Assessment of the Knowledge-based Decisions in the field of Urban Water Infrastructure in Iran and Brazil Using Nominal-based Multi-Criteria Group Decision Method

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Abstract

Among the most complex activities in water companies is extracting accurate operational data of Urban Water Infrastructure (UWI). Hence, the use of data-based methods would be faced limitations for asset management of the UWI. This shortcoming could be improved using knowledge-based decisions. In this study, using this method, Maintenance-Rehabilitation Planning (MRP) of urban water pipes is assessed. Hence, the criteria effective on the MRP of the pipes were firstly determined. Then, two groups of experts in Iran and Brazil were invited to rank the determined criteria. For this purpose, a Multi-Criteria Group Decision-Making (MCGDM) method was developed based on the nominal group technique. This MCGDM method was implemented based on two approaches; first, the viewpoints of non-weighted decision-makers were considered; and second, the experts were weighted to rank the criteria. Finally, the results of these approaches in the two countries were pairwise compared. This comparison led to improving the literature and management in water companies of Iran and Brazil by identifying the effective criteria for the MRP of the pipes based on knowledge-based decisions. Further in this field, it was found that weighting the experts have no decisive effect on the results; and this is only effective in groups where the decision-makers weights are identically distributed. Moreover, it was found that there is a relation between the similarity of results and the similarity of experts' profiles in knowledge-based decision groups of various countries such as Iran and Brazil.

Appendix 1: The questionnaire form of the nominal group technique used in this research

Expert Profile

First Name	First Name	Last Name	Organization	Position	Position	Position	Degree	Degree	Degree	Years' Experience (year)	Years' Experience (year)	Y...

Question: **How much the criteria presented below are important in planning maintenance-rehabilitation works of pipelines in urban water networks of your city/country?**	*Question:* **How much the criteria presented below are important in planning maintenance-rehabilitation works of pipelines in urban water networks of your city/country?**	*Question:* **How much the criteria presented below are important in planning maintenance-rehabilitation works of pipelines in urban water networks of your city/country?**	*Question:* **How much the criteria presented below are important in planning maintenance-rehabilitation works of pipelines in urban water networks of your city/country?**	*Question:* **How much the criteria presented below are important in planning maintenance-rehabilitation works of pipelines in urban water networks of your city/country?**	*Question:* **How much the criteria presented below are important in planning maintenance-rehabilitation works of pipelines in urban water networks of your city/country?**	*Question:* **How much the criteria presented below are important in planning maintenance-rehabilitation works of pipelines in urban water networks of your city/country?**	*Question:* **How much the criteria presented below are important in planning maintenance-rehabilitation works of pipelines in urban water networks of your city/country?**	*Question:* **How much the criteria presented below are important in planning maintenance-rehabilitation works of pipelines in urban water networks of your city/country?**	*Question:* **How much the criteria presented below are important in planning maintenance-rehabilitation works of pipelines in urban water networks of your city/country?**	*Question:* **How much the criteria presented below are important in planning maintenance-rehabilitation works of pipelines in urban water networks of your city/country?**	*Question:* **How much the criteria presented below are important in planning maintenance-rehabilitation works of pipelines in urban water networks of your city/country?**	*Q* **H m t c t p s b l a i p t i p n m r w o p i u b w t n w o y c l v u**
Code	**Criteria**	**Sub-Criteria**	**Sub-Criteria**	**Sub-Criteria**	**linguistic values**	**linguistic values**	**linguistic values**	**linguistic values**	**linguistic values**	**linguistic values**	**linguistic values**	
					Absolutely less important	**Much less important**	**Much less important**	**Less important**	**Equally important**	**More important**	**Much more important**	**A m i p t**
1.1	Hydraulic	Pipe Pressure	Pipe Pressure	Pipe Pressure								
1.2		Pipe Flow Velocity	Pipe Flow Velocity	Pipe Flow Velocity								
1.3		Pipe Flow	Pipe Flow	Pipe Flow								
2.1	Structure	Pipe Age	Pipe Age	Pipe Age								
2.2		Pipe Length	Pipe Length	Pipe Length								

2.3	Pipe Diameter	Pipe Diameter	Pipe Diameter
2.4	Pipe Depth	Pipe Depth	Pipe Depth
2.5	Pipe Roughness	Pipe Roughness	Pipe Roughness
2.6	Vulnerability of Pipe in the Installation	Vulnerability of Pipe in the Installation	Vulnerability of Pipe in the Installation
2.7	Pipe Lifetime	Pipe Lifetime	Pipe Lifetime
2.8	Pipe Maintenance Ease	Pipe Maintenance Ease	Pipe Maintenance Ease
2.9	External Loading Capacity of Pipe	External Loading Capacity of Pipe	External Loading Capacity of Pipe
2.10	External/Internal Corrosion of Pipe	External/Internal Corrosion of Pipe	External/Internal Corrosion of Pipe
2.11	Non-Floatable Ability of Pipe	Non-Floatable Ability of Pipe	Non-Floatable Ability of Pipe
2.12	Heat Resistance of Pipe	Heat Resistance of Pipe	Heat Resistance of Pipe
2.13	Seismic Resistance of Pipe	Seismic Resistance of Pipe	Seismic Resistance of Pipe

3.1	Operation	Pipe Failure Rate	Pipe Failure Rate	Pipe Failure Rate
3.2		Pipe Leakage Rate	Pipe Leakage Rate	Pipe Leakage Rate
4.1	Quality	Customers Complaints against the Water Quality	Customers Complaints against the Water Quality	Customers Complaints against the Water Quality
4.2		Residual Chlorine of Water in the Pipe	Residual Chlorine of Water in the Pipe	Residual Chlorine of Water in the Pipe
4.3		Water Age in the Pipe	Water Age in the Pipe	Water Age in the Pipe
5.1	Environment	Soil Type/Bedding around the Pipe	Soil Type/Bedding around the Pipe	Soil Type/Bedding around the Pipe
5.2		Soil Corrosion around the Pipe	Soil Corrosion around the Pipe	Soil Corrosion around the Pipe
5.3		Excavation Ease of the Soil around the Pipe	Excavation Ease of the Soil around the Pipe	Excavation Ease of the Soil around the Pipe

6.1	Urban	Pathway Type in top of the Pipe	Pathway Type in top of the Pipe	Pathway Type in top of the Pipe
6.2		Pathway Cover in top of the Pipe	Pathway Cover in top of the Pipe	Pathway Cover in top of the Pipe
6.3		Pathway Cover Thickness in top of the Pipe	Pathway Cover Thickness in top of the Pipe	Pathway Cover Thickness in top of the Pipe
6.4		Pathway Traffic Load in top of the Pipe	Pathway Traffic Load in top of the Pipe	Pathway Traffic Load in top of the Pipe
6.5		Pipe Location in the Pathway (in sidewalk or street)	Pipe Location in the Pathway (in sidewalk or street)	Pipe Location in the Pathway (in sidewalk or street)

6.6		Pathway Level in top of the Pipe	Pathway Level in top of the Pipe	Pathway Level in top of the Pipe
7.1	Customers	Type of Customers Covered by Pipe	Type of Customers Covered by Pipe	Type of Customers Covered by Pipe
7.2		Combination of Customers Covered by Pipe	Combination of Customers Covered by Pipe	Combination of Customers Covered by Pipe
7.3		Number of Customers Covered by Pipe	Number of Customers Covered by Pipe	Number of Customers Covered by Pipe
7.4		Density of Customers Covered by Pipe	Density of Customers Covered by Pipe	Density of Customers Covered by Pipe
7.5		Building Age of Customers Covered by Pipe	Building Age of Customers Covered by Pipe	Building Age of Customers Covered by Pipe

8.1	Facilities	Number of Connections in the Pipe	Number of Connections in the Pipe	Number of Connections in the Pipe
8.2		Number of Junctions in the Pipe	Number of Junctions in the Pipe	Number of Junctions in the Pipe
8.3		Number of Control Valves in the Pipe	Number of Control Valves in the Pipe	Number of Control Valves in the Pipe
8.4		Number of Pressure Valves in the Pipe	Number of Pressure Valves in the Pipe	Number of Pressure Valves in the Pipe
8.5		Number of Hydrants in the Pipe	Number of Hydrants in the Pipe	Number of Hydrants in the Pipe
9.1	Economic	Cost of Implementing/Installing the Pipe	Cost of Implementing/Installing the Pipe	Cost of Implementing/Installing the Pipe

9.2		Cost of operation the Pipe	Cost of operation the Pipe	Cost of operation the Pipe
9.3		Cost of Maintenance-Rehabilitation the Pipe	Cost of Maintenance-Rehabilitation the Pipe	Cost of Maintenance-Rehabilitation the Pipe
9.4		Return on Investment of the Pipe Renewal	Return on Investment of the Pipe Renewal	Return on Investment of the Pipe Renewal
10.1	Management	Municipal/Social Importance of Pipe	Municipal/Social Importance of Pipe	Municipal/Social Importance of Pipe
10.2		Political/Security Importance of Pipe	Political/Security Importance of Pipe	Political/Security Importance of Pipe
10.3		Quality of Installation Works of Pipe	Quality of Installation Works of Pipe	Quality of Installation Works of Pipe

10.4	Importance of Pipe in Water Supplying the Customers	Importance of Pipe in Water Supplying the Customers	Importance of Pipe in Water Supplying the Customers
10.5	Pipe Importance in regards to other Urban Facilities	Pipe Importance in regards to other Urban Facilities	Pipe Importance in regards to other Urban Facilities
10.6	Pipe Importance in Urban Management Plans	Pipe Importance in Urban Management Plans	Pipe Importance in Urban Management Plans

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Abstract

Among the most complex activities in water companies is extracting accurate operational data of Urban Water Infrastructure (UWI). Hence, the use of data-based methods would be faced limitations for asset management of the UWI. This shortcoming could be improved using knowledge-based decisions. In this study, using this method, Maintenance-Rehabilitation Planning (MRP) of urban water pipes is assessed. Hence, the criteria effective on the MRP of the pipes were firstly determined. Then, two groups of experts in Iran and Brazil were invited to rank the determined criteria. For this purpose, a Multi-Criteria Group Decision-Making (MCGDM) method was developed based on the nominal group technique. This MCGDM method was implemented based on two approaches; first, the viewpoints of non-weighted decision-makers were considered; and second, the experts were weighted to rank the criteria. Finally, the results of these approaches in the two countries were pairwise compared. This comparison led to improving the literature and management in water companies of Iran and Brazil by identifying the effective criteria for the MRP of the pipes based on knowledge-based decisions. Further in this field, it was found that weighting the experts have no decisive effect on the results; and this is only effective in groups where the decision-makers weights are identically distributed. Moreover, it was found that there is a relation between the similarity of results and the similarity of experts' profiles in knowledge-based decision groups of various countries such as Iran and Brazil.

***Keywords*:** Knowledge-based decisions; Urban Water Infrastructure; Maintenance and Rehabilitation; Multi-Criteria Group Decision-Making; Nominal Group Technique.

Plain Language Summary

In the field of water resource management, especially regarding asset management of urban water infrastructure, extracting the accurate operational data could be very complex due to the involved uncertainty. Thus, it seems that any plans which are based on a numerical and analytical assessment of these imprecise data could not be reliable. In this regard, there is an idea for authors of this research that in these situations, the knowledge of the experienced experts could be as important as the operational data. Accordingly, it could be revealed that without using the data-based complex analytical methods, it is possible to use simple and robust knowledge-based decision methods for planning many works in this field such as maintenance-rehabilitation activities. Indeed, although the plans are not obtained from the data-based methods, these are based on the deep experience of experts who were engaged with the water networks for many years. In this regard, it was essential to describe how the results of these knowledge-based decisions can be more effective. Therefore, this concern was considered in this research. In addition, to improve the idea of this research, it was tried to assess the viewpoints of various experts in two different countries (Iran and Brazil).

Abbreviations

DMM: Decision-Making Model

GDM: Group Decision-Making

MCDM: Multi-Criteria Decision-Making

MCGDM: Multi-Criteria Group Decision-Making

MRP: Maintenance-Rehabilitation Planning

NGT: Nominal Group Technique

UWI: Urban Water Infrastructure

WDN: Water Distribution Network

1. Introduction

Maintenance-Rehabilitation Planning (MRP) of the urban water pipes is among the main concerns in water companies [1]. Hence in this field, it is essential to consider the efficient methods which lead to optimizing the operation of Urban Water Infrastructure (UWI) [2, 3]. In the last two decades, many studies have been conducted to determine the optimized MRP for the water pipes [4-31]. One of the main methods that have been more considered in these studies is based on Decision-Making Models (DMMs) [1, 26, 31-44]. A DMM is a structured framework for a single or a group of decision-makers to achieve the determined purpose. This purpose is obtained by identifying the benefits and shortcomings of various alternatives in regards to different criteria [45-47]. The DMMs can be addressed to consider single criterion (SCDM: Single-Criterion Decision-Making) or various criteria (MCDM: Multi-Criteria Decision-Making) [48].

In general, since the various criteria are considered in decisions, the MCDM models are mostly more suitable in DMM [34, 49, 50]. Moreover, the DMMs with a Group Decision-Making (GDM) team could be more efficient than models which have a single decision-maker [51-58]. In water companies, it is essential to consider all technical, economic, urban, social, and security criteria for the MRP of the pipes [3, 8, 11, 12, 14, 18, 19, 59, 60]. Hence, most of the studies conducted in this field are based on MCDM methods [15, 21, 33, 36, 37, 40, 49, 61]. Furthermore, since data extracting of the aforementioned criteria is usually complicated, the use of data-based methods for the MRP of the pipes can be faced with significant limitations.

Hence, this shortcoming can be improved by using the collective knowledge of experts who are specialists in the field of pipe renovation. In addition, due to the significant costs related to the renovation works, the MRP should not be made individually; and, should necessarily be undertaken by the groups of specialists [41, 61, 62]. Accordingly, the use of methods based on Multi-Criteria Group Decision-Making (MCGDM) could be more efficient for the MRP of the pipes 7 [36, 41, 61, 62]. Nevertheless, it seems that fewer studies have been assessed the GDM in this field [36, 41, 59, 61, 62].

Yoon et al. (2017) [63] introduced a new method focusing on subjectivity issues in MCGDM. In this method, two concepts called preference clustering and mediating agent were used. The purpose of this study was to achieve a GDM method in which it is possible to please the various decision-makers with different tastes. Although the results of this study can be used to make group decisions in infrastructure asset management, the authors did not consider a water infrastructure.

Fontana and Morais (2017) [61] presented a GDM model for the segmentation of Water Distribution Networks (WDNs). In this study, they acknowledged that the zoning of WDNs is necessary to implement maintenance operations. Hence, the selection of insulation valves was conducted based on different criteria as well as different viewpoints of decision-makers. Although the model developed in this research can be useful for water companies, the effect of GDM on pipe rehabilitation planning was not considered.

Belošević et al. (2018) [64] have proposed a GDM method to develop infrastructure projects and to investigate accurately the uncertain data related to these projects. In this method, subjective and objective weighting methods are combined; and, ranking the alternatives is conducted using the VIKOR method. In this study, the project of railway line reconstruction has been specifically considered; and, the rehabilitation of WDNs has not been assessed.

RazaviToosi et al. (2019) [65] presented a comprehensive GDM model to develop watershed management. In this model 18 different effective criteria in the social, economic, managerial and environmental fields were used; and, the proposed model was based on the various judgments of different decision-makers. In this research, the interpretive structural modeling method was used for the relationship between criteria. In addition, the Fuzzy Analytical Network Process (ANP) method was used to assist in GDM. However, in this study, urban water management has not been considered by the authors.

Noori et al (2020) [66] presented a Fuzzy MCGDM model, based on the ELECTRE III method, to optimize water supply choice. In this study, due to the uncertainties involved in the quantitative and qualitative criteria, the experts' viewpoints were converted into triangular fuzzy numbers using GDM. The results of this method were compared with other MCGDM models including Fuzzy

TOPSIS and Fuzzy AHP (Analytic Hierarchy Process). However, it should be noted that in this study, the rehabilitation and maintenance of the WDNs were not considered; and also, the viewpoints of experts for GDM were not assessed.

Salehi et al. (2021) [59] recently proposed a new version of the WDSR model (Water Distribution System Rehabilitation), which they have introduced for the first time in 2018. The new model, called by RC-WDSR model (Risk Components-WDSR), is an MCGDM model. The RC-WDSR is used to determine the strategies for rehabilitation and maintenance of water pipelines based on the components of pipes risk. This model differs from its previous version, the WDSR model, which only gives priority to pipes and zones of WDNs for rehabilitation. However, in a study presented by these researchers in 2021, GDM was used to weight the criteria and were not assessed to determine the criteria affecting the pipe rehabilitation.

Zhu and Liu (2021) [67] have recently proposed a GDM model for urban flood risk management. In this research, four methods of multi-objective DMMs including variation coefficient method, Shannon weighting method, Critic and ideal point method have been used. The steps of this research were comprised of normalizing the data, weighting them, and finally aggregating the results obtained from the different decision methods. However, it should be noted that in this study, GDM was used only for weighting the data; and comparing the results obtained from the different GDMs was not considered.

Considering the studies conducted in the field of urban water management, it can be acknowledged that in most of these studies, GDM methods have been used only to weight the multiple criteria. Indeed, in the previous studies, the group decisions are not considered as a knowledge-based method to analyse the problems of water companies; accordingly, these problems have been assessed generally using data-based methods. This is while that the use of recent methods can be faced practically with many limitations due to the uncertainty involved in the operational data of WDNs.

Regarding this shortcoming, in this study, a knowledge-based GDM method is developed for the MRP of urban water pipes. Since this method is based on experts' knowledge and their experience, it is essential to verify the method by investigating the results in different case studies. For this purpose, in this research, the collective knowledge of Iranian and Brazilian experts in the field of UWI is assessed. In this regard, two groups of academic professors, as well as two teams of experts in water companies of these countries, have been invited to participate in this research.

Hence, the criteria of MRP are determined; and then, these criteria are ranked by Iranian and Brazilian decision-makers. In this study, by developing a GDM model based on the Nominal Group Technique (NGT) the criteria rankings are determined. This model is used based on two approaches; first, the viewpoints of non-weighted decision-makers are considered; and second, the decision-makers are weighted to rank the criteria. Finally, the results obtained from knowledge-based decisions of experts in these countries are pairwise compared. This comparison leads to improving the literature and management in water companies of Iran and Brazil by identifying the effective variables for the MRP of the pipes based on collective knowledge-based GDM.

The paper is organized as follows. Section 2 presents an overview of the methodology. Results and discussions are presented in Section 3; and finally, in Section 4, conclusions and implications of the research are assessed.

1. **Material and Methods**

In this research, the knowledge-based decisions for the MRP of the water pipes were assessed in Iran and Brazil. For this purpose, an MCGDM method has been proposed in NGT was used. This research is comprised of three steps as illustrated in Figure 1.

Figure 1 near here

1. **Step 1. Determination of the effective criteria for the MRP of the pipes**

One of the most important activities in water companies is the MRP of water network components, including pipes. Therefore, it is essential to determine the most important variables that affect the MRP of the water pipes. From 2013 to 2021, important studies have been presented in this field by the authors of the present research [13, 15, 20, 24, 36, 48, 59-61]. Based on the findings of these studies, it can be concluded that the most important variables affecting the rehabilitation of pipes can include hydraulic, structure, operation, quality, environment, urban, customers, facilities, economic and management factors. These categories are in turn subdivided into other subcategories, as follow:

1. Hydraulic variables: pressure, flow velocity and flow rate in pipes;

2. Structure variables: diameter, length, age and depth of pipes, as well as all variables related to the material of the pipes;

3. Operation variables: the failure rate of pipes and their leakage rate;

4. Quality variables: the customer complaints about water quality, residual chlorine in the water, and the water age in each pipe;

5. Environment variables: the soil type and bedding, soil corrosivity and soil excavation ease;

6. Urban variables: the variables related to the properties of the pathway located above the pipes;

7. Customers variables: the number and density of customers covered by the pipes, and other properties related to customers;

8. Facilities variables: the number of facilities connected to pipes such as the valves, junctions and connections;

9. Economic variables: the cost of operation, maintenance and rehabilitation of the pipes, and the return on investment resulting from these works; and

10. Management variables: all security, urban, social, political and operational variables that lead to prioritizing pipes for the MRP.

1. **Step 2. Knowledge-based group decisions of Iranian and Brazilian experts**

In this step, the collective knowledge of Iranian and Brazilian experts was used to rank the criteria for the MRP of the water pipes. For this purpose, Iranian and Brazilian decision-makers in this study were divided into two categories. The first category of these experts included two 5-member teams of Iranian and Brazilian academic professors. The second category of decision-makers in this research was consisted of again two 5-member teams of experts in Iranian and Brazilian water companies. It should be noticed that for the correct judgment of the results, the numbers of decision-makers in these teams were considered similar.

In these two countries, the water companies were selected based on the interest of their experts to participate in this work. Moreover, to improve the results of this research, the years' experience and expertise of these volunteers were considered. As shown in Figure 1, the water companies in Iran included the provinces of Fars, Isfahan, Khuzestan, Razavi Khorasan, and Tehran. In Brazil, the water companies of the states of Minas Gerais, Paraíba, Paraná, and Pernambuco participated. Furthermore, regarding the teams of academic professors in Iran and Brazil, the experts who are experienced specialist in the field of Urban Water Infrastructure (UWI) was selected for this research. The profile of experts in this research is presented in Table 1.

Table 1 near here

In this research as previously mentioned, for knowledge-based decisions of Iranian and Brazilian experts, an MCGDM method was used based on NGT (Nominal Group Technique). The NGT has been used firstly by Delbecq et al. in 1975 [68, 69]. The term "nominal group" used in this method means that the meeting of decision-makers is only nominally, and actually, this method is based on the individual input of experts in a group environment. Indeed, the interaction between decision-makers is omitted in the NGT [70]. This method could be more structured and accurate [69] in comparison with other methods such as brainstorming, the Delphi technique [69], and the method of Problem-Centered Leadership [71]. Therefore, the NGT is one of the most valid group decision-making methods [46].

In this technique, a questionnaire form is prepared and provided to each decision-maker separately and without any verbal interaction with other experts [69]. Since the survey form is filled out by each decision-maker independently, so the thoughts and experiences of different decision-makers are not effective to align the decision of other experts [68-70]. The questionnaire form of the NGT used in this research is presented in Appendix 1. As shown in this questionnaire, the linguistic values and bipolar scales were used to rank the criteria. These values are represented in Table 2.

Table 2 near here

As shown in Table 2, the linguistic values in the NGT proposed in this study have standard ranges of 7 including absolutely less important, much less important, less important, equally important, more important, much more important and absolutely more important [46]. Furthermore in this research, the bipolar scale was used to determine the rank of criteria numerically [47]. For this purpose, a number from 1 (Absolutely less important) to 10 (Absolutely more important) with equal intervals of 1.5 units were assigned to each of the linguistic values. The rank of criteria was determined using Eq. (1).

$$\textit{Criterion Rank} = \frac{\sum (W_{\mathrm{ci}} \times \mathrm{NV}_i)}{W_T} \quad (1)$$

c = 1-1, 1-2, …, 3-9
W_{ci} = The number of decision-makers who assign the i^{th} linguistic value to the c^{th} criterion
NV_i = The numerical value associated with the i^{th} linguistic value
W_T = The number of total decision-makers in each province of Iran

1. **Step 3. Pairwise Comparison of the viewpoints of Iranian and Brazilian experts**

As the last step of this study, the criteria rankings that have been obtained from the viewpoints of all experts in Iran and Brazil were compared pairwise. For this purpose, two approaches were considered. First, this pairwise comparison was conducted without weighting the decision-makers (non-weighted). In the second approach, the viewpoints of experts of Iran and Brazil were compared pairwise with the weights considered for decision-makers based on their experiences and degrees. The weights for this approach were considered based on Table 3.

Table 3 near here

Based on this table, the highest weight (3) was assigned to experts with the highest degree (PhD), and or specialists with experience of more than 20 years. Furthermore, for specialists with experience between 10 to 20 years as well as decision-makers with a Master degree, the weight of 2 was considered. The lowest weight was considered as 1 which was assigned to experts with experience lower than 10 years, and or experts with the lowest degree (Bachelor) in this research. For instance, a decision-maker with a master degree received a weight of 2; and also, when his years' experience was more than 20 years, his total weight increased to 6 (2×3). It means that the viewpoint of a decision-maker with these profiles is equal to the viewpoints of six experts with bachelor degrees and experiences lower than 10 years.

1. **Results & Discussion**

The results obtained in this research are divided into 3 categories. First, the results obtained for rankings of criteria are discussed; then, the different viewpoints of experts in Iran and Brazil are assessed based on their profiles. Finally, the criteria rankings and experts' profiles are compared pairwise. The discussion of these results is presented as follows:

1. **The criteria rankings**

The bipolar scales obtained for criteria and their rankings are presented in Figure 2 and Table 4. According to this figure and table, the results are discussed below:

Figure 2 near here

Table 4 near here

1. Based on the viewpoints of all experts in Iran and Brazil, the "Operation" criterion is of the highest importance (Figure 2). Furthermore, regarding the viewpoints of experts in Iran water companies this criterion is more important in comparison to other groups. Hence, the higher bipolar scales have been obtained by these decision-makers for this criterion. Accordingly, the "Operation" criterion received the highest bipolar scales including 9.6 and 9.7. These numbers indicate the linguistic values of "Much more important" to "Absolutely more important" for this criterion (Figure 2). Therefore, it can be concluded that based on knowledge-based decisions of experts in Iran and Brazil, the "Operation" criterion is of the greatest importance for the MRP of the water pipes;

2. Based on the rankings obtained by decision-makers of Brazilian universities and Iranian water companies, the "Economic" criterion is the second most important variable after the "Operation" criterion (Table 4). Meanwhile, according to the viewpoints of the Iranian universities' professors, the second important variable for the MRP of the water pipes is the "Hydraulic" criterion (Table 4). This rank has been assigned to the "Management" criterion by the experts of Brazilian water companies (Table 4). However, the knowledge-based decision-making of these two recent groups has led to assigning the "Economic" criterion to the 3rd and 4th ranks (Table 4). Thus, it can be acknowledged that this criterion can be considered as the most important decision criterion after the "Operation" criterion for the MRP of the water pipes in these two countries;

3. As represented in Table 4 and Figure 2, after the "Operation" and "Economic" criteria, the "Management" and "Hydraulic" criteria can be considered as important criteria for planning the renovation of the water pipes. In this regard, based on the rank-

ings assigned to these two criteria in Table 4, it is clear that mainly decision-makers of Iranian and Brazilian water companies emphasize the importance of the "Management" versus the "Hydraulic" criteria. Meanwhile, this knowledge-based decision in the universities of these two countries is reversed; and, their emphasis on the "Hydraulic" criterion is greater than "Management" variables. However, after weighting the decision-makers of Brazilian universities, the ranking of the "Management" criterion improved in comparison to the "Hydraulic" variable (Table 4). Thus, it can be concluded that in practice, after the "Operation" and "Economic" criteria, the "Management" criterion is more important than others criteria based on knowledge-based decisions of experts of UWI in Iran and Brazil;

4. The Iranian water companies' experts along with professors of Brazilian universities believed that the "Environment" criterion was less important than other criteria for the MRP of the water pipes (Table 4); thus, they assigned the range of "Much less important" to "less important" to this criterion (Figure 2). Whereas, for Iranian universities' professors and experts of Brazilian water companies, the least important criteria are in the range of linguistic values of "Less important" to "More important", and related to "Quality" and "Urban" criteria (Figure 2). Therefore, it can be acknowledged that the least important criteria for the MRP of the pipes in these countries are first the "Environment" criterion, and then, "Quality", and "Urban" criteria;

5. As illustrated in Figure 2, it can be concluded that there is no significant difference between the results obtained from the two approaches of knowledge-based decisions including non-weighted and weighted decision-makers. However, it is clear that weighting the experts has led to reducing the bipolar scales obtained by two groups of experts (Iranian water companies and Brazilian universities). Further, this has occurred in half of the results obtained by the Iranian universities' professors (Figure 2).

In the case of the viewpoints of decision-makers of Brazilian water companies, this situation is quite the opposite; hence, weighting the decision-makers has led to a relative increase in the bipolar scales of the criteria. However, as mentioned previously, the variations of these scales in all four groups were not such as to lead to changes in the linguistic values obtained for the criteria (Figure 2). Therefore, it can be concluded that in practice, weighting the decision-makers for knowledge-based decisions has not had a decisive effect in changing the importance of criteria for the MRP of the water pipes

1. Considering the highlighted cells for all groups in Table 4, it

seems that the differences of criteria rankings in the two approaches (non-weighted and weighted experts) are mostly related to the criteria which have medium ranks. It means that for the criteria with the highest ranks (operation and economic) as well as criterion with the lowest rank (environment), the experts in Iran and Brazil have similar knowledge and experience; so, leads to having no changes in the rankings of these criteria after weighting the experts (Table 4). While, regarding the criteria with medium ranks (Hydraulic, Management, Customers, Facilities, Structure, Urban and Quality), the knowledge of decision-makers are different; and, this could lead to change the rankings of criteria after weighting the experts.

Thus, it can be concluded that for the knowledge-based decisions in the field of UWI, weighting the decision-makers could be decisive to change only the rankings of criteria that have moderate importance for the MRP of the water pipes. This result shows that the experts in various countries could have a different experience in regards to criteria with moderate importance. Thus, it can be acknowledged that for knowledge-based decision-making in the field of UWI, weighting the experts is not essential when using the "Operation" and "Economic" criteria; whereas, the weighted experts could lead to change the results if the criteria with moderate importance are considered.

1. **The experts' profiles**

As represented in the last row of Table 4, comparing the rankings of criteria in two approaches (non-weighted and weighted decision-makers) for all groups, it is clear that the lowest similarities were obtained in the group of Iranian water companies (60%). While, in the case of the professors in Iranian universities, weighting the experts did not lead to any change in the criteria rankings (Table 4). For both groups of Brazilian experts (universities and water companies), there was an 80% similarity in the rankings of criteria after weighting the decision-makers. To discuss these results, it is essential to assess the profile of decision-makers and their weights in these groups (Tables 1 and 3). For this purpose, the weights of experts in these groups were determined based on their degree and years' experience. These weights which are shown in Table 5 were finally multiplied to determine the total weights of decision-makers. Tables 1, 3, 4, and 5 are discussed as follows:

Table 5 near here

1. As illustrated in Table 1, it is clear that the experts of Iranian water companies have more diversity in degree than other groups; so that, 80% of decision-makers have equally Bachelor and Master Degrees, and 20% of experts have PhD degrees (Table 1). Nevertheless, it should be mentioned that the degrees of these experts are localized mostly on Master and Bachelor

which have lower weights (Table 3). In this regard, there are two decision-makers with weights of 1 as well as 2, and one expert with the weight of 3 in this group (Table 5). Whereas, as illustrated in Table 5, it is clear that decision-makers in other groups have more than 50% of similarity in degree.

However, the variety of experience of experts in Iran water companies is less than other groups; and, it is focused mostly on further experiences in comparison to other groups (Table 1). Accordingly, these experts are mostly assigned to weights of 2 and 3 in regards to their experience (Table 5); so that in this case, more than 50% of the experts of Iran water companies have the weight of 3. While in other groups, all weights including 1, 2 and 3 were assigned to experts based on their experiences (Table 5). Thus, it seems that compared to other groups, a conflict existed in the profiles of decision-makers in Iran water companies led to having a completely identical distribution of experts' weights including 2, 3, 4, 6 and 9 (Table 5); whereas, in other groups, the weights of experts were not distributed identically (Table 5).

Therefore, it can be concluded that in knowledge-based decision-making for the MRP of the water pipes, the conflicting characteristics of decision-makers could lead to generating the identical distribution of experts' weights. In addition, based on what was found in Table 4, it can be said that when weighting the decision-makers, the identical distribution of experts' weights could change the rankings of more criteria with moderate importance for the MRP of the water pipes;

1. The profiles of the Iranian universities' professors were focused on two different ranges (Table 1). In this regard, all professors in this group were assigned to the weight of 3 based on their degrees (Table 5); while regarding the years' experience, they were mostly allocated to the weight of 2 (Table 5). It means that 60% of these experts have a total weight of 6 (Table 5). In the case of Brazilian decision-makers, the profiles of these decision-makers focused on two different ranges (Table 1). In this regard, the Brazilian universities' professors mostly had a weight of 3 in relation to their degree and years' experience (Table 5). This led to assigning a total weight of 9 for 60% of these experts (Table 5). Whereas, the weight assigned to most of the experts of water companies in Brazil was number 2 in both characteristics (Table 5). This led to assigning total weights of 4 and 6 equally to most of these decision-makers (Table 5).

Therefore, it is clear that there is no identical distribution of experts' weights in these groups (Table 5). However, as described in the previous paragraph, there is a difference between the profiles of the

Iranian professors and the Brazilian experts' characteristics. Hence, it seems that the similar weights of most Brazilian experts in regards to their degree and years' experience (in each group of Brazil) led to obtaining the same results for Brazilian groups in the last row in Table 4 (80% similarity). However, it should be mentioned that the same results (similarity of rankings) in these groups are related to various criteria (Table 4). Regarding Iran universities' professors, their different weights in regards to the characteristics led to no change of the rankings of criteria in two approaches of non-weighted and weighted experts (Table 4).

Relying on these findings, it can be acknowledged that in the case of decision-making groups whose characteristics of decision-makers are not identically distributed, the results of weighting experts are not significantly different from the results related to non-weighted decision-makers. In addition, it seems that occurring two conditions simultaneously for a group could lead to minimizing the change of the results after weighting the experts. These conditions are including the non-identical distribution of experts' weights and, the different characteristics of decision-makers. In this regard, it can be concluded that for the MRP of the water pipes, if the experts of the knowledge-based decision teams have educational and experimental similarities of more than 50%, it is possible to omit the weighting them. Moreover, it can be concluded that in the several decision-making groups which have a similar pattern of experts' distribution, when weighting the experts it is possible to obtain the same variations in the results of knowledge-based decisions of these groups (not necessarily the same results).

1. **The pairwise comparison of criteria rankings and experts' profiles**

To discuss the different viewpoints of decision-makers in Iran and Brazil for the MRP of the water pipes, it is necessary to compare pairwise the obtained rankings of criteria for these groups and the experts' profiles. These comparisons were considered in two approaches including non-weighted and weighted decision-makers separately. The obtained results of these comparisons are illustrated in Figures 3 and 4:

Figure 3 near here

Figure 4 near here

1. In 83.33% of the pairwise comparisons represented in Figure 3, it is obvious that the weighting of decision-makers has led to a decrease in the percentage of similarity in the ranking of criteria (Figures 3-a1, 3- a2, 3-b1, 3-b2, 3-c1, 3-c2, 3-e1, 3-e2, 3-f1 and 3-f2). However, only in one case of represented pairwise comparisons (Figures 3-d1 and 3-d2), weighting the decision-makers

increased the rankings similarity. This pairwise comparison is related to experts of water companies in Iran and Brazil. Considering the similarities of these experts' profiles including their degrees, years' experiences and weights in Figure 4, it is clear that only in these groups the experts' similarities are 60% equally in all characteristics (Figures 4-d1, 4-d2 and 4-d3). Accordingly, it seems that for knowledge-based decision-making groups with equal similarity of all characteristics of experts, weighting the decision-makers could align further the results of their decisions. In other words, it can be acknowledged that for the MRP of the water pipes, the different similarities of characteristics of decision-makers in various groups could increase the complexity of decision-making after weighting the experts. This complexity is related to decreasing the similarity of results for these groups;

2. As shown in Figure 3, the differences in approaches between university professors and experts of water companies in both Iran and Brazil are similar. In this regard, the similarity of the criteria rankings for experts of two decision-making groups in Iran is 30% in the first approach (non-weighted decision-makers) (Figure 3-a1). Regarding the second approach (weighted decision-makers), this similarity is 10% (Figure 3-a2). For Brazilian experts, these percentages were exactly repeated (Figures 3-b1 and 3-b2). By comparing the characteristics of these two groups in Iran and Brazil, it is quite clear that the similarity of the degree and experience of experts in water companies and universities in both countries is the same and is equal to 20% and 60%, respectively (Figures 4-a1, 4- a2, 4-b1 and 4-b2). It seems that these similarities can be the cause of the same results shown in Figures 3-a1, 3-a2, 3-b1 and 3-b2. However, it should be noted that the weight similarities of these groups in Iran compared to Brazil has obtained different results (Figures 4-a3 and 4-b3). Based on these findings, it can be concluded that in knowledge-based decisions for the MRP of the water pipes in Iran and Brazil, the existence of equal similarities of the characteristics of decision-makers can lead to the same similarities in the results;

3. Considering the pairwise comparison diagrams related to the viewpoints of academic professors in Iran and Brazil, as well as the experts of water companies in these two countries, it is obvious that compared to the viewpoints of experts of water companies, the professors' viewpoints are more aligned (Figure 3-c1, 3-c2, 3-d1 and 3-d2). This alignment is associated with nearly all criteria. However, investigating the Figures 4-c1, 4-c2, 4-c3, 4-d1, 4-d2 and 4-d3 which are related to pairwise comparison of experts' profiles, it is found that there is no significant difference in the similarities of characteristics of these groups.

However, it seems that the 100% similarity of the degrees of Iranian and Brazilian academic professors has led to results that are more similar. Based on this finding, it can be concluded that in knowledge-based decisions for the MRP of the water pipes, the more similar the characteristics of a decision-making group are to the profiles of another group, the viewpoints of these two groups may have a more similar trend;

4. As shown in Figures 3-e1, 3-e2, 3-f1 and 3-f2, it is quite clear that the viewpoints of experts in Iranian water companies are significantly aligned with the professors of Brazilian universities. Hence, the similarities of the criteria rankings for these two groups are equal to 60% and 50% relating to the two approaches of non-weighted and weighted decision-makers, respectively. These rankings similarities are the highest similarities between decision-making groups in this study. In addition, the trend of the graph related to the ranking of criteria in these two groups is significantly similar to each other. Meanwhile, By investigating the pairwise comparisons of the characteristics of these two groups as well as experts of Brazilian water companies and professors of Iranian universities (Figures 4-e1, 4-e2, 4-e3, 4-f1, 4-f2 and 4-f3), It is clear that the experts of Iranian water companies and the professors of Brazilian universities have the high similarity in their years' experiences (80%). However, it should be noted that the similarity of experiences for two other groups is also 100%; whereas, their viewpoints in Figures 3-f1 and 3-f2 shows fewer similarities. Meantime, it should be mentioned that the similarity in weight of experts of Iranian water companies and Brazilian professors (60%) is more than this similarity in two other groups (40%). Accordingly, It seems that the high similarities in years' experience as well as weights of experts in Iranian water companies and Brazilian professors, has led to a significant similarity in their results. Therefore, it can be concluded that for the MRP of the water pipes, the simultaneous high similarities of years' experience and weights of experts in two decision-making groups can lead to more similarity of the results in their knowledge-based decisions.

1. Conclusion

Among the main problem in the management of Urban Water Infrastructure (UWI) is monitoring the operating conditions of the facilities related to this infrastructure. In this field, decisions are mainly made based on the operational data of UWI. Since these data have considerable uncertainty, the decisions made based on the operational data, which have not acceptable accuracy. In addition, access to these data is another problem leading to many complexities in the management of UWI. Therefore, these reasons can be a pretext to introduce alternative methods for managing the UWI. In this study, a Multi-Criteria Group Decision-Making (MCGDM) method based on the collective knowledge of experts was proposed for this purpose. This method is based on an approach which states that the knowledge and experience of experts can be trusted for important decisions such as rehabilitation and maintenance of network pipes. However, since the results of this method can be different based on the various knowledge and experience of decision-makers, it is necessary to compare the obtained results in different groups. In this study, 4 groups of experts in two different countries, namely Iran and Brazil, were invited for knowledge-based decisions for Maintenance-Rehabilitation Planning (MRP) of the water pipes. The invited decision-makers had the necessary knowledge and experience for this research. Then, an MCGDM method has been developed, in which one of the applied group decision-making methods, Nominal Group Technique (NGT), was used. The results of this study indicate the importance of operational, economic and managerial criteria for the MRP of the water pipes in the infrastructure of Iran and Brazil. It was also found that environmental, qualitative and urban criteria in these two countries are the least important for these plans. In addition, it was found that in knowledge-based decisions in the field of UWI, the weighting of decision-makers based on their experience and knowledge does not make decisive changes in the results; and the effect of this weighting is only on groups in which the experts' profiles are identically distributed. Further, weighting the experts can be effective to change the rankings of criteria which are of moderate importance for planning the rehabilitation of pipes. However, since the criteria of moderate importance are placed after the criteria of operation, economic and management, they are not the main basis in decisions. Therefore, according to the findings in these two countries, it can be acknowledged that for knowledge-based decisions in the field of UWI, weighting the decision-makers can be ignored. Furthermore, interesting results were obtained in terms of the decision-makers' profiles in the field of UWI. These results indicate that it is better to form the decision-making groups by different parts of the organization (e.g. water companies); and, it is better that the experts with different knowledge and experience participate identically in the decision-making groups. It was also found that when the characteristics of decision-makers are significantly similar, their weighting will not have a significant effect on changing the results. Additionally, having similar distributions of experts in different decision-making groups, as well as similar characteristics of experts in different groups, lead to the further similarity of results for these groups. While, in situations where the characteristics of the decision-makers of the two groups in the field of UWI are not the same, the weighting of these experts can intensify their conflicts leading to the final decisions with complexities. However, it should be noted that the results obtained in this study were taken from 4 decision-making groups in two different countries to plan the rehabilitation of the pipes. Therefore, comparing the results of this study with the decisions of experts in other countries can provide more comprehensive results, which in the coming studies will be considered by the researchers of this study.

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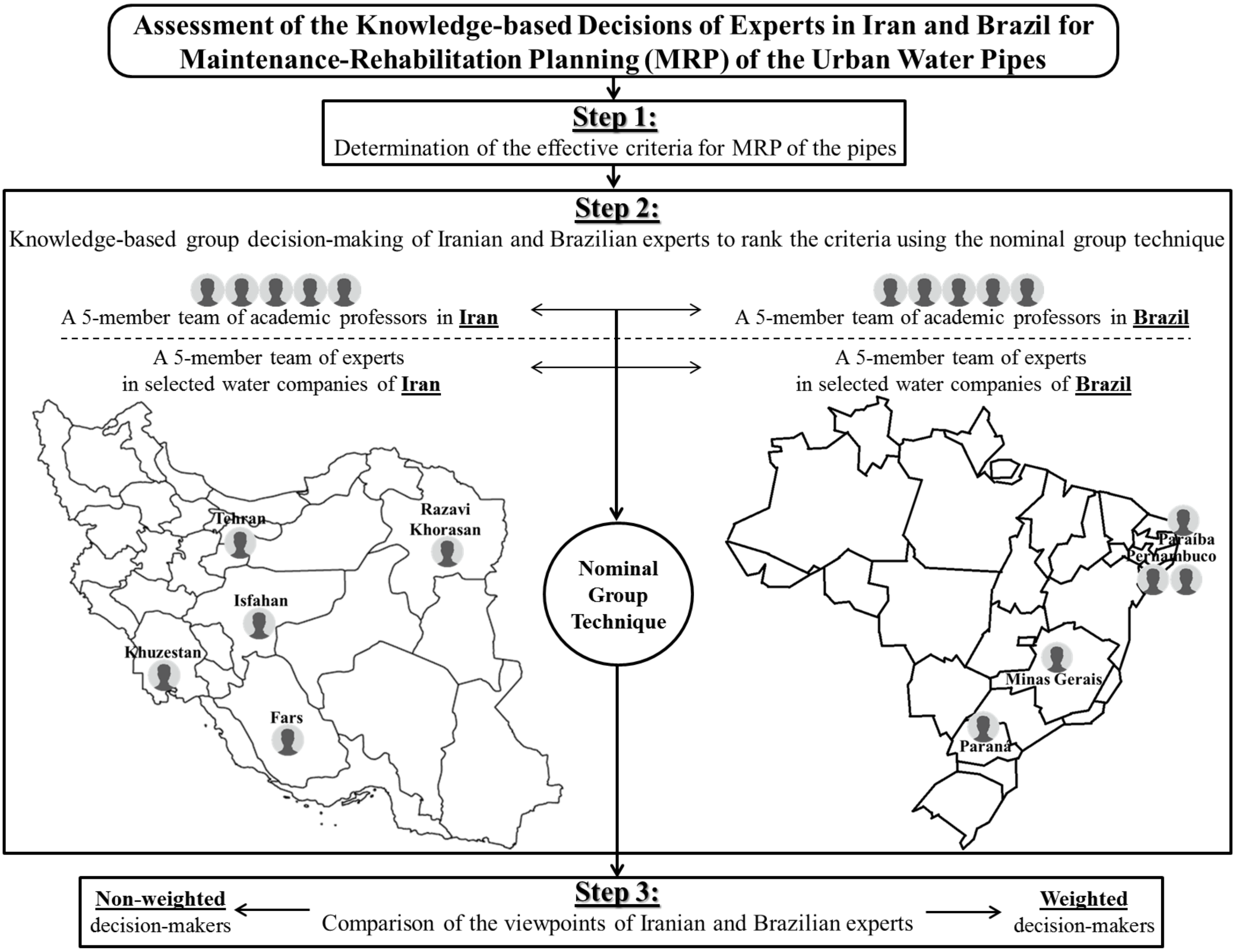

Figure 1: The methodology steps in this work

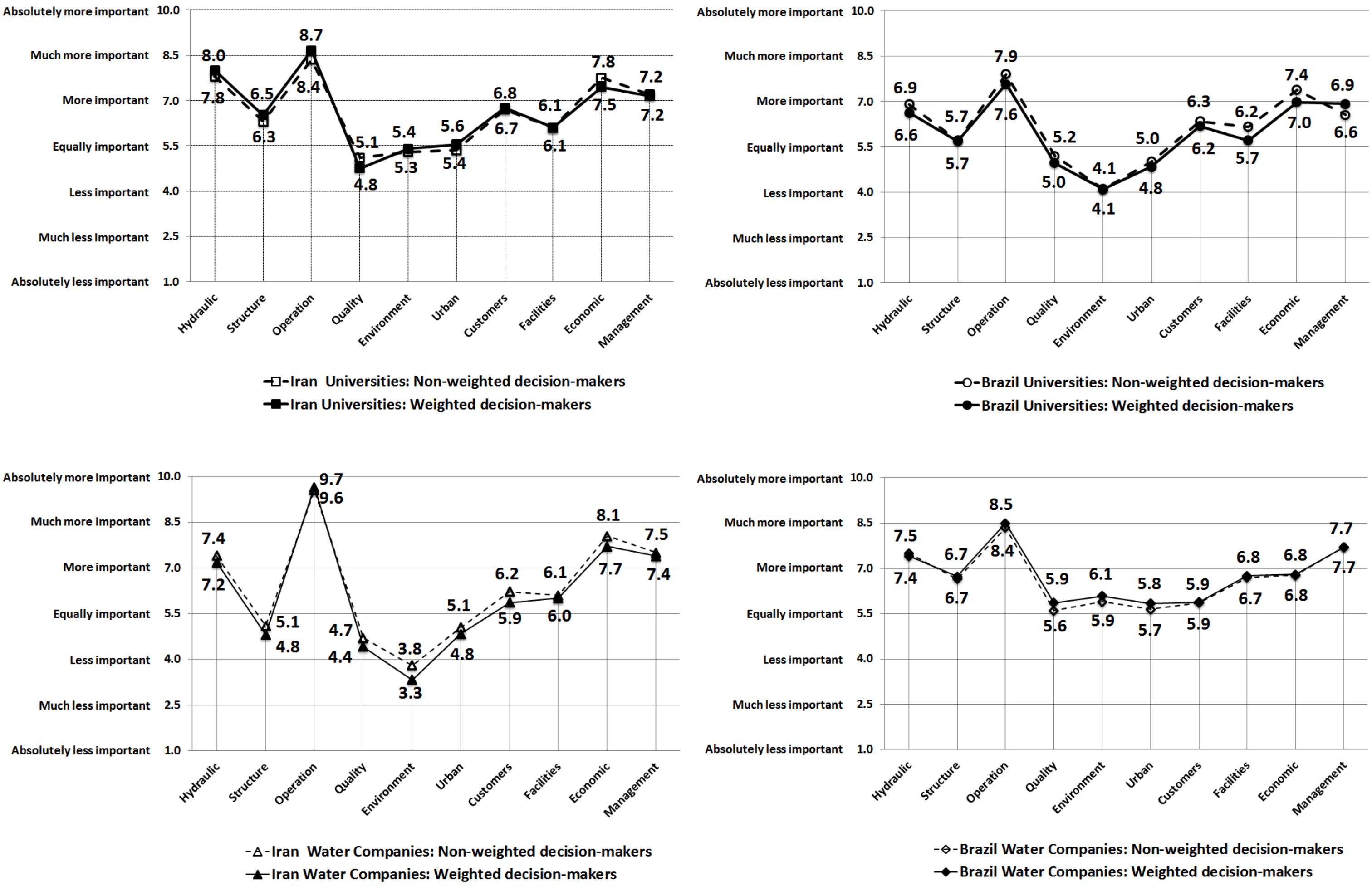

Figure 2: The bipolar scales obtained by non-weighted/weighted decision-makers

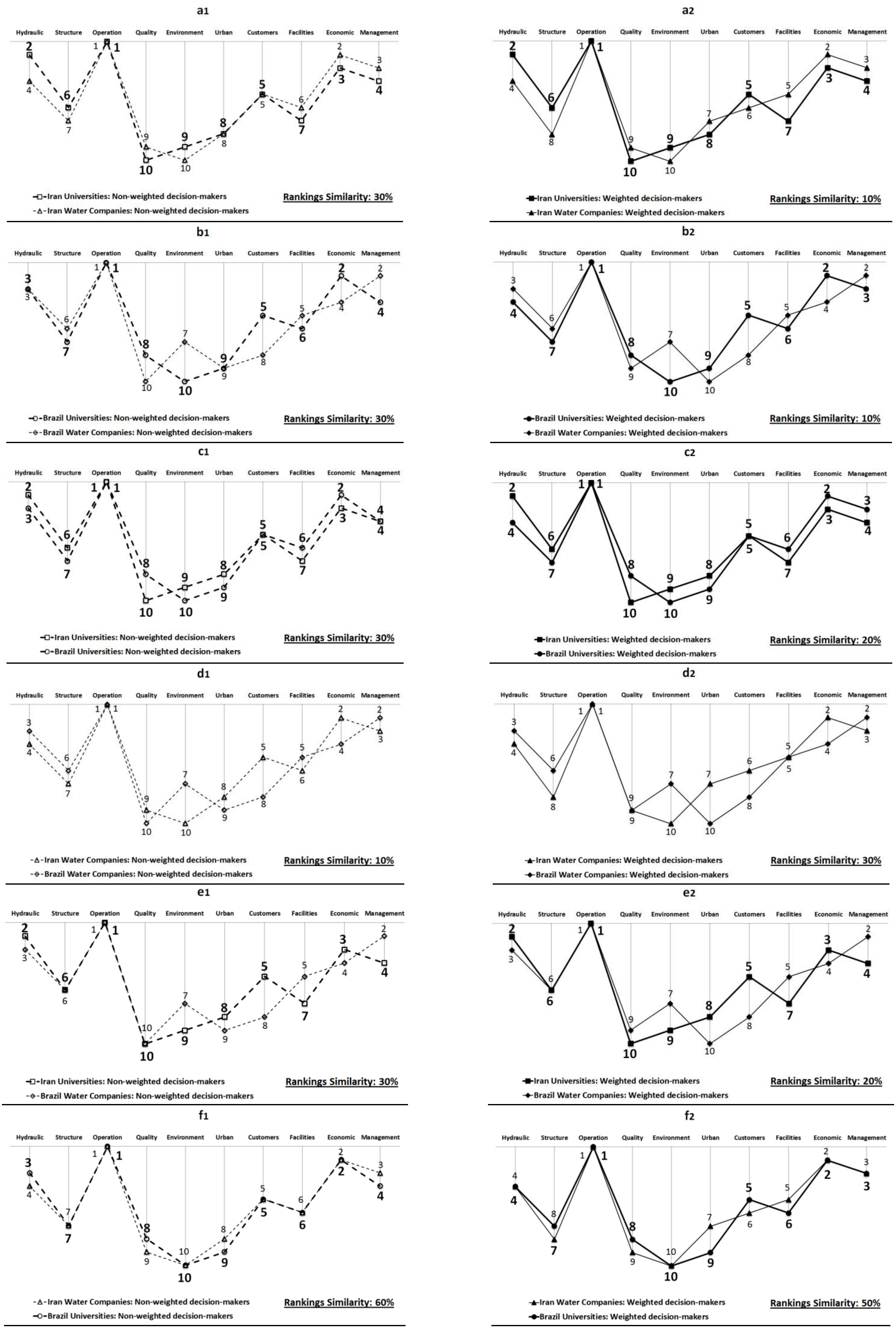

Figure 3: The pairwise comparison of the rankings of criteria

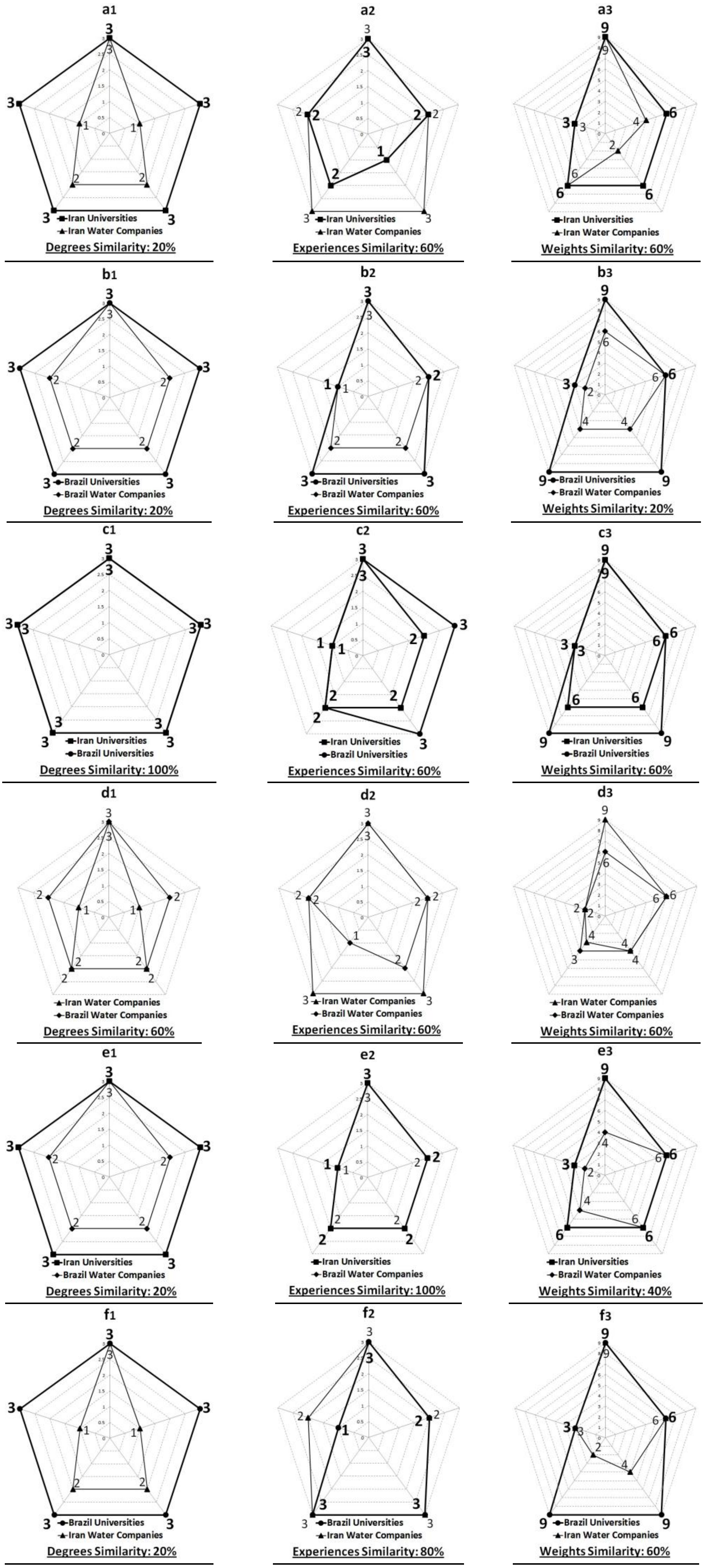

Figure 4: The pairwise comparison of decision-makers' weights and their profiles