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FACULTY OF COMPUTER SCIENCE AND AUTOMATION

COMPUTER SCIENCE MEETS AUTOMATION

VOLUME II

- Session 6 - Environmental Systems: Management and Optimisation
- Session 7 - New Methods and Technologies for Medicine and Biology
- Session 8 - Embedded System Design and Application
- Session 9 - Image Processing, Image Analysis and Computer Vision
- Session 10 - Mobile Communications
- Session 11 - Education in Computer Science and Automation

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Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

Professor Peter Scharff
Rector, TU Ilmenau

Professor Christoph Ament
Head of Organisation

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Th. Westerhoff / B. Scharaw

Model based management of the drinking water supply system of city Darkhan in Mongolia

1. Abstract

Within the framework of realizing the German BMBF-program objectives, Mongolia is proposed as a model region (MoMo) for the development, solution and implementation of integrated water resources management (IWRM). The working package 5 (WP) of MoMo project is dealing with the management of drinking water supply system of city Darkhan. The management of the water supply system is considered as three general working steps: modelling of the drinking water supply system (DWSS) calibration of the model and system parameters and management of the daily operating strategies as a decision support system.

Key words

Model region Mongolia, drinking water supply system, pump stations, pipeline network, simulation, management

2. Introduction

The purpose of the water supply plan of Darkhan with a population of around 120,000 inhabitants is to define the development and management policy of the water supply facilities of the city in order to meet the expected requirements until 2020, including those likely to arise from the progressive urbanisation of the *ger* (or yurts) areas. One specificity of city Darkhan is the existence, beside a conventional urban area commonly referred to as *the core area* and equipped with all the facilities of modern cities, of large informal housing areas combining small houses and *ger* (Mongolian name for yurt). These *ger* areas regroup more than one half of the population of Darkhan, mainly the traditional and newly settled families and are not connected to DWSS. The DWSS structure in Darkhan is compared to other cities relatively simple. The tank area is located between the pump field and the city on a hill and the city on the opposite side of this hill is supplied by the tanks without any additional pump in free fall. So the hydraulics calculation time can be reduced by subsumption of all demands in these loops to one sum demand for each loop and so reducing the network structure to a manageable amount of main pipes and hydraulic elements. The operation of inefficient pumps has resulted in some problems, including high electrical expenses and water supply shortages in *ger* areas. In addition, the existing water supply facilities remain in need of repair. Its water supply system consists of 225.3 km pipelines, 3 tanks and 18 well-pumps located one pumping field. The daily water demand is about 28.000 m^3. The average elevation of the nodes is between 670 m and 780 m aSL.

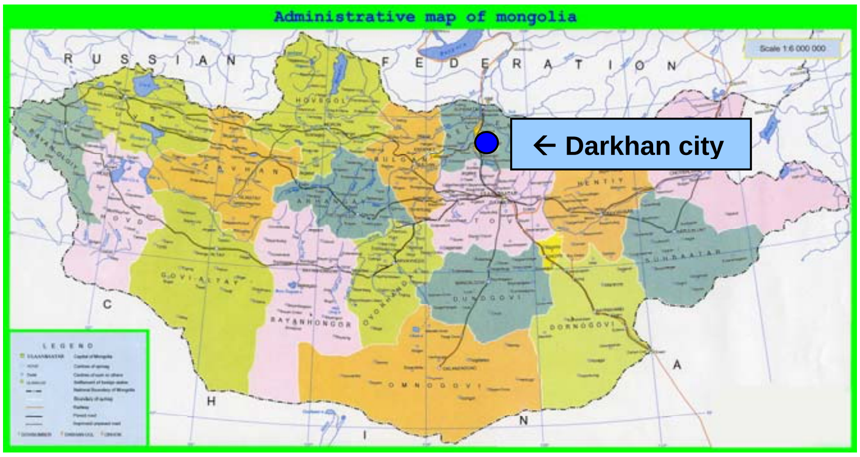

Figure 1: Map to show position of Darkhan city

In DWSS of city Darkhan we have several contrary goals of managing under the extreme climatic conditions of Mongolia. There is the planning for improvement of the technical situation and the expansion of the DWSS for *ger* areas. Therefore, it is desired to reduce the operation costs by optimal planning and operations of DWSS. Other task of WSS in Darkhan is to fulfill the water demand of the consumers. Different approaches have been proposed in the literature for simulation and optimization of DWSS. The software packet EPANET was used by Rossmann L.A. (1994), for simulating water networks and an augmented Lagrangian method was used for solving the NLP problem. Linear programming (LP) was proposed to solve large-scale WSS optimization problems (Diba et al. 1995, Sun et al. 1995). The optimization algorithms have been used for solving the optimal control of DWSS in Berlin (Burgschweiger, J., Gnädig, B. and Steinbach, M.C. (2004)).

3. Problem Formulation

The production and supply of drinking water for basic necessities of life requires a long-term careful approach to the resource water. To fit the permanent growing demands on drinking water quantity and quality, a continuous work of practical orientated research is necessary for further development and application of new methods and their combinations. We consider dynamical management for DWSS with the purpose of planning the reconstruction of DWSS and minimizing its total operating costs. A typical WSS consists of source reservoir, from which water is pumped into pipe networks, of storage tank that floats on the system, of the various components of pumps and valves and of a collection of pipes connected to nodes. The water consumption at the nodes and the initial water level of tanks, the setting and parameters for pumps and valves are needed for the run of simulation. Such DWSS can be modelled by model-based decision support system, which can perform the hydraulic behaviour within pressurized pipe networks, the flow rate with velocity in each pipe, the pressure at each node and the water level in each tank in static and dynamic form under the given system conditions.

3.1 Hydraulic Formulation

The water from pump stations will be transported to consumers through the pipeline network. The operation task is to fulfill water demands and pressure restrictions at specific locations in the network, i.e.

$$Q_{\min l} \le Q_l(t) \le Q_{\max l} \qquad l = 1, \cdots, L \tag{1}$$

$$p_{\min k} \le p_k(t) \le p_{\max k} \qquad k = 1, \cdots, K \tag{2}$$

Decision variables in this problem are the outlet flow rates $Q_i^P(t)$ and pressures $p_i^P(t)$ of the pump stations. The pipeline network may be very large and complex. The formulation of relations between the input variables Q_i^P, p_i^P and output variables Q_l, p_k, leads to a large-scale nonlinear algebraic equation system. A feasible solution to the equation system means to look for proper Q_i^P, p_i^P so that (1) and (2) are satisfied. However, it is not a trivial task to find a feasible solution, since (1) and (2) are multiple constraints with a high dimension.

Let the flow-headloss relation in a pipe between nodes i and j be given as:

$$p_i - p_j = h_{ij} = rQ_{ij}^n + mQ_{ij}^2; \tag{3}$$

where p = nodal head, h = headloss, r = resistance coefficient, Q = flow rate, n = flow exponent, and m = minor loss coefficient.

The second set of equations that must be satisfied is flow continuity around all nodes:

$$\sum_j Q_{ij} - V_i = 0; \tag{4}$$

where V_i is the flow demand at node i and by convention, flow into a node is positive.

For a set of known heads at the fixed grade nodes, we seek a solution for all heads p_i and flows Q_{ij} that satisfy Eqs. (1) and (2).

The Gradient solution method begins with an initial estimate of flows in each pipe that may not necessarily satisfy flow continuity. At each iteration of the method, new nodal heads are found by solving the matrix equation:

$$JH = F \tag{5}$$

where **J** = an (NxN) Jacobian matrix, **H** = an (Nx1) vector of unknown nodal heads, and **F** = an (Nx1) vector of right hand side terms.

The diagonal elements of the Jacobian matrix are:

$$A_{ii} = \sum_j p_{ij} \tag{6}$$

while the non-zero, off-diagonal terms are:

$$A_{ij} = -p_{ij} \tag{7}$$

where p_{ij} is the inverse derivative of the headloss in the link between nodes i and j with respect to flow. Each right hand side term consists of the net flow imbalance at a node plus a flow correction factor:

$$F_i = \left(\sum_j Q_{ij} - V_i \right) + \sum_j y_{ij} + \sum_f p_{if} H_f \tag{8}$$

where the last term applies to any links connecting node i to a fixed grade node j and the flow correction factor y_{ij} is:

$$y_{ij} = p_{ij} \left(r \left| Q_{ij} \right|^2 + m \left| Q_{ij} \right|^2 \right) \operatorname{sgn}(Q_{ij}) \tag{9}$$

After new heads are computed by solving Eq. (5), new flows are found from:

$$Q_{ij} = Q_{ij} - (y_{ij} - p_{ij}(H_i - H_j)) \tag{10}$$

If the sum of absolute flow changes relative to the total flow in all links is larger than some tolerance (e.g., 0.001), then Eqs. (5) and (10) are solved once again. The flow update formula (10) always results in flow continuity around each node after the first iteration.

3.2 Pumping operation

The task of a pump station is to supply a given flow rate with a required pressure to the water network. We consider frequency-controlled pumps in parallel operation in a pump station. The time-dependent operating cost of pump j ($i = 1, \cdots, J$) in station i can be expressed as

$$C_{i,j}^{P}(t)=\left(a_{i,j}+b_{i,j}\,Q_{i,j}^{P}(t)\,\frac{n_{i,j}^{S}}{n_{i,j}(t)}\right)\left(\frac{n_{i,j}(t)}{n_{i,j}^{S}}\right)^{3} \qquad (11)$$

Minimization the total operating costs of the pump station means to search for an optimal selection of pumps and optimal flow rates to be distributed on each individual pump. The total flow will be

$$Q_{i}^{P}(t)=\sum_{j=1}^{J}Q_{i,j}^{P}(t) \qquad (12)$$

The flow rate of a single pump is a function of its pressure drop $\Delta p_{i,j}$ and operating frequency $n_{i,j}$ that can be described as

$$Q_{i,j}^{P}=\frac{n_{i,j}}{n_{i,j}^{S}}\left(\frac{1}{\beta_{i,j}}\left(1-\frac{1}{\alpha_{i,j}}\frac{\Delta p_{i,j}}{\Delta p_{i,j}^{S}}\left(\frac{n_{i,j}^{S}}{n_{i,j}}\right)^{2}\right)\right)^{1/\gamma_{i,j}}Q_{i,j}^{S} \qquad (13)$$

The parameters $\alpha_{i,j},\beta_{i,j},\gamma_{i,j}$ and standard operation values $Q_{i,j}^{S},n_{i,j}^{S},\Delta p_{i,j}^{S}$ in (10) can be obtained from the characteristic lines provided by pump manufacturers. The constraints in the operation of a pump include limitations of its flow rate, pressure drop and motor rotary frequency, i.e.

$$Q_{\min i,j}^{P}\leq Q_{i,j}^{P}(t)\leq Q_{\max i,j}^{P} \qquad (14)$$

$$\Delta p_{\min i,j}\leq \Delta p_{i,j}(t)\leq \Delta p_{\max i,j} \qquad (15)$$

$$n_{\min i,j}\leq n_{i,j}(t)\leq n_{\max i,j} \qquad (16)$$

It should noted that constraint (16) is usually strict, since in practice the operating frequency is desired to be set near its standard value. It means the frequency ratio in (13) is often restricted by

$$u_{\min i,j}\leq \frac{n_{i,j}}{n_{i,j}^{S}}\leq u_{\max i,j} \qquad (17)$$

During operation some pumps may be switched off, due to the varying total flow rate requirement. Thus, the flow rate of a pump should be zero, if it is not selected. To deal with this problem, an integer variable $y_{i,j}\in\{0,1\}$ for each pump has to be introduced ($y_{i,j}=0$ denotes the pump is off and $y_{i,j}=1$ it is on), such that

$$Q_{i,j}^{P}=\frac{n_{i,j}}{n_{i,j}^{S}}\left(\frac{1}{\beta_{i,j}}\left(1-\frac{1}{\alpha_{i,j}}\frac{\Delta p_{i,j}}{\Delta p_{i,j}^{S}}\left(\frac{n_{i,j}^{S}}{n_{i,j}}\right)^{2}\right)\right)^{1/\gamma_{i,j}}Q_{i,j}^{S}\,y_{i,j} \qquad (18)$$

This leads to a problem with (12) and (18) as equality and (14) and (17) inequality constraints. The objective function of this optimization problem is defined as the minimization of the total energy consumption of the pump station during the time period considered

$$\min\ f_{i}=\sum_{t=1}^{24}\sum_{j=1}^{J}\left(a_{i,j}+b_{i,j}\,Q_{i,j}^{P}(t)\,\frac{n_{i,j}^{S}}{n_{i,j}(t)}\right)\left(\frac{n_{i,j}(t)}{n_{i,j}^{S}}\right)^{3}y_{i,j}(t) \qquad (19)$$

where $a_{i,j},b_{i,j}$ are parameters in the correlation of power consumption of a pump. Decision variables are the flow rate and operating frequency of each pump. The pressure drop and total flow of the pump station are defined by solving the optimization problem of the water network. Another important issue to be considered is that frequent on-and-off of pumps sometimes is not allowed. This problem can be addressed by adding extra constraints or a penalty term in the objective function (19).

4 Conclusions

To solve such problems, the model based computer program HydroDyn is developing. HydroDyn allows the calculation of management strategies for pumps and valves while regarding the mechanical parameters, the behaviour of the consumers and the energy costs. Furthermore HydroDyn can be used for tracking the water network status (design of networks, calculation of hydraulic and quality in pressurized pipe networks and distribution system. We will apply the proposed approach to the management of reconstruction planning of the drinking water supply system of Darkhan city and to minimize the operation costs of large-scale water supply networks. Operating policies of water processing plants and pump stations can be developed by the proposed approach.

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