIKOR in the literature can be defined as below.

- Selecting best alternative
- Evaluating risk, situation, process, etc.
- Scoring things
- Material selection and
- Prioritizing

VIKOR is one of most appropriate methodology when more than one criterion needs to be considered in same time.

In this thesis, VIKOR approach is implemented to define the goal, main and sub criteria, and alternatives to create decision matrix with IF methodology.

For this aim, goal, alternatives and criteria are defined as first step of VIKOR.

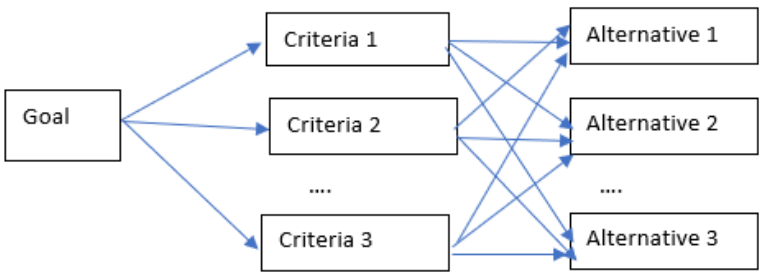

Figure 3.1 Goal and criteria definition

At second step decision matrix is created with collected data. In third step normalized

decision matrix is created with following condition to keep away from unit's impact the other reach contrasts on the choice to be made in model qualities. F_{ij} represents the member of decision matrix for i alternative and j criteria. Also, r_{ij} represents the member of normalized decision matrix for i alternative and j criteria.

$$f_j^+ = max_i f_{ij} \quad \textbf{(3.5)}$$

$$f_j^- = min_i f_{ij} \quad \textbf{(3.6)}$$

$$r_{ij} = \frac{f_j^+ - f_{ij}}{f_j^+ - f_j^-} \quad \textbf{(3.7)}$$

Fourth step is having weighted normalized decision matrix to reflect the effect levels of the criteria on the decision. v_{ij} represents the member of weighted normalized decision matrix for alternative i and criteria j.

$$v_{ij} = r_{ij} w_j \quad \textbf{(3.8)}$$

Next, individual regret and group utility values are determined. Group utility addresses to the complete weighted standardized worth to be acquired assuming the option is chosen, while individual regret demonstrates the biggest record that will happen in light of a measure on the off chance that the option isn't chosen. S represents the group utility for alternative i while R represents the individual regret for alternative i.

$$S_i = \sum_{j=1}^{n} W_j \frac{f_j^+ - f_{ij}}{f_j^+ - f_{ij}^-} = \sum_{j=1}^{n} V_{ij} \quad \textbf{(3.9)}$$

$$R_i = max_j \left(w_j \frac{f_j^+ - f_{ij}}{f_j^+ - f_{ij}^-} \right) = max_j V_{ij} \quad \textbf{(3.10)}$$

In 6th step, indexes of ranking are determined. The agreement measure (Q_i) is determined to guarantee the group utility and individual regret criteira are consolidated to settle on other alternatives.

$$Q_i = \theta \times \frac{S_i - S^+}{S^- - S^+} + (1 - \theta) \times \frac{R_i - R^+}{R^- - R^+} \quad \textbf{(3.11)}$$

In next step, the most appropriate alternatives are ranked. To verify whether the

results are met the states following or not is observed.

First state is valid advantage which is supposing the alternative with the lowest Q with the Q (x') value, the second-best alternative with the (Q (x ")) .

$$D(Q) = 1 / (m - 1) \quad \textbf{(3.12)}$$

It is acceptable when below equation is satisfied.

$$Q (x") - Q (x') \geq D(Q) \quad \textbf{(3.13)}$$

Meeting above state means that best alternative which is selected is also acceptable.

Second state is stability acceptance which is the selection with the best Q_i value should be met the condition of being best alternative from the point of group benefit and / or individual regret criteria. In case of both states are met, the Q_i value is selected as the most appropriate alternative for the solution. However, if only state 1 is fulfilled, two alternatives which have best value of consensus criterion are selected as the best alternative. In case of state 1 is not satisfied, next-best alternatives will be calculated until following equation is satisfied.

CHAPTER 4

RESEARCH BACKGROUND

Supplier selection has long been an important research topic, and many different methods for selecting the best supplier based on application areas and data type have been proposed in the literature. Even most popular methodologies for multi-criteria decision-making supplier selection problems are TOPSIS, ANP, AHP, VIKOR, and hybrid solutions of with IF, ANOVA, VIKOR, etc. have also been applied in previous research. Over the last twenty years, in more than one thousand VIKOR is implemented. Also, in more than seven hundred and fifty research IF approach is applied to supply chain problems. In previous research, VIKOR is generally used with combining fuzzy AHP, ANP, ELECTRE and BWM while intuitionistic fuzzy is combining with AHP, Multimoora, Promethee,etc. Although there are many research for supplier selection problems and IT fields separately, there are very limited research about supplier selection problem in IT field. Especially, using qualitative criteria and data in IT field has a lack of research in the literature.

4.1 Literature Review of MCDM Applications

In past, VIKOR was used integrated with a Type 2 fuzzy methodology that best or worst solves a green supplier selection problem [15]. Authors benefit from VIKOR for multi-criteria decision making and benefit from Best Worst for the elimination of subjectivity. Integrated VIKOR and fuzzy AHP approach for the problem of multi-level supplier selection. In the study, criteria weights are defined with fuzzy AHP and supplier ratings are used with fuzzy VIKOR [16]. A combined methodology is implemented for evaluating performance of suppliers. In the study, Decision makers are rated as intuitive when using Analytical Hierarchy Process as an MCDM methodology. In addition, human judgment is incorporated into the techniques and three sites and four criteria are selected in the study [17]. With combining fuzzy TOPSIS and IF methodologies a solution is proposed to green supplier selection problem [15]. In the study, subjectivity in collecting data from decision makers is

eliminated by intuitive fuzzy. A hybrid methodology is verified for the supplier selection problem in an uncertain environment and subjectivity using ANP with intuitionistic fuzzy. [18]. The combination of VIKOR and ELECTRE is applied to use the evaluation of suppliers in an uncertain area. The study examines the outranking of the novel using MCGDM. Fuzzy VIKOR with a systematic and rational process of selecting partner issues in IS/IT projects is verified [20]. Fuzzy TOPSIS and OPA in large scale MCDM with missing values in project selection problem. Principal components analysis was used for the clustering criteria, K-algorithm was chosen as clustering alternatives, and finally fuzzy TOPSIS and OPA were chosen as ranking clusters [21]. AHP, TOPSIS and Taguchi loss function are combined to solve supplier selection problem for heavy locomotive producer in India. Quality, lead, cost are selected as criteria in the problem [44]. Neutrosophic ANP and VIKOR are applied together to select appropriate supplier in uncertain environment and lack of knowledge. ANP is used for calculating weights of main criteria and sub-criteria, then VIKOR is applied to determine best solution [45]. Moreover, fuzzy ANP method is implemented for supplier selection problem for production in Indian electronic switches company [46]. TOPSIS is selected as an approach for supplier selection problem considering not only profit as criteria but also green management [47]. A sustainable supplier selection problem with multi-criteria problem is solved by intuitionistic fuzzy TOPSIS approach. There are nine main, and thirty sub-criteria are considered in the problem [48]. AHP and TOPSIS methods are applied for supplier selection for steel industry in Iran. CO2 emissions, number of workers in the country of vendor, water consumption and distance are considered as main criteria [49]. Lastly, TOPSIS is applied in government banking industry considering ten ratios [50]. Summary of most used multi-criteria decision-making methodologies for supplier selection problems is shown in Table 4.1.

Table 4.1 Summary of literature review for supplier selection problems

Author	**VIKOR**	**Best-worst**	**IF**	**Fuzzy AHP**	**Electre**	**Fuzzy TOPSIS**	**TOPSIS**	**Fuzzy VIKOR**	**ANP**
Wu Qun, et al.	√	√							
Awasthi Anjali et al.	√			√					
Çalı Sedef, et al.	√		√		√				
Memari Ashkan, et			√				√		

al.									
Wei G.W, et al.		√							
Vaid K. et al	√								
Kumaran S.	√								
Surange V. et al	√								
Wu Y. Et al	√								
Kumar R. et al	√			√					
Baset M. et al	√								√
Vinodh S. et al									√
Kamalakannan R. et al	√								
Memari A. et al			√				√		
Azimifard A. et al				√			√		

4.2 Literature Review of Speech Recognition Vendor Comparison

Although, need for automation is popular topic because of COVID-19 and technology, number of various research with different disciplines is quite less. Generally, research in literature about IT contains only specific criteria which solution has. Also, these criteria are mostly quantitative data in literature. For example, word-of-error rate is most used criterion in the literature to compare speech recognition vendors. However, there are many different criteria to select most appropriate vendor as a supplier of speech recognition. Best supplier is not only most quality or cheaper one, but also it should be most flexible, easy to use one, too. Because of uncertainty, qualitative data is very important as criteria. Because of this situation, there are much supplier selection research which considers not only quantitative but also qualitative data. On the other hand, there is a gap in literature for supplier selection problem in IT industry with these criteria while research about supplier selection field is still increasing day by day. The study ranks five speech-to-text engine vendors based on levels of accuracy, word error rates, and performance. Different types of audios are used in the study to make evaluations in a different type of audio format [22]. Various measurement techniques are being studied to classify the engines according to their performance. The study also considers different accents in a language as an issue [23]. Cloud based speech recognition engines are examined for analyzing human- machine interaction. In the study, accuracy of intent

recognition and effect of background noise are considered [25]. Speech recognition performance is evaluated in Sindhi language based on accuracy criteria for isolated words [28]. Moreover, Bootstrap estimates are used for evaluating speech recognition performance. Word error rate is considered as criteria with using bootstrap for significance test [31]. In the literature, research is more about new algorithms or approaches to increase accuracy or applying speech recognition solutions to different industries. Although there is research for comparing different speech recognition engines for accuracy, there is a lack of research about comparing them with different criteria.

Table 4.2 Literature review of comparison for speech recognition engines

Authors	**WER**	**Performance**	**Format of audio file**	**Multi-language**
Joshua Y. Kim1 et al.	√	√	√	
Andrey L. Herchonvicz et al.	√	√		√
Bisani M et al.	√			
Dharmani Aarti H et al.	√			√
Gonzalez Maria et al.	√			

CHAPTER 5

COMPUTATIONAL CASE STUDY

This part of the study handles making-decision to select most appropriate alternative for speech to text engines by using an integrated VIKOR and Intuitionistic fuzzy approaches. Intuitionistic fuzzy is applied to eliminating subjectivity of data, because there are not only quantitative but also qualitative data in the problem. Also, VIKOR is selected as multi-criteria decision-making methodology, because problem includes more than one but limited alternative, and profit criteria and cost criteria in same time. Therefore, considering group utility and individual regret in VIKOR methodology is provided advantage to consider all criteria.

5.1 Existing Situation

Based on the previous works which are mentioned in Table 4.2, scientists usually work on measurable data to compare speech to text brands, also in general, they applied same approach in their methodologies. This makes these approaches restrictive is considering only quantitative data. This study aims to propose a more comprehensive method by adding different benchmarking points to the problem. Also, as previously mentioned in first section, speech to text consists of artificial intelligence and neural network technologies to develop itself perpetually. Because of this, making decision with only using existing situation of the vendor is not true when other vendors are currently working on better technologies.

5.2 Suggested Improvements

As mentioned in previous section, quantitative data and limited criteria are not enough to make sustainable decision. Therefore, multi-criteria decision-making methodologies are considered to improve current situation. For this, new criteria which includes qualitative data are added to the problem. A combined multi-criteria decision-making approach is proposed to solve the Speech to Text vendor selection problem in computer technology industry, because the problem has finite alternative

and more than one criterion. At this point, previous works are examined to decide which approach is most useful to solve the problem. In Table 4.1 previous works are collected for supplier selection field and most popular criteria are revealed. After considering the literature a hybrid solution is applied. Main and sub-criteria are defined under cover of previous research about speech recognition engine comparisons and supplier selection problems in different fields. New point of view is intended while comparing speech to text providers with adding qualitative items to the problem. Under the light of previous research, quality, agility, maintenance, and cost are found as popular criteria. Then, twelve sub-criteria under the four main criteria are defined. First, recognition success is selected as sub-criterion under the quality because it is the easiest to measure and most scientific data in the literature. It is calculated by dividing the number of incorrect words by the total number of words. Also, it effects the overall user experience for virtual assistants and IVRs. Then, using and adapting newest artificial intelligence technologies which is technological leadership is considered second sub-criterion under the quality. Also, it shows the power of research and development activities of the speech recognition provider, because of symbolizing consistent advancement. Secondly, unit price of the speech recognition product is defined as one sub-criterion under the cost main criteria, because it effects the total cost directly and it is another quantitative and easy to measure data for comparing different alternatives. Hardware requirements for running speech recognition engine is the other sub-criterion under the cost criteria, because if server cost is very huge it drops the profitability quickly. Thirdly, three sub-criteria are defined for maintenance. These sub-criteria are mostly qualitative, but they have great importance to reach overall aim in IT projects. For example, using same workflow tool with stakeholders, providers and customers benefits to follow required tasks very easily for all level of project calendar. On the other hand, different customers may have different type of audio files to recognize. Therefore, supporting many different types as much as possible gives an advantage to integrate with customers easily for IVRs, virtual assistants, bot providers. Another important topic for information technology projects is service-level agreements. Service-level agreements is agreement which provides a commitment between customer and service provider. Meeting service-level agreements can be achieved with excellent

support teams and processes, so support activity is defined as sub-criterion for maintenance criteria. In today's conditions where borders are stretched and different cultures live together, supporting more than one accent for a language has a great effect on speech recognition success. For instance, when an agent who has Irish accent in a call center and a customer who has Australian accent have a conversation, the speech to text engine should transcribe both accents in same time and same language model. At this point, handling as much as different accent is significant while selecting speech to text supplier. In last, agility or flexibility is another qualitative topic for supplier selection problems. The topic is not implemented in previous research although it has effects on success for speech recognition projects. Like supporting different accent for a language, supporting different languages is also very important to expand market share in worldwide. Moreover, having easy installation process should be considered for comparing alternatives due to indirect effect to project cost for not only customer side but also provider side. Providing low code integration and products is also significant in software industry because no one wants to use or work with hard to understand or breakable application programming interfaces. Also, having great know-how in different industries like call center, banking, insurance, telecommunication etc. is provide huge advantage for suppliers, because if the supplier has experience in the industry where it’s customer in, the supplier can understand the customer’s need and problems in advance. A summary of main and sub-criteria for speech recognition supplier selection problem is described in below.

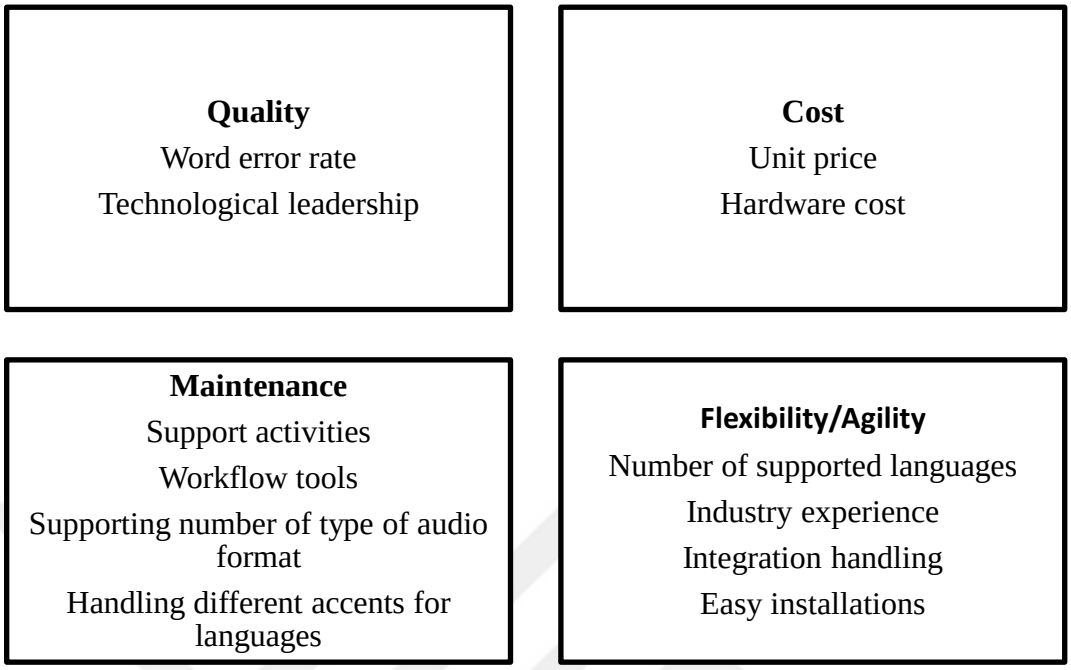

Figure 5.1 Main and Sub Criteria

The supplier selection problem in the study consists of many main criteria, sub criteria and alternatives. Because of existing limited number of alternatives and multiple criteria multi-criteria decision-making methodologies should be implemented. VIKOR is most appropriate, because it considers more than one factor in same time with grouping them group utility and individual regret. On the other hand, due to existing qualitative data and subjectivity, fuzzy technique is used to decreasing uncertainty and lack of information. The solution is proposed in Figure 5.2. Solution starts with the defining main goal and criteria, later decision makers are obtained with considering criteria which are defined. After, solution is applied with a selected methodology. Results are obtained by methodologies and as a last step, solution is needed to be verified. Therefore, sensitivity analysis and real-life comparisons are made according to results.

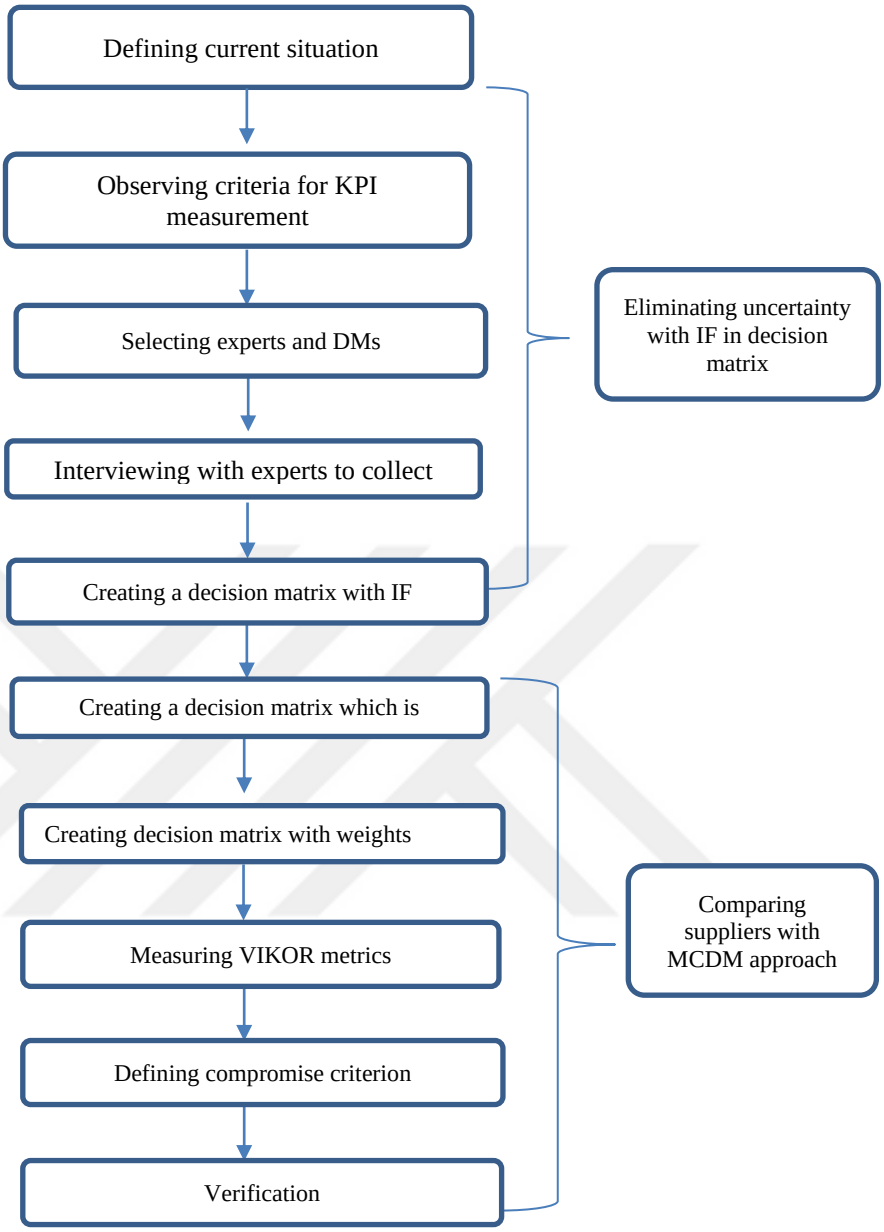

Figure 5.2 Suggested Methodology

5.3 Creating Solution for Decision Making

The problem has not only quantitative data but also it has qualitative data collected from experts. It causes uncertain environment and lack of objectivity. Therefore, intuitionistic fuzzy is applied to matrix, then suppliers are compared by VIKOR.

5.3.1 Data Collection

In the thesis, real-life supplier selection problem is handled to observe hybrid method of intuitionistic fuzzy and VIKOR approaches. A company which runs in call center industry is selected as purchaser for speech recognition product. The company needs the product to transcribing audio to text in their IVRs and call center operations to decrease operational cost and increase quality and customer satisfaction. While choosing the alternatives, it was considered that they have similar success rates, similar market shares and similar solutions. Moreover, decision makers are selected based on their expertise and knowledge about speech recognition and other call center software. Lead of development team (Dev), product manager (PM) and lead of R&D (RD) team are chosen for this case. Verbal importance of alternatives and importance of verbal criteria are collected in Table 5.1 and Table 5.2. Furthermore, data are collected from experts with making online and in person interviews. Answers from the experts are collected and applied to linguistic scale. Intuitionistic fuzzy scale is selected for data for transforming words to numbers. IF provided to eliminating subjectivity and uncertainty of expert's opinions.

Table 5.1 Significance of suppliers verbally

Significance of suppliers	**IFNs**
Definitely Little (DL)	(0.05, 0.95)
Little (L)	(0.2, 0.65)
Reasonably Little (RL)	(0.35, 0.55)
Averagely Low (AL)	(0.5, 0.5)
Reasonably High (RH)	(0.65, 0.25)
Exactly High (EH)	(0.8, 0.05)
Definitely High (DH)	(0.9, 0.1)

Table 5.2 Verbal criteria importance

Verbal significance of criteria	**IFNs**
Ineffective (I)	(0.15.0.8)
Little Effective (LE)	(0.2, 0.65)
Average -Little Effective (AL)	(0.4, 0.45)
Average Effective (AE)	(0.5, 0.5)
Average - Exact Effective (AEE)	(0.55, 0.3)
Exactly Effective (EE)	(0.7, 0.2)

Data are collected in interviews as in Table 5.3 and Table 5.4 with considering verbal terms.

Moreover, weights of decision makers are defined as 0.35 for lead of development team, 0.4 for product manager and 0.25 for lead of research and development team considering their knowledge, experience levels and closeness to the problem. Product Owner has highest weight, because s/he is the person who has the knowledge about the solutions. Next, because of its highest knowledge about maintenance, adaptability and security developer has second highest weight. Lastly, because of having knowledge about speech recognition technology researcher is selected as decision-maker with lowest weight.

Table 5.3 Information of four alternatives

	Decision-Makers	**Supplier -1**	**Supplier -2**	**Supplier -3**	**Supplier -4**
Word error rate	Dev	DH	DH	EH	RH
	PM	EH	DH	RH	AL
	RD	DH	DH	RH	AL
Leadership in technology	Dev	AL	EH	EH	EH
	PM	EH	DH	DH	AL
	RD	RH	DH	EH	AL
Unit cost dollar/minute	Dev	DH	L	RL	AL
	PM	DH	RL	M	RH
	RD	DH	AL	RL	AL
Hardware requirement	Dev	EH	EH	EH	EH

as cost	PM	DH	EH	RH	RH
	RD	EH	DH	DH	EH
	Dev	RH	RH	RL	L
	PM	EH	AL	AL	RL
Support process	RD	P	RL	AL	AL
	Dev	FM	EH	EH	RL
	PM	RL	EH	AL	AL
Tools for task follow	RD	RH	AL	AL	AL
	Dev	DH	DH	DH	RH
Supporting number of	PM	EH	DH	RH	RH
types of audio format	RD	EH	EH	EH	AL
	Dev	DH	EH	RH	RL
Handling different	PM	EH	DH	AL	L
accents for languages	RD	DH	RH	RL	RL
	Dev	F	EH	DH	AL
Number of supported	PM	RL	RH	DH	AL
languages	RD	F	RH	DH	RL
	Dev	EH	DH	EH	RH
	PM	EH	DH	DH	RH
Industry experience	RD	RH	EH	DH	VH
	Dev	DH	EH	VH	VH
	PM	EH	RH	RH	AL
Integration handling	RD	EH	EH	RH	AL
	Dev	RH	DH	DH	EH
	PM	F	DH	DH	DH
Easy installations	RD	RL	DH	DH	EH

Table 5.4 Significance weights of criteria

	Dev	**PM**	**RD**
Word error rate	DE	EE	DE
Technological leadership	AEE	EE	DE
Unit price dollar/min	I	DE	LE
Leadership in technology	EE	I	AE

Support activities	DE	EE	AL
Workflow tools	AEE	EE	AE
Unit cost dollar/minute	EE	AE	AEE
Capability of handling all accents	LE	AEE	DE
Multiple languages	LE	EE	AE
Hardware requirement as cost	LE	DE	EE
Integration capability	DE	EE	AE
Easy deployment	DE	AEE	LE

CHAPTER 6

RESULT AND DISCUSSION

6.1 Results

Constructed decision model and collected data in previous section shows that there are qualitative and quantitative data need to be considered. Also, uncertainty and incomplete information is existing in the problem. Therefore, solution is started with transforming linguistic data to measurable data scientifically.

To do this, at the first stage, the SIFWA operator determines an intuitionistic fuzzy decision matrix by below formula, the results of which are presented in Table 6.1. In the formula, r_{ij} represents the elements of decision matrix for alternative i and criteria j. Also, u_{ij} shows that the first number of linguistic set while v_{ij} is showing second.

$$r_{ij} = \left(\frac{\prod_{k=1}^{3} u_{ij}^{k\,\lambda k}}{\prod_{k=1}^{3} u_{ij}^{k\,\lambda k} + \prod_{k=1}^{3} (1-u_{ij}^{k\,\lambda k})}, \frac{\prod_{k=1}^{3} v_{ij}^{k\,\lambda k}}{\prod_{k=1}^{3} v_{ij}^{k\,\lambda k} + \prod_{k=1}^{3} (1-v_{ij}^{k\,\lambda k})} \right) \quad \textbf{(6.1)}$$

In the formula indexes represent the following information.

i→ alternatives,

j → criteria, and

k → decision makers.

Also, C_i shows the criteria while A_i shows the alternatives in the problem.

Table 6.1 IF decision matrix and subjective weights of criteria

	Cri-1	Cri-2	Cri-3	Cri-4	Cri-5	Cri-6	Cri-7	Cri-8	Cri-9	Cri-10	Cri-11	Cri-12

Alt1	(0.86,0.07)	(0.67,0.19)	(0.9,0.1)	(0.85,0.07)	(0.6, 0.2)	(0.48,0.46)	(0.84,0.06)	(0.87,0.07)	(0.44,0.52)	(0.77,0.08)	(0.84,0.06)	(0.52,0.42)
Alt2	(0.9,0.1)	(0.87,0.08)	(0.32,0.57)	(0.83,0.06)	(0.52,0.42)	(0.74,0.10)	(0.88,0.08)	(0.82,0.10)	(0.71,0.15)	(0.88,0.084)	(0.75,0.10)	(0.9,0.1)
Alt3	(0.71,0.15)	(0.85,0.07)	(0.41,0.53)	(0.78,0.12)	(0.45,0.52)	(0.62,0.26)	(0.80,0.13)	(0.52,0.53)	(0.90,0.10)	(0.87,0.08)	(0.71,0.15)	(0.90,0.10)
Alt4	(0.55,0.41)	(0.62,0.26)	(0.56,0.39)	(0.75,0.10)	(0.32,0.57)	(0.45,0.52)	(0.61,0.30)	(0.28,0.56)	(0.46,0.51)	(0.69,0.17)	(0.62,0.26)	(0.85,0.07)
w	(0.84,0.13)	(0.72,0.20)	(0.48,0.44)	(0.40,0.52)	(0.73,0.20)	(0.60,0.30)	(0.59,0.33)	(0.54,0.34)	(0.46,0.42)	(0.65,0.27)	(0.75,0.21)	(0.6,0.28)

Next, to eliminate uncertainty, decision matrix will be normalized. For this aim, in next step, normalized decision-matrix and weight of criteria are obtained in Table 6.2.

Formula for normalized decision-matrix is shown in below.

$$w_j^s = \frac{u_j + \frac{u_j}{(u_j+v_j)}\pi_{ij}}{\sum_{j=1}^{n} u_j + \frac{u_j}{(u_j+v_j)}\pi_j} \quad \textbf{(6.1)}$$

$$\pi_j = 1 - u_j - v_j \quad \textbf{(6.2)}$$

Moreover, best and worst ideal solution with intuitionistic fuzzy are observed. At real-life problem, unit price and hardware cost criteria are defined as cost criteria while the remaining are defined as benefit criteria. It means that higher value for cost criteria are causes the individual regret while higher value for other criteria provides to increase group utility for alternatives. Then, intuitionistic fuzzy of all sub-criteria are calculated based on objective weighting approach. Value of total w indexes should be equal to one.

Table 6.2 Normalized DM and criteria weights

	Cri-1	**Cri-2**	**Cri-3**	**Cri-4**	**Cri-5**	**Cri-6**	**Cri-7**	**Cri-8**	**Cri-9**	**Cri10**	**Cri11**	**Cri12**

Sup1	0.08	0.76	0.00	0.06	0.01	0.96	0.11	0.01	1.00	0.52	0.02	1.00
Sup2	0.06	0.03	1.00	0.16	0.53	0.00	0.07	0.08	0.35	0.02	0.37	0.06
Sup3	0.47	0.08	0.86	0.72	0.80	0.45	0.30	0.77	0.00	0.04	0.56	0.06
Sup4	0.99	1.00	0.59	0.97	1.00	1.00	0.99	1.00	0.96	1.00	1.00	0.11
w_{jS}	0.11	0.10	0.07	0.05	0.10	0.08	0.08	0.08	0.07	0.09	0.10	0.09

Then, IFEs for all sub-criteria are calculated and shown in Table 6.3 by objective weighting approach.

$$w_j^O = \frac{1- E_j}{\sum_{j=1}^{n} 1- E_j}, \; 0 \leq w_j^O \leq 1 \qquad \textbf{(6.3)}$$

$$E_j = - \frac{1}{mln2} \sum_i^m (\mu_{ij} \, ln\mu_{ij} \; + \; v_{Aij} ln v_{ij} - (1- \pi_{ij}) \ln(1- \pi_{ij}) - \pi_{ij} \ln 2) \qquad \textbf{(6.4)}$$

and summation of w should be equal to one.

Table 6.3 IFE values and objective weights of criteria

	Cri-1	**Cri-2**	**Cri-3**	**Cri-4**	**Cri-5**	**Cri-6**	**Cri-7**	**Cri-8**	**Cri-9**	**Cri-10**	**Cri-11**	**Cri-12**
Ej	0.6511147	0.6398145	0.8462855	0.5132329	0.9452717	0.8725696	0.6016354	0.7272703	0.7938721	0.5444011	0.6575706	0.5900361
WjO	0.0964591	0.0995833	0.0424987	0.1345803	0.0151312	0.0352317	0.110139	0.0754038	0.0569898	0.125963	0.0946742	0.113346

Then, weight is calculated by following equation.

$$W = w_j^O \theta + (1-\theta) w_j^O \qquad \textbf{(6.5)}$$

ɵ indicates the degree of importance between group utility and individual regret. In this problem, it is decided as 0.5 for simplicity. Also, changes in the result are calculated for different ɵ values to understand sustainability of the solution.

Table 6.4 Weighted normalized DM

	Cri-1	**Cri-2**	**Cri-3**	**Cri-4**	**Cri-5**	**Cri-6**	**Cri-7**	**Cri-8**	**Cri-9**	**Cri-10**	**Cri-11**	**Cri-12**
Alt1	0.008	0.076	0.000	0.006	0.001	0.057	0.011	0.001	0.062	0.055	0.002	0.100
Alt2	0.007	0.003	0.054	0.015	0.030	0.000	0.007	0.006	0.021	0.002	0.036	0.006
Alt3	0.048	0.008	0.046	0.068	0.045	0.026	0.029	0.058	0.000	0.004	0.054	0.006
Alt4	0.101	0.099	0.032	0.092	0.057	0.059	0.094	0.076	0.059	0.107	0.096	0.011

With using below equation, group utilities and individual regrets are determined.

$$S_i=\sum_{j=1}^{n} W_j \frac{f_j^+ - f_{ij}}{f_j^+ - f_{ij}^-} =\sum_{j=1}^{n} V_{ij} \quad \textbf{(6.6)}$$

$$R_i=max_j\left(w_j \frac{f_j^+ - f_{ij}}{f_j^+ - f_{ij}^-} \right) =max_j V_{ij} \quad \textbf{(6.7)}$$

$$Q_i = ɵ \times \frac{S_i - S^+}{S^- - S^+} + (1- ɵ) \times \frac{R_i - R^+}{R^- - R^+} \quad \textbf{(6.8)}$$

Table 6.5 Value of group utilities and individual regrets

	S_i	**R_i**	**Q_i**
Supplier 1	0.376271	0.099785	0.572289
Supplier 2	0.186553	0.053566	0
Supplier 3	0.392623	0.067966	0.284011
Supplier 4	0.881708	0.10659	1

Finally, results are evaluated with following states.

State 1: Valid advantage

Supplier 2 has the lowest Q_i value which is 0 and supplier 3 is secondary. Because of

this following state is controlled.

$$D(Q) = \frac{1}{(4-1)} = 0.33 \quad \textbf{(6.9)}$$

$$Q_3 - Q_2 = 0.28 - 0 = 0.28 \quad \textbf{(6.10)}$$

$$0.28<0.33 \quad \textbf{(6.11)}$$

Therefore, valid advantage state is not met.

At next step supplier 1 is the third best due to below calculation.

$$Q_1\text{-}Q_2=0.57\text{-}0=0.57 \quad \textbf{(6.12)}$$

Therefore, it is met the acceptable advantage.

State 2: Sustainability acceptance in result

Supplier 2 has not only best alternative for group utility but also it is the best alternative for individual regret value.

In conclusion, supplier 2 is found as most appropriate alternative in this real-life problem due to providing two valid states of VIKOR approach.

6.2 Sensitivity Analysis

In the VIKOR approach, the ratio of group utility and individual regret can be defined as different values. However, at the case study, it is assumed that they have an equal significance which means the value of ɵ is 0.5. If group utility is more significant than individual regret the ɵ value should be greater than 0.5. Otherwise, ɵ should be smaller than 0.5. In the study, different ɵ values are also included the result to observe sustainability of the solution.

Table 6.6 Summary of sensitivity analysis for different ɵ values

Supplier/Q_i	**ɵ=0**	**ɵ=0.25**	**ɵ=0.5**	**ɵ=0.75**	**ɵ=1**
Supplier 1	0.871664	0.721977	0.572289	0.422602	0.272914
Supplier 2	0	0	0	0	0
Supplier 3	0.271584	0.277798	0.284011	0.290224	0.296438

Supplier 4	1	1	1	1	1

In case of ɵ is equal to 0;

Q_3-Q_2=0.271584-0 =0.272 < D(Q). **(6.13)**

Q_1-Q_2=0.872-0=0.872 > D(Q) **(6.14)**

Means the result is observed as supplier 2 and supplier 1. Therefore, the decision maker may select one of them. Moreover, in case of individual regret has great importance, supplier 2 is best choice, too.

In case of ɵ is equal to 0.25;

Q_3-Q_2=0.28-0=0.28 < 0.33. **(6.15)**

It means Q_1-Q_2 should be calculated as next step and it is found as 0.72. As a result supplier 2 and supplier 1 can be selected equally.

In case of ɵ is equal to 0.75;

Q_3-Q_2=0.29-0=0.29 < 0.33 **(6.16)**

Then, as next step and it is found as Q_1-Q_2 is found as 0.42. Therefore, supplier 2 and supplier 1 can be selected equally.

In case of ɵ is equal to 1;

Q_1-Q_2=0.27-0= 0.27 < 0.33 **(6.17)**

Next step Q_3-Q_1=0.3 < 0.33, too. **(6.18)**

Third step Q_4-Q_2=1 > D(Q). Moreover, in case of group utility has great importance supplier 2 and supplier 4 are best alternatives. In conclusion, supplier 2 is found as most appropriate alternative for all weights of group utility and individual regret. However, second best alternative may change based on the ɵ value.

CHAPTER 7

CONCLUSION

Nowadays, companies need to increase automation in their processes because competitiveness is more challenging than ever. With COVID -19 there are many changes are occurred in people's daily lives. Many of strong old habits such as working in the office have been destroyed and employees in many fields have started to work from home. Also, number of internet users are increased exponentially due to doing daily works from internet such as grocery shopping, attending school classes, etc. Transformation of people's habits caused need for automation. At this point, IT market size also increased dramatically. For example, compound annual growth rate assumption for speech and voice recognition market in 2025 is calculated as 26.8 billion dollars which means 17.2% greater than current. Because of new advances like AI and man-made consciousness, the mechanization steps can be applied effectively and productively. Particularly, far off correspondence among clients and providers has incredible significance due to Covid-19. Additionally, choosing the best provider has been perhaps the main issues for associations for drawn out year. While choosing a provider for basic cycles expects more to meet more than one measure. Now, it turns into a MCDM issue in a questionable climate. While examining the issue, an organization maintaining a business in the client commitment industry is chosen because of its items that are bots, IVRs, and versatile applications, need Speech Recognition innovation which the organization doesn't exist. For this issue, four principal measures and twelve sub-models are characterized. Main criteria are selected as quality, cost, maintenance, and flexibility. Quality means, more accurate automation for IVRs, virtual assistants, etc. For example, if speech recognition engine recognizes an utterance wrongly, other components may recognize the user intent wrongly, too. It causes worse customer experience and higher cost in processes because of lack of automation. Moreover, unit price and other costs are very significant criteria for selecting supplier, because one of the certain constraints for companies is budget. Furthermore, maintenance is important for building sustainable customer service systems. Therefore, all

component of the system should maintain in best way and correctly. Lastly, adaptability is important criteria, because even a speech recognition has highest quality, cheapest or maintain perfectly, it does not mean it is appropriate for a company if the suppliers does not support adequate integration or installation solutions.

The greatest point of the review is to close the hole in the writing about assessing discourse acknowledgment items in light of quantifiable rules as well as immense ones. It assesses providers without missing the benefits and impediments of various rules. This study gives a way to deal with close the hole in the writing about considering subjective information to analyze Speech Recognition providers. Also, in the thesis, gap in the literature about comprising suppliers of speech recognition tried to be closed with considering different kind of criteria in same time. After applying combination of methodologies, alternative 2 is found as best alternative. Result is found as appropriate to reality by decision makers because the alternative has highest quality level and technology leadership based on most of their opinion. In future, problem can extend with adding security main criteria because security is getting more and more important every day due to reaching personal information easily. Keeping personal information in secure is very important and complex topic for all vendors. Also, keeping way the solution from cyber-attacks is very significant security topic to provide interrupted service, because according to Gartner's report a cyberattack will be occurred and cause huge damage and G20 will respond with physical one [53]. Moreover, constraints can be extended in future research to get closer the real-life problems. In conclusion, personalized security models can be implemented for the issue since data security is getting more significant step by step with enormous information and cloud applications in future.

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