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FUZZY RULE-BASED APPROACH WITH Z-NUMBERS IN SOLVING GROUP MULTI-ATTRIBUTE DECISION MAKING PROBLEMS

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By

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Multi-Attribute Decision Making (MADM) process is the most well-known branch of decision making and it is one of the most important tasks that have received a lot of attentions in many areas. In solving MADM issues, the parameters of decision making are often faced problems, such as imprecise, vague, uncertainty or incomplete information which lead to inaccurate decision-making. To cope up with these problems, the researchers apply fuzzy set theory as the best-developed approach. Among different fuzzy methods, fuzzy rule- based system (FRBS) due to its flexibility, simplicity, and experts' knowledge modeling is an adequate technique to solving MADM problems. The main objective of this research is to apply experts' opinions by Z-numbers in MADM issues as improvement in ranking performance in decision making process.

Based on extensive literature review on MADM issues using FRBS and Z-numbers, two main problems are addressed in this work. The first problem is inaccurate ranking results drew from the process of aggregating experts' opinions before converting them into one opinion due to data losses, and the second problem is regarding inadequate information in the experts' opinion, which lead to some degree of decision uncertainties. Indeed, in FRBS research to ranking, the reliability level (Z-numbers) in experts' opinions within the decision-making process has not been taken into account. Whereas, the Z-numbers play a key role in decision-making process to reach more precise decisions affecting the final ranking results.

The methods which have been applied and proposed in this study were aimed to increase the accuracy of decision making in solving MADM problems with easing computational process. In the FRBS-TOPSIS method, the initial data preparation is conducted and later FRBS are applied to rank the experts' opinions individually to obtain the final score of alternatives. Finally, aggregation of experts' opinions is performed by applying TOPSIS conventional technique. The proposed method was compared using the published data from another study by obtaining the final score of each alternative for all experts individually. In the Z-FRBS approach, by considering experts' opinion in form of Z-numbers to deal with inadequate information and modeling experts' knowledge through FRBS, the process of making decision is performed without using conventional techniques which resulted in a more accurate solving MADM problems. The effectiveness and validity of the main method is approved with an illustrative example, sensitivity analysis, and comparison with three others validated method.

In one of the comparisons, the findings showed among 25 alternatives, the Spearman Rho Coefficient (SRC) amount as decision making accuracy in the proposed method increased from 0.850 to 0.862. Indeed, based on the achieved results, with using the data from the other three methods, it is proven that the Z-FRBS method has made more efficient and accurate decisions than the compared methods in solving MADM problems. The advantages of the proposed methods are improvement in ranking performance by means of FRBS, easing computational process, and flexibility.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENDEKATAN BERDASARKAN PERATURAN FUZZY DENGAN NOMBOR Z DALAM MENYELESAIKAN KEPUTUSAN MULTI-ATTRIBUTE MEMBUAT MASALAH

Oleh

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Proses Pembuatan Keputusan Multi-Atribute (MADM) adalah cabang membuat keputusan yang paling terkenal dan ianya adalah salah satu tugas yang paling penting yang telah menerima banyak perhatian dalam pelbagai bidang. Dalam menyelesaikan isu-isu MADM, parameter membuat keputusan sering menghadapi masalah seperti maklumat tidak tepat, kabur, tidak pasti atau tidak lengkap yang membawa kepada pembuatan keputusan yang tidak tepat. Untuk mengatasi masalah ini, penyelidik menggunakan teori set kabur sebagai pendekatan terbaik yang dibangunkan. Antara kaedah kabur yang berbeza, disebabkan oleh kebolehlenturan, kesederhanaan, dan pemodelan pengetahuan pakar, sistem berasaskan peraturan kabur (FRBS) adalah teknik yang memadai untuk menyelesaikan masalah MADM. Objektif utama penyelidikan ini adalah menerapkan pendapat pakar melalui nombor-Z dalam isu MADM seterusnya meningkatkan prestasi pemangkatan dalam proses membuat keputusan.

Berdasarkan tinjauan literatur yang luas mengenai isu-isu MADM menggunakan FRBS dan nombor-Z, dua masalah utama ditangani dalam kerja ini. Masalah pertama adalah keputusan pemangkatan yang tidak tepat kerana kehilangan data yang terhasil dari proses mengagregasikan pendapat pakar sebelum mengubahnya menjadi satu pendapat, menyebabkan kehilangan data, dan masalah kedua adalah mengenai maklumat yang tidak mencukupi di dalam pendapat pakar, yang membawa kepada beberapa peringkat ketidakpastian keputusan. Sesungguhnya, dalam penyelidikan FRBS bagi pemangkatan, tahap kebolehpercayaan (nombor-Z) dalam pendapat pakar di antara proses membuat keputusan yang telah tidak diambil kira. Sedangkan, nombor-Z memainkan peranan penting dalam proses membuat keputusan

untuk mencapai keputusan yang lebih tepat yang mempengaruhi keputusan kedudukan akhir.

Kaedah yang telah diguna pakai dan dicadangkan dalam kajian ini adalah bertujuan untuk meningkatkan ketepatan membuat keputusan dalam menyelesaikan masalah MADM dengan meringankan proses pengiraan. Dalam kaedah FRBS-TOPSIS, penyediaan data awal dijalankan dan kemudiannya FRBS digunakan untuk menarafkan pendapat pakar secara individu untuk mendapatkan skor akhir alternatif. Akhirnya, agregasi pendapat pakar dilakukan dengan menerapkan teknik konvensional TOPSIS. Kaedah yang dicadangkan telah dibandingkan dengan menggunakan data yang telah diterbitkan daripada kajian lain dengan mendapatkan skor terakhir setiap alternatif bagi semua pakar secara individu. Dalam pendekatan Z-FRBS, melalui pertimbangan pendapat pakar di dalam bentuk nombor-Z untuk menghadapi maklumat yang tidak lengkap dan memodelkan pengetahuan pakar melalui FRBS, proses pembuatan keputusan dilaksanakan tanpa menggunakan teknik konvensyenal di mana memberi keputusan lebih tepat menyelesaikan masalah MADM. Keberkesanan dan kesahan kaedah utama terbukti dengan contoh ilustrasi, analisis sensitif dan perbandingan dengan tiga kaedah yang telah disahkan.

Dalam salah satu perbandingan, penemuan telah menunjukkan di antara 25 alternatif, jumlah Spearman Rho Coefficient (SRC) sebagai ketepatan pembuatan keputusan di dalam kaedah yang dicadangkan telah meningkat dari 0.850 kepada 0.862. Sesungguhnya, berdasarkan keputusan yang dicapai, dengan menggunakan data daripada tiga kaedah yang lain, ianya telah terbukti bahawa kaedah Z-FRBS telah menghasilkan keputusan lebih berkesan berbanding dengan kaedah lain yang dibandingkan dalam menyelesaikan masalah MADM. Kelebihan kaedah yang dicadangkan adalah meningkatkan prestasi pemangkatan dengan FRBS, mengurangkan proses pengiraan, dan fleksibel.

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LIST OF ABBREVIATIONS

MCDM	Multi-Criteria Decision Making
MCGDM	Multi-Criteria Group Decision Making
MADM	Multi-Attribute Decision Making
GDM	Group Decision Making
MODM	Multi-Objective Decision Making
FMCDM	Fuzzy Multi Criteria Decision Making
SSP	Supplier Selection Problem
MAGDM	Multi-Attribute Group Decision Making
FRBS	Fuzzy Rule Base System
AHP	Analytical Hierarchy Process
DEA	Data Environment Analysis
DMU	Decision-Making Unit
AHPFDEA	Analytic Hierarchy Process Z-number Data Environment Analysis
DS	Dempster-Shafer
HULZN	Hesitant Uncertain Linguistic Z-number
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
VIKOR	VIseKriterijumska Optimizacija I Kompromisno Resenje
FTOPSIS	Fuzzy TOPSIS
ANP	Analytical Network Process
FANP	Fuzzy ANP
SCM	Supply Chain Management
ANN	Artificial Neural Network

SCCOL	Supply Chain Collaboration
PROMETHEE	Preference Ranking Organization METHod for Enrichment of Evaluations
ELECTRE	ELimination Et Choix Traduisant la REalité
COA	Center of Area
MISO	Multi Input Single Output
FIS	Fuzzy Information System
FRBS	Fuzzy Rule Base System
SCOR	Supply Chain Operations Reference
ZWAPA	Z-numbers Weight Arithmetic Power Average
ZWGPA	Z-numbers Weight Geometric Power Average

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter presents the context on the issues that are pertinent to the topic of this research. Multi-Attribute Decision Making (MADM) is a branch of Multi-Criteria Decision Making (MCDM) that has been used for the selection of the best choice between many alternatives. MADM has many applications in many fields but one of the significant and main usages of it is in decision-making issues. One of the main objectives in MADM problems is to achieve the best decision among different choices. It is obvious that solving any problem by using the experts' opinions is to make the decision more confident.

In this chapter, a brief account of the background of the research is described firstly. And after that, the problem statement of the research is followed by the research objectives, scope and limitations, research contributions, and organization of the thesis.

1.2 Background of the Research

The decision making process is one of the most important tasks that has received a lot of attention in many domains such as computer science, engineering, management, mathematics, business, tourism, agriculture, and related problems in other fields (Salih, Zaidan, Zaidan, & Ahmed, 2019; Zavadskas, Govindan, Antucheviciene, & Turskis, 2016). Indeed, in this process, multiple criteria have been conflicted together and are famous for multiple criteria decision making (MCDM) issues. Also, this process is implied to identify alternative method which fits with defined objectives, goals, desires, and values (Harris, 1998). In general, there are two basic approaches for MCDM problems: the first one is Multiple Attribute Decision Making (MADM), and the second is Multiple Objective Decision Making (MODM). The MADM is the most well-known branch of decision making that deals with decision problems under the attendance of the number of decision criteria. The MADM approach requires the selection to be made among decision alternatives described by their attributes. It assumes that the problem is related to a predetermined number of decision alternatives (Malczewski, 1999).

In the MADM problems, the decision-maker (DM) attempts to choose the best alternatives which are characterized by a set of multiple attributes. In real-world MADM issues, it is hard to consider all aspects of decision problems for the individual DMs due to the limited practical experience and knowledge. Thus, to ensure the accuracy and rationality of decisions, they use multiple experts' opinions about the specific field as DMs or group decision making (GDM) play a key role in this respect (Tavana & Hatami-Marbini, 2011). In GDM, for choosing the best alternative (or for ranking), the experts' opinions are under the process of aggregation. In this process, all experts' opinions are aggregated at first, and then in the next steps, it is faced solely with one opinion. Meanwhile, in the aggregation process, the type and the sequence of its effects are the final decision (Wan, Wang, & Dong, 2016). The study on how to develop multi-attribute group decision-making (MADM) issues is at the center of attention nowadays especially for practical applications (He, Wang, & Zhexue, 2016) (Salih et al., 2019).

Obtaining the experts' opinions can be established by numeric or linguistic (L A Zadeh, 1975). But in real-world situations, experts express their opinions about alternatives by using linguistic variables (Chen, 2000). Furthermore, it is preferable for a DM to employ linguistic variables instead of real numbers in the most complex and ill-defined decision-making environment (L A Zadeh, 1975), because the use of information by linguistics, reinforces the flexibility and reliability of classical decision models (Peng & Wang, 2017). Naturally, performed linguistic variables are considered imprecise, vague, uncertain, or incomplete data. Fuzzy set theory has been used for modeling decision-making processes (that is one of the most key challenges in decision making) based on imprecise and vague information such as the judgment of the decision-makers. Still, this theory has an advantage over the traditional set theory when measuring the ambiguity of concepts that are associated with human beings' subjective judgments (Salih et al., 2019).

Concerning the values associated with the parameters in the real world, MADM problems are often imprecise, vague, uncertain, or incomplete so hybridize fuzzy sets in MADM techniques are widely used by researchers for dealing with ambiguous data (Zavadskas et al., 2016). For this purpose, a wide range of studies has combined MADM techniques with a fuzzy set theory which is called fuzzy MADM (FMADM). Some of them are fuzzy TOPSIS (Chen, 2000), fuzzy AHP(Chen & Yang, 2011), fuzzy VIKOR (Shemshadi, Shirazi, Toreihi, & Tarokh, 2011), fuzzy ELECTREE (Sevkli, 2010), fuzzy ANP (Vinodh, Ramiya, & Gautham, 2011) and fuzzy PROMETHEE (Ying-hsiu Chen, Wang, & Wu, 2011).

It is logical and acceptable that reliable information will result in reliable and accurate decisions. Because of different knowledge, expertise, and experience, the reliability of experts' opinions and judgments has become an essential property of information. Therefore, in real problem situations, it is necessary to take the reliability of the information in the decision-making process to arrive at suitable decisions. Lotfi (Lotfi A. Zadeh, 2011) introduced the concept of Z-number as the most adequate concept for the description of real-world information. A Z-number is an ordered pair Z = (A, B) of fuzzy numbers used to describe a value of a variable X, where A is an imprecise constraint on values of X and B is an imprecise estimation of reliability of A and is considered as a value of probability (confidence, sureness, reliability) measure of A. Decisions making based on Z-information are more realistic and more adequate to real-life decision problems (Zeinalova, 2014). This concept is new and it is a vital issue which in recent years few researchers have been accepted (Jiang, Xie, Zhuang, Shou, & Tang, 2016).

In this study, at first, modifying the type of aggregation of experts' opinions through a fuzzy inference system and rank the alternatives by a conventional technique intend to solve MADM problems more efficiently. Moreover, the other goal is to develop a reliable fuzzy intelligence system for solving group MADM problems through Z-numbers to select the best alternatives based on priorities. To accomplish this main goal, it is needed to define an issue on supplier selection problem (SSP) as a MADM problem under group decision making. The robustness of the proposed method is demonstrated with sensitivity analysis. And also, it should be compared with three other compound conventional methods in order to have a strong validity. To evaluate another goal, it will be compared with the method which is used in its data.

1.3 Problem Statement

In the real world, there are many issues in the area of decision-making that solving with sophisticated mathematical calculations is highly difficult. In these situations, using experts' opinions and utilizing decision makers' knowledge as experience to solve them is inevitable. Besides, using experts' opinions to solve MADM issues, the parameters of decision-making are often faced problems, such as uncertainty, vagueness, incomplete information, and impreciseness which lead to inaccurate decision-making. To cope up with these problems, researchers apply the fuzzy set theory as the best-developed approach (Amindoust, Ahmed, Saghafinia, & Bahreininejad, 2012). Among different fuzzy methods, fuzzy rule-based system (FRBS) due to its flexibility, simplicity, and experts' knowledge modeling is a required technique in solving MADM problems (Osiro, Lima-Junior, & Carpinetti, 2014).

In reviewing the papers related to FRBS or a combination of it with conventional techniques, these key points were derived. Firstly, variables used in fuzzy numbers can be crisp (numerical) or linguistics but used terms by linguistics are easier, more tangible, and closer to the real world for experts that express their experience (Ghadimi, Dargi, & Heavey, 2017). Furthermore, using information by linguistics reinforces the flexibility and reliability in decision-making models (Peng & Wang, 2017). Secondly, using experts' knowledge can be performed individually or in groups, but utilizing them by group decision-making (GDM) to solve MADM problems is more rational, and more accurate (Salih et al., 2019).

Accordingly, the reviewed papers such as Mahmoudi, Sadi-nezhad, and Makui (2016) related to FRBS or combination of it with conventional techniques indicated that in GDM, all experts' opinions are aggregated together at first, and then researchers faced with only an opinion in the form of a decision matrix. The decision matrix plays a key role in solving MADM problems. As well, the type of aggregation of experts' opinions (that how, and in what way be done) affects the final ranking results (Wan et al., 2016). Besides, in carrying out the aggregation process, we are faced with the challenge of data losing (Salih et al., 2019) that leads to inaccurate results. Therefore, as regards this problem, the researcher intends to improve data loss and ranking performance by modifying the type of aggregation process by presenting a new approach. In order to overcome this problem, it is supposed to used FRBS for obtaining the final score of each expert individually, and TOPSIS conventional technique for aggregating all experts' opinions and ranking the alternatives by using it.

But concerning the second problem, as mentioned before, Lotfi and Zadeh (2011) introduced the concept of a Z-number as a more adequate concept for the description of real-world information. A Z-number is an ordered pair Z= (A, B) of fuzzy numbers that are used to describe a value of a variable X, where A is an imprecise constraint on values of X and B is an imprecise estimation of reliability of A and it is considered as a value of probability measure of A. Often in the real world decision-making issues; because of different knowledge, expertise, and experience; the reliability of experts' opinions become as an essential property of information. So that reliable information gives more reliable results in decisions. Therefore, in real issue situations, it is necessary to take the reliability of the information in the decision-making process to arrive at suitable decisions.

Also, a key point that was derived by studying the papers related to Z-numbers shows that ranking of Z-numbers is very important and it is still a challenging issue in solving MADM problems (Salih et al., 2019). On the other hand, the study of papers related to FRBS shows that this technique has the necessary potential to rank Z-numbers. Besides, considering experts' opinions by Z-numbers as a critical property of information leads to an increase in the level of reliability in the decision-making process. It has also significant effect on final ranking results. But unfortunately, this issue in experts' opinions within the decision-making process by using FRBS has not been taken into account so far in solving MADM problems. Considering the experts' opinions in form of Z-numbers leads to dealing with inadequate information that can be handle the uncertainty issue better. So, in order to overcome this problem, the researcher intends to present a new approach based on Z-number to rely on FRBS. This approach which is proposed for the first time, will rank Z-numbers using only FRBS and without relying on conventional techniques. Although only Yaakob and Gegov (2015) were able to do this ranking, they were not able to perform ranking alternatives by relying on the maximum degree of influence on the expert's knowledge.

It is worth mentioning that in the Yaakob method, the FRBS technique has been used along with the TOPSIS technique in a way neither of them directly has used the FRBS for ranking. It means that the main body of their ranking has been performed by conventional techniques and not through FRBS. Also, the practice of ranking in their method was not systematic. On the other hand, in the Yaakob method, it can be seen that the Z-number has been converted to a type-1 fuzzy number that led to the loss of data, and then the TOPSIS technique to extract points has been used. And finally, according to what they proposed, an FRBS has been used for ranking is Z-TOPSIS, not Z-FRBS.

1.4 Objectives

The main objective of the study is to design a new method by using a fuzzy rule-based system under Z- number to solve multi-attribute group decision-making (MADM) problems. To have more reliable decision making, modeling experts' knowledge, and utility function, and improving accuracy in decision making are the basic issues and the main reason for the researcher who pursued this study. To do so, the following objectives are supported:

- To modify the aggregation process to improve data loss and ranking performance.
- To propose a new approach based on Z-number to complete information in modelling expert’s knowledge through FRBS for more precise decision making in solving group MADM problems.

1.5 Scope of the research

Making a decision is an important issue that everyone deals with it in daily life. It is an interdisciplinary domain that is applied in many areas and has been paid attention to by many researchers. On related issues in this scope, every researcher deals with some criteria and alternatives that have a conflict with each other and their main purpose is choosing the best alternative by considering those criteria. These issues are known to multi-attribute decision-making (MADM) problems. In recent decades, many techniques have been developed to solve MADM problems by researchers whose main focus is on one matter and it's the precision of decision making. Indeed, in their opinion, a good technique is the one that makes the decision more accurate, certain and precise, and close to the human mind and real world. The first technique is attained by modifying the process of aggregation in solving MADM problems through combining FRBS and a conventional technique such as TOPSIS. This technique can increase decision-making accuracy. On the other hand, in recent years, with the advent of the Z-number concept (2011), the issue of ranking Z-numbers for more precise decision making, has been at the center of attention of researchers in this scope and it is still an open issue for researchers. Therefore, the main scope of this research has been concentrated on developing a new approach with modeling expert's knowledge utilizing FRBS which derived from the first method but with considering Z-number in expert's opinions in ranking actions to complete information for more precise decision making in solving group MADM problems, independently. The proposed method is used to solve any MADM problems with some criteria and sub-criteria but, the method is open-ended. Furthermore, there is a limitation to this research. The expert's opinion in this method works only in the form of linguistics. The effectiveness and evaluation of the main method is approved with an illustrative example, sensitivity analysis, and comparison with three others validated method which has used a combination of FRBS technique or Z-number concept.

1.6 Contribution of the Research

The main contribution of this research is to develop a new method by the means of a fuzzy rule-based system to solve any group MADM problems under Z-number. This method, which is proposed for the first time, is used to rank the experts' opinions in terms of Z-number, including two components, score of performance and its reliability. The novel features of the proposed approaches are as follows:

- An improved aggregation process in order to reduction data loss in rank performance.
- A new approach based on Z-number to complete information in modelling expert’s knowledge through FRBS for more precise decision making in solving group MADM problems.
- Determining experts’ weight in decision-making based on the reliability of their opinions indicated that experts with high reliability have more weight in decisions making.
- Considering flexibility in the new approach in solving MADM problems.

1.7 Organization of the Thesis

Hereby, the organization of all chapters related to the thesis is introduced as follows.

As stated earlier, Chapter 1 figured out the research background, problem statement, objectives, scope of the research, and contribution of the research.

In Chapter 2, first, some subjects about theoretical background related to the research are expressed then it will be reviewed on reusable techniques, and after that literature on techniques based on fuzzy rule base systems and Z-numbers are reviewed. There will also be a critical discussion sub-section on what has been studied and reviewed. Also, the summarized gaps in the previous works and the potential for future works will be discussed.

In Chapter 3, the methodologies that have been used to complete this research are described. Indeed, the readers can follow the process of establishing the whole research here.

In Chapter 4, at first, there will be a review of previous works. Then two proposed methods are presented. One technique based on FRBS and TOPSIS is proposed on the aggregation of experts' opinion process for more accurate make-decision. Thereafter, considering experts' opinions by the form of Z-numbers, the previous FRBS point of view in the first method is developed as a new approach for ranking independently.

In Chapter 5, with presenting a numerical example, each method separately will be validated and then will be demonstrated the proposed methods in Chapter 4 which are working properly. Thereafter, the proposed methods will be compared with other methods. The Z-FRBS method will be implemented for the first time to rank Z-numbers through the fuzzy rule base technique. Therefore, to demonstrate that the technique is a reliable one with a strong validity that is practical for ranking Z-numbers, it is required to be compared with three other methods.

In Chapter 6, the summary of the work and conclusions are brought and after that, the directions for the future works and researches are suggested. Publications from this research are the end of this study. Finally, references and appendices are presented.

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BIODATA OF STUDENT

Saeed Bahrami was born in Qazvin, Iran, in 1971. He is married and has a son. He received his B.S. degree in Computer Software Engineering from the Qazvin Azad University in 1997. From 1999 to 2001, he had studied for an M.Sc of Computer Software Engineering at Najafabad Azad University. After gaining work experience in the fields of education and research, he began his doctoral studies at UPM University in the field of computer science, majoring in intelligent systems in the second semester of 2015-2016. Her field of work was solving decision problems by using fuzzy rule base system. The title of his thesis was "fuzzy rule-based approach with z-numbers in solving group multi-attribute decision making problems". He succeeded in defending her thesis in May 2021. He succeeded to extract three papers from his research, as well.

From 2000 up to now, he is a faculty member of Farhanghian University in Iran. This University is special to teacher training for the ministry of education. He has experience in teaching at some other universities as Azad University and PNU University as he is interested in teaching. His area of research interests includes Mobile agents, E-learning, Decision-Making and Fuzzy Logic.

Moreover, he has conducted some research projects for universities and has published dozens of papers, as well as four books. He was honored as the best lecturer at Farhanghian University in 2011. He is currently working as the director of the Center for Innovation and Entrepreneurship at Farhangian University in Qazvin.

LIST OF PUBLICATIONS

Saeed Bahrami, Razali Yaakob, Azreen Azman, Rodziah Atan, (2018), A Review on Z-numbers, *International Journal of Engineering & Technology*, 7(4.31), 487-490.

Saeed Bahrami, Razali Yaakob, Azreen Azman, Rodziah Atan, (2020), An Integrated of Fuzzy Rule Base System and TOPSIS Technique for Multi-Attribute Decision Making Problems, *International Conference On Software Engineering AND Information Management (ICSIM2020), Sydney, Australia, January 12-15, 2020*.

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