A Multiobjective Analysis Model for Negotiations in Regional Water Resources Allocation

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Abstract

Conflicts between or among water users often happen in regional water resource allocation. Even though the water authority can use water laws to resolve such conflicts, a technical analysis tool which allows the combination of the science and art of system analysis is often helpful for conflict negotiations.

In this paper, a multiobjective analysis framework for negotiations in regional water resources allocation is presented. The benefits or expectation of individual groups are specified as objectives, and the integration of those objectives with the physical constraints related to the regional water distribution system, and the policy related considerations constitute the analysis model.

The model brings the individual parties with various expected benefits together, which is important for negotiation, and the model is of value in helping negotiators to understand the behavior of the environmental system. The resulting analysis will show the tradeoffs between or among those objectives, and the tradeoff information on one hand, will be helpful for the water management authority to negotiate the conflict among the water users , and on the other hand, it will be critical for different water users to know how their benefit goes down or up when the benefits of others change. This kind of relationship will make different decision makers understand each other, which is finally helpful for them in reaching a consensus.

This paper will focus on two points: (1) introducing a multiple objective analysis framework for negotiation in regional water resources allocation; and (2) discussing analysis procedures to provide information to support negotiation. A case study will be given for the conflict negotiations between hydroelectric power generation and the downstream irrigation occurring in the Syrdarya River basin in central Asia.

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Introduction

Today water has been a major factor in the development of many regions in the world, and conflicts in regional water allocation have become into a very large problem in water resources planning and management. Downstream farmers may find that a upstream hydroelectric power plant does not release enough water for their irrigation use in vegetation periods; recreational agencies may complain that the industrial companies damage the recreational benefit by discharging too much wastewater into the water system. The most serious conflict happens in some international river basins, in which limited water is shared by two or more than two countries, and resolving the conflicts is an important international issue.

The traditional method used to resolve conflicts is through the public forum, in which individual groups are able to express their views, and then argue their own benefits based on the information acquired in the group interactions. However, models have been used to support negotiation for many years, especially in public-policy related issues. Walton and McKersie (1965) argued that interactive solutions resulted from a shared definition of the problem and development of shared information concerning the requirements of others can support negotiation problems. Kraemer (1985) show that models, as integrative approaches in negotiation could help negotiators to reconcile their divergent interests and achieve joint benefit rather than to try to maximize individual benefits. Following these ideas, several computer-based models used for negotiation in water resources have been studied (Reitsma et al. 1996), and most of them are simulation models. In this paper, first we present a multiple objective analysis framework for negotiation in water resources, and then discuss how much information the model is able to provide to support negotiation. Finally, a case study is presented for conflict negotiation between hydroelectric power generation and downstream irrigation in the Syrdarya River basin in central Asia.

Multiple Objective Analysis Model Framework For Negotiations

In a multiple objective analysis model, multiple objectives , which the model users are interested in, with all constraints related to the objectives are formulated into an integrative and analytical mode. The general formulation of a multiple objective analysis model is :

$$Z = \mathit{max}\ /\mathit{min} \quad g\ (\ Z_1(\mathbf{x}),\ Z_2(\mathbf{x}),\ Z_3(\mathbf{x}),\ \ldots\ Z_n(\mathbf{x})\ ) \tag{1}$$

$$\text{st.} \quad F(\mathbf{x}) = 0 \tag{2}$$

in which $\mathbf{x}$ is the decision variable vector, Z_i (i=1, 2, ... n) is an objective , g is a function to aggregate all the objectives in a single formulation, and F is a vector of constraint functions.

One of the popular operational formulations is to assign a weight to each objective, and write the objective function as:

$$\text{Max(min)} \quad Z = \sum_{i}^{n} w_i \, Z^*_i \qquad (3)$$

in which w_i is the weight assigned to objective Z_i, and Z^*_i is a scaled objective index. All objective indices are scaled to the same numerical level, i.e. (0,1), therefore, all the objectives will be compatible in the objective function.

Without loss of generality, we assume that each negotiator has his own benefit, which is competitive to that of any other negotiator. If any two of more negotiators have the same expectation, then they can be combined into a single one. We further assume that for each negotiator’s benefit, there exists a measure to express the benefit quantitatively. With these assumptions, we can take each negotiator’s benefit as an objective, and then bring all negotiators’ benefits together by putting the corresponding objectives into the objective function.

Now, the weight for an objective, which represents how important the associated objective is related to other objectives, becomes a key for the negotiation. The objective weights form a bridge for the interactions between the model and the negotiator, and also the interactions between negotiators. We discuss this aspect later.

We can also use the constraint equations to express some aspects related to negotiations. For regional water resources allocation, a multiple objective analysis model generally consists three kinds of constraints: (1) physical constraints, (2) policy related constraints, and (3) the system control constraints. The physical constraints have no direct implication for negotiation, but these constraints help all the negotiators understand the problem, especially how their expectations are limited by the physical system. The policy constraints can contain some policies that represent the common perspective of all negotiators. The system control constraints can be used to create various scenarios for negotiators to do what-if analysis.

The multiple objective analysis framework for negotiations stated above has the following significance: (1) bringing all negotiators together into common definition of the problem, which is fundamental to negotiations; (2) integrating all negotiators’ expectations into an analytical formulation, which is critical for tradeoff analysis between negotiators; (3) carrying out what-if analysis, which lets negotiators to understand more about the problem, know more about other negotiators, and know better about what they seek. In the next section, we discuss what specific information the model framework is able to provide for negotiations.

Information For Negotiations Based On Model Result Analysis

When a model is built and verified for use, the model is run in various situations, and the results are expected to provide information to support negotiations.

The Payoff table

A model may be available for both the whole negotiator group and individual negotiators. Each negotiator can use the model for his own interesting operations. If a negotiator sets the weight for his own benefit as 1.0, while the weights for all other's objectives are 0.0, then the model becomes a single objective optimization model. The result shows the "best" benefit for that negotiator. Each negotiator can find his own "best" benefit. Putting all such solutions into a table, we get a so-called payoff table. From the payoff table, each negotiator can see the "best" and 'worst" benefit of any other negotiator, as well as of his own.

Tradeoff analysis

Running the models under various sets of objective weights generates a number of solutions. If the number of weight sets is large enough, and the solutions cover as many potential solutions as possible, then the analysis of those solutions is able to show the tradeoff relationships between/among negotiators. Based on the tradeoff relationships, we may find a solution which can be accepted by all or most negotiators.

What-if analysis

The whole negotiator group or each individual negotiator may define various scenarios based on their interests or judgments. For example, one negotiator may want to know if his benefit reaches an expected level, what are the effects to all the other negotiators. This scenario can be implemented in the model, and some information can be obtained from the model result. What-if analysis lets each negotiator explore the problem as his own wish, and also, the whole group may test some solution with "equal benefit" to all individuals or some potential solutions that have high group preference.

Sensitivity analysis

Sensitivity analysis is used to find the effects on the negotiation information from the uncertainty in the physical system. In water resources allocation problems, the most uncertain thing is how much water is available from the natural world , which is of much uncertainty. The sensitivity analysis to the parameter of water availability can make negotiators aware of how much risk is associated with benefits due to the uncertainty in the real world.

Case Study

The Syrdarya River, originates in the countries of Kyrgystan and Tajikistan and flows through Uzbekistan and Kazakstan until finally reaching the Aral Sea (Fig. 1). The major source of the river comes from the mountainous republics of Kysgystan and Tajikistan, and this source has been controlled by the Naryn-Syrdaryar cascade reservoirs of which Toktogul Reservoir is the major one. The downstream countries do not have much local source, but they do have large irrigated lands and they must rely on the releases from the upstream countries. Therefore two obvious competitive objectives exist in the water management in this river basin. Kysgystan's objective in managing the river is to maximize the production of hydroelectric power in the Naryn-Syrdarya Cascade. In some conflict with this are the downstream countries, Uzbekistan and Kazakstan, whose objectives are to maximize their utilization of water for irrigation. This situation has led to a major international conflict over the waters of the Syrdarya.

To support the negotiations occurring in the Syrdarya River basin, a multiple objective analysis model has been developed to help decision makers from the Syrdarya basin Republics come to an agreement for the allocation of water releases from the Naryn-Syrdarya Cascade on the Syrdarya River (Mckinney, 1996). The benefit of Kyrsgystan is expressed as an objective of power generation, with emphasis on minimizing power deficit in winter periods; the benefit of the downstream republics is expressed as an objective of water supply, with emphasis on minimizing irrigation water supply deficit in vegetation months. In the constraint equations of the model, some policy related considerations are implemented. These considerations include the water allocation agreements among the republics, minimum inflow to the Aral Sea, which is critical for the ecology of the whole river basin, and reservoir releases limit for flood control, etc.

Some results are presented in the following (refer to [McKinney 1996] for detail model and results). The model was run for 36 months for the results presented here. Table 1 (payoff table) shows the minimum and maximum values of power deficit and water supply deficit under three kinds of hydrologic levels (see notes with table 1). Fig. 2 shows the power deficit and water supply deficit from a number of solutions, and the tendency of the point distribution shows the tradeoff between power deficit and water supply deficit.

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Tab. 1 The payoff table for power and water deficit under three hydrologic levels

Hydrologic Levels	n-n-n		d-w-n		d-d-d	
Objective Items / Weights	w1= 1 w2= 0	w1= 0 w2= 1	w1= 1 w2= 0	w1= 0 w2= 1	w1= 1 w2= 0	w1= 0 w2= 1
Water supply Deficit (km^3)	4.06	14.8	6.7	30.7	37.1	50.1
Power Supply Deficit (Gwh)	12338	8311	12190	8007.0	11678	10730

Note : n-n-n three consecutive normal hydrologic years ; n-d-n , the first and the third year, normal, and the second year, dry hydrologic year; d-d-d three consecutive dry hydrologic years.; w1, weight for water supply objective, w2, weight for power generation objective

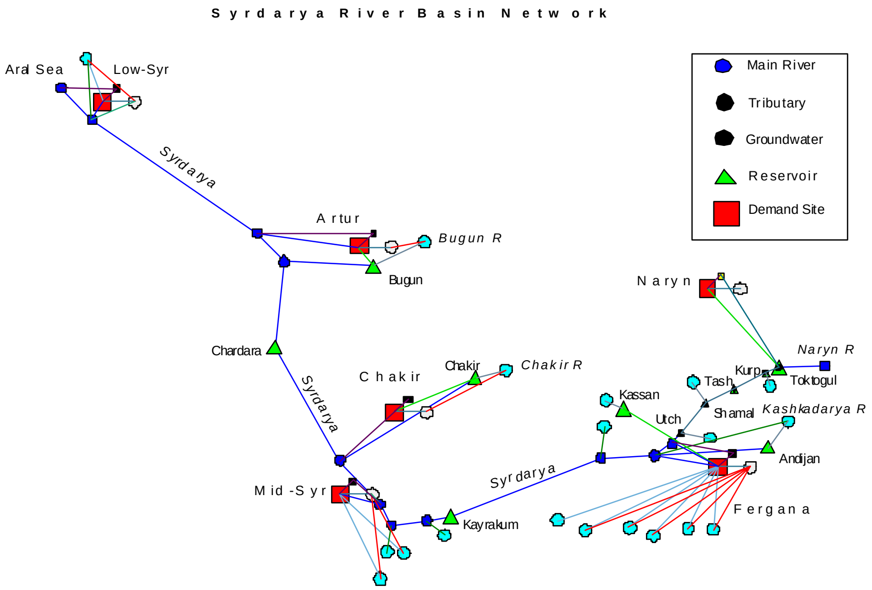

Fig.1 Network Representation of the water system in Syrdarya River System

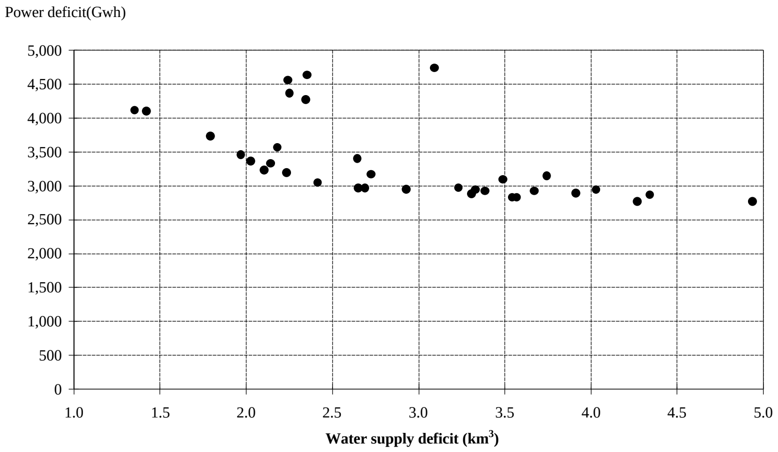

Fig. 2 Relation between power and water deficit under normal hydrologic levels