# Case Study: Application of Multicriteria Decision Making to Urban Water Supply

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**Abstract:** Presented herein is an attempt to put into practice the multicriteria decision making technique of compromise programming for a real urban water management case study in the city of Zahidan in Iran. Zahidan, the capital of Sistan and Balouchistan Province, faces serious water problems in terms of both quality and quantity. To satisfy future water demands, a long-distance water transmission project is being implemented. Compromise programming is applied to aiding decision makers in selecting the best possible alternatives for distribution of both available and the transmitted water in the city. The results obtained reveal that the method is capable of being employed by decision-makers for comprehensive urban water management studies.

**DOI:** 10.1061/(ASCE)0733-9496(2005)131:4(326)

**CE Database subject headings:** Urban areas; Water management; Water supply; Decision making; Sensitivity analysis; Iran; Case reports.

## Introduction

Multicriteria/multiobjective decision-making methods provide efficient tools to deal with operations research problems with more than one criterion or objective. There are many different concepts and methods for multicriteria decision making (MCDM). Some of the potentially useful techniques are goal programming, compromise programming, multiattribute utility theory (MAUT), analytical hierarchy process (AHP), ELECTRE I-III, PROMETHEE, and cooperative game theory.

To assess the utility of the various proposed techniques and identify the appropriate methods for a specific problem, the evaluation criteria and recommendations are given among others by Cohon and Marks (1975); Szidarovszky et al. (1986); and Nachtnebel (1994). The decision analyst should choose a decision aid method suitable for the problem. As different MCDM techniques may yield different results for the same problem the optimal choice of a technique would occur after applying several methods on the real decision problem.

Water resources planning and management takes place in a multiple criteria environment. The application of MCDM methods to various aspects of water resources planning and management has been demonstrated in a number of studies, including Duckstein and Opricovic (1980), dealing with multiobjective optimization in river basin development; Tecle et al. (1988), on selecting the best wastewater management alternative; Simonovic (1989), on formulating national water master plans; Duckstein et al. (1991), on selection of estimation techniques for fitting extreme floods; Duckstein et al. (1994), on ranking groundwater management alternatives; Corderio Neto et al. (1996), on design of long-term water supply in Southern France; and Abrishamchi and Tajrishi (1997), on water planning for agricultural development.

The many applications of multicriteria decision making (MCDM) techniques show they are well-suited to water resources planning as efficient tools in the decision making process. In real-world water management problems, however, there remains a gap between theory and practice due to the complex nature of real systems. As pointed out by Corderio Netto et al. (1996), most real-world water resource planning problems are characterized by (1) various degrees of uncertainty; (2) multidimensional goals in a complex objective space; (3) difficulty associated with identifying the real decision-maker(s); and (4) a sophisticated structure of alternative solutions which often combine in sequence several elementary actions and various planning horizons (i.e., short, medium, and long-term).

The city of Zahidan with a population of about 550,000, the capital of Sistan and Balouchistan Province, Iran, faces serious water problems in terms of both quality and quantity. To meet the water demand by the city in the coming years, a long-distance water transfer project is being implemented. Given the scarcity of water resources and financial limitations, it is a general belief among water managers and authorities that no water transfer project of this scale could be envisaged in the future.

Considering the interdependence of water and urbanization, the addition of new water supplies to Zahidan will encourage massive migration to the city and produce life-style changes that demand more consumption of water and improved water quality. From a management viewpoint, crucial issues demanding special

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Note. Discussion open until December 1, 2005. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on September 23, 2002; approved on October 4, 2004. This paper is part of the ***Journal of Water Resources Planning and Management***, Vol. 131, No. 4, July 1, 2005. ©ASCE, ISSN 0733-9496/2005/4-326–335/$25.00.

attention to avoid an impending crisis include: (1) defining restrictions on population growth and migration into the city, and (2) establishing environment-friendly life-styles so as to exercise proactive measures aimed at conservation of the present resources. Due attention must be given to water recycling and reuse, which ultimately may be conductive to diminishing demands rather than continuously increasing supply (Vlachos and Braga 2001).

The design of urban water systems centers on the knowledge of socioeconomic requirements and the policy alternatives related to sustainable development rather than simple, but inequitable economic growth. Seen from this perspective, technology is not a fundamental limitation in design endeavors based on integrated, coordinated, and long-range approaches in planning and management. However, there are various factors such as population explosion and the ensuing institutional and social changes that further complicate the efforts toward sustainable development. Vlachos and Braga (2001) ascribe these changes to fundamental shifts in values, to technological developments, and to external conditions such as climatic anomalies.

Urban water managers in Zahidan are increasingly concerned about the unprecedented magnitude of urbanization and the resulting water consumption due to changes in life-style. They have expressed their worries and have raised doubts about the adequacy of the available means to provide safe urban water to the growing population in the city. Recently, Sistan and Balouchistan Provincial Water Company approached the Environment and Water Research Center (EWRC) to seek expert advice on alternative water distribution systems and the criteria for comparing the alternatives on a rational basis.

In response to this query, the present study was carried out to show how MCDM can help decision makers in selecting the best possible alternatives for distribution of both available and transmitted water in the City of Zahidan. Considering the suggested criteria in literatures for the selection of a suitable MCDM technique and observing the present institutional constraints, the selection of MCDM techniques is itself a multicriteria problem. Among different candidate techniques for the present study, compromise programming was selected as the first trial, essentially because of its easiness to explain and be understood by the decision makers. A general discussion of the urban water management in Iran is followed by a description of the case study. The general procedure of MCDM is then presented, along with the compromise programming (CP) technique used in this study. Application of CP to the case study is then presented, followed by results and conclusions.

## Overview of Urban Water Management in Iran

Iran is an arid and semiarid country with scarce and sensitive water resources. Increasing water demands have caused an alarming decrease in annual per capita renewable water resources, presently estimated to be about 2,000 $m^3$ for a population of around 65 million. With the current trend in population increase, per capita water availability is predicted to fall below 1,000 $m^3$ by the year 2025, when Iran will probably be in the category of countries with chronic water scarcity. Since available water resources are unevenly distributed in terms of time and space, water resources in many areas are already under pressure.

The uneven distribution of water across the country, on the one hand, and the increase in water demand from growing populations and the desire for economic status and higher living standards by the public, on the other, have led to conflicts over water supply and water demands and resulting water shortages for urban and domestic uses. In most areas, local water resources have already been tapped while there is still more demand to be satisfied beyond the capacity of the existing water resources.

Many efforts have been put to and great achievements have been made in the development and exploitation of water resources for domestic uses in Iran. These efforts have been essentially based on maximum water supply for the increasing demands. Acting upon a traditional outlook in water management in Iran, water managers find water transfer to arid zones the only option to satisfy the demands. Each year, new proposals are put forward to the government for new interbasin/long distance water transfer projects, which are normally backed up by political and public pressures.

Interbasin/long distance water transfer is a response to a distribution of human population and related activities where they do not match the spatial distribution of water resources. Reducing water shortages that are considered to account for the most serious hindrance to sustained development of regions short of adequate local water resources is a significant advantage of long distance water transfer. However, the fundamental principles of water resources management explicitly states that prior to the development of any interbasin water transfer (IBWT) scheme, the need for water transfer should be minimized. One of the several measures that may be used to cope with the shortage of high quality water is consideration of alternative schemes of water distribution and delivery in urban areas (e.g., dual networks, public fountains, water vendors, water kiosks, bottled water, etc.). Furthermore, thorough assessments of social and environmental impacts must be made and care must be taken to minimize adverse impacts due to water transfer both in the donor and receiving areas (Cox 1999).

As in many other countries, water management in Iran has been governed by a traditional technical paradigm developed at the beginning of the 20th century in Europe and North America. The most succinct observation that one can make is that water resources have been used to accommodate rather than shape the future. Recent developments point out that planning must be carried out with sensitivity to all affected environments, by assessing impacts and considering a wider spectrum of alternatives, and by forecasting future water resources environments in a more comprehensive manner and within a normative context by understanding sustainable development through the linkage of society, economy, and environment (Vlachos and Braga 2001).

The reaction to the shortcomings of traditional water policy and planning has brought forward improved Iranian National Policy and Strategy for Water Management. The National Policy and Strategy emphasizes promotion of productivity and efficiency, while heeding the economic, security, and political value of water in water abstraction, supply, and consumption and establishing compatibility between efficiency and social justice.

The strategies and guidelines of the urban water sector set according to the National Water Policy include: (1) determination of a household water consumption structure based on minimum use (basic needs) in accordance with geographical and climate conditions; (2) priority given to short term rapid-return projects and reduction of project execution time; (3) diversification in water supply through bottled water, water kiosks, water vendors, public standpipes, and dual networks especially in areas where good quality water is scarce; and (4) rehabilitation, upgrading, and optimization of the existing infrastructure to improve productivity and save on new investments.

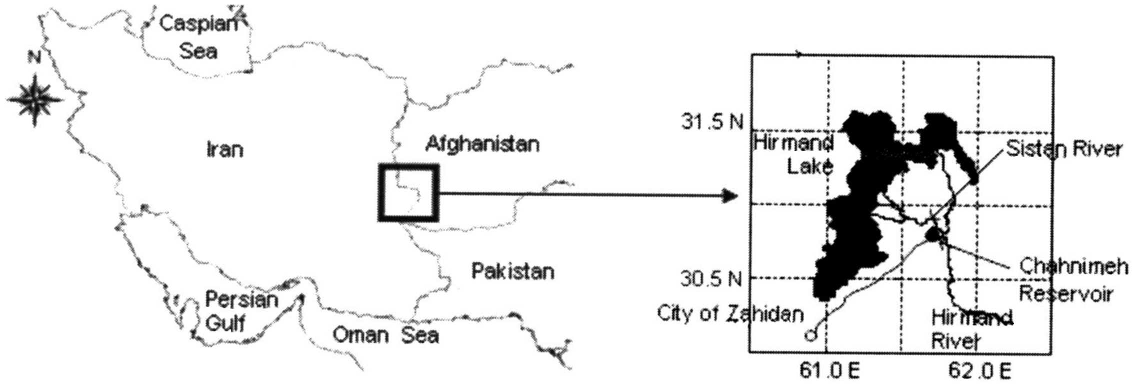


**Fig. 1.** Zahidan intrabasin water transfer

## Case Study Description

The city of Zahidan faces serious water problems in terms of both quality and quantity. The region is characterized by desert to semidesert climate with long, dry, and hot summers; but short, dry, and cold winters, where evaporation potential is high and precipitation is low.

Zahidan has two separate water supply systems, one supplying sanitary water (brackish) and the other supplying drinking water. Currently, sanitary water for the city is distributed by a network with water abstracted from groundwater resources and drinking water is distributed by a small network with public valves (water standpipes) at several points across the city. The city of Zahidan has no wastewater collection system (it is under construction) and the wastewater is discharged into pits. Population growth and the corresponding increased water abstractions along with the drought over recent years have resulted in declining water table levels and increased groundwater salinity. The average EC of groundwater within the city is presently around 4,000 $\mu$S and in some areas has increased up to 7,000 $\mu$S. This is while the biological quality of the groundwater has also deteriorated due to recharge by wastewater disposal.

Long service and the excessive salinity of the water have caused the sanitary water distribution network to become damaged and deteriorating. This is while only 65% of the households are covered by sanitary water supply service. The drinking water distribution network is very small and limited and public standpipes deliver water to the people. The deficiencies of the water distribution system and the recent drought years have resulted in repeated interruptions and failures in supplying drinking water over long periods of time. Therefore most people obtain their drinking water from vendors who deliver water in tankers. The tanker trucks take fresh water from a number of wells located in the west and the southeast of Zahidan to distribute in the city. In addition to the health problems associated with this method of water delivery, overuse has recently caused the discharge from these wells to decline drastically. Due to the persistent water shortage, per capita water consumption in the city has reduced from 160 L per day in 1976 (both sanitary brackish water and fresh drinking water) to 110 L in 2001.

To meet the water demand by the city in the coming years, a long-distance water transmission project is under development that will convey water from Chahnimeh off-channel reservoirs over a route of 200 km with a pumping head of 1,800 m, and will convey an annual volume of 28 $10^6$ $m^3$ of water from the Sistan River (Fig. 1). The Chahnimeh reservoirs with a live storage of 350 $10^6$ $m^3$ serve as off-channel storage fed through an inlet channel off-taking the Sistan River near Hirmand fork where Hirmad River coming from Afghanistan bifurcates into two branches at the point of entry into Iran. The total cost of the transmitted water is estimated at 5,000 Rials per cubic meter (8,600 Rials = US$1). This will increase to 10,000 Rials once the costs of the construction of the new water distribution network are also added. This is while the average price of 1 $m^3$ of water in the city is around 400 Rials and the average in Iran is around 600 Rials.

As the commissioning and operation of the project draws nearer, certain issues are emerging which await solutions. These include the method of distributing water among users and consumption patterns in the city as well as the problems arising after water is conveyed to the city (such as the expected abrupt population increase and the increase in per capita consumption). It is worth mentioning that the Sistan and Balouchistan Provincial Water and Sewage Company is in the process of designing and implementing a new water network to distribute the transmitted water. A per capita daily consumption of 100 L is assumed in the design. The Company is also considering the rehabilitation and development of the two existing water supply networks. Two problems seem to be novel about the new network. First, the practical and possible mechanisms of controlling the per capita consumption at 100 L/day are not clearly defined. Second, assuming a per capita consumption of 100 L/day, the water transmitted from the Sistan River will barely suffice the water demands of the city in the next 10 years. Therefore it is essential to plan for the conjunctive use of the transmitted water and the groundwater resources.

## General Procedure of Multicriterion Decision Making

There are two levels of managerial and engineering to the multicriterion decision making as applied to water resources management (Duckstein and Opricovic 1980). The managerial level is a higher level that sets the goals and objectives and identifies the criteria. The decision makers can effect their decisions at this level to the plans developed by the engineering level. The engineering level comprises the intermediate and the design sublevel, out of which the plans are derived.

The intermediate sublevel is of a technical nature carried out by the "analyst." It explores and defines different alternatives and points out consequences of choosing any one of them from the view point of various criteria or measure of effectiveness. The intermediate sublevel, which may be regarded as providing decision-making aid to the managerial level, is of key interest in the present study.

Several writers (Duckstein and Opricovic 1980; Szidarovszky et al. 1986; Tecle and Duckstein 1994; Eskandari et al. 1995) have identified the basically similar general steps for the MCDM process. Based on the procedures proposed, the procedure adopted in the present study has the steps outlined below:

1. Identify the problem; define the desired goals, objectives, or purposes that the system is to fulfill;
2. Identify the desired set of engineering specifications and constraints;
3. Establish the criteria for system evaluation that relate system performance to specifications and, hence, to goals;
4. Develop alternative systems for attaining the goals and determine their performance in terms of evaluation criteria;
5. Generate a matrix whose elements represent values of each alternative against each criterion (i.e., system versus criteria matrix);
6. Run the MCDM model, perform sensitivity analysis, and document the study;
7. Present the results to the decision maker(s) [DM(s)]; and
8. If the solution is not acceptable to the DM(s), gather new information and go into the next iteration starting at step 2.

Steps 1, 2, and 8 are performed at the highest policy level by the decision makers. Other steps are technical tasks at the engineering level carried out by the analyst.

The key element in any decision-making process is the presence of the decision maker. The DM is the person or the group of persons whose desires must be somehow satisfied by the outcome of the multicriterion decision making process. The DM must identify the problem requiring a decision and specify the objectives of that problem. The analyst, on the other hand, is responsible for defining the decision model and conducting the multicriterion decision process in the form of appropriate problem formulation and quantitative and qualitative analysis of that problem. The decision maker in turn provides directly or indirectly the final judgment upon which the alternatives are ranked by the analyst and a level of satisfaction is defined. Of vital importance in these works are some interactions between the DM and the analyst.

A preference structure must be built into the MCDM process, which is usually reflecting the importance of each criterion. This is normally a difficult aspect of the process and involves an assessment of the weight of each criterion. The weights are assigned by the decision makers to identify the relative importance of an objective/criterion to one another. Previous experience with multicriterion technique applications shows that the preference structure of the DM can radically influence the final evaluation of results. Manipulations in weights are possible in order to obtain satisfactory solutions.

The decision-maker has the advantage of trying out a variety of weights or preferences iteratively to arrive at desirable solutions while also gaining insights into the possible tradeoffs between each solution. Obviously, any reformulation of the preference structure also provides the possibility of manipulating the procedure to obtain finally, what was originally expected (wanted) but "confirmed" now by an "objective" technique (Cohon and Marks 1975).

## Compromise Programming

Compromise programming belongs to a class of multicriterion analytical methods called "distance-based" methods. Compromise programming is an approach which identifies solutions closest to the ideal one by some distance measure. There is one value among the achievable scores for the $i$th criterion that is preferred to all remaining ones (Zeleny 1973). For example, $f_i^* = \mathrm{Max}_x f_i(x)$, $i=1,\ldots,I$. The vector $f^*$ whose elements are all such maxima is called the ideal vector: $f^* = (f_1^*,\ldots,f_n^*)$. When a feasible solution set $X$ takes the form of a number of discrete alternatives, the solution set changes into a finite set of $x$ points ($x \in X$). Now, let the subscript $i$ designate different criteria ($i = 1,\ldots,I$) and further let $f_i(x)$ and $f_i^*$ represent the value for criterion $i$ in alternative $x$ and the ideal value of criterion $i$, respectively, then the conventional form of the parameter distance from the ideal, $L_p(x)$, can be expressed as

$$L_p(x) = \left[ \sum_{i=1}^{I} w_i^p \left| f_i^* - f_i(x) \right|^p \right]^{1/p} \tag{1}$$

For cases where an absolute ideal value is too difficult to identify, an approximation will be the best value in a given set of values of $f_i(x)$. The best value $f_i^*$ is a maximum value only if $f_i(x)$ is to be maximized; otherwise, $f_i^*$ is a minimum (Duckstein and Opricovic 1980).

When dealing with objective functions $f(x)$ which are not expressed in commensurable units, then a scaling function is defined to ensure the same range for every objective function by normalizing all objective functions (usually in the dimensionless range of 0 and 1). If the scaling function is linear, then the distance parameter given in Eq. (1) is rewritten as

$$L_p(x) = \left[ \sum_{i=1}^{I} w_i^p \left| \frac{f_i^* - f_i(x)}{f_i^* - f_{i^*}} \right|^p \right]^{1/p} \tag{2}$$

where $f_i^*$ and $f_{i^*}$ = ideal and anti-ideal values for criterion $i$, respectively [i.e., the maximal and minimal values of $f_i(x)$].

In most real problems, "the true ideal point" is not identified; one must, therefore, employ the "displaced ideal" approach proposed by Zeleny (1973, 1982) and used by many writers (Duckstein and Opricovic 1980):

$$f_{i,b} = \text{best value of } f_{ij}, \quad i = 1, \ldots I, \quad j \in J \tag{3}$$

$$f_{i,w} = \text{worst value of } f_{ij}, \quad i = 1, \ldots I, \quad j \in J \tag{4}$$

where the subscript $j$ represents different alternatives. Following this approach, the distance parameter given in Eq. (2) is rewritten as

$$L_p^i = \left[ \sum_{i=1}^{I} w_i^p \left| \frac{f_{i,b} - f_{ij}}{f_{i,b} - f_{i,w}} \right|^p \right]^{1/p}, \quad j = 1, \ldots, J \tag{5}$$

where $L_p^j$ = distance metric; $w_i$ = weight of criterion $i$ ($i = 1,\ldots I$); $f_{ij}$ = value of criterion $i$ in alternative $j$; and $p$ = parameter reflecting the decision-makers' concern with respect to the maximal deviation.

Having determined the distance of different alternatives, $x$, from the ideal, the compromise solution, $x_{cp}$, is obtained from the solution of the optimization problem after appropriate values are assigned to $p$ and $w_i$

$$\text{Minimize} \quad L_p(x), \quad x \in X \tag{6}$$

Compromise programming involves two types of parameters. The first is the parameter $p$ ($1 \leqslant p \leqslant \infty$) that reflects the importance of the maximal deviation from the ideal value. The second is the weight $w_i$, reflecting the relative importance of the $i$th criterion to the decision maker. Freimer and Yu (1976); Yu and Leitmann (1976); and Duckstein and Opricovic (1980) indicate that the parameter $p$ has a balancing effect on the utility and distance from the ideal so that increasing $p$ reduces utility but, at the same time, reduces the distance from the ideal point. When $p=1$, all distances (absolute deviations) are weighted equally (i.e., perfect compensation between criteria). With $p=2$, each deviation is weighted in proportion to its magnitude; the larger the deviation, the larger the weight. The value $p=2$ is used to penalize large deviations from the ideal. $P=1$ corresponds to simple averaging; in the case of $P=2$, a simple Euclidean distance is calculated. As $p$ becomes larger, the alternative with the largest distance receives an increasingly larger weight. For $p=\infty$, there is no compensation among criteria; the largest deviation from the ideal dominates the assessment and the compromise programming leads to the min-max criterion (i.e., maximum deviation from the ideal point is minimized). In this case, the solution is obtained from the following relation:

$$\min \max \left| \frac{f_{i,b} - f_{ij}}{f_{i,b} - f_{i,w}} \right|, \quad i = 1, \ldots, I, \quad j = 1, \ldots, J \tag{7}$$

Obviously, the choice of $p$ reflects the decision makers' concern with respect to the maximal deviation; therefore it is useful to the DM that the system analyst provides compromise solutions with different values of $p$.

The CP algorithm has several steps, which can be included in step 6 of the MCDM general procedure. Among the different steps of MCDM, this step is especially important, since it varies with the type of multicriterion algorithm selected and also with other factors such as the administrative structure, the actual interaction between the DM(s) and analyst, the ability of DM to articulate his/her preference, and the uncertainties involved in MCDM.

The adopted procedure makes use of the following steps:

1. Choose the coefficient $p$;
2. Generate different sets of weights for each DM;
3. Calculate the distance from the "ideal point" and rank all alternatives for all generated weight sets at step 2 with the coefficient $p$ chosen; and
4. Examine the ranks and define the proposed solution.

Different values 1, 2, 3, 10, and $\infty$ for the parameter $p$ are examined in this study.

## *Application of the Compromise Programming Technique to the Case Study*

In the Iranian administrative structure, urban water and wastewater management is generally planned at two levels: (1) within the water and wastewater companies of the provinces and (2) by the national government. The provincial companies have responsibility for water and wastewater management in their provinces. The central government is responsible for policy-making at the national level for urban water and wastewater management for all provinces in the country. One can identify four groups of stakeholders taking part in the urban water and wastewater decision-making process: (1) the Provincial Water Company (PWC); (2) the Provincial Water and Sewage Company (PWSC); (3) the National Water and Sewage Company (NWSC); and (4) Management and Planning Organization of Iran (MPO). In the case of urban water, the first two governmental players (affiliated to the Ministry of Energy) are responsible for supply and distribution of urban water, respectively. NWSC is responsible for approving the proposed projects. It is worth mentioning that PWCs and the MPO do not take part in the urban water distribution decision-making process since the MPO is responsible for final approval of projects and allocating funds and the PWCs are only responsible for supplying water to the urban areas. Water distribution projects are funded from the PWSC incomes, but not from national budgets. Nevertheless, PWCs maintain roles in the overall water management policies in the urban areas of their responsibility.

**Table 1.** Selected Objectives and Criteria

| Objective | Criterion | Unit |
|---|---|---|
| Economic | Total cost | Billion Rials |
| Social | Public appraisal | Qualitative |
| | Political impact | Qualitative |
| Public health | Quality of water | Qualitative |
| | Health impact | Qualitative |
| Technical | Flexibility | Qualitative |
| | Water demand control | Qualitative |
| Sustainability | Time of water shortage | Year |
| | Population impact | Qualitative |

Note: 1 billion Rials is equivalent to 116,000 US Dollars.

## Objectives and Criteria

Objectives indicate the directions the changes in a system take as desired by decision maker(s). Considering the views held by water managers and authorities at the regional and national levels, and along the lines of policies and guidelines set by the Ministry of Energy for the urban water sector, the following objectives were identified requiring optimization for this problem: economic, social, public health and environment protection, technical, and sustainability (longevity). Based on these objectives and through discussions held with several members of the regional and national stakeholders, nine criteria were adopted to be used in the evaluation of the alternatives. These criteria have economic, sociopolitical, health, environmental, technical, and sustainability bearings. Table 1 lists the objectives and criteria, specifying for each criterion the units and its direction of preference (increasing or decreasing preference). The criteria are as follows: (1) total cost; (2) public appraisal; (3) political impact; (4) water quality; (5) health impact; (6) flexibility (i.e., the capability of the system to cope with several types of uncertainties); (7) water demand control; (8) time of water shortage; and (9) population impact.

## Alternatives

Compromise programming can be used in both mathematical programming (design problem) and decision analysis (Nachtnebel 1994). In the present feasibility study, we used the CP technique at step 6 of the MCDM general procedure for decision analysis where a discrete set of different alternatives comprising several elements are available.

Increasing the water supply services coverage is a main concern in most existing and new urban drinking water supply systems. However, it is always the case that a portion of the population must rely on means other than the service connection (most often, public standpipes, water vendors, water kiosks, etc.) due to water shortage and economic constraints. Given the water resources limitations in the city of Zahidan and the disadvantages of service connections including high investment costs, financing

**Table 2.** System Versus Criteria Array

| Criterion | Alternative system 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| (1) Total cost | 116 | 53 | 50 | 138 | 76 | 49 | 52 | 52 |
| (2) Public appraisal | VH | H | M | H | M | VL | L | L |
| (3) Political impact | VH | H | M | H | M | VL | L | M |
| (4) Quality of water | VH | H | M | H | M | M | M | M |
| (5) Health impact | VL | L | M | L | M | VH | H | H |
| (6) Flexibility | VL | M | M | L | VH | M | M | H |
| (7) Water demand control | VL | L | M | M | H | VH | VH | M |
| (8) Time of water shortage | 4 | 11 | 11 | 2 | 5 | 6 | 5 | 5 |
| (9) Population impact | VH | H | H | H | M | L | L | M |

Note: VL = very low, L = low, M = medium, H = high, and VH = very high.

problems, and the increasing water consumption, other water distribution means seem more feasible.

At the same time, to put the existing systems to their best possible use, efforts must be focused on water conservation and management. Rehabilitation of old systems and refurbishment of deteriorating structures can lead to reduction of water leakage and to improvement of service quality. Controlled water consumption by individuals also promotes water conservation. A simple economic incentive can lead to self-limits on the demand for water, while still preserving the freedom of the user to choose the level of comfort desired. Results of a recent study show that the setting of fee schedules can be an effective "demand management" tool under certain conditions (Roche et al. 2001). However, a number of factors may prevent fee schedules from having an inhibitory effect on water consumption. Given the socioeconomic conditions of the region and regarding the fact that only modest increases have been effected in water rates over the past years in the country, it does not seem possible, at least in the near future, to price water high enough to be economically "relevant" to the consumer. This is rooted in public expectations from the government and in their social attitude towards water; high rates meet their resistance and opposition.

Based on the economic, social, technical, and physical ease to implement and achieve the desired objectives, the results from preliminary discussions with the local water managers and authorities of the city of Zahidan, and drawing upon the policies and guidelines defined by the Ministry of Energy for the urban water sector, eight alternatives with common features are considered for the distribution of both the existing and transmitted water as follows:

1. Construction of a new water supply system for the whole city. This system is supposed to distribute the transmitted water for both sanitary and drinking water demands by individual service lines;
2. Construction of a new water distribution network for the new part of the city, rehabilitation of the existing sanitary water supply system, extension of the small drinking water distribution system with public standpipes (30 km long) within the old part of city, water vendors, and water kiosks;
3. This system is essentially similar to system 2, but the small drinking water distribution network with public standpipes is extended to over a length of 60 km within the old part of the city;
4. Construction of a new drinking water supply system for the whole city and rehabilitation and extension of the existing sanitary water system;
5. Construction of a new drinking water distribution system for the new part of the city, rehabilitation and extension of the existing sanitary water distribution network, the existing small drinking water standpipes, water vendors, and water kiosks;
6. Extension of the small drinking water distribution network with public standpipes (30 km long) within the whole city, rehabilitation and extension of the existing sanitary water distribution network, water vendors, and water kiosks;
7. This system is essentially similar to system 6 above, but the small drinking water distribution network with public standpipes is extended over a length of 60 km; and
8. This system is essentially similar to system 7 with the possibility of private service connections. For private service

**Table 3.** System Versus Criteria Array (Numerical Values)

| Criterion | Alternative system 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Supr. | Best | Worst |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Total cost | 116 | 53 | 50 | 138 | 76 | 49 | 52 | 52 | Minimum | 49 | 138 |
| (2) Public appraisal | 5 | 4 | 3 | 4 | 3 | 1 | 2 | 3 | Maximum | 5 | 1 |
| (3) Political impact | 5 | 4 | 3 | 4 | 3 | 1 | 2 | 3 | Maximum | 5 | 1 |
| (4) Quality of water | 5 | 4 | 3 | 4 | 3 | 3 | 3 | 3 | Maximum | 5 | 3 |
| (5) Health impact | 1 | 2 | 3 | 2 | 3 | 5 | 4 | 4 | Minimum | 1 | 5 |
| (6) Flexibility | 1 | 3 | 3 | 2 | 5 | 3 | 3 | 4 | Maximum | 5 | 1 |
| (7) Water demand control | 1 | 2 | 3 | 2 | 4 | 5 | 5 | 3 | Maximum | 5 | 1 |
| (8) Time of water shortage | 4 | 11 | 11 | 2 | 5 | 6 | 5 | 5 | Maximum | 11 | 2 |
| (9) Population impact | 5 | 4 | 4 | 4 | 3 | 2 | 2 | 2 | Minimum | 2 | 5 |

**Table 4.** Assessment of Importance of Each Criterion

| Objective | Criterion | Decision maker 1 | Decision maker 2 |
|---|---|---|---|
| Economic | | | |
| | Total cost | M | H |
| Social | | H | M |
| | Public appraisal | VH | M |
| | Political impact | VH | H |
| Public health | | H | H |
| | Quality of water | H | M |
| | Health impact | VH | H |
| Technical | | H | M |
| | Flexibility | H | M |
| | Water demand control | M | H |
| Sustainability | | M | H |
| | Time of water shortage | M | H |
| | Population impact | M | H |

connections, the household must pay the cost of connection to the small network.

The following assumptions underlay all the systems considered: (1) the per capita consumption from the water distribution network (both drinking and sanitary water), drinking water distribution network, and standpipes are 100, 30, and 10 L/day, respectively; (2) water for the sanitary water distribution network will be supplied conjunctively from groundwater and transmitted water while the other system components will be supplied by transmitted water; and (3) due to the water resources limitation, treated municipal wastewater should be reused for specific demands such as landscaped areas in order to alleviate pressure on high quality water (transmitted water) as well as on brackish groundwater.

## Evaluation of the Alternatives

Alternative systems versus criteria array is shown in Table 2. Among the criteria considered, the costs and sustainability (the time distance of the water shortage from 2005) were estimated quantitatively. The rest of the criteria were estimated subjectively, according to the performance levels of the different alternatives and taking into account the results of discussions with local decision makers and stakeholders such as the City of Zahidan Public Health Office, Zahidan Municipality, and the Province Governor Office authorities. Numerical values have been substituted for the qualitative ratings in Table 2 to yield Table 3. It is assumed that the "true ideal point" is not known so that the approach of "displaced ideal" proposed by Zeleny (1977) and adopted by many others is used. The ideal point is defined by the "best" value in Table 3. At the opposite end of the best value, the "worst value" of the criterion function is introduced.

## Weights

After discussions with DMs, a five-level scale was adopted (very low, low, medium, high, and very high importance). Numerical values were substituted for the qualitative ratings of the weights. As pointed out by many, the methods requiring a prior articulation of preferences among different objectives or criteria, place rather heavy demands on decision makers in terms of information requirements. Considering two actors taking part in the decision-making process for this problem, and taking into the account the results from discussions with DMs, two sets for the weights were generated by the procedure explained below. The first set represents the local decision-maker (PWSC), while the second set represents the national DM (NWSC). Moving from local to national weights, the importance attached to some sociopolitical criteria decreases but more importance is attached to the economic and sustainability criteria.

In the present study, it was difficult to determine the weight of each criterion in the first place by pairwise comparisons. Therefore a four-step procedure was adopted to compute the criteria weights as follows:

1. Determine the weight of each objective, reflecting the relative importance among the objectives (Table 4);
2. Determine a preliminary weight for each criterion reflecting the relative importance among criteria within each objective (Table 4);
3. Compute the normalized weight of each criterion by dividing the assigned weight in step 2 by the sum of the criteria weights within each objective; and
4. Compute the final criteria weight by multiplying the normalized criteria weight by the objective weight.

## Sensitivity Analysis

In compromise programming, uncertainties are not accounted for in an explicit manner. However, the disadvantage is partially compensated for by a sensitivity analysis. At the decision-making level, sensitivity analysis was performed with regard to (1) change in the values of the subjectively determined criteria, and (2) change in weighting coefficients. For sensitivity analysis concerning the weighting coefficients, we considered two sets of numeric values and generated two sets of weights belonging to each DM (Corderio Netto et al. 1996). The five-level linguistic scale, shown in Table 4 (VL, L, M, H, and VH), was transformed into numeric ones using the two sets of numeric scales (1, 2, 3, 4, 5) and (1, 3, 5, 7, 9). Thus a linear value function was used with two different slopes. Final criteria weights computed by a four-step procedure as outlined above are shown in Table 5. For sensitivity analysis concerning subjective criteria, we used the same consideration. As population and per capita water consumption forecasts, which partly determine the sustainability of alternatives, are the basic difficulties of this case study due to their associated uncertainties, we preferred not to generate different scenarios for population growth and water consumption, but rather to see indirectly their implications in flexibility, water demand control, and population impact criteria.

## Results and Discussion

Relations (3)–(6) were used in the computation of $p=1,2,3,10$, while relation (7) was used for $p=\infty$. In sensitivity analysis of the results for the values of $w_i$, two sets of numeric scales were used. Various compromise solutions for $p=1$ and 2 are given in Tables 6 and 7. It is observed that alternative 2 is ranked first (i.e., compromise solution) to both decision makers and for all values of $p$, regardless of the numeric scale used for the weight coeffi-

**Table 5.** Weight Coefficient Used in Sensitivity Analysis

| Variant | | Criterion | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| DM | Numeric scale | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| PWSC | 1,2,3,4,5 | 3.0 | 2.0 | 2.0 | 1.8 | 2.2 | 2.3 | 1.7 | 1.5 | 1.5 |
| PWSC | 1,3,5,7,9 | 5.0 | 3.5 | 3.5 | 3.1 | 3.9 | 4.1 | 2.9 | 2.5 | 2.5 |
| NWSC | 1,2,3,4,5 | 3.0 | 1.3 | 1.7 | 1.7 | 2.3 | 1.3 | 1.7 | 2.0 | 2.0 |
| NWSC | 1,3,5,7,9 | 5.0 | 2.1 | 2.9 | 2.9 | 4.1 | 2.1 | 2.9 | 3.5 | 3.5 |

**Table 6.** Values of $L_p$ Metrics

| Variant | | $P=1$ | | | | | | | | $P=2$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DM | Numeric scale | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| PWSC | 1,2,3,4,5 | 8.9 | 6.0[a] | 7.9 | 10.4 | 7.8 | 10.0 | 8.7 | 8.0 | 2.9 | 1.7[a] | 2.2 | 2.9 | 2.1 | 3.0 | 2.6 | 2.3 |
| PWSC | 1,3,5,7,9 | 15.2 | 10.4[a] | 13.8 | 17.8 | 13.3 | 17.4 | 15.1 | 13.8 | 3.7 | 2.3[a] | 2.9 | 3.7 | 2.8 | 4.0 | 3.4 | 3.0 |
| NWSC | 1,2,3,4,5 | 8.8 | 5.6[a] | 7.2 | 10.3 | 7.7 | 8.8 | 7.8 | 7.5 | 2.8 | 1.7[a] | 2.2 | 2.9 | 2.1 | 2.8 | 2.4 | 2.3 |
| NWSC | 1,3,5,7,9 | 15.0 | 9.5[a] | 12.4 | 17.6 | 13.2 | 15.0 | 13.3 | 13.0 | 3.7 | 2.2[a] | 2.8 | 3.7 | 2.8 | 3.7 | 3.2 | 3.0 |

[a]Denotes the compromise solution.

**Table 7.** Values of $L_p$ Metrics (Minmax)

| | $P=\infty$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Alternative system | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| $L_p$ | 1.0 | 0.7[a] | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

[a]Denotes the compromise solution.

**Table 8.** Normalized Deviation from the Ideal Value, $D_i$

| | Alternative system | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Criterion | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1 | 0.75 | 0.05 | 0.02 | 1.00 | 0.31 | 0.00 | 0.03 | 0.03 |
| 2 | 0.00 | 0.25 | 0.50 | 0.25 | 0.50 | 1.00 | 0.75 | 0.50 |
| 3 | 0.00 | 0.25 | 0.50 | 0.00 | 0.50 | 1.00 | 0.75 | 0.50 |
| 4 | 0.00 | 0.50 | 1.00 | 0.50 | 1.00 | 1.00 | 1.00 | 1.00 |
| 5 | 0.00 | 0.25 | 0.50 | 0.25 | 0.50 | 1.00 | 0.75 | 0.75 |
| 6 | 1.00 | 0.50 | 0.50 | 0.75 | 0.00 | 0.50 | 0.50 | 0.25 |
| 7 | 1.00 | 0.75 | 0.50 | 0.75 | 0.25 | 0.00 | 0.00 | 0.50 |
| 8 | 0.78 | 0.00 | 0.00 | 1.00 | 0.67 | 0.56 | 0.67 | 0.67 |
| 9 | 1.00 | 0.67 | 0.67 | 0.67 | 0.33 | 0.00 | 0.00 | 0.00 |

cients. In other words, alternative 2 is the best alternative to both DMs and it is not sensitive to weight coefficients.

The results also revealed that alternatives 5 and 3 rank second and third, respectively, and alternative 4 is almost the worst alternative in all cases. Therefore it can be concluded that alternative 2 enjoys the best status compared to others.

In sensitivity analysis concerning subjective criteria, the compromise solutions are the same as Tables 6 and 7, regardless of the numerical scale used for the subjective criteria. This is expected as the normalized deviation from the ideal value is not sensitive to the numeric scales used in this problem.

Considering the surrogate utility function as $U=1/l_p$ (i.e., $U_1=0.17$) and the normalized deviation from the ideal value as $D_i$, then we see that if $p$ increases from 1 to $\infty$, neither total utility nor individual regrets (here distance from ideal) change, despite the fact that any deviation $D_i$ in the $l_p$ metric appears as $D_i^p$. To partially explain this behavior, Table 8 shows that for any value of $p$, the maximal individual deviation in alternative 2 that is $D_7=0.75$, is less than the maximal individual deviation in any other alternative which is equal to 1. Thus the compromise solutions for $p=2$, 3, 10 as well as the minmax solution for $p=\infty$ are the same as for $p=1$ and alternative 2 is always the compromise solution. This result shows that in this particular problem, parameter $p$ has no role of the "balancing factor" between the "group utility" and the maximum of the individual regrets: and as $p$ increases, both the group utility and individual regret remain unchanged.

Comparing alternative 2 to alternative 5 (solution rank 2), alternative 2 is noticed to be better than alternative 5 with respect to all criteria, except for criteria 6, 7, and 9. Comparing alternative 2 to alternative 1, alternative 2 is found to be better than alternative 1 with respect to all criteria, except for criteria 2–5 (namely, public appraisal, political impact, water quality, and health impacts, respectively). This result shows that alternative 1 is more social objective oriented, whereas the proposed alternative is more in favor of total cost, water quality, flexibility, population impact, and time of shortage. In the light of limits of water and financial resources for the city of Zahidan, special attention given to these criteria is very advantageous. One may argue that this system is not quite sustainable (i.e., only 11 years), but it should be noticed that it is the best possible alternative. Given the water resources limitations and the fact that groundwater recharge by wastewater pits will no longer be used as the wastewater collection system is under construction, this time of shortage is expected. In addition to the above advantages, the main benefits expected from this system include conservation of public living standards and habits, higher supply of good quality water, and the opportunity for PWSC to focus their efforts on long range water conservation measures, wastewater reuse, and other feasible projects such as groundwater recharge (i.e., rainwater harvesting).

MCDM studies are sometimes not related to real-world problems as they reflect the optimistic view that the DMs' behavior can be encoded into simple techniques and, simultaneously, may not ascertain whether real case applications fit the conceptual model. Being aware of the actual decision process, we must assume that discrepancies between theory and practice may occur. From a theoretical point of view, it must be recognized that the final advice may not have been to focus on alternative 1, which was initially considered by PWSC. It is noteworthy that after this MCDM procedure and its components were explained to the DMs, they found the results and the proposed solution reasonable and sound. What the city is doing in the first stage is some elements of alternative 2, i.e., construction of a new water distribution network for the new part of the city, rehabilitation of the existing sanitary water supply system, and water kiosks by private sector.

## Conclusions

A major problem dealt with in this study is the use of scarce water resources to meet the growing urban water demands. Planners and decision makers must be aware of creative system analysis as a powerful tool in maintaining a lasting and sustainable balance between demand and available resources (i.e., water resources, financial resources, etc.) through innovative water conservation and demand management techniques.

In developing countries, the application of MCDM to real water resource management problems may be limited by many factors, but mainly institutional constraints. Yet, this first-time application of MCDM theories to urban water management in Iran appeared to be realistic and promising, and provided insight into this case study. We found that the CP procedure is easily understandable and may result in further complementary discussions between the analysts and the DMs so as to cast more light on the decision process. The experience gained in this project offers a favorable view of the systems approach to water management in Iran. The results obtained revealed that the method used in this study is capable of solving urban water management problems.

## Acknowledgments

The study presented in this paper was conducted at Sharif University of Technology. The writers are grateful to the reviewers for their constructive comments and suggestions. The writers also thank Sistan & Balouchistan Water Company, Zahidan Water and Sewage Company, and the National Water and Sewage Company for providing valuable information and data.

## Notation

*The following symbols are used in this paper:*

$D$ = normalized deviation from the ideal;
$f_1(x)$ = value of criterion $i$ in alternative $x$;
$f_i^*$ = ideal value for criterion $i$;
$f_{i^*}$ = anti-ideal value for criterion $i$;
$f_{ij}$ = value of criterion $i$ in alternative $j$;
$f_{i,b}$ = substitute ideal value for criterion $i$;
$f_{i,w}$ = substitute anti-ideal value of criterion $i$;
$I$ = total number of criteria;
$i$ = subscript designating different objectives or criteria;
$J$ = total number of alternatives;
$j$ = subscript designating different alternatives;
$L_p(x)$ = parameter distance from ideal;
$L_p^j$ = distance of the alternative $j$ from the ideal solution;
$p$ = parameter that reflects the importance of the maximal deviation from the ideal value;
$U$ = surrogate utility function;
$w_i$ = weight reflecting the relative importance of the criterion $i$;
$X$ = feasible solution set;
$x$ = alternative $x$; and
$x_{cp}$ = compromise solution.

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