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Designing a Water Resources Management Decision Support System: An Application of the WSR Approach

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The *wuli*, *shili*, *renli* (WSR) systems methodology (an oriental systems approach to the dynamic unification of the study of the objective world, organization, and human factors during intervention) is discussed. After a brief description of WSR, the paper concentrates on its application to the development of a computer-supported water resources management system. The working process of the WSR approach is illustrated through this case study. Also, the "added value" of WSR is made clear: in contrast with other Chinese methodologies which might be applied to handle a "technical" project of this nature, WSR makes the need to deal with human relations more visible. It therefore embodies the insight, common to Western systems methodologies, that human relations are integral to the success of interventions—but in a manner that is both philosophically and practically meaningful to a Chinese audience.

KEY WORDS: systems methodology; *wuli*; *shili*; *renli*; China; WSR; human relations; water resources management; decision support systems; systems engineering.

1. INTRODUCTION

In our view, until the 1970s, complexity (such as that found in socioeconomic and environmental systems) was not adequately addressed by systems approaches. This led researchers and systems practitioners to investigate and develop alternative systems methodologies. Checkland's (1981) Soft Systems Methodology (SSM) is one of those alternatives. SSM regards complex systems as issues: instead of a usual problem-solving process, a *learning* process ensues which includes various activities such as analysis, debate, and conceptual modeling. The idea is to achieve a practical, satisfactory result that takes account of

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the constraints of the situation. In the Orient, Japanese researchers have put forward the Shinayakana systems approach, which emphasizes human support and interaction during system modelling (Sawaragi *et al.*, 1988). Chinese scientists have proposed the Meta-Synthesis method (Qian *et al.*, 1993), which emphasizes the synthesis of collected information from various kinds of experts, and connecting quantitative methods with qualitative knowledge when dealing with complex, open, giant systems. Pressman (1992) has synthesized Western systems inquiry and the Eastern mode of practice, considering human factors and their connection with the physical world.

Through studies of these various systems methodologies and our own Eastern philosophies, and by reflecting on our experiences of working on different projects, the *Wuli*, *Shili*, *Renli* (WSR) systems approach was born. See Gu and Zhu (2000) and Zhu (2000), both in this special issue, for more details of WSR philosophy, theory, and methodology.

1.1. The *Wuli*, *Shili*, *Renli* Systems Approach

During the process of system analysis, design, and implementation in WSR, three aspects of work are always carried out—whether purposefully or unintentionally. These are *wuli*, *shili*, and *renli*. The *wuli* refers to knowledge about the physical world. This aspect involves using the methods of natural science. Considering *wuli*, we require honesty and truth so as to keep our systems practice results in accord with the physical world. *Shili* denotes knowledge about how we build a reasonable order or organization by which to manage or control reality and achieve a satisfactory outcome. This aspect requires methods from the management and systems sciences. *Renli* refers to knowledge about human effects on the system, or how we deal with human interrelations. Initially, *renli* may be the experience or the art that leaders use in dealing with interrelations between their subordinates and themselves to create harmony. The aim of *renli* is to initiate human creativity, enthusiasm, and participation and to explore human wisdom. This aspect requires knowledge of the human sciences.

Systems practice activities are constituted by the “dynamic unification” of knowledges of the physical world, system organization, and human relations. Inquiries and interventions must deal with all three aspects and their dynamic interconnection. So the aim is to connect *wuli*, *shili*, and *renli* in order to get (as far as possible) a comprehensive picture of the project, problem, or issue, and thereby find a satisfactory and feasible result. Again, see Gu and Zhu (2000), in this special issue, for more details of the WSR principles and methodology. Here, the focus is on one particular intervention in a water resources management system.

1.2. A Water Resources Management Decision Support System: The Qinhuangdao Project

Situated in North China, Qinhuangdao is an important medium-sized city and seaport, which is very famous for its tourism. Since the 1980s, the city has endured a water shortage. In order to manage this serious situation, the local government has invested heavily in constructing tunnels to divert water from the Qinglonghe River to supplement the city's water resources and connect all water plants by pipelines. Hence, Qinhuangdao's water resources system has expanded greatly: there are multiple transbasin water resources, reservoirs, water plants, and water links. A specific management institution, the Yinqing Management Bureau, was founded for the management of the expanded water resources system.

To improve the management of the expanded water resources system, the local government invested RMB 6,000,000 *yuan* to develop a computer-based automatic system, the Qinhuangdao HydroEngineering Management Information and Decision Support System (QHEMIDSS), which is characterized by its *telemetric*, *telecommunication*, *telecontrol*, and "*teleregulating*" capacities. As far as we are aware, the use of WSR in the design of QHEMIDSS is the first case of the purposeful practicing of a systems engineering methodology for the large-scale control and management of a water resources system in China [see Liu *et al.* (1993) and Zhang *et al.* (1993) for other papers on the subject].

The design of the computer information system needed to draw upon a variety of knowledge bases and technologies: automation, systems science, management, information systems, hydrology, computer networking, etc. The system design and implementation was complicated by multiinstitutional, multiobjective, and interdisciplinary concerns; conflicting goals; contradictory "facts"; and a lack of necessary data. The WSR systems approach was helpful in addressing these issues during the whole period of designing QHEMIDSS, making it possible to finish the project successfully and on schedule.

2. APPLICATION OF THE WSR APPROACH TO QHEMIDSS

2.1. Working Process of the WSR Approach to QHEMIDSS

Figure 1 depicts the theoretical seven-step working process of the WSR approach, which is really just a framework into which purposeful activities may be placed. In specific projects, the process of moving through these steps will be tailored to the perceived needs of the situation. Although Fig. 1 depicts a circular pathway, people may need to jump back to previous stages at any time to revise their understandings. Therefore, Fig. 1 should be regarded as an "ideal" rather than as a rule-book to be followed systematically. To aid presentation of the case study, however, each step of the process is discussed in turn.

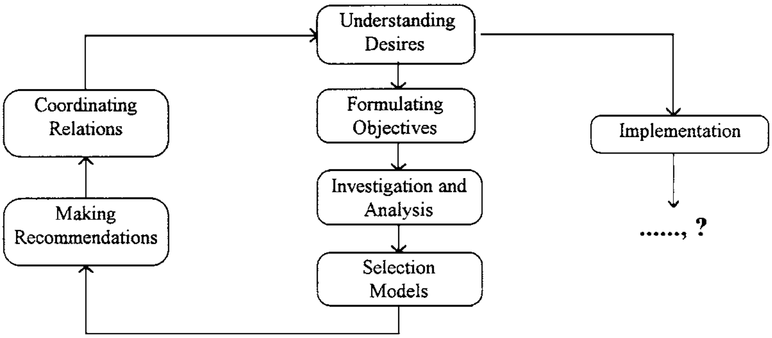

Fig. 1. The working process of the WSR approach.

2.2. Understanding Desires

During the preliminary system analysis period, the project managers had frequent conversations with local managers to determine the key problems. The most important problem faced by local managers, they said, was supplying enough water for industrial and municipal uses, irrigation, tourism, etc.—while flood control was also important in the summer. Hence, water supply/allocation and flood control were the two key issues to be addressed.

Hydrology experts were then recruited to the research group to give reports of rainfall–runoff relations for flood control. Experts in the use of optimization techniques were asked to give decision support to managers involved in both water supply/allocation and flood management. There was also a real-time data supervisory group for collecting, processing, and storing data. The functions of the whole project and the main tasks of the researchers became clearer after on-the-spot investigations and several rounds of dialogue with local managers.

Based on these dialogues with Qinhuangdao water resources managers, the Qinhuangdao water supply system is shown in Fig. 2.

For administrative reasons, Shihe Reservoir, whose release met almost all water demands of the Shanhaiguan water plant (except during severe drought years), was not within the Yinqing Management Bureau's supervision. The Haigang and Liucun water plants were controlled by a pump station, so those two water plants were regarded as one. The next stage was to simplify the diagram of the water resources system even further to provide an easy to understand model for everybody to work with (Fig. 3), facilitating greater problem clarification.

Up until this point the picture of water resources management had been only roughly sketched. Now the main tasks could be determined more precisely: (1) dealing with the water supply and allocation issues, (2) handling the Yanghe

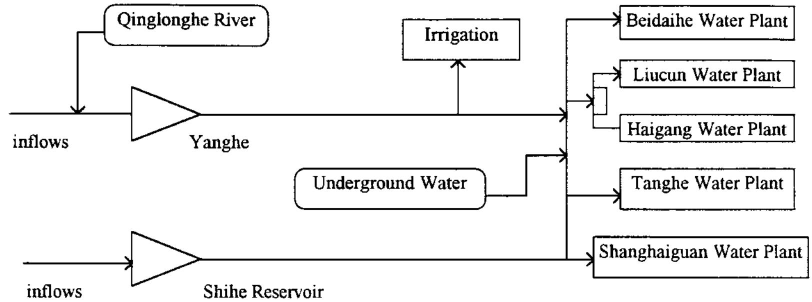

Fig. 2. Scheme of the Qinhuangdao water resources system.

Reservoir system flood control issues, and (3) forecasting the reservoir inflows (using different time intervals depending on different local needs).

2.3. Formulating Objectives

By looking through relevant research work abroad and at home, the research group members realized that mathematical programming models could be used for the first task. It was proposed to build a dynamic programming model for reservoir operation and a goal programming model for water allocation. For the operation model, the operating criteria were defined first (economic criteria for reservoir operations were used extensively). Routing models (essentially, one kind of simulation model) for flood management worked in addition to dynamic programming models. The forecast of reservoir inflows by various intervals (yearly, monthly, hourly, etc.) was formulated using other models: specifically, time series models for tendency forecast (yearly and monthly) and hydrological forecasting models for real-time inflow forecast (with the lowest interval set at 15 min). After consulting with experts, the precision of the forecasting mod-

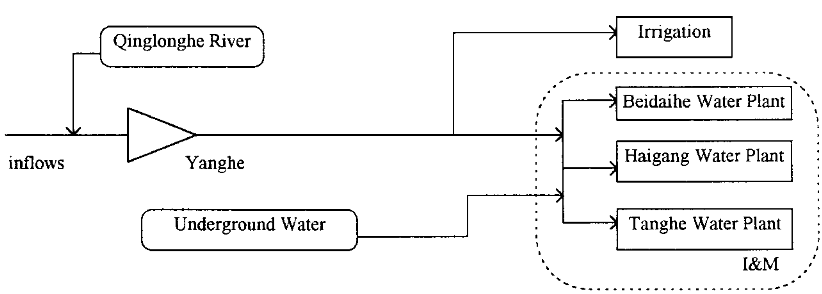

Fig. 3. Simplification of the Qinhuangdao water resources system.

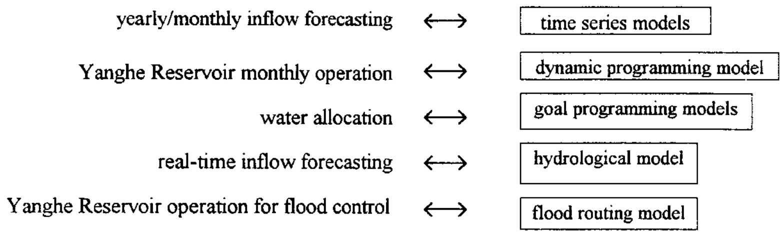

Fig. 4. Initial system analysis.

els was increased using shorter intervals. Impressed by the difficulties in water resources management research, the group members presented a first-round system analysis report for further discussion with local managers. The contents list from this (and a list of the models used) is presented in Fig. 4.

2.4. Investigation and Analysis

The research team members then went to Qinhuangdao to conduct more detailed investigations. Activities included dialogue with local managers at different hierarchical levels, searching out data for the models, examining the data, and processing and analyzing the data to test a hypothesis we had established (that the inflow records would fit a supposed Pearson Type III probability distribution).[2]

It was clear that local high-level managers were concerned about whether appropriate reservoir operating criteria were being used. They questioned the usual, economic method of calculating reservoir operating returns. Reservoir inflow forecasting methods and their precision were also questioned: there was some disagreement here, and it emerged that different managers needed different levels of forecasting precision. As a result, two new tasks were added to those already represented in Fig. 4: developing new economic operating criteria and developing new formulae for monthly inflow forecasts in low-flow seasons.

2.5. Selecting Models

Not only did high-level managers reject the usual means of calculating reservoir operating returns, but they also distrusted alternative economic methods we suggested. Finally, it was proposed to depict the users satisfaction with reservoir storage, which proved to be more acceptable. Therefore, a satisfaction criterion model (SCM) was formulated, computerized, and put into trial use.

[2] By calculation and analysis, the yearly and monthly inflow to Yanghe Reservoir fit a *P*-III distribution by the Kolmogorov–Smirnov test with a confidence level of 0.20 (Tang and Gu, 1993a; Tang *et al.*, 1994).

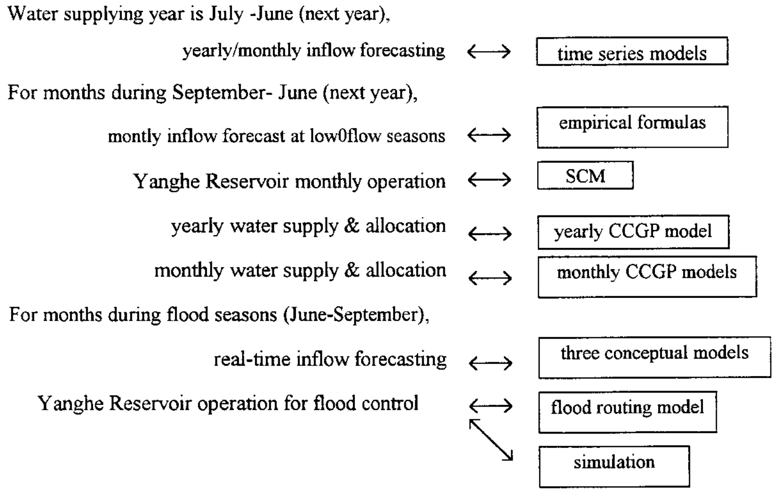

Fig. 5. Model sets.

For the real-time rainfall–runoff forecast, the geographic characteristics of the Yanghe Reservoir made it difficult to forecast reservoir inflow in the short term. The hydrologists proposed two models, the Xin-an-jiang model, which had been developed by Chinese researchers and used extensively in China, and the Danish NAM (Nedbor-Afstromings model), which had been successfully applied in other countries but had never been used in China. The hydrologists, in cooperation with local hydrological engineers, then made the first successful application of the NAM model in China and extended the use of the Xin-an-jiang model.

Formulae for forecasting monthly inflows during low-flow seasons were programmed along with the time series models for forecasting yearly and monthly inflows. All long-term and midterm forecasting models were put into trial use. It was forecast that there would be less water during 1993–1994, while there would be an increase in storage during 1994–1995. This was because the Qinhuangdao system faced drought during 1993–1994, but the heavy rainfall in the summer of 1994 did not result in flooding since the reservoir operators had spilled some previously stored water for flood control.

Our systems practice activities made our research group different from the activities of other groups involved in developing QHEMIDSS. The latter paid attention only to computer programming and the design of interfaces, while our group concentrated on model validation—meaning validation in dialogue with users. By this stage, the number of models being tested had expanded somewhat (see Fig. 5).

2.6. Making Recommendations

The end users were not satisfied with the Satisfaction Criterion Model (SCM) in trial use. Through discussion and further analysis, the modelers found two problems: (i) the model did not correctly represent the policy of diverting water (so relevant modifications were made), and (ii) the way satisfaction had been represented in the SCM led to misunderstandings and inappropriate data returns. Hence, the results were not in accord with the perceived reality of end users. Discussion with further users, and the provision of clearer explanations to high-level managers, enabled us to define more adequate parameters for the SCM. A comparison was also set up between the satisfaction data and drought/flood yearly inflow rates. This allowed "verification" of the SCM by testing the subjective perceptions of end users against empirical data (Tang, 1995).

With consideration of the natural flow to the Reservoir and Qinglonghe, a CCGP (chance-constrained GP) model was also applied to yearly and monthly planning for water supply and allocation. However, the end users felt confused by the simultaneous use of the CCGP and SCM models, since they lacked a mechanism for integrating them into a systemic whole to support their management practice. This needed to be addressed.

2.7. Coordinating Relations

Much coordination work was done during QHEMIDSS, even within the research group. For the SCM, some relationships were considered particularly important—e.g., the relationships between academics and engineers, between management functions and models, and between users and modelers.

Through the process of coordination, the reservoir system operating routine was learned step by step, and this resulted in a set of models for water supply and reservoir operation along with the principle for those models' construction, integration, and use (Gu *et al.*, 1993).

In order to build the mechanism to connect the models of reservoir operation and water allocation, and to clarify the interrelation of the CCGP models and the SCM, modelers investigated the water supply working routine with local managers, studied their operating principles and rules, asked for advice from managers for water supply and allocation planning and operations, and taught them how to define constraints for GP (which had been learned by the operator). Then the principles to connect models were set up, as shown in Fig. 6.

The coordinating unit used empirical knowledge to balance the results of GPY and GPMP and to make an initial, feasible diverted-water policy for DPSI (see Fig. 6 for explanations of these abbreviations). The resulting hierarchy conformed to the natural flow through the reservoir and the working standards of

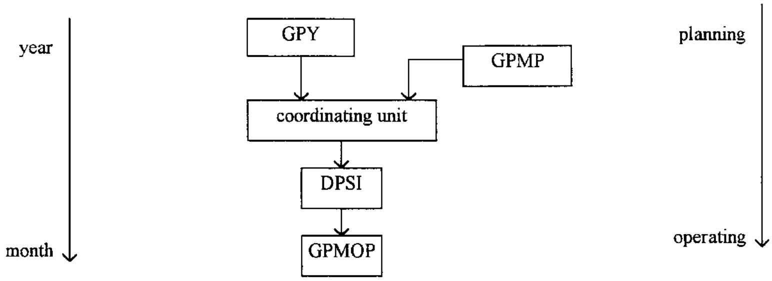

Fig. 6. Hierarchy of modules for Yanghe Reservoir system management. [GPY, yearly planning module (CCGP model); GPMP, monthly planning module (CCGP model); DPSI, reservoir operation module (SCM); GPMOP, monthly operating module (GP model)].

water resources management. With detailed explanation, the end users overcame their initial confusion with the parallel uses of models. Moreover, the original water-diverting policy was also changed by the DPSI so that water was diverted and released before the flood seasons. Regulation is very important to ensure sufficient water on demand. If the water level is high at the start of the flood period, then the excess water needs to be spilled for flood control. The release can be used for hydroelectric energy generation, which is another benefit for the reservoir managers. So diverting more water within set parameters was preferred to saving it, and a practicable policy was developed. The local managers felt satisfied with the results, and indeed use of the SCM within the DPSI increased.

However, there were difficulties with the rainfall–runoff models. Due to local interests, the hydrologic engineers proposed their own Xin-an-jiang model (the researchers' models were viewed as being imposed from "outside"), and the local managers went along with the wishes of their local engineers, despite their respect for the results from the researchers' models. We therefore suggested that all three models be accepted and compared to see which benefited the end users most. In the end, both managers and operators accepted the researcher's models.

2.8. Implementation

During implementation of the computer system, one of the most important tasks was the design of the system interfaces which might affect the running of the system, the users' understanding of the results, and their ability to solve practical problems. Prototypes of interfaces were quickly generated to serve as an interacting or coordinating tool for users and modellers. These prototypes were also used as training tools. The modelers learned about the end users' needs, and the end users studied how to adapt themselves to the new working routines and were simultaneously enabled to express their requirements more clearly. Even the complicated relationships between different modelers were reflected in the design of the interfaces. For example, a choice panel was added just to integrate three rainfall–runoff models with different inputs and outputs into the interface for real-time flood control.

Most interfaces were improved to satisfy users. After repeated training, end-users also gave up some demands that we perceived as unreasonable, having come to understand the inevitable limitations of the technology. Through dialogue, all the interfaces were finally accepted by the end users.

It was found that, even with just one reservoir operating model, several iterations of model selecting, coordination with users, examination of constraints, and modeling were needed. There were many recursive procedures using the seven-step working process within the QHEMIDSS project cycle.

3. THE ADDED VALUE OF *WULI*, *SHILI*, *RENLI* (WSR)

In many ways, this project is fairly typical of a variety of practical applications reported in both Western and Eastern operational research journals, in that it required a sustained focus on a variety of complex issues and the appropriate use of information technology to provide decision support. However, unlike most of the reports of practice in these journals, which focus almost exclusively on mathematical innovations, WSR brings something else into visibility: the importance of human relationships to the success of projects. Certainly, data about the physical world (*wuli*) and the methods used (*shili*) should not be neglected, but (in our view) reporting on these while hiding the dynamics of human relations does a disservice to future generations of systems practitioners, who then have to find out by themselves that relationships with stakeholders in local situations can make or break a project.

Of course, this insight is not new to Western writers on systems practice: indeed, most (if not all) of the papers published in *Systemic Practice and Action Research* take it for granted. However, for a Chinese audience which has remained relatively isolated from debates in the Western systems community [see Midgley and Wilby (2000) in this special issue], it is indeed new. The challenge is to present the insight in a manner that is meaningful to Chinese systems practitioners—hence the birth of WSR.

To reflect for a moment on the intervention we have just reported, we can highlight several aspects that are made visible through WSR but might be neglected, or even be hidden, in a more conventional presentation of Chinese systems practice.

First, there was the constant iteration between dialogue with end users and modeling, which enabled the models and computer support to be designed in a manner that was demonstrably useful to the end users—despite the many difficulties encountered along the way.

Next there was the development of the Satisfaction Criterion Model (SCM), which allowed the quantification of subjective perceptions, and could be verified against empirical data about droughts and floods. While it is not unusual for operational researchers to develop models which represent the perceptions of end users, there tends to be a distrust in contemporary Chinese society of the subjective side of life [see Zhu's (2000) comments on scientism in China in another paper in this special issue]. Chaneling the end users' subjective views into a model gave them a legitimacy that they might not otherwise have enjoyed.

There was also the emphasis on system interface design in the final implementation phase. It was not enough that the system was technically effective; it also had to be understandable and useable by nonexperts.

Then there was the conflict between the researchers and local engineers over which rainfall–runoff model should be used. To many Chinese operational researchers, the local interests which led to the engineers designing their own model would be perceived as irrelevant or, at best, an irritation. However, seeing the project through the "lens" of WSR, we took these interests seriously, realizing that they could have a significant effect on the outcome of the project. By showing our respect for the model produced by the local engineers, they were able to accept that the three models should be the subject of an evaluation. The fact that the researchers' models emerged as the most effective is irrelevant: the comparison was seen as fair by all sides.

Finally, there was an overall emphasis in the project on mutual learning. We could say that WSR provided a "learning-satisfying" process. The modelers learned about unfamiliar water resource management issues. The end users learned about the advantages and limitations of advanced technologies and how to integrate them into (and adapt) their management systems. The users also learned a great deal about systems thinking and practice which they said they found particularly useful (indeed, they began to use the ideas to deal with other problems). For both users and practitioners, there was a committment that learning would not end until a satisfactory result was achieved. Nobody's knowledge and understanding remained unchanged by the process.

4. SUMMARY

This paper has outlined the *wuli*, *shili*, *renli* (WSR) systems approach and reported on its application to a practical project in which computerized decision support was provided for water resources management. WSR provided both the project participants and the researchers with a "learning-satisfying" process, and opportunities to debate, evaluate, compromise, and, finally, achieve some harmony among themselves. This way of seeing systems practice, while common in the West, is relatively new to Chinese practitioners. Hence the need for WSR, which, we argue, makes the human element of systems practice visible in a way which is both philosophically and practically meaningful to a Chinese audience.

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