OPTIMIZATION AND MANAGEMENT OF LOCAL AREA WATER SYSTEM (LAWS) CASE STUDY: JORDAN UNIVERSITY CAMPUS

BY

MAHER GHAZI ALOKUSH

SUPERVISOR

Dr. ZAIN EL-ABIDEEN TAHBOUB

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE MASTER'S DEGREE OF SCIENCE IN INDUSTRIAL ENGINEERING / INDUSTRIAL MANAGEMENT

FACULTY OF GRADUATE STUDIES

UNIVERSITY OF JORDAN

MAY, 2005

This thesis (Optimization and Management of Local Area Water System, Case Study: Jordan University Campus) was successfully defended and approved on 30th, May 2005.

Examination Committee	**Signature**
Dr. Zain El-Abideen Tahboub, Chairman Industrial Engineering Department University of Jordan	……………………
Dr. Khaldoun Tahboub, Member Industrial Engineering Department University of Jordan	……………………
Dr. Sulaiman Al-Tarawneh, Member Civil Engineering Department University of Jordan	……………………
Dr. Fawwaz Elkarmi, Member Electrical Engineering Department Amman Al Ahliyya University	……………………

Dedication

This work is dedicated to my father

Acknowledgement

I would like to express my deepest gratitude to my teacher and supervisor Dr. Zain Tahboub for his continuous encouragement, guidance and support during this research. It has been a pleasure working with him.

My thanks go to the maintenance department staff at Jordan University for their help and cooperation.

I would like sincerely to express my great thanks to the members of the examination committee for their constructive, helpful and useful remarks.

Finally, none of this work would have been possible without my wife's patience, encouragement and love.

Table of Contents

MODEL BUILDING AND SOLUTION

DEVELOPMENT OF PROPOSED SCADA SYSTEM

List of Tables

List of Figures

Symbols and Abbreviations

i	: the tank, pump, valve or node number *i*.
t	: the hour number within one day time domain. Assume that One day = 12-hours
$Z_{t,i}$	: variable to indicate total time for pump or valve *i* operation
	: water flow rate for pump or valve *i* while running
K_i	: water flow rate available at supply side or node *i*
S_i	: stored quantity of water at the reservoir *i*
I_i	: incoming water quantity to node *i*
O_i	: outgoing water quantity from node *i*
c	: the cost of regular operation or running of water distribution equipment
p	: the cost of shortage. Usually it should be high penalty
V_i	: water flow rate required at demand point *i*
Y_i	: water shortage quantity at node *i*
h	: Water storage cost per unit per one
r	: Cost per unit to distribute water using University water distribution network
c	: Cost per unit to distribute water using emergency tank (truck) pertinent to the Univ
s	: Cost per unit to distribute water using subcontractor from outside the University
u	: Cost of overhead per one unit of undistributed water
I_o	: Total stored water units at the beginning of an annual distribution program
I_{12}	: The desired total stored water units at the end of an annual distribution
R_t	: Regular water distribution capacity through University water distribution network during month number *t*.
E_t	: Emergency tank (truck) water distribution capacity pertinent to the University during month number *t*.
S_t	: Subcontractor water distribution capacity from outside the University and during month number *t*.
D_t	: Forecasted demand on water during month number *t*.
U	: Total unused capacity of water units
$P_j(t)$	: Pressure at node j at time t
$P_{\max_j}$	: Minimum pressure required at node j
$P_{\min_j}$	: Maximum pressure allowed at node j
$V_k(t)$	: Flow velocity of pipe k at time t
$V_{\max_k}$	: Maximum allowable flow velocity for pipe k
$TV_{\min_k}$	: Minimum water storage volume required at tank k
$TV_k(t)$	: Water storage volume of tank k at time t
$TV_{\max_k}$	: Maximum water storage volume allowed for tank k
TV_k^{final}	: A specified water storage volume of the tank k at the end of an operation period

TV_k^0 : Final water storage volume of the tank k computed for the current trial booster pump & motorized valves operation set
ΔTV_k : Tolerance of the final water storage volume for tank k
SW_k : Number of pump or motorized valve switching for the pump or the motorized valve number k
$SW_{\max_k}$: Maximum number of pump or motorized valve switching for the pump or the motorized valve number k
$S_k(t)$: Control setting of pump or valve number k at time t
ANN : Artificial Neural Network
CASE : Computer Aided Software Engineering
CRT : Cathode Ray Tube
DI : Discrete input
DO : Discrete output
DTE : Data Terminal Equipment
DCE : Date Communication Equipment
FA : Functional Analyses
DN : Nominal pipe diameter
FDS : Functional Design Specifications
FIX : a SCADA software
FRV : Flow Regulating Valve
GENESIS : a SCADA software
GUI : Graphical User Interface
HMI : Human-machine-interface
MMI : Man-machine-interface
HO : Human Operator
JEPCo : Jordan Electricity Power Company
LANs : Local Area Networks
LAWS : Local Area Water System
LCD : Liquid Crystal Display
LEMA : Water service provider at Amman
PM&C : Process Modeling and Control
MLP : Multilayer perceptron
MODBUS ™ : Fieldbus system for data communication interface
MTU : Master Terminal Unit
OOP : Object Oriented Programming
OSI : Open System Interface
P&ID : Pipe and Instrument Diagram
PCU : Process Control Unit
PICA : Power Industry Computer Application conference
PLC : Programmable Logic Controller
ppm : Part per million
PROFIBUS : Fieldbus system for data communication interface
bps : bit per second
Ch : Frequency Channel
RTOdB : Real-time On-line Data Base
RTU : Remote Terminal Unit

RTDB	: Real Time Data Base
SCADA	: Supervisory Control And Data Acquisition
TRC	: Telecommunication Regulatory Commission
UHF	: Ultra-high Frequency
UPS	: Uninterrupted Power Supply
VDU	: Video Display Unit
VCR	: Video Cassette Recorder
CONTROL VIEW	: SCADA software
WAJ	: Water Authority of Jordan
WATERNET	:A pioneer European project for water management
WIZCON	: a SCADA software
S	: Water flow rate coming from the **S**ource
C	: **C**apacity of the distribution network
D	: **D**emanded water flow rate (Quantity **D**emanded)
OR	: Operations research
DG#1	: Distribution Group number 1
DG#2	: Distribution Group number 2
DG#3	: Distribution Group number 3
TORA	: Optimization Software
NeuralWare	: Neural networks simulation software
EPS	: Extended Period Simulation

Optimization and Management of Local Area Water System (LAWS)

By

Maher G. Alokush

Supervisor

Dr. Zain El-Abideen Tahboub

Abstract

This thesis addresses the problem of managing local area water system using Supervisory Control and Data Acquisition (SCADA) technology. Jordan University water distribution network has been adopted as a case study throughout this research. Although properties of local area water networks are very close to regular large scale networks, the dire need for water, in general, and the currently encountered problems in supplying enough water to all University's buildings, make us believe in utilizing an advanced monitoring and control technology that can be harnessed to serve the current small-size water network at the Jordan University. Hopping to make this work as a pilot research for other local area water systems in Jordan.

In order to facilitate the monitoring, control and management of the University water network, a software & hardware system was developed in this thesis to assist in building automated data acquisition network / SCADA system with decision support intelligence. The software manages the data and utilizes it in taking the necessary decisions. Two major types of decisions are addressed, predicting shortage and minimizing operating cost.

The methodology started with collecting a comprehensive data from maintenance department of the University concerning demand on water, evolution of the water network and

encountered operating problems. Then enough information pertinent to the internal water distribution network of the University campus was acquired. The work included the study and diagnosing the water feeding network for each building within the University campus. This led to developing a primary design document, sufficient to know what data must be collected by the proposed SCADA network. A list of signals to be monitored and manipulated was produced then. This includes discrete inputs, discrete outputs, analogue inputs, remote terminal units addresses, server, peripherals and operator interfaces.

Control strategy was set such that water network current status is acquired through a SCADA system, get consumption demand patterns from historical archive system, and finally feed acquired data to an Artificial Neural Network to forecast demand and feed its output to remote terminal units in order to influence the process main control components accordingly, and provide efficient decision support system as a result. Water distribution problem has been presented also using transportation as well as transshipment model as a trial to find optimal / near optimal solution for water distribution routing.

INTRODUCTION

1 Preface

Waterworks enterprise, in general, may be started through the initiative of an individual or a group of persons who focus attention on the need for such a utility. Water systems usually start and grow with a community. The design and construction of a complete water system for an old community or premises is not usual.

Expansion, extension, repairs, maintenance and improvement of existing systems are most common. Water systems are seldom complete, they are continuously wearing out and becoming outgrown. As a result, projects for revising, maintaining, improving management and reducing cost of operating an existing water system will be a continuing activity, Babbitt, Doland & Cleasby (1999).

The water system consists of several parts such as reservoirs, elevated tanks, main & service pipe lines, valves, pumping plant, measuring instruments and others. Since these parts are geographically dispersed over the area to be served, it would be important to monitor/control these parts and optimize their function as a process. Hence, obtain timely information on which to base day-to-day operation, maintenance decisions and operation schedules.

Managing and maintaining water distribution system needs skills in dealing with the system, based on its current situation, and knowledge of all system details. Automated supervisory control and data acquisition (SCADA) system forms a powerful decision supporting tool and process follow up, since it continuously monitors the water distribution network.

Automation, control and instrumentation are closely associated. Recently they represent a trend in management and controlling water systems. Controls may be considered to be devices to aid in the manipulation of the equipment. In addition, methods and devices for transmitting signals to the controlled devices are an integral part of the control system. Water pumping motors may be controlled from a local monitoring and control center through computer. Instrumentation constitutes control devices and controlled devices, indicating, recording and integrating devices and other physical equipment auxiliary to the main purpose of the water utility.

Control instruments can be classified into: primary devices for measuring field parameters such as flow rates, water level, pressure … etc and secondary devices for control, transmission, monitoring, archiving and reporting. Pump controls may, for example, be arranged on the time cycle or programmed cycle involving starting and stopping at some predetermined time schedule pertinent to the demand. Controls may constitute a simple pressure switch on pump discharge line actuated by pressures in the line or a level control in a storage tank which shuts off the pump when the tank is full.

2 Scope of work

The work in the thesis will be demonstrated at the University of Jordan main campus. It will entail designing a system that utilizes computer and communication technologies to automate the monitoring and control of Local Area Water System.

As a case study, the system will be customized to provide periodic reporting of field conditions (local area water system of the University of Jordan) by monitoring signals which represent measurements and/or status conditions at remote field locations of the water supply source and distribution system.

The design shall meet some of the needs of Maintenance & Operation Department in the University, as well as finding a solution and optimizing the problems that the responsible people for water distribution encounter during various seasons and semesters.

3 Problem Definition

The research problem proposed in this thesis is to design a Supervisory Control And Data Acquisition network (SCADA) for management and control of Local Area Water System (LAWS). The design shall entail: Collection / acquisition of required data, processing, algorithms, decision-support & control and performance measurement of the system compared to existing conventional management and control systems.

4 Objectives

The main objective of this proposal is to design a centralized Supervisory Control And Data Acquisition System (SCADA) to manage, optimize and control local area water distribution system. A case study shall be applied at the University of Jordan water supply and distribution system as demonstration of the work. Such a system will provide a real-time database and powerful control device in the hand of the operating team.

5 Assumptions

Throughout this research, the following assumptions shall apply:

1- Upon obtaining enough details about the setout of the available water network inside the University of Jordan, the network shall be simplified such that small-diameter pipes as well as small-capacity tanks are eliminated. Water network topology can then be considered to be either star-structured, tree-structured, cascade structure or mesh-structured upon performing the reduction.

2- Assume the existence of all necessary measuring instruments i.e. flowmeters, pressure transmitters, level transmitters, flow switch, pressure switch … etc wherever not available and ought to be available to have proper control and operation for the SCADA.

3- Radio communication shall be the medium for data exchange between different main sites and the assumed control center. Bearing in mind that the communication system design, calculations and licensing are beyond the scope of this thesis.

4- In case that actual historical records of operation, demand patterns and water consumption amounts were not available / archived by the maintenance department in the University, provisional records of demand patterns were used in order to be able to perform the forecasting and set the process.

6 Importance of the work

Importance of the work becomes prominent when we talk about the need to have detailed information (real-time database) about the status of each component along the water distribution network quickly and precisely e.g. (Water level in different tanks / reservoirs, water flow rate, pressure reading, pumps and valves status).

In our case we are interested in Local Area Water Systems, which are usually similar in principle with other types of water distribution networks, except having smaller overall size and some special requirements depending on served buildings demand.

7 Functions

The basic purpose of any water distribution network is to supply and retain continuous availability of water to the served location / area. Throughout the water distribution network there are a group of functions to be performed manually or automatically. Type and complexity of these function depend on the size of the network, operation constraints, philosophy of operation, supply and demand requirements. Typical example of performed functions is to start and stop an electrical pump based on receiving tank water level e.g. stop the pump if water level becomes high, and start if water level becomes low. Same principle shall apply if the water flow is by gravity toward a receiving reservoir, but operation shall be using manual or motorized valve this time.

If water supply feeds water to the served area continuously, then primitive function similar to the abovementioned example would suffice to grant perfect performance of the water network.

In reality, water supply might operate based on water availability i.e. intermittent water supply, same as we have in Jordan. In this case abovementioned functions might be performed based on other constraints or optimization procedures to grant near-optimal utilization of the distribution network and improve the performance to the best possible degree.

8 The Current System Management

For our case (The University of Jordan local area network), there is an operation & maintenance section. It is responsible for many activities, one of these activities is maintaining and pursuing water distribution issues.

The management has adopted a manual - periodic distribution. Sometimes, services become a function of received water shortage and complains coming daily from different buildings. If distributed water quantity is not enough at one building or there is no water coming through the network, the problem causes need some time to be investigated and this can be done only during University working hours. As an immediate action the maintenance people usually send emergency tank to the concerned building in order to fill its tanks and compensate water shortage. During summer time, contract is set with an external Contractors to supply additional amounts of water and compensate severe shortages.

There is no coordination between LEMA (the water service provider) and the University maintenance & operation team vis-a-vis available water quantities at the source side or duty pumping and distribution schedule.

9 Expected Benefits

The main objective is to show current setout of water distribution network inside the University campus and to find near optimal solution for water distribution problem inside the university as well as to allow enough electronic data exchange between LEMA (water service provider) and the University maintenance & operation team in order to improve the ability to encounter emergency seasons..

The following list shows the main advantages that can be obtained upon affecting the system:

1- Comprehensive monitor and control water network equipment and resources.

2- Collect and share real-time as well as historical data with users on different system levels.

3- Respond faster and more effectively to the water distribution process conditions.

4- Maximize water network effectiveness, improve productivity and satisfaction, reduce cost and waste.

5- Benefit from fully secure system that delivers high level of data integrity.

10 Local Area Water Network

Any water distribution network consists of a group or a number of interconnected pipes, reservoirs, pumps, valves and other hydraulic elements which convey water to demand nodes from the supply area, with specific pressure levels to provide a good service to consumers. The hydraulic elements in a network may be classified into two main categories: active and passive.

The active elements are those which can be operated to control the flow and/or the pressure of water in specific parts of the network such as pumps and valves. The pipes, tanks and reservoirs are passive elements, so far as they receive the effects of the operation of the active elements, in terms of pressure and flow, but they can not be directly manipulated.

Through out our case study we have a lot of active components (that can be manipulated) and passive components as well, we list here small table to show sizes and quantities of such components within our case study:

Table 1: Quantities of main components at University of Jordan local area water system (LAWS)

Component size and type	Total quantity
Distribution reservoir	3
Elevated distribution reservoir	2
Ground reservoir	23
Ground tank array	17
Domestic tank	140
Emergency tanker	4
Big size pump	4
Conveyor pump	51
Manual valve	2
Motorized valve	3
Water meter	3
Level transmitter	67

Please refer to Figures A.3, A.4 and A.5 to have more details about aforementioned components.

We list hereunder a concise table to show and compare different types of water networks based on systems categorization followed by Water Authority of Jordan:

Table 2: Water network categories.

Type of water network	Size or Pipe diameter	Main Components & Operation	Main Problems
National Network	800mm - 1400mm	Wells, Rivers, Springs, Dams to support under ground water table. Huge pumps are used to transfer water. Monitoring of the national network is usually done using National Control Center.	Scarcity / lack of water sources, Aging in pumping equipment, Political reasons.
City Network	300mm - 700mm	Storage reservoirs, big size pumps, water-surge protection system. Control is performed through distributed control centers.	Aging in distribution pipe lines. Intermittent pumping reduces operational life, Coordination and operational problems implies using outside Contractor to manage water distribution operations.
Distribution District	200mm - 300mm	Pressure reducing valves, Air relief valves, Isolation Valves, Chlorination systems, Distribution reservoirs. Control and operation is performed through small control center.	Continuous leakage and waste of nearly 52% of total pumped amounts. Pollution problems due to fresh water pipe lines exposure to waste water.
Local Area Network	51~153mm(2"- 6")	Small size pumps, Altitude valves, Flow-control valves, ground reservoirs and elevated tanks. Control and operation is usually done manually by dedicated team.	Random pumping schedule, shortage of received amount of water specially during summer time, Continuous expansion in the network.
Building Network	19~26mm(3/4"-1")	Float valves, check valves, control valves, booster pump, medium-size tanks. Control is done either manually or by small control circuitry.	Stolen water by some citizens, malfunction of some water meter, Air pocket problems, irregular distribution schedules.
Apartment Network	13~19mm(1/2"-3/4")	Small size mechanical float valves, regular / manual isolation valves, 1~2m^3 tanks. Control is usually manual.	Stolen water by some citizens, malfunction of some water meter, Air pocket problems.

11 Water Network Topologies:

Due to the lack of enough documentation and due to successive contracts for expanding and refurbishment of the water distribution network inside the University campus, it was not possible to plot a precise pipe line diagram and consequently define the water distribution network topology.

However, the topology of any water distribution network can be categorized according to the following main types:

1- Star-structure water network.

2- Tree-structure water network.

3- Cascade-structure water network.

4- Mesh-structured water network.

Please refer to Figure 1 that shows more details about each structure. Mesh topology can be considered as the best since redundancy principle in supplying water is adopted.

As for the university network, it comprises a combination of the aforementioned topologies. In this case study the network topology were simplified to Tree type mainly. Please refer to Figure A.2.

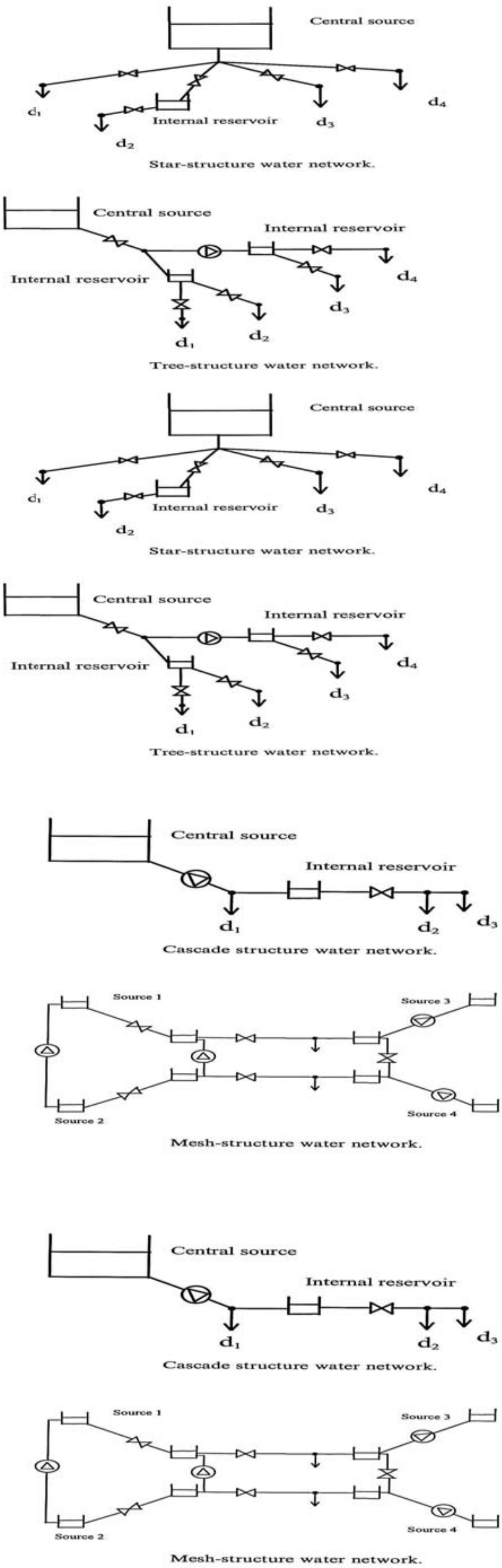


Figure 1 Water network topologies.

12 Overview of the thesis

This thesis falls into six chapters; through this chapter a brief introduction to water distribution networks and local area water systems were presented, the problem was defined as designing a Supervisory Control And Data Acquisition network (SCADA) for management and control of Local Area Water System (LAWS) at the campus of the Jordan University. Chapter 2, discusses exemplary and theoretical background of SCADA systems and their functional analyses, optimization features and how knowledge can be acquired from these systems through the use of machine learning concepts. At the end of the chapter, the importance of the SCADA systems and its participation in integrated maintenance were presented. Chapter 3 presents a trial to tackle the water distribution problem as an OR model, where the control function of the University water network is reduced to three major factors i.e. (water flow rate coming from the source, capacity of the distribution network and demanded water flow rate), for consistency measuring units for the three major factors is set in cubed meters per hour. To describe the relation between these three major factors, we devised four cases to handle the problem. Although exact solution was not possible, a heuristic solution using Gant-charts presentation was used. Chapter 4 deals with the development of the proposed SCADA system, system components and its configuration, in such a way that managing and communication method within the system is divided into four groups. Chapter 5 discussed integrating the SCADA system to an Artificial Neural Network in order to develop a proper decision support system and recognize precise water demand patterns based on the huge a mount of data collected by the SCADA system for prolonged period of time, transportation and transshipment models were also built to simulate the water network. Finally Chapter 6 provides a discussion and conclusions of this research, in addition to providing the interested parties with the recommendations for the future work in the field of managing local area water system using SCADA. Appendix 3 illustrates theoretical background about the SCADA system.

LITERATURE REVIEW

1 Introduction

The pace of change in technology and new systems at the end of the 1990s has been extraordinary. Technologies for design, processing, control, information systems and communication are rapidly converging. There is no way to predict the future, but it is clear that new systems and system features will continue to be developed, Rehg & Kraebber (2005).

By the beginning of the 1960s, remote monitoring and supervisory control of several industrial processes was a developing technology, Boyer (2004).

The technology of controlling and monitoring water systems evolved very quickly during the last four decades due to the expansion of the networks and continuous increase in water demand.

Water networks are generally composed of a large number of interconnected pipes, reservoirs, pumps, valves and other hydraulic elements which convey water to demand nodes from the supply area, with specific pressure levels to provide a good service to consumers. The hydraulic elements in a network may be classified in to two main categories: active and passive. The active elements are those which can be operated to control the flow and/or the pressure of water in specific parts of the network such as pumps and valves. The pipes, tanks and reservoirs are passive elements, so far as they receive the effects of the operation of the active elements, in terms of pressure and flow, but they can not be directly manipulated.

Controlling and monitoring water networks was confined on noticing changes or reading process parameters directly from the field by the operators, and reporting collected data to the operations management. After that, proper decision can be made upon performing suitable calculation, tabulating of collected data and consulting archived records through long time-consuming and groovy process. A primitive electrical control circuitry where introduced at each point that needs continuous monitoring and/or control. For example, an electrical circuit can locally monitor a point/element but was not communicating with other remote circuitry, such that simple pieces of data be gathered from element/equipment located where it was either difficult or impossible to staff observers or operators.

At that time, non-computer systems had central stations and control sites that had grown in complexity; they required up to several thousand relays.

Upon introducing the programmable logic controllers (PLCs) in different fields of industry, monitoring and controlling deferent equipment became more efficient and automating become easier to implement. Much attention has been placed on utility/plants automation as a necessary strategic decision for cost reduction.

“As more and more automated systems are installed, society will feel their effects, and so will industrial engineers. Some of these effects are impossible to predict. Other effects, however can be forecasted with reasonable confidence”, Groover and Hughes (1984).

Paul (1985) indicated that the real problem in implementing automation is not the technical change itself, but the human changes that must accompany technical innovations.

Keim (1985) concluded that making automation a productive experience requires preparation by management through determining the information requirements and prioritizing them from the very beginning. Bellini & Garrett (1992) stated a number of constraints that are peripheral to the technical requirements of any automation project, however, they dictate how the project is to be implemented.

The development in automation led to build more and more sophisticated plants, especially after communication between PLCs become possible.

Another technology called Telemetry (means: tele-metering) was devised.

It is often necessary to locate an indicating instrument at some distance from the point where measurements are taken. When a transmission channel between the sending and receiving point carries other than the basic measurement, the system is called telemetry. Usually such systems use transducers to convert the measurement into a proportional direct current or voltage. In the more sophisticated systems which feed into data systems or computers, the signal from the transducer is converted to digital form before transmission.

In such technology, field instruments installed at the system to be monitored, were able to send signals to dedicated electronic boards or PLCs, and the last communicate with each other and report date to an indication panel or Mimic panel located usually in central control room dedicated to show process readings.

Radio telemetry (radio-based telemetry) then evolved over time by improving the reliability of the radio system, increasing the density of the data that could be transmitted, developing error-detecting and even error-correcting codes, and miniaturizing the equipment.

Consequently, operators become more and more reducing their visits to the field for operation and monitoring purposes.

Radio telemetry continued to be for a long time as a one-way system; data was gathered from the remote site and transmitted toward central location in one way only.

By the mid-1970s, radio became the communications path of choice for most newly installed two-way telemetry systems to fixed location facilities.

At the same time that radio was moving into the ascendancy, another electronic technology was developing - that was digital computer.

Digital computers made their debut in remote monitoring and supervisory control systems in the early 1960s. The increased flexibility they offered was very attractive to the designers of these systems.

2 SCADA Systems

In 1973, SCADA was first shown up in publication in the first PICA (Power Industry Computer Application) conference. SCADA is acronym that is formed from the first letters of the term (Supervisory Control And Data Acquisition). SCADA systems where developed to serve extended plants or utilities, the word telemetry began to fall out of use in describing two-way systems, Boyer (2004). Supervisory control is a technology that enables users to collect data from one or more distant facilities and/or send limited control instructions to these facilities. SCADA makes it unnecessary for an operator to be assigned to stay or frequently visit remote locations, when those remote facilities are operating normally.

The SCADA technology matured slowly during the mid of 1970s. Improvements in software resulted in better human-machine interfaces (HMI). Report writers were developed to provide the information that was wanted when it was wanted.

As was the case with most industrial technologies, the development of powerful minicomputers had a profound effect on the development of SCADA.

In case of water distribution applications, SCADA allows an operator to make set point changes on distant process controllers, to open or close valves or switches, to monitor alarms and to gather measurement information from a location central to a widely distributed process. When the dimensions of the process become very large – hundreds or even thousand of meters from one end to the other – one can appreciate the benefits SCADA offers in term of reducing the cost of routine visits to monitor facilities operation. SCADA can be traced to the development of telemetry and automation from the first half of the century, Boyer (1993).

This is where SCADA is today. It is expected that computer and communications improvements will continue to influence the development of the technology. Local area networks (LANs), which are dedicated high-speed methods for communicating between digital hardware, are the hot communications subject now.

According to Giling & Van (1996), the use of computer has been extended from controlling the greenhouse climate, to the control of water supply. The use of new sensors and the integration of different models into an economically optimal controlled system are one of the first to-introduce object-oriented control techniques.

Nowadays, the graphical user interface (GUI) is a new tool to produce lively animations of both active and passive elements such as piping, buffer tanks, motors and valves. Diagrams pop up at the click of a mouse button and graphs allow the user to scroll through sets of historic data. Supervisory hardware interconnects with hardware for monitoring and control through LAN systems (e.g. Ethernet, Novell etc.) or fieldbus Systems (e.g. MODBUS. BITBUS. PROFIBUS etc.). Standard communication protocols, like the OSI reference model for network facilities, enable an open structure. Commercially available supervisory control and data acquisition (SCADA) software use standardized protocols to enable an open structure of a real time on-line database (RTOdB) for hardware and software of third parties. Examples of commercial SCADA packages in industrial automation are: ONSPEC, FIX-DMACS, FactoryLink, GENESIS, CONTROL VIEW and WIZCON. Most of these packages incorporate tools like computer aided software engineering (CASE), object-oriented programming (OOP), knowledge base techniques, PID, fuzzy and neural network-based control algorithms.

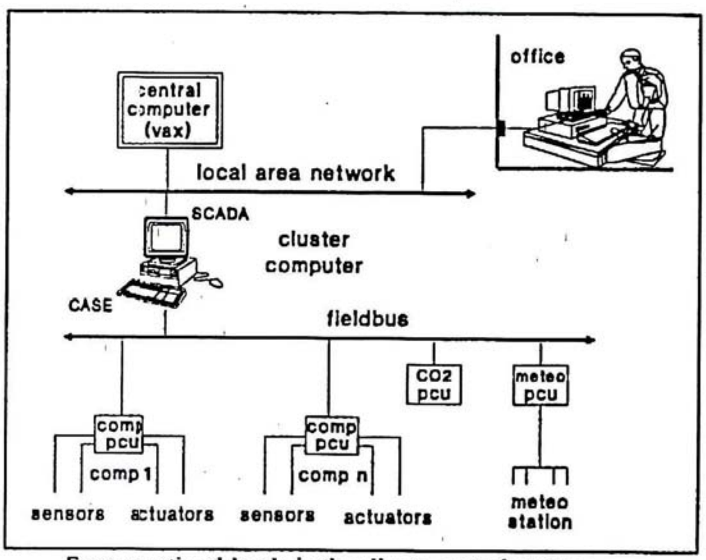
Models are developed and applied on-line with the controlled process: mathematical models to support the control and systems engineer. Measurements are performed and the resulting data are expected to be available on-line with the models and to be stored for off-line data processing. Data can be received from sensors, from manual input, from a knowledge base, from a database or from on-line calculations. Researchers always expect that their programs, processes and data can be monitored from desktop workstations in their own office through a LAN connection. A system comprising all these options is depicted in Figure 2 which shows four levels of operation.

1) A local Process Control Unit (PCU) acquires sensor data and controls actuators. Process control is completely performed at this lowest hierarchical level. All standard control algorithms perform their function at this level. The PCUs are clustered in groups. They are interconnected by means of a fieldbus, headed by their cluster computer as bus master.

2) The cluster computer stores the data of a clustered group of local Process Control Units in its RTOdB. The cluster computer facilitates process control as simply managing setpoint data and controller parameter data in the RTOdB. Control algorithms between cells of the RTOdB perform additional supervisory control actions. A GUI eases operator actions with animated process drawings. diagrams and pictures. Each cluster computer connects to an ethernet LAN.

3) The physical and software layers of the ethernet LAN. They consist of hardware interfaces, a software protocol and at least one server. The LAN interconnects main- frames, desktops, workstations, cluster computers, printers, plotters and hard disks.

4) The researcher/operator at his desk, where a desktop PC or workstation connects to the LAN for program development, changing setpoints, data acquisition and data processing.



Four operational levels in the climate control system

Figure 2 :

Four operational levels in the climate control system

3 SCADA functional analysis

Lambert, Riera & Matel (1998) stated that the supervision of production systems or processes is becoming more and more complex to perform, not only because of the number of variables always more numerous to monitor, but also because of the numerous interrelations existing between them. Some times it becomes very difficult to interpret when the process is highly automated. Because of this, an efficient functional analysis techniques have been devised.

In general, the supervisory operator has a tendency to wait for the alarm to act, instead of trying to foresee or anticipate abnormal states of the system. So, to make operator's work more active, the design of supervisory systems has to be human centered in order to optimize Man-Machine interactions.

To reach this objective, Functional Analysis (FA) seems to be a promising research method. In fact, by allowing the running of the process equipment to be understood, functional analyses will permit designers to determine the good information to display through the supervisory interfaces dedicated to each kind of supervisory task (monitoring, diagnosis, action, etc.)

Supervision consists of commanding a process and supervising its working - in our case study, the process will be: Water Supply Process Control (WSPC). To achieve this goal, the supervisory system - SCADA must collect, supervise and record important sources of data linked to the process, to detect the possible loss of functions and alert the Human Operator (HO). When aiming at the optimization of the criteria linked to production and economy objectives, the human operator must supervise the process states and act in such a way as to maintain it as near as possible to its nominal working point.

According to Rouse (1983), the supervisory operator's tasks are: the control, the follow-up tasks in normal working conditions, the transition tasks linked to the running changes, the default detection tasks, the diagnosis and the resumption tasks of defaults.

According to Moray (1986), a supervisory operator monitors a process when he supervises the displayed information without executing any action which may change the system state. So, the purpose of monitoring tasks is only to update his knowledge about the system state and to detect occurrence of defaults.

So, the supervision of industrial processes includes a set of tasks aimed at controlling a process and supervising its operation. One can notice that monitoring tasks requires a global vision of the process to allow efficient supervision, whereas the diagnosis tasks require a hierarchical vision of the process.

The control consists of acting on the process by means of "orders", as shown in Figure 3 Accordingly, control involves a top-down flow of information which acts on the lower levels. On the contrary, the supervision is a bottom-up flow of information called "information feed-backs" of which source is the signals sent by the process.

Lambert, Riera & Matel (1999) stated that supervisory system works in two different contexts: *off-line* and *on-line.*

3.1 Off-line, the supervisory system allows, in deferred time, some reports to be produced and thus the production performances to be analyzed. In this case, some actions can then be undertaken in order to improve the safety of working (reliability, maintainability, availability and security) of the production equipment. In addition, the archived data linked to the loss of functions are very interesting because they permit, for instance, the preventive maintenance policy to be defined. The supervisory system is therefore useful in all plants because it is an important source of information. In fact, as well as the maintenance, the automation team, and a lot of actors of the plant are interested in this collected information which is centralized in the control room.

3.2 On-line, the supervisory system allows, on the one hand, access to the measurable information relative to the process and, on the other hand, the ability to signal the operator in the occurrence of important events.

At different levels of a process, the nature of tasks is different. At the levels near to the operative part (see Figure 3), data used by machines are numerical (operative or software tasks, for instance). On the contrary, far from the process, at the high levels, data should be more symbolical as it is being used by a human operator. Indeed, this one is at the top of the process and achieves cognitive tasks thanks to the information coming from the process and communicated via the Man-Machine Interfaces (MMI).

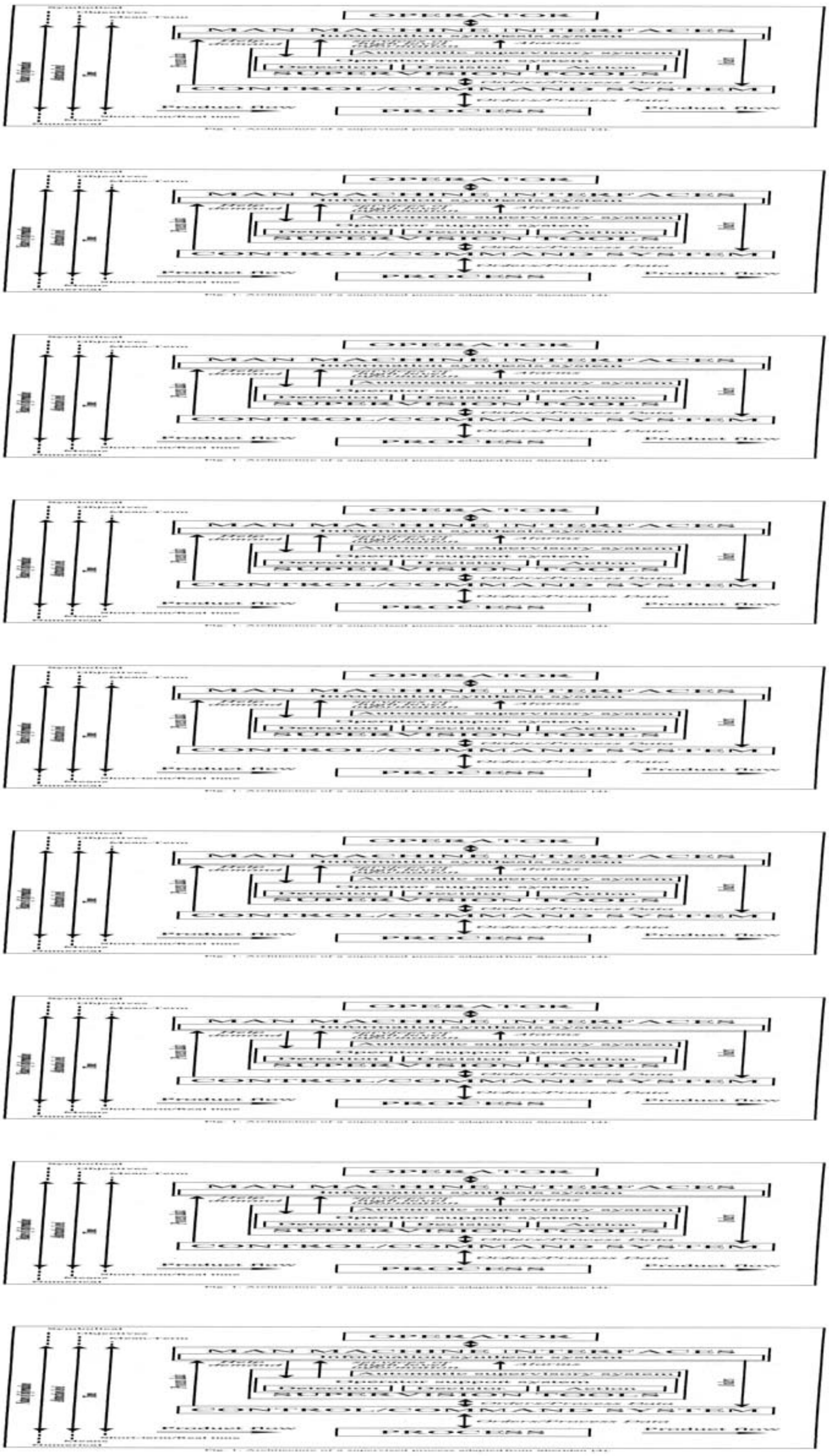


Figure 3:

Architecture of a supervised process.

4 Optimal control for water networks

To talk about optimizing water distribution processes, we first notify that water utility industry has started investigating different types of optimization techniques since 1970s according to Cembrano & Wells (2000). Computer software and systems were used intensively in an effort to reduce operating costs and provide more reliable operations. Supplying drinking water can consume large amounts of electricity, if distribution system does not use gravitational flow. In general energy costs constitute the largest expenditure for nearly all water utilities worldwide and consume up to 65 percent of a water utility's annual operating budget.

One of the greatest potential areas for energy cost saving is the scheduling of daily pump operations. Many techniques for optimal control, scheduling and operation of a local water distribution system were developed. Any proposed technique must determine the best pump scheduling / operation policy for each pump group in the water distribution system whilst satisfying target hydraulic performance requirements and customers satisfaction. The operation policy for a pump station represents a set of temporal rules or guide lines (individual pump operating times or operating schedules) that indicate when a particular pump or group of pumps should be turned On or Off over the control period (one week usually in our case).

Optimization of water distribution process is a very important topic nowadays. Implementing a successful optimization strategy will certainly lead to customer's satisfaction, stable operation, easily maneuvered and controlled system.

In Jordan this issue has an extra importance over other concerns in the local water distribution industry. In one part of this research we are going to study, analyze and find a solution for water distribution problem upon integrating the data from the SCADA network. The solution shall manage practical local area water supply system of the University of Jordan – Amman as a case study.

A lot of candidate decision variables would affect water distribution process. Some of these variables might be the volume of demand on water, available water quantities, capacity of available resource, wasting rates, consumers numbers … etc.

Reduction of chlorination requirement comes second in the optimization task list.

However, minimizing this requirement does not imply reducing water quality criteria. Even if pumping operations are optimized, the new sequence has to ensure that a sufficient chlorine level (0.5 ~ 1.5 ppm) is provided in the treated distributed water. Chlorine is a cost-efficient, easy-to-use disinfectant, effective in killing bacteria and having residual properties far better than those of ozone. But unfortunately, it produces odors that are easily recognized by customers. When solving the problem of operational optimization of the water distribution network, efforts shall be made to find a compromise between sufficient chlorination (to ensure bacteriological quality) and providing the network with water which consumers find pleasant to drink.

Creasey (1988), reviewed the appropriate mathematical techniques to solve the problem of operational optimization for water distribution networks, insisting particularly on the pump-scheduling problem. He concludes that better pump scheduling could save £ 1 0 million (1988) a year to the UK water industry alone.

In Jordan, energy costs are function of the energy usage and the energy rate – energy rate is a function of total consumed amount of monthly kWh. Worldwide, energy rates are normally structured to promote off-peak energy usage with lower rates and penalize peak period energy usage with higher rates. JEPCo shall encourage large water consumers to utilize usage of electrical energy during off-peak time by offering special prices during such periods

Energy-saving measures in water supply and distribution systems can be realized in many ways, from field testing and proper maintenance of equipment to the use of optimal computer control. Energy usage can be reduced by decreasing the volume of water pumps (e.g., adjusting pressure zone boundaries), lowering the head against which it is pumped (e.g., optimizing tank water level range), or reducing the price of energy (e.g., avoiding peak hour pumping and making effective use of storage tanks such as filling them during off-peak periods and draining them during peak periods), and increasing the efficiency of pumps (e.g., insuring that pumps are operating near their best efficiency point).

Utilities can further reduce energy costs by integrating the adopted optimization strategy with an on-line monitoring and control systems, i.e. Supervisory Control And Data Acquisition Systems (SCADA), and by managing their energy consumption more effectively and improving overall operations using optimized pumping operations and reservoir control.

As we mentioned, there have been several attempts in the recent years to develop optimal control algorithms to assist in the operation of complex water distribution systems. The various algorithms where oriented toward determining least-cost pump scheduling policies (proper On – Off pump operation) and where base on the use of linear programming, nonlinear programming, dynamic programming, enumeration techniques, and general heuristics. Examples of application of dynamic programming on small-scale systems can be found in Rao and Bree (1977), Wood and Rayes (1981), Goldberg and Kuo (1987), Coulbeck (1988) and Brdys (1992).

4.1 Limited acceptance of optimal control models:

Unfortunately, the success of these procedures has been very limited and very few have actually been applied to real water distribution systems. The limited acceptance of optimal control models in engineering practice is partly because:

* Such techniques are generally quite complex involving a considerable amount of mathematical sophistication (e.g., requiring extensive expertise in system analyses and careful setting up and fine tuning of parameters).

* They are generally highly dependent upon the number of pumps and storage tanks being considered along with the duration of the operating period.

* They are generally subject to over simplification of the network model and its components along with several simplifying assumptions to accommodate the nonlinear network hydraulics.

* They may be easily trapped at local optima and may not lead to the global optimal solution.

* Large heterogeneity of water distribution networks in terms of control structures, management strategies, and varying geometry with continuous expansion and changes in demand.

Another very important reason for their lack of acceptance and use was the unavailability of suitable and user-friendly pump optimization packages.

As a result most optimal control models developed to date have been mainly used as a research support tool.

4.2 Story of successful models:

Although the work conducted in this field is still at the stage of research, a number of recent European research programs have attempted to produce tools applicable to a variety of water utilities across Europe. The most advanced, WATERNET - European project - aims to demonstrate the benefits of introducing optimization techniques in the water distribution sector. Cembrano et al. (2000), are part of this research program. Their work proves the advantages of optimal control methods on the water distribution network of a Portuguese district. However, although they successfully integrated their model within the existing supervisory control system (SCADA), they were unable to obtain integer strategies for pumping operations, which is the final objective of the WATERNET research program.

As we have a predictive control problem in most of water distribution plants as well as in our case study, it requires therefore the anticipation of a consumer demand profile, which can be obtained from historical data that will be collected by the SCADA system and monitoring of the network. Optimization can be realized in real-time, in the sense that the actual optimized volumes in the reservoirs are fed back before the calculation at the next time-step takes place. Biscos & Mulholland (2003).

5 Machine learning and water distribution networks

Water distribution networks represent a promising application domain for machine learning, Camarinha-Matso & Martinelli (1998). Such networks show a large heterogeneity in terms of control structures, management strategies, and varying geometry with continuous expansion and changes in demand along their life. Due to these characteristics, water distribution companies face the problem of data and knowledge integration related with control and optimal exploitation. In most cases there is no adequate model of the networks in terms of their behavior and, therefore, the control and supervision strategies are based on manual procedures and some heuristic rules.

It is widely recognized that applying standard learning algorithms to real world problems is quite an art. Some of these algorithms are unable to take into account background knowledge and, therefore, it is up to the engineers to perform a set of preparatory actions/transformations on raw data in order to get, for instance, useful rules or decision trees.

5.1 Main difficulties encountered when applying learning techniques:

Learning techniques can be applied to identify water demand profiles along the time or to capture the heuristics and manual procedures used in the operation of new or modified networks. Camarinha-Matso & Martinelli (1998), summarized the main difficulties encountered during applying learning techniques by:

*Identification of potential learning tasks that can lead to useful knowledge from the users point of view, and that are feasible based on the available historical data or data that can be collected in the future;

*Preparation of raw data in order to feed the learning algorithms.

*Assessment of the generated knowledge. A careful assessment of the extracted knowledge is necessary to guarantee that it is adequate and meaningful.

*Integration of the learning system with the supervision systems.

5.2 Water network modeling:

Camarinha-Matso & Martinelli (1998), defined what so called the Multilevel Flow Modeling- methodology (MFM) to represent all functions and goals of complex industrial systems using multiple interconnected levels to represent the physical structure and how stuffs flow inside the system.

Figure 4 shows a part of a station diagram with the identified qualitative relationships. The elements used in this notation have the following meaning:

+ Represents a positive influence;

- Represents a negative influence;

& Represents the logical connective AND;

I Represents the logical connective OR.

Taking the first example, it can be said that:

IF G1 OR G2 decreases AND V5 decreases, then N1 increases.

This notation has another advantage in this application. The station has many variables that could be expressed as a binary value. For example: G1 and G2 represents the situation of a group. They receive values "On" or "Off"; V5 represents the situation of a valve that could be Open or Closed.

Analyzing these equations it is easy to create a causal graph representing the relationships among all studied variables. The causal graph at Figure 5, created from the table shown in Figure 4, can be easily understood, the black circles represent the existence of a causal relationship between variables.

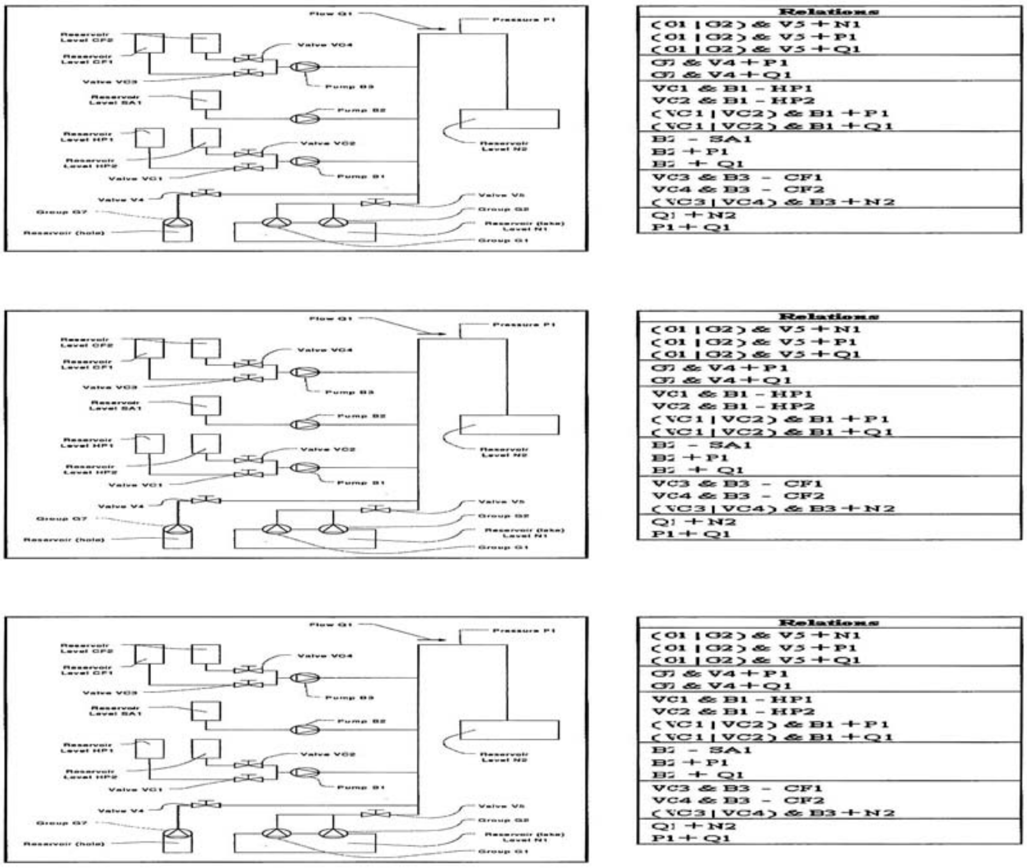


Figure 4:

Part of station diagram and part of the corresponding qualitative model

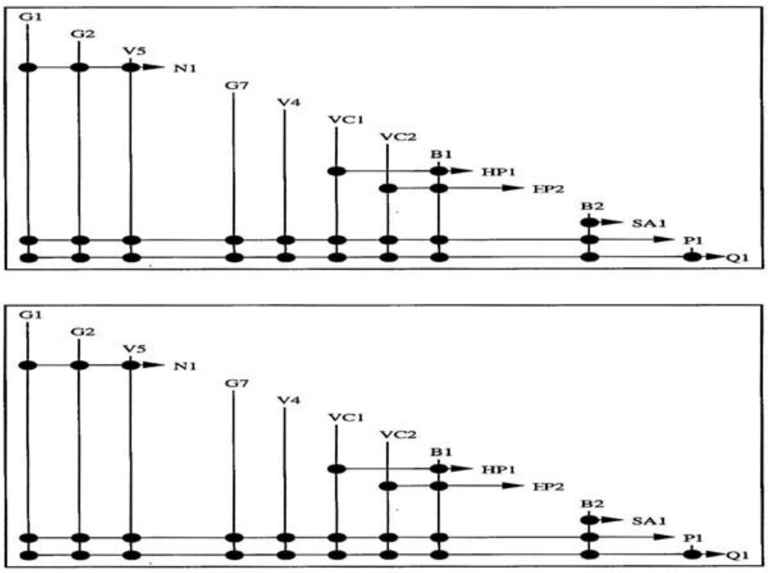


Figure 5:

Causal graph derived from the station described in the above figure

6 SCADA system as an integrated maintenance tool

It is evident that machine and plant maintenance are major cost centers in any water distribution enterprise. The money spent in this area add no direct value to the product or service produced in the enterprise; however, if maintenance is ignored, an efficient and/or successful operation for the enterprise would be impossible!

One of the main objectives of the integrated SCADA system is to enable maintenance programs to be better controlled and resource to be properly utilized. Many maintenance strategies can include the identification of real time and historical data required to measure visualize and quantify the progress of maintenance activities. W. Ip, Lee, Yug & Yam (2000).

Modern maintenance strategies employ many techniques such as corrective maintenance, Blanchard et al (1995); fixed-time maintenance, Jardine (1987); condition-based maintenance, Neale (1985) and improvement maintenance, Harrington (1995).

Recent researchers Blanchard *et al.,* (1995); Smith (1995) considered that the use of condition monitoring techniques and simulation models would add value to current maintenance practices. Priel (1974) has defined the principles of maintenance management as the effective use and coordination of information and resources to achieve the following objectives:

*Ensure equipment availability to meet short term and long term utilization targets.

*Preserve equipment performance to meet output targets.

*Balance the levels of preventive and corrective work to achieve the best possible tradeoff between direct and indirect maintenance costs.

These mentioned techniques can help engineers to predict the moment at which the equipment will fail and plan the required maintenance procedures, McCusker (1995). In real life situations, the inputs of the above maintenance methods have been based on historical data. However, rapid changes in maintenance practices have introduced difficulties in applying the above maintenance strategies (Lee *et al.,* 1997a, 1997b). Therefore, in addition to the existing maintenance strategies for data capturing and analysis, it is important to employ a real-time monitoring system i.e. SCADA system. This approach ensures that historical and real-time data are collected and evaluated continuously.

SCADA is an expert system for real-time monitoring and control, since this system contains two main parts, these being the data capturing devices and the man-machine interface (MMI) or human-machine interface (HMI). According to W. Ip, Lee, Yug & Yam (2000), the integrated maintenance management model which employs SCADA system can be illustrated as shown in Figure 6

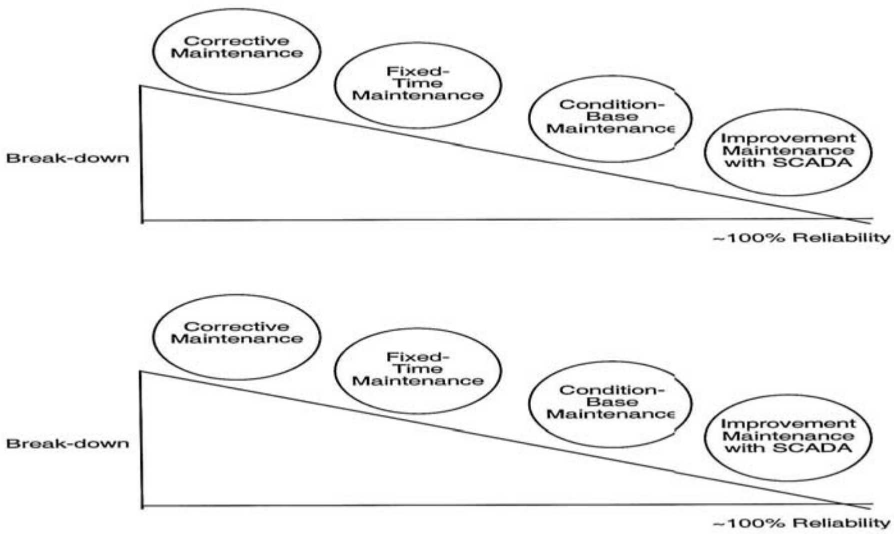


Figure 6:

Maintenance model with SCADA

7 Framework of the research work

Many big water distribution utilities are investing in installing and operating a SCADA system within their facilities to improve the performance of their networks and increase overall control level. As a small water distribution network for the University (Local Area Water Network) LAWS, investment of such type can be justified due to the water shortage problem we are encountering in Jordan in general and due to the lack of effective overall control and follow-up of the current water distribution network conditions inside the University campus.

Although almost every computerization of a system is led by market and technology driven success factors, it is of the most importance to measure to what extent the goals, set prior to the investment decision making stage, are achieved after the SCADA system has been installed. However, many attempts at optimizing water distribution process have been conducted worldwide, but unfortunately, have led to very small successes and few prominent benefits.

The new technologies are extremely complex, and applying such technologies might cause significant changes into the entire work system, and that the new technologies might have ripple effects on each other as well as throughout the entire water distribution plants. But we still believe strongly that adopting and applying such technology to the current university water distribution system will lead to great improvements in the system performance and increase the ability of the maintenance and operation team to manage the network more effectively.

This research examines the process of new technology adoption at local area water networks LAWS, and the decision to automate such small-size networks in particular, from a strategic perspective. In order to deal with complexities involved, enough data was collected about the main buildings within the University campus and how they are fed with water. Collected data are illustrated at special drawings and tables. A SCADA system configuration to deal with these data is set within a proposed master host computer at the water network control center such that an Artificial Neural Network is fed with huge amount of collected data from the field along an extended period of time to come out with a smart solution to manage this water network and have strong decision support system.

MODEL BUILDING AND SOLUTION

1 Introduction

Through this research at water distribution system Jordan University was adopted as a case study for local area water systems; LAWS. The main goal in this chapter is to formulate the water distribution problem and try to find an optimal solution (water distribution schedule) using operations research techniques. In order to have a global view over the candidate decision variables through this problem, please have a look at attached layout drawing Figure A.2. at the appendix.

1.1 Main Components of the Water Distribution System for university campus:

1.1.1 The main water source for the university is from Um El-Shujairat reservoir at the eastern area of the university. The capacity of this reservoir approaches 12000m^3 and feeds public water distribution network by gravity through DN600mm pipe in addition to the university network. The public distribution network consists of several different distribution zones. Each zone has its own manual gate valve which is manipulated by LEMA distribution people and according to prepared schedule based on intermittent water distribution principle. The University receives water from three different feed-points, each belongs to different distribution zone. Through this case study the three different points were named as follows:

* DG#1 - Distribution group number 1 as shown in Figure A.3 at the Appendix. It consists of DN150mm pipeline coming from one of the public distribution zones adjacent to the university computer center building. This pipe line feeds a group of ground reservoirs direct by gravity after passing through motorized control valve as shown in the layout drawing Figure A.2, meanwhile, other branch feeds some higher group of buildings through 5.6kW booster pump. These two branches can be operated one at a time i.e. mutually exclusive running. Average flow from LEMA through group 1 feeding pipeline

follows a certain supply pattern see Figure A.13. At the beginning of this group there is no main reservoir to receive or collect water from the main supply. The water is sent by gravity or through the booster pump into looped water distribution network with maximum flow capacity of $50m^3/h$ governed by flow regulation device (flow control valve) either if the booster pump is running or the motorized valve. This looped network feeds then a group of ground reservoirs with different capacities for each served building. The total capacity for all served ground reservoir in this distribution group sum up to about 2160 m^3, such that the booster pump feeds a total reservoir volume equivalent to 1158 m^3, and the motorized valve feeds a total reservoir volume equivalent to 1002 m^3. Water supply pattern coming from LEMA at the inlet of distribution group#1 follows the same shape shown at Figure A.13 but with the following maximum flow values: 50 m^3/h during Jan up to Apr, 46 m^3/h during May up to Oct and 40 m^3/h during both of Nov. and December.

* DG#2 - Distribution group number 2 as shown in Figure A.4 at the Appendix. It consists of DN150mm pipeline coming from other public distribution zone adjacent to the University Mosque. This pipeline feeds two storage reservoirs connected in parallel with a total capacity of 1600 m^3. Average flow from LEMA through group 2 feeding pipeline follows similar supply pattern shown at Figure A.13 but with the following maximum flow values: 25 m^3/h during Jan up to Apr, 23 m^3/h during May up to Oct and 20 m^3/h during both of November and December. The water is sent by gravity into looped water distribution network with maximum flow capacity of $14m^3/h$ governed by flow regulation device (flow control valve). This looped network feeds then a group of ground reservoirs with different capacities for each served building. The total capacity for all served ground reservoir is about 1082 m^3.

* DG#3 - Distribution group number 3 as shown in Figure A.5 at the Appendix. It

consists of DN70mm pipeline coming from other public distribution zone adjacent to the University Model School. This pipeline feeds two storage reservoirs connected in parallel with a total capacity of 950m^3. Average flow from LEMA through group 3 feeding pipeline follows similar supply pattern shown at Figure A.13 but with the following maximum flow values: 5.5 m^3/h during Jan up to Apr, 5.25 m^3/h during May up to Oct and 4.5 m^3/h during both of November. and December. The water is sent by gravity from one elevated reservoir into looped water distribution network with maximum flow capacity of 5m^3/h governed by flow regulation device (flow control valve). This looped network feeds then a group of domestic tanks above each served building with different capacities. The total capacity for all served domestic tanks along all served buildings is about 220 m^3.

1.1.2 The sizes of the ground reservoirs are shown in Figure A.3, A.4 & A.5, sizes was based on the average number of students per each served building as well as the available area of land plot at the date of constructing the reservoir.

Based on historical data and maintenance / operation teem census, on average 62% of total received water quantity is distributed through the two branches of distribution group#1, 31% through distribution group#2 and only 7% through distribution group#3 this is due to density of consumers, number of students consideration and design requirements at the date of water network design.

Total supplied water amount from Um El-Shujairat toward the University zone can be estimated around 75m^3/h in average. Meanwhile, the maximum distributed water amount at this zone cannot exceed 80m^3/h during the period extending from the beginning of Jan. until the end of Apr. Where as supplied amount drops down to 65m^3/h during November & December. where LEMA follows rigorous water distribution program to adapt with restricted water amounts coming from the main source during this period. Please see Figure A.13.

1.1.3 At the Jordan University local area water system we have the following major parts in the water supply/demand chain:

-Water source from LEMA;

-Booster pump, motorized valves & distribution network with specific flow capacity;

-Ground reservoir, standby tanks & domestic tanks.

We can use the [m^3/h] as a measuring unit of the passing water quantity through any of the above mentioned three major parts of the chain.

Assume that S: water flow rate coming from the **S**ource in [m^3/h]

C: **C**apacity of the distribution network, i.e. maximum flow rate in [m^3/h]

D: Quantity **D**emanded. (**D**emanded water flow rate in [m^3/h])

There are four different cases describing the relation between these three major parts in the water supply/demand chain:

1.1.3.1 **Case I S > C > D**,

and this is the desired case for any water distribution system.

Where, the total supplied / available [m^3/h] of the source is greater than the total [m^3/h] passing capacity of the motorized valves & booster pump, and the capacity of the last is greater than estimated total [m^3/h] demanded in the distribution network. In this case, the estimated demand will govern how many [m^3/h] shall pass through the distribution chain. Hence, motorized valves &booster pump operation can be scheduled easily according to percentage duty cycle less than 100% to cover required demand.

1.1.3.2 **Case II S > C < D**,

Where, the total supplied / available [m^3/h] of the source is greater than the total [m^3/h] passing capacity of the motorized valves & booster pump, and the capacity of the last is less than estimated total [m^3/h] demanded in the distribution network. In this case, the total capacity of the motorized valves & booster pump will govern how many [m^3/h] shall pass through the distribution chain. The solution required to fulfill demand is to replace the small sizes motorized valves & booster pump with larger sizes, but not exceeding the maximum available water source limits. Meanwhile, to adapt with such condition, emergency tank (truck) can be utilized to cover the shortage or even a contract can be set with an external contractor to cover any sever shortage especially during June.

1.1.3.3 **Case III S < C > D**,

Where, the total supplied / available [m^3/h] of the source is less than the total [m^3/h] passing capacity of the motorized valves & booster pump, and the capacity of the last is greater than estimated total [m^3/h] demanded in the distribution network. In this case, the total [m^3/h] available or supplied water source will govern how many [m^3/h], as maximum, shall pass through the distribution chain. The solution of this case comes from seeking for other water supplies to feed the distribution chain. Meanwhile, to adapt with such condition, the motorized valve can be left fully open to allow all the available water quantity - coming from the supply - to pass freely.

1.1.3.4 **Case IV S < C < D**,

Where, the total supplied / available [m^3/h] of the source is less than the total [m^3/h] passing capacity of the motorized valves & booster pump, and the capacity of the last is also less than estimated total [m^3/h] demanded in the distribution network. In this case, firstly, the total [m^3/h] available water source, secondly, the total passing capacity of the motorized valves & booster pump will govern how many [m^3/h], as maximum, shall pass through the distribution chain. The solution for such case is to seek for additional water sources and increase the motorized valves & booster pump sizes to commensurate with the increase resulting from introducing additional water sources.

2 Defining Objective Function

To deal with our case study as an OR problem, we are concerned in finding near-optimal operating schedule for the main water control equipment i.e. motorized valves & booster pump, in such a way that will grant maximal availability of water at the inlet of ground reservoirs of the served buildings. This goal can be achieved by minimizing the total time of shortage along any water distribution cycle. Other goal - although it contradicts the above goal - might be to minimize the total cost of consumed energy as found usually in worldwide applications. Of course due to the fixed tariff of (kWh) price for the University, we shall be concerned with achieving maximal availability of water to the served building and reduce customer inconvenience. i.e. to find a set of time-dependent control rules that indicate when a particular group of valves should be turned On or Off over a specified period of time. The last sentence applies only when the available m^3/h, at water source exceeds or equal to the capacity of the motorized valves & booster pump at least, and most importantly that the expected demand pattern is less than the last two components.

3 Defining Decision Variables & Constraints

A lot of variables compete to be considered as decision variables in building the optimization model. Upon several visits to University water network and talking to the operating crew, we end up with the following findings:

3.3.1 Cost of Electrical Energy:

Jordan Electric Power Company JEPCo has set constant tariff for monthly consumption of electric power for different sectors in Jordan.

It is set to be 0.038 JD/kWh for the University. This tariff is fixed all the time, day and night almost at any consumption amount. Consequently, scheduling the pumping & distribution process during nighttime or away from the peak hours does not make a difference pertaining energy rate/tariff. But as mentioned above, attention should be given to the booster pump & motorized valves operation time periods as well as how many valve to operate along selected time domain.

The concept of optimizing water distribution network based on minimizing costs subject to known constraints does not compare well to real studies as water distribution networks actually involve many tradeoffs between multiple objectives.

3.2 Unscheduled System Stoppage / Failure:

Some times, especially at summer time and peak hours, the University might encounter partial cease in power supply due to external reasons and electrical grid loading. Also some of the motorized valves or the booster pump might stick or is overloaded due to different reasons. Unscheduled stoppage or failure rate cannot be considered as decision variable since it is random and persists for rationally short period of time. Fortunately, stored water in the ground reservoirs and LEMA's reservoir can overcome such short delay or stoppage in distribution.

3.3 Waste Rate:

According to the operating crew and their estimates pertaining waste rate in different old water distribution networks, the following mathematical compensation factors will be considered to have constant role in our OR model affecting the demand portion along the time: Mathematically, and based on the information obtained from the maintenance and operation team in the University, the scheduled pumping periods in case of low dissipation rate networks (Distribution Group#1) will be extended by multiplying the obtained results by 1.05 compensation factor. As for the old networks with high dissipation rates, the extend scheduled distribution periods, in case of (Distribution Group#2), are multiplied by 1.1.

3.4 Distribution Area with Special Requirement:

Under any condition, water stoppage must not extend more than 24 hours during maximum demand periods i.e. May & June for group#3 region. This strict constraint is due to the critical need for water supply demanded by the residency and a lot of other vital premises.

3.5 Water Supply Constraints:

Based on Water Authority of Jordan WAJ and LEMA records, average monthly available water quantity to serve the University were summarized as shown in Figure A.13.

3.6 Water Demand Constraints:

Based on the University operating and maintenance team and their previous records, we summarized average monthly consumption of water as shown in Figure A.14.

As we have the three distribution groups being fed and undergo the same shape of demand pattern shown in Figure A.14 – except during February and September where the proportion does not apply during vacations time – we show here in table 1a, listing demanded values in m^3/h for each group consequently:

Table 1a:

Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
40.3	4.2	43.4	43.4	46.5	49.6	40.3	40.3	4.2	43.4	43.4	40.3
20.1	2.1	21.7	21.7	23.2	24.8	20.1	20.1	2.1	21.7	21.7	20.1
4.5	3.7	4.9	4.9	5.2	5.6	4.5	4.5	3.7	4.9	4.9	4.5

Since Booster pump and Motorized valve can not be operated in the same time to avoid pressure drop and consequent disturbances, the first raw of table 1a shall be divided to the following sums as per table 1b – representing demand at booster pump network and motorized valve network:

Table 1b

Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
20.15	2.1	21.7	21.7	23.25	24.8	20.15	20.15	2.1	21.7	21.7	20.15
20.15	2.1	21.7	21.7	23.25	24.8	20.15	20.15	2.1	21.7	21.7	20.15

4 Assumptions

Through this research the following conditions are assumed:

1- Fill-up time:

Through Figure A.7.1 - bar-chart #1 up to #4, all bars with black color represent continuous pumping and/or distribution with constant flow that cannot be interrupted except in case of emergency, where the schedule activities will be shifted according to the length of interruption period.

As for bars with gray color, they represent the fill-up time of the concerned reservoir, at the beginning of the gray bar, physically, the conveyor motor that match reservoir to the domestic tanks is stopped. But pumping and/or flow distribution persists until the reservoir is filled. This fill-up time is assumed to be 43, 77 & 44 hours for each of distribution group 1, 2 & 3 consequently. Although fill-up time might be less than these amounts in reality.

2- Water portions:

As mentioned before, portions of total available water amount must be distributed all the time as follows: 62%, 31% & 7% for each of distribution group 1, 2 & 3 consequently. Although consumption in reality might be more or less than these average ratios.

3- Practical operating parameters:

System constraints such as the maximum and minimum allowable junction node pressure, maximum pipe velocity*area (flow) where not considered. Further, we assumed that pump and line efficiencies persist ideal all the time.

5 Solution methodology

As we have the demand patterns and average available quantities of water supply based on monthly estimates, we will tackle the problem solution month by month but still under the main four categories that govern relation between Water Source, booster pump & motorized valves Capacity and Demand at ground reservoirs as discussed previously.

5.1 Solution for Case I:

Where S>C>D, the total available [m^3/h] of the source is greater than the total [m^3/h] capacity of the booster pump & motorized valves, and the capacity of the last is greater than estimated total [m^3/h] demanded in the ground reservoirs.

According to Figure A.13, Figure A.2 and Figure A.14 details, we conclude that this case applies during the months of January, February, July, August and September. In this case, the estimated demand represents the bottle nick of the distribution chain, consequently, it will govern how many [m^3/h] shall pass through the distribution chain. Hence, booster pump & motorized valves running can be scheduled easily to cover estimated demand. This can be shown through Bar-chart No. 1 at Figure A.7.1, where the duty cycle of the booster pump & motorized valves are modulated to reflect the percentages:

Ratio = [(expected demand at month *i*)/(nominal booster pump & motorized valves capacity)]*100%

Ratio = (D/C)*100% , S>C>D

through scheduling process, the fill-up times was considered and On/Off switching times were distributed to minimize the no pumping and/or distribution periods through any cycle.

This intermittent pumping or water distribution arrangement can guarantee almost continuous availability of water supply to the ground reservoirs due to the short periods of stoppage between the cycles.

Although it was possible to schedule cycles to operate the booster pump & motorized valves continuously to a specific percentage of the total week hours i.e. (62%*168Hours) On and the rest Off, but this will cause long period of water cease even though it will satisfy the required duty cycle theoretically.

5.2 Solution for Case II:

Where S>C<D, the total available [m^3/h] of the source is greater than the total [m^3/h] capacity of the booster pump & motorized valves, and the capacity of the last is less than estimated total [m^3/h] demanded & by the ground reservoir. According to Figure A.13, Figure A.2 and Figure A.14 details, we conclude that this case might apply during Mar., Apr., May, Jun. And Oct. In this case, the total capacity of the booster pump & motorized valves will govern how many [m^3/h] shall pass through the distribution chain.

The solution for such case – if the option of replacing small sizes booster pump & motorized valves by larger sizes is not possible – is to run all the booster pump & motorized valves continuously around the hour, and this might cover good percentage of the demand during this period of the year.

Such case can be shown through Bar-chart # 2 – Figure A.7.1, where distribution group 2 & 3 are operated on full duty, whilst distribution group 1 pay the price of this compromising due to the unavailability of storage reservoir as per other distribution groups. This shortage can be noted prominently during stoppage of LEMA supply where the served building might suffer water shortage.

The disadvantage of this adopted solution is the continuous running of the control equipment, which causes high failure rate possibility and might need continuous availability of maintenance people around the hour.

5.3 Solution for Case III:

Where S<C>D, the total available [m^3/h] of the source is less than the total [m^3/h] capacity of the booster pump & motorized valves, and the capacity of the last is greater than estimated total [m^3/h] demanded in the distribution network & ground reservoirs

According to Figure A.13, Figure A.2 and Figure A.14 details, we conclude that this case applies only during December.

For December specifically, solution mentioned through Bar-chart # 1 applies as the duty cycle of the booster pump & motorized valves is modulated to reflect the 94% ratio i.e.: ratio= [(expected demand during December)/(nominal booster pump & motorized valves capacity i.e. 69 m^3/h)]*100%

= (DDcecember/C69)*100% , S<C>D

(65/69)*100% = 94%

this result cannot be applied since the available amount of water at the source side is less than the capacity of the motorized valve / booster pump. Therefore, practical solution would be to keep the motorized valves / booster pump continuously opened i.e. 100% duty cycle, this is to pass all the available amount of water from source side.

Through scheduling process, the fill-up time was considered and On – Off switching times were distributed to minimize the no pumping or no distribution periods during any cycle.

As for November and December, the total [m^3/h] available water source during this couple of months will govern how many [m^3/h], as maximum, shall pass through the distribution chain. This can be shown through Bar-chart # 3 – Figure A.7.1, through this two charts we adopted a combinatorial/ heuristic solution to schedule the water pumping process, bearing in mind that the main objective is to minimize the total length of stoppage periods subject to satisfying the applicable constraints during that period of time such as avoiding operating both of Group#1 booster pump and motorized valve during peak-hours at June, avoid stoppage of water pumping toward distribution group 3 for more than 24 hours in any case and minimize the number of starting and stopping of the booster pump & motorized valves.

5.4 Solution for Case IV:

Where S<C<D, the total available [m^3/h] of the source is less than the total [m^3/h] capacity of the booster pump & motorized valves, and the capacity of the last is also less than estimated total [m^3/h] demanded in the distribution network & ground reservoir.

According to Figure A.13, Figure A.2 and Figure A.14 details, we conclude that this case might apply during Nov. only. In this case, firstly, {the total [m^3/h] available water source}, secondly {the total capacity of the booster pump & motorized valves} will govern how many [m^3/h], as maximum, shall pass through the distribution chain.

This can be shown through both of Bar-chart #3 and #4 – Figure A.7.1. In this two charts we also adopted a combinatorial/ heuristic solution to schedule the water pumping and distribution process, bearing in mind that the main objective is to minimize the total length of stoppage periods subject to satisfying the applicable constraints during that period of time such as avoid stoppage of water pumping toward distribution group 3 for more than 24 hours in any case and minimize the number of starting and stopping of the booster pump & motorized valves. But at the end we will suffer some water shortage as the demand is greater than both of the supply and the capacity of distribution network. Therefore, to contract with an external supplier to compensate shortage would be a practical solution.

6 Network Maximal Flow Test:

Consider the main three groups layout for the University water distribution network, Figure A.2 at the appendix, during normal running conditions water is distributed to the destination points through pipe line network matching the feeding points to the destination points through intermediate reservoirs. Each pipe segment has a finite maximum rate of water flow (or capacity).

Since the operation and maintenance department posses four emergency trucks dedicated for distributing water from abundance points to shortage points within the university campus, some pipe segments or connection arcs between the different nodes might be unidirectional or bi-directional, depending on its design and whether emergency truck is allowed to transfer water from and to a certain node. Table 3 below demonstrate a typical flow matrix that represent all possible water transfer routing based on m^3/h as a transfer unit:

	Source	DG1	DG2	DG3	SC	2T1	3T1	1GR1	1GR2	2GR1	3GR1	Sink
Source		47	23	5	5	0	0	0	0	0	0	0
DG1	0		0	0	0	3	3	25	25	3	3	0
DG2	0	0		0	0	20	3	3	3	3	3	0
DG3	0	0	0		0	3	4.5	3	3	3	3	0
SC	0	0	0	0		5	5	5	5	5	5	0
2T1	0	0	0	0	0		3	3	3	14	3	0
3T1	0	0	0	0	0	3		3	3	3	5	0
1GR1	0	0	0	0	0	3	3		3	3	3	25
1GR2	0	0	0	0	0	3	3	3		3	3	25
2GR1	0	0	0	0	0	3	3	3	3		3	25
3GR1	0	0	0	0	0	3	3	3	3	3		5
Sink	0	0	0	0	0	0	0	0	0	0	0	

Table 3: Water flow matrix inside the University campus

Upon feeding the contents of the above table to the maximal flow calculator within the TORA program, the maximum capacity of the network between dummy Source point / feed points (DG#1,2,3 and the SC) and the consumer points (1GR1, 1GR2, 2GR1 and 3GR1) / dummy Sink point turned out to be 80 m^3/h, this outcome was shown after twenty iterations, please refer to Table A.5 at the appendix to review the outcome of the capacitated water distribution network as well as the pertinent maximum flow drawing at Figure A.20

As the average water demand rate might reach 49.6 m^3/h at first distribution group and 24.8 m^3/h at second distribution group during some seasons, we conclude that the current water network capacity can withstand water demand rate and might not need more expansion to accommodate the excessive water demand during summer time. Consequently, an OR solution for this network problem shall be possible theoretically with out the need for expansion or redesign for the water network capacity.

7 Problem Formulation

7.1 Special Constraints:

To grant maximal availability of water at the inlet of ground reservoirs of the served buildings while conveyor pumps are switched off, the objective function shall be to minimize the total number of shortage cubed meters as well as to minimize the running cost for each distribution group motorized valve and booster pump along every distribution cycle. Considering the following notation & Figure 7:

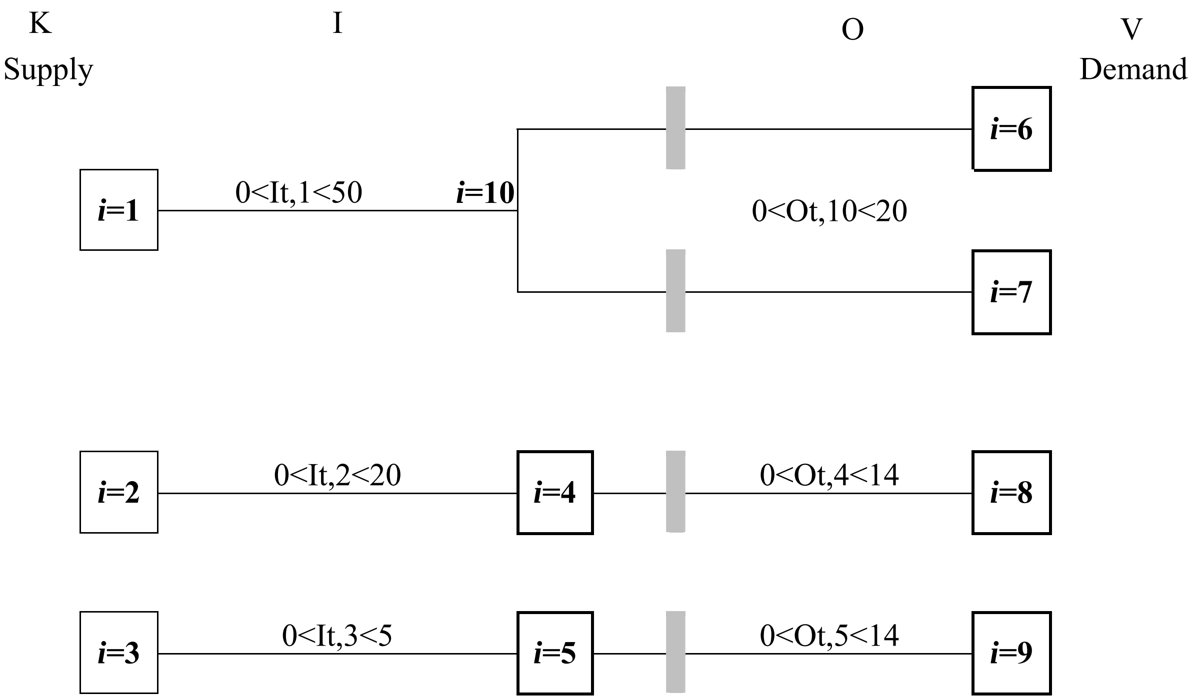


Figure 7: Key map for problem formulation

Notation:

Assume i as the tank, pump, valve or node number *i*.

t as the hour number with in one day time domain. Assume that One day = 12-h

$Z_{t,i}$ as variable to indicate total time for pump or valve *i* operation

L_i as water flow rate for pump or valve *i* while running

K_i as water flow rate available at supply side or node *i*

S_i as stored quantity of water at the reservoir *i*

I_i as incoming water quantity to node *i*

O_i as outgoing water quantity from node *i*

c as the cost of regular operation or running of water distribution equipment

p as the cost of shortage. Usually it should be high penalty

V_i as water flow rate required at demand point *i*

Y_i as water shortage quantity at node *i*

Objective function shall be:

$$\min\left(\sum_{t=1}^{12} cZ_{t,i} + \sum_{t=1}^{12} pY_{t,i}\right)\text{......... ....,}\quad i = 4,5,6,7,8,9$$

Subject to:

* Water consumption law at in the middle reservoirs

$$I_{t,i} + S_{t-1,i} \geq O_{t,i} + S_{t,i}\text{.......... ....}\forall t, i = 4,5,10$$

* Water flow or pumping consumption law

$$O_{t,i} = L_i Z_{t,i}\text{.......... ....}\forall t, i = 4,5,10$$

* Water inlets consumption law

$$0 \leq \sum_{i=1}^{3} I_{t,i} \leq \sum_{i=1}^{3} K_{t,i}\text{.......... .....}\ \forall\ t$$

* Water outlets consumption law and shortage value

$$Y_{t,i} = [(V_{t,i} + S_{t,i}) - (O_{t,i} + S_{t-1,i})] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \forall t, i = 6,7,8,9$$

* Pump or valve operating law

$$0 \leq Z_{t,i} \leq 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \forall t, i = 4,5,10$$

* Law to prevent the possibility of water storage at some nodes

$$S_{t,i} = 0 \ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots .\forall t, i = 1,2,3,10$$

* Water consumption law at the discharge manifold and in accordance with passage capacity of the concerned pump or valve

$$0 \leq \sum_{t=1}^{12} O_{t,10} \leq 240$$

$$0 \leq \sum_{t=1}^{12} O_{t,4} \leq 168$$

$$0 \leq \sum_{t=1}^{12} O_{t,5} \leq 60$$

* Water consumption law at the influent manifold and in accordance with passage capacity of the concerned pipe

$$0 \leq \sum_{t=1}^{12} I_{t,1} \leq 600$$

$$0 \leq \sum_{t=1}^{12} I_{t,2} \leq 240$$

$$0 \leq \sum_{t=1}^{12} I_{t,3} \leq 60$$

* Water storage consumption law for each reservoir node

$$0 \leq S_{t,i} \leq 1600 \ldots\ldots\ldots\ldots \forall t, i = 4$$

$$0 \leq S_{t,i} \leq 950 \ldots\ldots\ldots\ldots \forall t, i = 5$$

$$0 \leq S_{t,i} \leq 1158 \ldots\ldots\ldots\ldots \forall t, i = 6$$

$$0 \le S_{t,i} \le 1002 \ldots\ldots\ldots\ldots\ldots \forall t, i = 7$$

$$0 \le S_{t,i} \le 1082 \ldots\ldots\ldots\ldots\ldots \forall t, i = 8$$

$$0 \le S_{t,i} \le 220 \ldots\ldots\ldots\ldots\ldots \forall t, i = 9$$

* Defining supply flaw law. The defined value can be adjusted based on the prevailing supply pattern

$$0 \le K_{t,1} \le 50 \ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots \forall t$$

$$0 \le K_{t,2} \le 20 \ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots \forall t$$

$$0 \le K_{t,3} \le 10 \ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots \forall t$$

* Defining demand flaw law. The defined value can be adjusted based on the prevailing demand pattern

$$0 \le V_{t,6} \le 25 \ldots\ldots\ldots\ldots\ldots\ldots \forall t$$

$$0 \le V_{t,7} \le 25 \ldots\ldots\ldots\ldots\ldots\ldots \forall t$$

$$0 \le V_{t,8} \le 20 \ldots\ldots\ldots\ldots\ldots\ldots \forall t$$

$$0 \le V_{t,9} \le 5 \ldots\ldots\ldots\ldots\ldots\ldots \forall t$$

Based on aforementioned setout the OR problem counted 440 different variables related with 220 constraints. Feeding the objective function and the related different constraints to the TORA optimization software was not possible.

In real life, we have much more other hetero-constraints that might not be integrated easily to the objective function and its related constraints, please have a look at the following examples as a formulation/modeling for real life general constraints:

7.2 General Constraints:

Real network constraints on the optimization problem represent system performance criteria and may include constraints on junction node pressure (*P*), pipe velocity (*V*), tank water level (*TL*) and booster pump or motorized valves operation switching for a given network loading condition.

7.2.1 Node Constraints:

For each operational time interval, the pressure at any junction node *J* may vary between a maximum value and minimum value. This can be expressed as:

$$P_{\min_j} \le P_j(t) \le P_{\max_j} \text{.......................................} \forall j, \forall t$$

where $P_j(t)$ represents the pressure at node *j* at time *t*; $P_{\min_j}$ is the minimum pressure required at node *j*; and $P_{\max_j}$ is the maximum pressure allowed at node *j*.

*7.2.2 Pipe (Velocity*Area) Constraints:*

The velocity*area (flow rate) associated with any pipe *k* during time interval *t* may be constrained by a maximum value expressed as:

$$V_k(t) \le V_{\max_k} \text{...} \forall k, \forall t$$

where $V_k(t)$ is the flow velocity of pipe *k* at time *t* and $V_{\max_k}$ represents the maximum allowable flow velocity for pipe *k*.

7.2.3 Tank Constraints:

A storage tank in a water distribution system must also be operated within a minimum and maximum allowable water level what so ever was the command from the scheduling algorithm. The bounds on the tank water levels can be expressed as:

$$TV_{\min_k} \le TV_k(t) \le TV_{\max_k} \text{...} \forall k, \forall t$$

where $TV_{\min_k}$ represents the minimum water storage volume required at tank *k*; $TV_k(t)$ is the water storage volume of tank *k* at time *t*; and $TV_{\max_k}$ denotes the maximum water storage volume allowed at tank *k*. To ensure hydraulic periodicity for the next operating period, the tanks must be refilled to a prescribed storage volume at the end of a scheduling period (resulting in tank trajectories that begin and end at specified target elevations), given as:

$$\left|TV_k^{final} - TV_k^0\right| \le \Delta TV_k \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \forall k$$

where TV_k^{final} designates a specified water storage volume of the tank *k* at the end of an operation period; TV_k^0 is the final water storage volume of the tank *k* computed for the current trial booster pump & motorized valves operation set; and ΔTV_k denotes the tolerance of the final water storage volume for tank *k*. In most cases, the beginning and ending tank water levels should be the same.

7.2.4 Booster Pump and or Motorized Valves Switching Constraints:

Energy cost may be reduced by turning a pump or a motorized valve On and Off many times during a control period. However, the more frequent a pump or valve switches On and Off the greater the resulting maintenance cost due to increasing wear on the device. The number of device switching can be used as a surrogate variable for measuring the device maintenance cost. To restrict the device-wear-off cost to an acceptable level, the number of pump or valve switching must be less than a maximum allowable value, given as:

$$SW_k \le SW_{\max_k} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \forall k$$

where SW_k represents the number of pump or motorized valve switching for the pump or the motorized valve number k while $SW_{\max_k}$ designates the maximum number of pump or motorized valve switching for the pump or the motorized valve number *k*.

7.2.5 Booster Pump and or Motorized Valve Control Setting Values:

For each pump or motorized valve groups, the device control setting is either On or Off at a specific time t, given as:

$$\forall k, \forall t, \forall S_k(t) \in S^0 = \{1,0\}$$

where $S_k(t)$ designates the control setting of pump or valve number k at time t and takes a value of either 1 (device ON/OPEN) or 0 (device OFF/CLOSE).

8 Solution Bar charts

As a heuristic solution for water distribution model inside the University campus, please refer to the operation bar-charts shown through Figure A.7.1 at the Appendix I.

9 Concluding remarks

Many optimal control models for water distribution processes have been devised and developed. Although, the success of these models were very limited and very few have actually been applied to real water distribution systems, since a lot of practical constraints and engineering practices basics have been neglected, simplified or assumed to take a constant ideal values during running such optimization problem.

At the end of this chapter, bar-chart heuristic solution was adopted for determining near optimal booster pump & motorized valves operation policies that will best meet expected demands and target hydraulic performance requirements of the water distribution system for a given time horizon (normally 1 week). This solution is then utilized to produce an improved booster pump & motorized valves schedule that automatically satisfies the explicit variable constraints and that seeks to minimize the objective function in an iterative process repeated until the best solution is found.

The adopted heuristic approach were designed to assist water distribution system operators in selecting and scheduling efficient and cost-effective pump & distribution combinations to plan and operate better system, while maintaining satisfactory levels of service in producing the best possible distribution schedules with a minimum effort and at a significant cost-savings.

The plotted schedules/results have to be tested at University water distribution system to test their performance in alleviating interruptions and random water transportation process, which take place currently.

DEVELOPMENT OF PROPOSED SCADA SYSTEM

1 Methodology

The adopted methodology throughout this research was as follows:

Step 1 - Conducting literature review

Many references have been consulted in order to have a holistic treatment for the different extended topics that overlap with the main research title. The following fields were found to be useful:

Water networks	*[2],[3],[8],[6],[8],[9]*
Sustainable Water Resources Management	*[8],[6],[22]*
Rehabilitation of Water Distribution Systems	*[2],[3]*
Water Distribution Modeling and Management	*[3],[6],[9]*
Automation Systems	*[10],[7]*
Control Systems	*[11],[13]*
Data Acquisition Technology	*[12],[13]*
Measurements and Automation	*[10]*
Industrial Data Communications	*[19],[12]*
Radio-based SCADA Systems	*[13],[20],[18],[15],[21]*
Supervisory Systems	*[17],[21]*
Scheduling	*[4],[23]*
Application of Machine Learning in Water Distribution Networks	*[16]*
Application of functional analysis techniques in supervisory systems	*[17]*
Optimization	*[1],[23]*
Integrated maintenance management	*[20]*
Operations Management	*[5],[23]*

Step 2 - Collection and acquiring of required data

Comprehensive data was acquired from maintenance and operation department at the University of Jordan pertaining the internal water distribution network of the University campus. Water Authority of Jordan and LEMA Company were also another main source of data regarding water distribution system at Al-Jubaiha district and the area around and including the University campus.

Step 3 - Constructing design strategy

** Define the problem from the SCADA point of view:*

The research problem proposed in this thesis is to design a Supervisory Control And Data Acquisition network (SCADA) for management and control of Local Area Water System (LAWS). The design entailed: Collection / acquisition of required data, processing, algorithms, decision-support & control and performance measure of the system compared to existing conventional management and control systems.

** Gathering information & studying the requirements:*

Detailed data was acquired from maintenance department of the University of Jordan regarding the current water distribution network in the University and its troubles. Great effort was exerted in helping to solve their problems and understand their needs pertaining management and operating the current water network. Based on jointly discussion we succeeded to create and set "System Requirements".

** Generate Database:*

Upon obtaining enough details about the existing system, we started to produce detailed list of signals to be monitored and manipulated, a samples of such list are shown through Figures 9 up to 17. This included discrete inputs, discrete outputs, analogue inputs, analogue outputs, remote terminal units addresses, server, peripherals and operator interfaces.

** Develop functional design specifications:*

Upon recognizing all necessary elements to be controlled, we defined its relationship with other passive components in the system in a simplified manner. What is called “Operation Philosophy” for all the system was tailored based on extended discussion and listing with maintenance department requirements in order to be implemented in the forthcoming steps.

** Set processing steps & interlocks:*

All functions that will be performed by the system were defined in detail. For example control loops was set based on water levels inside concerned reservoir, automatic control functions between different sites as well as inside each site was developed similarly.

2 SCADA network

SCADA system enables an operator to remotely view real-time measurements, such as the level of water in a reservoir, and remotely initiates the operation of water network elements such as pump and valves, as well as supports the management to manipulate the mobilization of emergency water-trucks in case of severe water shortages. SCADA system can be set up to sound alarms at the central host computer (MTU) when a fault within the water supply system is identified. It can also be used to keep a historical record of the temporal behavior of various variables in the system such as tank and reservoir levels.

Most of the above features available within any SCADA system are based on dealing with an instantaneous actions and supporting the operator to take the necessary reaction instantaneously as well. Forecasting and future water supply demand prediction is not possible. Hence, the water network is managed based on current-time-conditions and not based on future (predicted) conditions. The availability of management technique such as the last will enable the water network operating crew to control the water system even more efficiently and economically.

There are four major elements in SCADA network: the operator, master terminal unit (MTU), communications and remote terminal unit (RTU).

The operator exercises control through information that is depicted on a video display unit (VDU). Input to the system normally initiates from the operator via the master terminal unit's keyboard. The MTU monitors information from remote sites and displays information for the operator. The relationship between MTU and RTU is analogous to master and slave. SCADA systems are capable of communicating using a wide variety of media such as fiber optics, telephone, dedicated leased lines, or radio.

In the case of installing SCADA system at an existing facility (old plant like water supply or distribution system), radio option is the optimum choice, as it saves excavation works necessary for installing wires and in the same time saves running costs in case of other options such as hiring leased line or telephone.

At the heart of the system is the master terminal unit (MTU). The master terminal unit initiates all communications, gathers data, stores information, sends information to other systems, and interfaces with operators.

The MTU also communicates with other peripheral devices like monitors, printers or other information systems. The primary interface to the operator is the monitor that portrays a representation of (valves, pumps, levels, flow … etc) in our case. As incoming data changes, the screen is updated.

Remote terminal units gather information from their remote site from various input devices/instruments, like (valves, pumps, alarms, meters, water tanks … etc).

Essentially, data is either analog (continuous) or digital (discrete). The remote terminal units hold the information gathered in their PLCs memory and wait for a request from the MTU to transmit the data. But it can be programmed and use their PLC to perform direct control or sequences over the remote site without directions of the MTU.

3 Defining system requirements

Since the main objective of this research is to Design an Information System that Supports Operating and Maintenance Process for Local Area Water Systems through developing a user-friendly man-machine-interface system for management and control; this system shall be - data gathering oriented - the control center and operators are the center of its universe, whilst remote control and monitoring equipment are merely distributed in the field to collect data.

In order to design such a system, a detailed overview plant drawings has been prepared - for the area to be monitored and controlled "local area water system in our case", this includes site details, components' location, manipulated equipment … etc. Please refer to Figures A.3, A.4, A.5 & A.6.

Main features of the proposed system has been set to obtain a powerful system at the end, such as having a system with low maintenance cost, easy to program, reliable, compatible with future upgrade requirements, open architecture and eventually capable to satisfy the requirements of operation and maintenance personnel. Upon several visits to the maintenance and operation section at the University, these visits helped us and led to develop what so called Functional Design Specifications of the proposed system.

4 Functional Design Specifications (FDS)

Through this system it is assumed to be able to monitor 70 different locations, one of them is located outside the University (Um El-Shujairate reservoir), while the others are distributed inside the University campus as shown in Figure A.3, A.4, A.5 & A.6. These Figures comprise Pipe and Instrument Diagrams (P&ID) which can be considered as a real primary design document detailed enough to built the system database on it.

As we have three main sites were water access the University from, each of these three main sites must be equipped with main Remote Terminal Unit (RTU) to communicate with the control center Master Terminal Unit (MTU), proposed at the maintenance and operation section building.

Abovementioned three main sites feed the water to their related distribution group physically, and also we selected to have each of these three main sites' RTU to pull data from its related RTUs distributed inside the group itself.

Each RTU inside any group must report its ground reservoir water level, conveyor pump status & trip conditions if any, domestic tank low level, power supply condition of the RTU itself to the main RTU each time it is asked to do this. Please see Figure 16 as a typical example.

Same logic will be applied at each of the three main RTUs, where each of them must report its storage reservoir water level (except for Distribution group #1 level), balancing pump status & trip conditions, emergency pump status & trip if any, motorized valve status & trip, power supply condition of the main RTU itself to the MTU at the control center each time it is asked to do this. Please see Figure 13 as a typical example.

As for the RTU located outside the University, it should be a small unit that interface and integrate Um El-Shujairat water level signal and main distribution butterfly-valve Open / Close status to our proposed SCADA system inside the University.

This is to keep complete coordination and data integration around the hour with LEMA as a main and lonely water supplier to the University. Please see Figure 17.

All of this acquired data must be fed to the main control center MTU located at proposed operation and maintenance building.

The SCADA system in our case shall be considered as a hands-on tool rather than an automatic control system; the MTU / PC must show detailed graphical screens with dynamic and static fields to enable fast and meaningful feedback to the operator so that he can monitor the status of the 70 different sites simultaneously.

The SCADA software shall include alarming facility to alert the operator about any trip or Low/High reservoir level condition at any site continuously. Alarms shall be logged at a dot-matrix printer whenever it takes place while operator is not present.

The SCADA software shall be able to produce time series/plots for flow measurements and reservoir level and store the plotted data at an archiving file continuously to enable the maintenance and operating team to study and discern consumption patterns along any period of time around the year. Pleases refer to Figure A.16 as a typical example.

Retention of this historical data shall be possible for five years at least to allow enough data availability for future information.

The SCADA software shall be able to produce reports on daily, monthly, quarterly or yearly basis about consumed amounts of water using a dedicated report-format at a laser printer.

The three main RTUs must comprise some intelligence (PLC) programmed to manipulate related equipment i.e. govern the functionality of inlet valve installed at the main line coming from the water source if water level in the receiving reservoir become high. Also to prevent operating the booster pump and the motorized valve simultaneously in case of distribution group#1 in order to avoid disturbance and pressure drop. Also to execute downloaded optimization algorithm / water distribution schedule coming from the MTU.

5 Calculating scan intervals

Electrical machines can talk to each other in several ways. Depending on three main factors:

1- The purpose of their conversation

2- The required speed

3- The machines' status relative to each other

In our case the MTU at the provisional maintenance and control center will interrogate four main RTUs located at Um El-Shujairate Reservoir, Distribution Group #1, #2 and #3. Each of the last three main RTUs will interrogate its related RTUs located within its control domain.

We have selected "master-slave" arrangement as a communication method to carry out this interrogation process, since we have a big number of RTUs distributed over three main groups and one residing outside the university. Figure A.2.

The process of talking to each RTU in order and then going back to the first RTU to begin the cycle all over again is called Scanning.

Best rate at which to scan the RTUs in our case depends on three main factors:

1- Number of RTUs that have to be scanned

2- Amount of data that must be passed on each conversation

3- The data rate or number of bits per second that can be transmitted over the communication medium i.e. Radio.

4- Communication efficiency, which is the result of (Time spent moving the data of interest) / (Total time spent communicating) * 100%. In our case, as we adopted radio-communication due to the extreme difficulty to perform excavation and laying of cables between the current buildings, this ratio approaches 40%, and considered to be very low comparing to the obtained ratios from other communication medium.

To start calculations with Distribution Group #1:

- It will initially have twenty RTUs (multi drop)
- The largest RTU is #52 and has the following point counts:

7 status points	7
9 alarm points	9
3 measurement points	48
(at sixteen bits each)	___
Total points	64

- Data rate is based on UHF radio, baudrate is selected to be 9600bps
- Based on radio communication, communication efficiency will be 40%

Therefore, 20 RTUs * 64 points = 1,280 bits to move at a data rate of 9600 bps, which would take 1280 bits / 9600 bps = 0.13 seconds at 100% efficiency. But for our case we have 40% communication efficiency, the scan interval would be 0.133 seconds / 0.4 = 0.33 second. It would be good design practice to round this 0.33 second up to 1 second.

For Distribution Group #2:

- It will initially have thirty two RTUs (multi drop)
- The largest RTU is #19 and has the following point counts:

2 status points	2
5 alarm points	5
1 measurement point	16
(at sixteen bits)	___
Total points	23

- Data rate is based on UHF radio, baudrate is selected to be 9600bps
- Based on radio communication, communication efficiency will be 40%

Therefore, 32 RTUs * 23 points = 736 bits to move at a data rate of 9600 bps, which would take 736 bits / 9600 bps = 0.076 seconds at 100% efficiency. But for our case we have 40% communication efficiency, the scan interval would be 0.076 seconds / 0.4 = 0.2 second.

Also it would be good design practice to round this 0.2 second up to 1 second.

For Distribution Group #3:

- It will only have two RTUs (dual drop)
- Both of these two RTUs have the following point counts:

2 alarm points	2
1 measurement point	16
(at sixteen bits)	___
Total points	18

- Data rate is based on UHF radio, baudrate is selected to be 9600bps
- Based on radio communication, communication efficiency will be 40%

Therefore, 2 RTUs * 18 points = 36 bits to move at a data rate of 9600 bps, which would take 36 bits / 9600 bps = 0.004 seconds at 100% efficiency. But for our case we have 40% communication efficiency, the scan interval would be 0.004 seconds / 0.4 = 0.01 second.

It would be good design practice to round this 0.01 second up to 1 second.

With this calculation, the scan time for the RTUs of Distribution Group 1,2 & 3 will be almost one second.

To calculate the scanning time of the MTU for the four main RTUs, we start first with:

MTU located at the operations and maintenance center:

- It will initially have four main RTUs (multi drop)
- The largest main RTU is DG#1 and has the following point counts:

64	collected points	64
3	status points	3
3	alarm points	3
1	measurement points	16
	(at sixteen bits each)	___

Total points 86

- Data rate is based on UHF radio, baudrate is selected to be 9600bps
- Based on radio communication, communication efficiency will be 40%

Therefore, 4 RTUs * 86 points = 344 bits to move at a data rate of 9600 bps, which would take 344 bits / 9600 bps = 0.035 seconds at 100% efficiency. But for our case we have 40% communication efficiency, the scan interval would be 0.035 seconds / 0.4 = 0.09 second.

It would be good design practice to round this 0.09 second up to 1 second.

6 Radio frequencies

Above calculations were based on four different UHF radio channels working simultaneously at different links and as follows:

RF-Link between	RF-Channel number
RTU DG#1 & its related RTUs	Ch1
RTU DG#2 & its related RTUs	Ch2
RTU DG#3 & its two RTUs	Ch3
MTU & each of RTU LEMA, DG#1,2 & 3	Ch4

Radio communications were selected in our case due to its high flexibility and its low cost comparing with other communication medium if we considered cable-laying problem.

Figure 8 shows proposed SCADA system architecture.

Proposed SCADA System Architecture

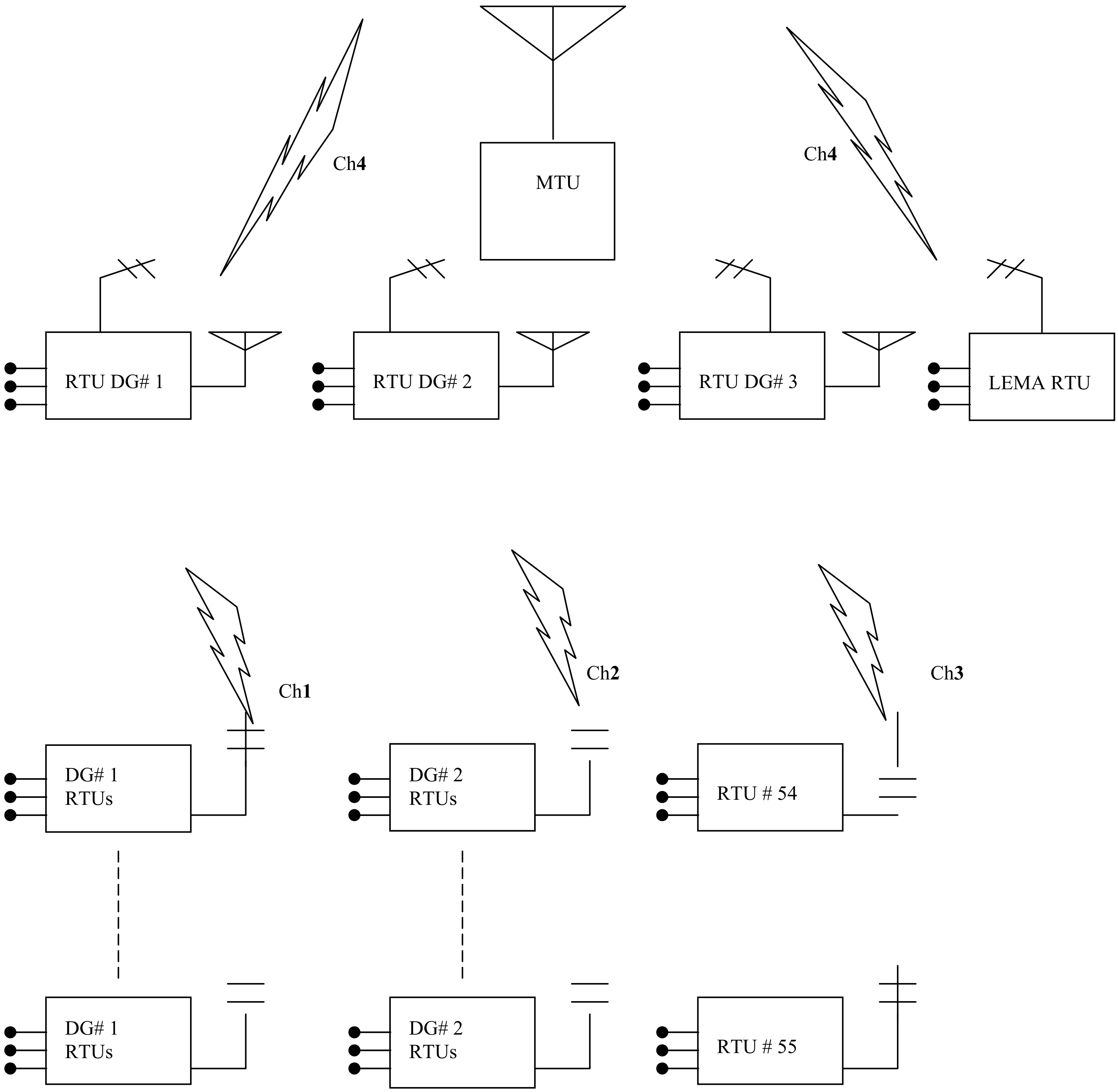


Figure 8: Proposed system architecture

7 System components

Our system shall consist of the following main components:

7.1 Telemetry network:

A telemetry network provides the communication pathway within the SCADA system. Through our proposed system, it is made up of the following component settings:

- Topology : Point-to-multipoint
- Transmission mode : Master-slave (point-to-multipoint adopted topology)
- Link media : Multiple radio frequencies (UHF-band)
- Communication protocol : MODBUS open-protocol

7.2 Date communication equipment:

This equipment named also (DCE), its main duty is to carryout the link function between the transmission medium and the data terminal equipment (DTE) which is basically a microprocessor-based device such as PC, RTU or PLC.

It can be viewed as the data transport mechanism between the host computer (MTU) and the remote terminal units (RTUs).

In our case the DCE shall be an integrated radio-modem set. This acquisition set shall use communication format called master-slave.

7.3 The master station:

The master station is called also master terminal unit (MTU) or host computer.

As the VAX or UNIX-based computers are used usually in extremely large applications such as oil refineries or chemical industries complex, we will confine on using personal computer PC since our application and total number of signals to be exchanged within it can be classified as small-to-medium-sized application.

7.4 Remote terminal units:

The remote terminal unit (RTU) is a modular microprocessor-based unit, specifically designed for real-time processing of input and output data in industrial applications.

In our proposed system, reporting its status to the master station and carryout the command from the master station are the original functions of each RTU. Yet, we propose to support all the RTUs of the buildings that comprise conveyor pump and source and destination reservoirs with an automatic control algorithm to manipulate these components continuously without people intervention.

RTUs were selected to store the control algorithm by itself rather than to store the control algorithms of each RTU at the main control center (MTU) and download them to each RTU. This is to increase system autonomy, reliability and avoid glitches that might take place due to MTU stuck.

Figure 8 shows the proposed SCADA system architecture. As this setout encompasses the transfer of data between the central host computer (MTU) and number of remote sites (RTUs), multiplexing function between the MTU and the 70 different RTUs is essential to operate the system using the aforementioned four frequency channels. The multiplexing function serves to route data to and from the 70 RTUs on a local network, while using a few links on a Wide Area Network backbone to pass data back to the central host computer.

The details of the generic architecture blocks shown at Figure 8 can be described as follows:

- For the Remote Terminal Unit (RTU):

Each RTU unit gathers information from the field about metered amounts e.g. flow meter reading, alarm points e.g. motor trip condition and status points e.g. valve open/close status. It keeps this information available in memory until the MTU asks for it.

Main components of each RTU shall be:

1- Communication set, comprising omni-directional or directional antenna with feedline and surge protection device, succeeded by integrated radio-modem unit with communications interface.
2- Programmable Logic Controller, comprising CPU, Memory for (program, configuration & field data) and field interface including modular Digital Input card(s) for discrete inputs & modular Analogue Input card for continuous inputs.
3- Small-size Uninterruptible Power Supply (UPS) unit, comprising switch-mode power supply with backup batteries and electronic interface with the PLC.

- For the Master Terminal Unit (MTU):

At the center of any SCADA system is the device that issues all commands, gathers all data, stores some information, pass other information on to associated systems, interfaces with the people.

Main components of the Master Terminal Unit shall be:

1- Host computer, will be commercial PC with Windows XP operating system, exploitation software to carryout SCADA main functions and applications software for the purpose of archiving/data management.
2- Communication equipment, to allow proper interface between the host computer and the pertinent front-end RTUs.
3- Operator interface devices, comprising CRT or LCD monitor, keyboard, mouse, reports laser printer, alarms log dot-matrix printer and any other necessary media interfaces.

Figure A.15 shows photograph for proposed typical RTU cabinet.

Architecture has been built for hardware, client layer and data server layer; the first caters man-machine-interface and the second handles most of the process data control activities. Please see Figure A.3, A.4 and A.5. This included design of communication network of PC connected to many PLCs and determining pulling rate – frequency of collecting data. Since pulling goes through discrete polling times (scans) to acquire the data, there might be a heavy burden on the processor due to the big number of pulled RTUs. Although, scan rate calculations indicated almost 1 second of maximum updating time.

As for software, Windows XP operating system will be adopted as well as any set of application software from international market, software configuration can be developed easily for management & control of the LAWS different sites upon defining and constructing a clear and detailed database for the process parameters (data to be collected from the field) e.g. see Figures 15, 16 and 17.

8 System configuration

Figures 8 up to 17 show typical example of proposed system configurations

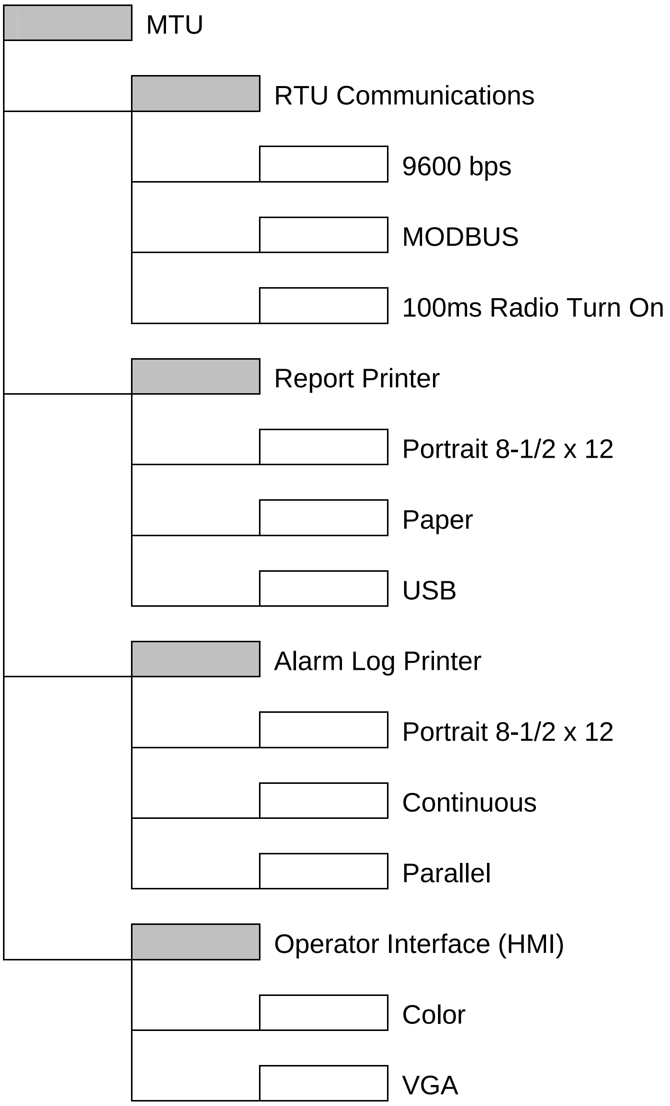


Figure 9: Configuring the MTU

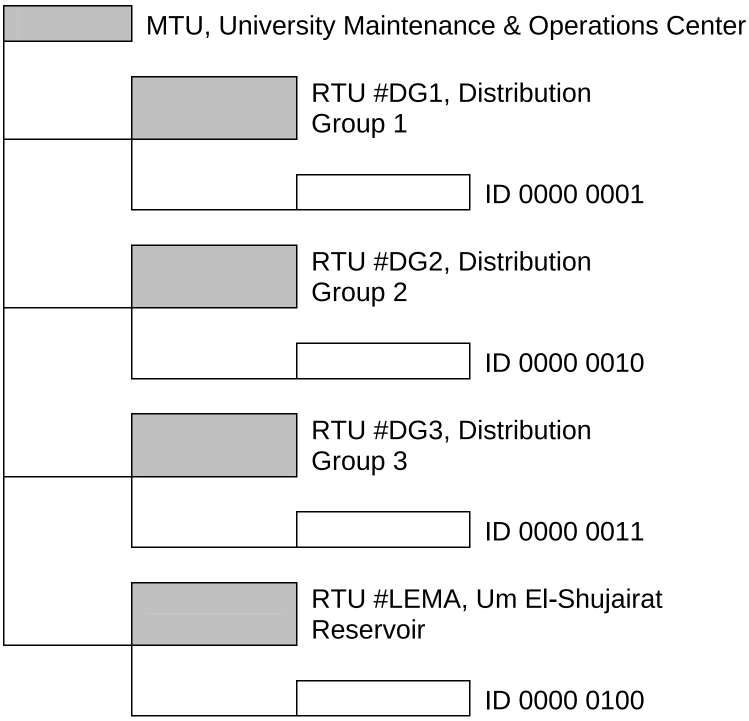


Figure 10: Main RTUs and their Identification Numbers

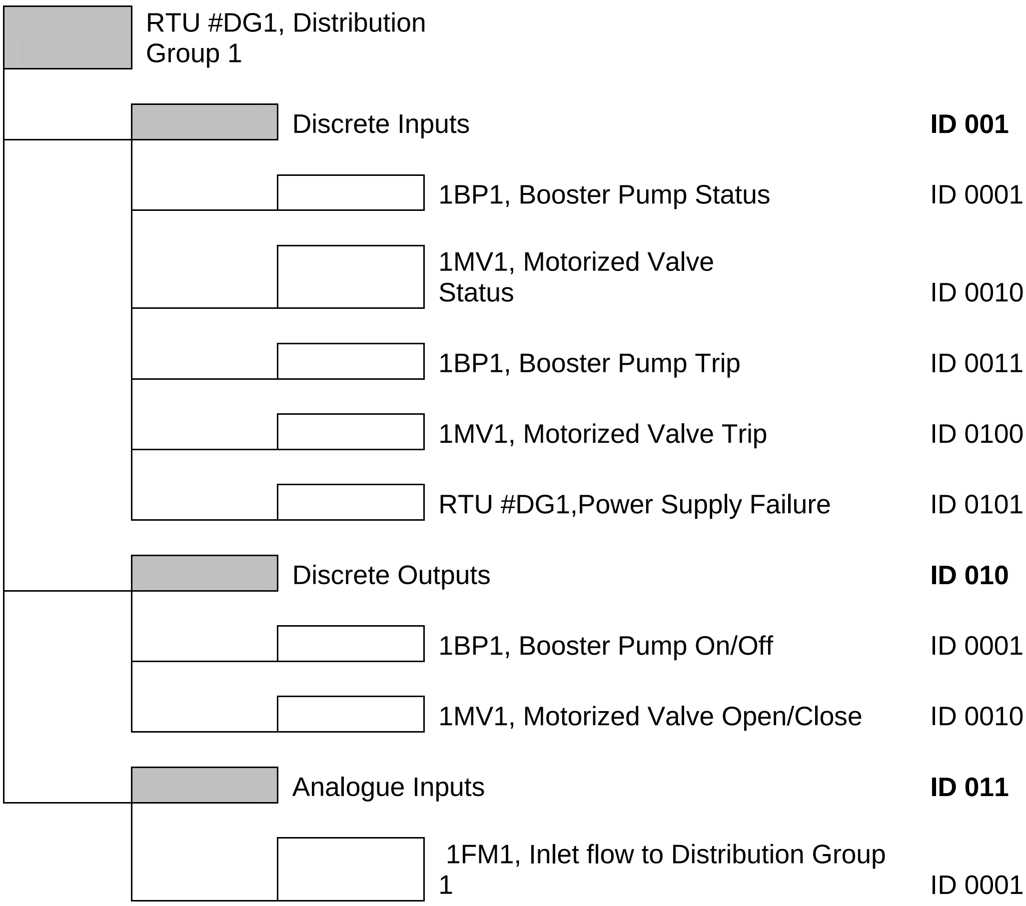


Figure 11: Grouped Inputs to and Outputs from RTU #DG1

- RTU #DG2, Distribution Group 2
  - Discrete Inputs — **ID 001**
    - 2P1, Balancing Pump Status — ID 0001
    - 2P2, Emergency Pump Status — ID 0010
    - 2MV1, Motorized Valve Status — ID 0011
    - 2P1, Balancing Pump Trip — ID 0100
    - 2P2, Emergency Pump Trip — ID 0101
    - 1MV1, Motorized Valve Trip — ID 0110
    - RTU #DG2,Power Supply Failure — ID 0111
  - Discrete Outputs — **ID 010**
    - 2MV1, Motorized Valve Open/Close — ID 0001
  - Analogue Inputs — **ID 011**
    - 2FM1, Inlet flow to Distribution Group 2 — ID 0001
    - 2T1, First Reservoir Level Reading — ID 0010
    - 2T2, Second Reservoir Level Reading — ID 0011

Figure 12: Grouped Inputs to and Outputs from RTU #DG2

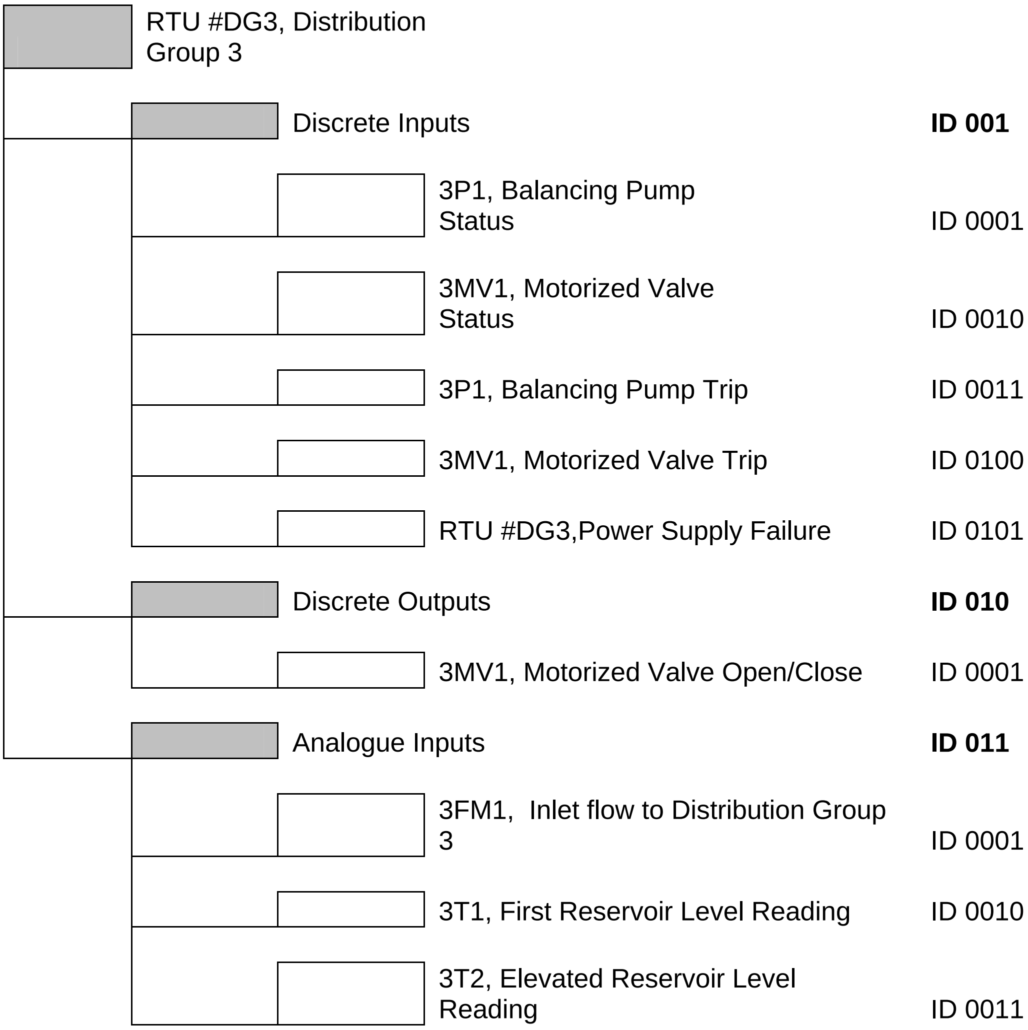


Figure 13: Grouped Inputs to and Outputs from RTU #DG3

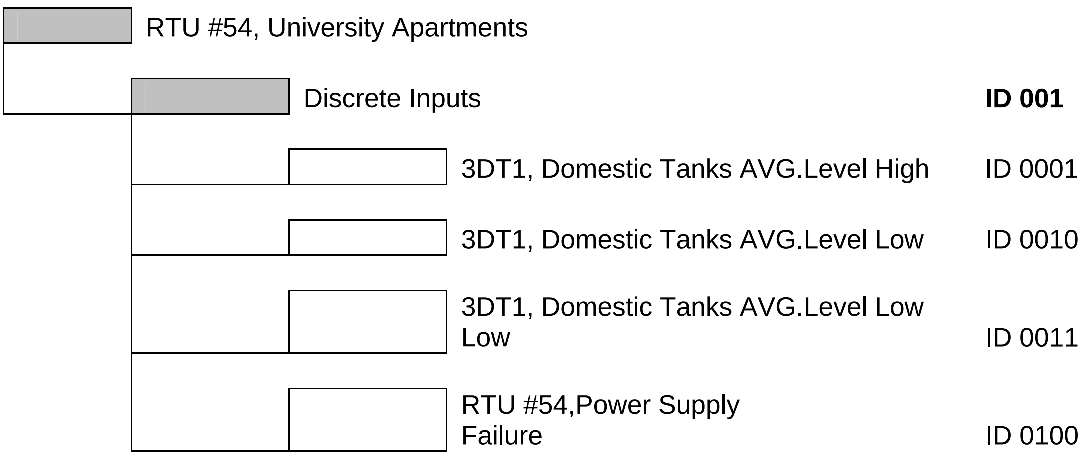


Figure 14: Grouped Inputs to RTU #54
"As an Example for one of Distribution Group#3 RTUs"

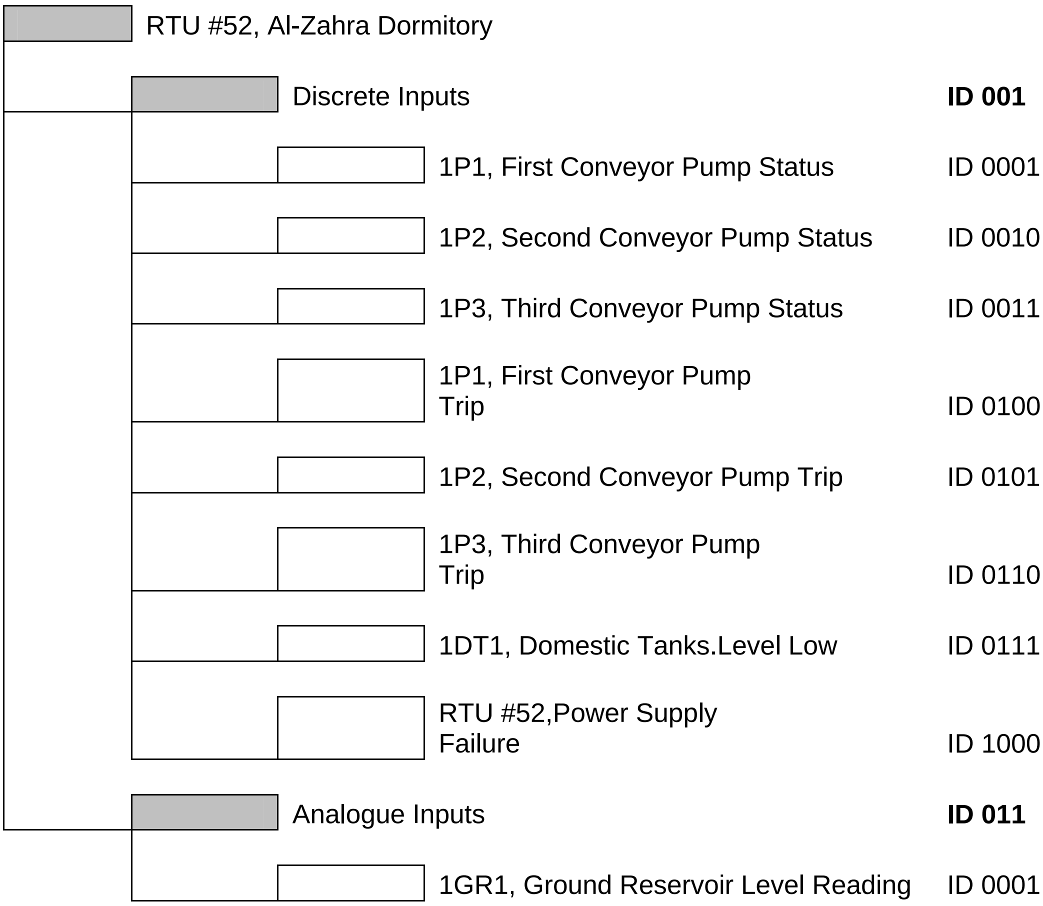


Figure 15: Grouped Inputs to RTU #52
"As an Example for one of Distribution Group#1 RTUs"

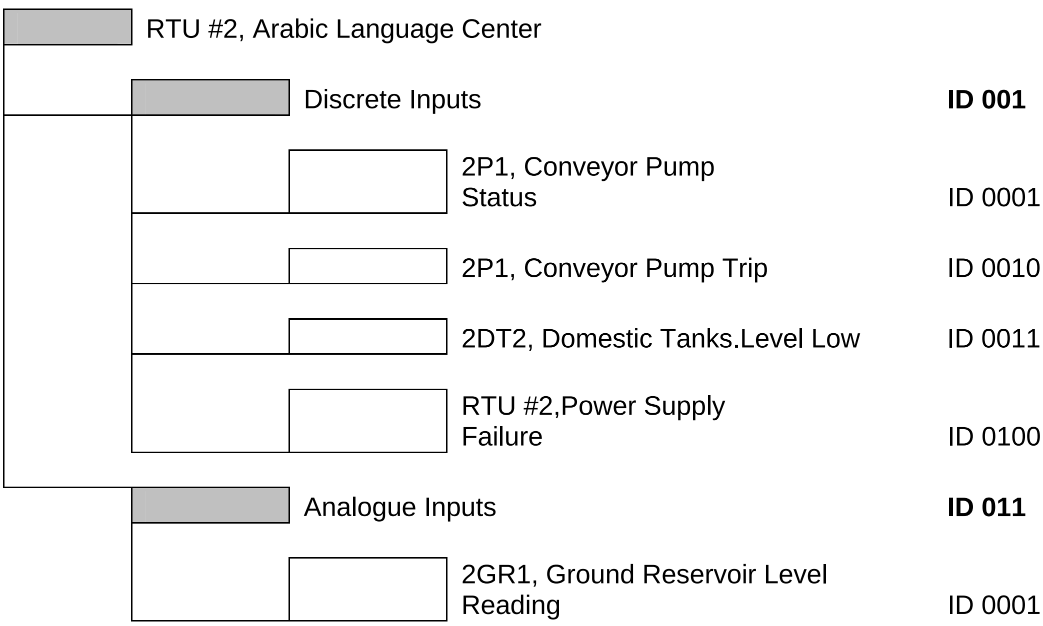


Figure 16: Grouped Inputs to RTU #2
"As an Example for one of Distribution Group#2 RTUs"

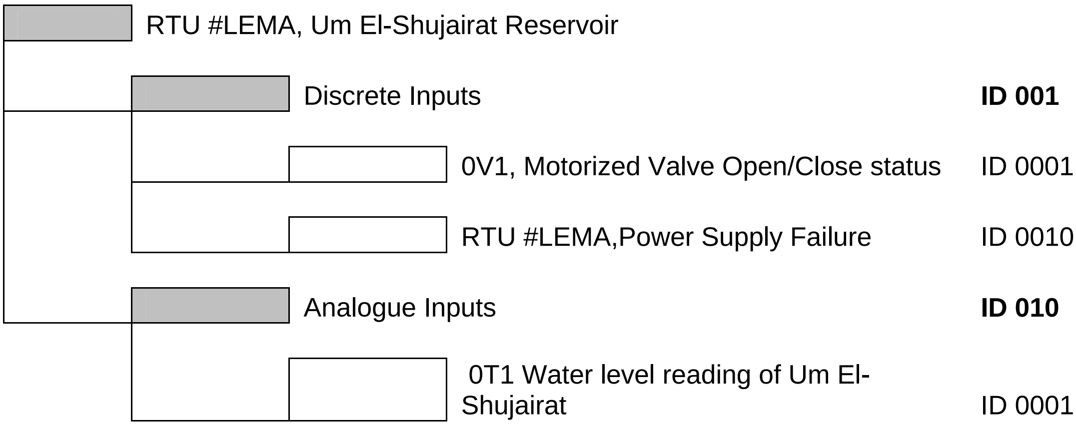


Figure 17: Grouped Inputs to RTU #LEMA

9 System functionality

Our system shall be able to perform the following main functions:

9.1 Access control

Proposed SCADA users are allocated to groups, which have defined read/ write access privileges to the process parameters in the system and often also to specific functionalities. System manager will have the highest priority.

9.2 MMI

The SCADA supports multiple screens, which can contain combinations of synoptic diagrams and text. Pleases refer to Figures A.3, A.4 and A5 .as an example of the adopted screens.

Most of the SCADA decompose the process in "atomic" parameters (e.g. a water flow reading, its maximum value, it's on/off status, etc.) to which a Tag-name is associated. The Tag-names used to link graphical objects to devices can be edited as required, for example the tag of booster pump at distribution group # 2 is 1PB2, please refer to Figure A.2. The SCADA software packages include a library of standard graphical symbols, many of which would however not be applicable to the type of applications encountered in the experimental physics community, but can be customized to do this function with proper Tag.

Standard windows editing facilities are provided zooming, re-sizing, scrolling… On-line configuration and customization of the MMI is possible for users with the appropriate privileges. Links can be created between display pages to navigate from one view to another.

9.3 Trending

The SCADA system provides trending facilities and can summarize the common capabilities as follows.

- The parameters to be trend in a specific chart can be predefined or defined on-line.
- A chart may contain more than 8 trended parameters or pens an unlimited number of charts can be displayed (restricted only by the readability), Figure A.16.
- Real-time and historical trending are possible, although generally not in the same chart.
- Historical trending is possible for any archived parameter.
- Parameter values at the cursor position can be displayed, i.e. exact reading can be displayed accommodated with date and time of acquisition.

The trending feature can be embedded into a synoptic display, XY and other statistical analysis plots.

9.4 Alarm Handling

Alarm handling is based on limited and status checking and performed in the data servers. More complicated expressions (using arithmetic or logical expressions) can be developed by creating derived parameters on which status or limited checking is then performed. The alarm are logically handled centrally, i.e., the information only exists in one place and all users see the same status (e.g., the acknowledgment), and multiple alarm priority levels are also supported.

It is generally possible to group alarms and to handle these as an entity (typically filtering on group or acknowledgement of all alarm in group). Furthermore, it is possible to suppress alarms either individually or as a complete group. The filtering of alarms seen on the alarm page or when viewing the alarm log is also possible at least on priority, time and group. However, relationships between alarms cannot generally be defined in a straight forward manner. E-mails can be generated or predefined actions automatically executed in response to alarm conditions, to alert system manager if needed.

9.5 Logging/Archiving

The terms logging and archiving are often used to describe the same facility.

However, logging can be thought of as medium-term storage of data on a disk, whereas archiving is long-term storage of data either on a disk or another permanent storage medium, based on the desire of the operating team. Logging is typically performed on cyclic basis, i.e., once a certain file size, time period or number of pointed is reached the data is overwritten. Logging of data can be performed at a set frequency, or only initiated if the value changes or when a specific predefined event occurs. Logged data can be transferred to an archive once the log is full. The logged data is time-stamped and can be filtered when viewed by a user. The logging of user actions is in general performed together with either a user ID or station ID.

9.6 Report Generation

One can produce report using SQL type queries to the archive, RTDB or logs. Although it is sometimes possible to embed EXCEL charts in the report, a "cut and paste" capability is in general not provided. Facilities exist to be able to automatically generate, print and archive reports. Reports format can be set on daily, weekly, monthly or yearly bases.

9.7 Automation

The majority of SCADA systems allow actions to be automatically triggered by events, e.g. start or stop a pump based on reservoir's water level. A scripting language provided by the SCADA products allows these actions to be defined. In general, one can load a particular display, send an Email, run a user defined application or script and write to the RTDB.

Sequencing is also supported whereby it is possible to execute a more complex sequence of actions on one or more devices. Sequences may also react to external events. But we will not use such feature in our system due to its small size and the primitive control comparing with other SCADA applications.

10 System redundancy

Redundancy is a term used to describe hardware that is duplicated, or redundant, for the purpose of having a backup in case of device failures in such a way that increases the reliability of the SCADA system.

Since we do not have any safety considerations, billing system or sever or critical process that entails continuous availability and functionality of the SCADA system, we preferred not to install any redundant hardware.

Meanwhile the system might not operate reasonably when field communications become critical or fail.

11 Concluding remarks

SCADA technology, provides a rich and meaningful addition to standard monitoring and control techniques. Through this chapter, a user-friendly man-machine-interface system was developed to facilitate management and control of water distribution system requirements. The drawing that shows Distribution Group # 1,2 & 3 were adopted as primary design document following simple control concept pertaining starting / stopping feeding pump based on destination tank water level e.g. to start feeding pump if water level at destination reservoir become low, and to stop the feeding pump if water level at destination reservoir become high. Scanning time or updating time was calculated for each sub-network within the SCADA system and based on the proposed number of signals to be transferred to the main control center. Maximum pulling cycle found to be not exceeding one second for each sub-network. Therefore, we will enjoy a fast data collecting system that provides the operator with real-time information about field conditions.

Radio frequencies were set to be four different channels to serve the four main RTU groups, avoid any interference or obstacle problems and save extra hardware necessary to achieve system redundancy.

DEVELOPMENT OF DECISION SUPPORT SYSTSEM

1 Introduction

SCADA system enables an operator to remotely view real-time measurements, such as the level of water in a reservoir, and remotely initiate the operation of water network elements such as pump and valves, as well as support the management to manipulate the mobilization of emergency water-trucks in case of severe water shortages. SCADA system can be set up to sound alarms at the central host computer (MTU) when a fault within the water supply system is identified. It can also be used to keep a historical record of the temporal behavior of various variables in the system such as tank and reservoir levels.

Most of the above features available within any SCADA system are based on dealing with an instantaneous actions and supporting the operator to take the necessary reaction instantaneously as well. Forecasting and future water supply demand prediction is not possible. Hence, the water network is managed based on current-time-conditions and not based on future (predicted) conditions. The availability of management technique such as the last will enable the water network operating crew to control the water system even more efficiently and economically.

To connect and efficiently integrate SCADA system to a local area water distribution network - such as the one in our case study, detailed and precise technical information about the water distribution network topology, pipe routing, sizes and used components should be available.

Unfortunately, such precise details are not available in our case study due to lake of proper documentation, successive and not coordinated expansions, replacements and modification works for the water distribution network executed usually by external contractors.

To overcome this dilemma, the local area water system LAWS is assumed to be a black box, disregarding any intricacies caused by using different piping or fittings inside this black box. But this black box has a well known number of input points and output points, i.e. (DG#1,2 & 3 main water-feed-points in addition to the equivalent volume of ground reservoirs for each distribution group separately 1GR1,1GR2,2GR1 & 3GR1).

Using the SCADA system and the archiving function located in the MTU (the center computer of the SCADA system) a big amount of readings pertinent to input points and output points of the assumed black box can be acquired and stored around the hour and along all water distribution seasons, such that water supply quantity readings at every feed point is logged by the SCADA system every hour, and the same for water demand readings at the ground reservoir for each water distribution group. These acquired data shall be fed continuously to an artificial neural network ANN so that this network become trained and able to predict outputs based on specific inputs, i.e. The management of the Water Network becomes able to predict demand, based on supply readings. As an example the demand can be controlled during shortage periods based on available data (predicted outputs developed by the ANN model).

The major problem in the University water distribution network is seasonal water shortage. Installing an efficient water management and prediction system based on precise and continuous data acquisition network to have all necessary data from the field to the main control center can solve this problem.

Upon collecting enough amounts of data, management system can easily alleviate water-shortage problem and produce water demand patterns based on precise forecasting obtained from an ANN model.

2 Data processing

Collected data from the water distribution system to the MTU memory can be converted to organized information and then can be converted to precise knowledge at the end. This can be done according to the following three main steps:

After collecting and archiving big amount of readings from the field through the SCADA network, these readings become important pieces of information. Based on the developed ANN prediction model and its outputs, solid knowledge will become available in the hand of the water management team. This knowledge shall be able to describe the water distribution process precisely and continuously at any season or time domain.

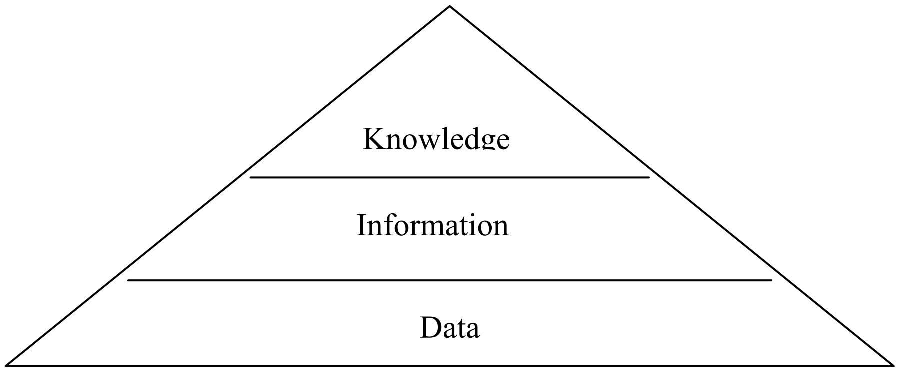


Figure 18: Data conversion hierarchy

If the SCADA system is set to acquire one reading hourly from each field instrument e.g. (a reading from flowmeter at Distribution Group #1 every one hour) for an extended period of time, we will have a huge amount of data pertaining every important input or output point under monitoring.

These collected data (data-mine) are fed to an Artificial Neural Network (ANN) for farther processing, analyses, model building and seasonal demand pattern recognition.

3 Artificial Neural Networks

Artificial Neural Networks are relatively crude electronic models based on the neural structure of the brain. The brain basically learns from experience. It is natural proof that some problems that are beyond the scope of current computers are indeed solvable by small energy efficient packages. This brain modeling also promises a less technical way to develop machine solutions. This new approach to computing also provides a more graceful degradation during system overload than its more traditional counterparts.

A neural network is a powerful data modeling tool that is able to capture and represent complex input/output relationships. The motivation for the development of neural network technology stemmed from the desire to develop an artificial system that could perform "intelligent" tasks similar to those performed by the human brain. Figure 19.

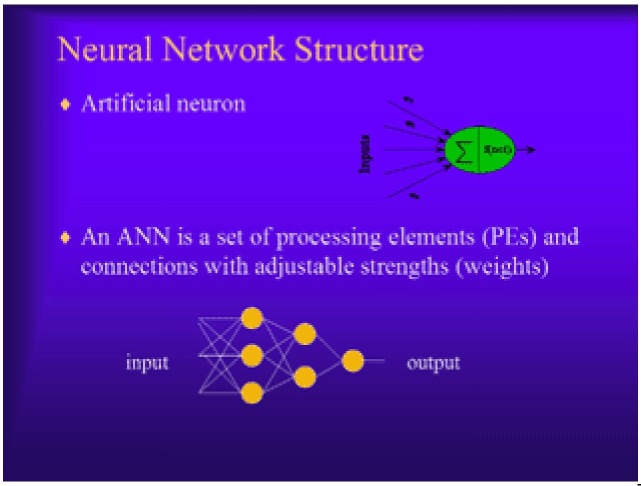


Figure 19: Neural network

The true power and advantage of neural networks lies in their ability to represent both linear and non-linear relationships and in their ability to learn these relationships directly from the data being modeled.

The most common neural network model is the multilayer perceptron (MLP). It will be adopted in our case study. This type of neural network is known as a supervised network because it requires a desired output in order to learn. The goal of this type of network is to create a model that correctly maps the input to the output using historical data so that the model can then be used to produce the output when the desired output is unknown. A graphical representation of an MLP is shown at Figure 20 below.

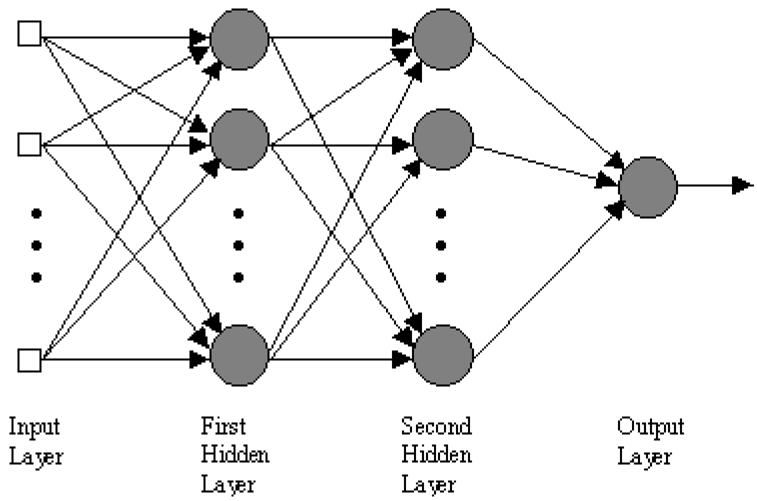


Figure 20: multilayer perceptron (MLP) ANN

3.1 Supervised network learning:

The functionality of a neural network is determined by the combination of the topology (number of layers, number of units per layer, and the interconnection pattern between the layers) and the weights of the connections within the network. The topology is usually held fixed, and a certain training algorithm determines the weights. The process of adjusting the weights to make the network learn the relationship between the inputs and targets is called leaning, or training.

The network is trained by providing it with inputs and desired outputs (target value). These input-output pairs are provided by an external teacher - SCADA system archived data files in our case study. The difference between the real outputs and the desired outputs is used by the algorithm to adapt the weights in the network Figure. 21 It is often posed as a function approximation problem – given training data consisting of pairs of input patterns *x*, and corresponding target, the goal is to find a function *f(x)* that matches the desired response for each training input.

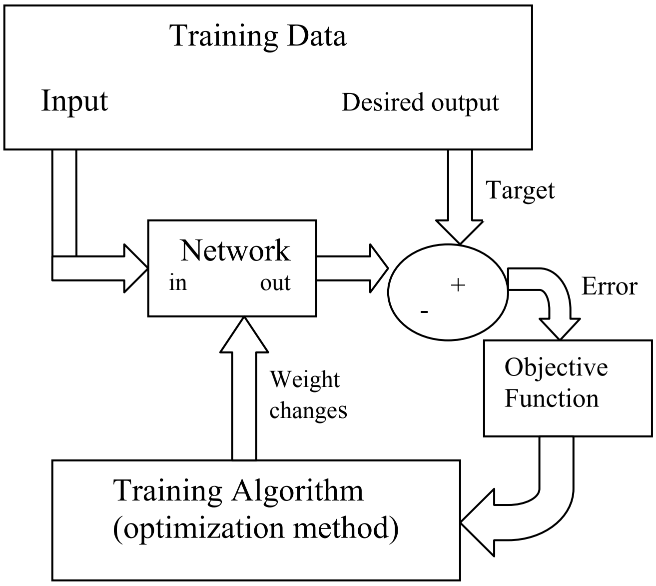


Figure 21: Learning mode

Eventually the ANN model shall be able to predict outputs based on fed inputs, and this is what will be done for the proposed black box within our water distribution problem.

4 Management's Decision Algorithms

4.1 Decisions based on demand, forecasted data and supply:

At any time during running the ANN algorithms, a repeated question must be asked (is Demand greater than Forecast?), based on the answer the necessary action can be carried out e.g. (update ANN model, store water, startup emergency action and or priority steps … etc). This can be represented by the following key objective function and constraints:

minimize

Total number of shortages

Subject to:

Demand

Supply

Capacity of the network

The decision algorithm of the water network management team is set as shown in the following diagram, Figure 22.

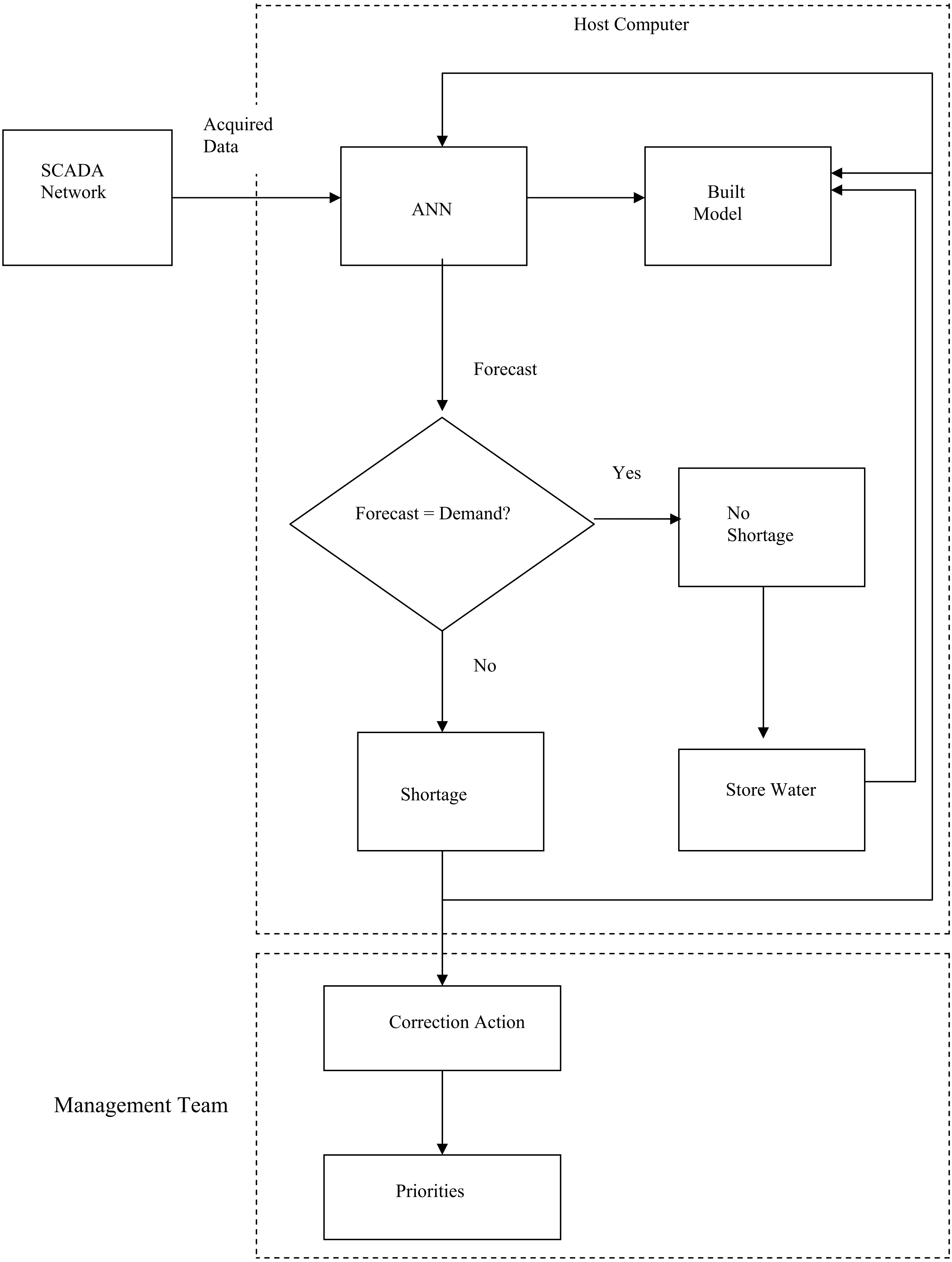


Figure 22: Management Team Decision Algorithm Based on ANN.

Supply-Demand pattern based on ANN was developed using (NeuralWare) application software & (Excel) software package. Table 4 below shows the outcome of the developed model.

Prediction using *NeuralWare* software package

	Supply			Demand			
Month	**DG1**	**DG2**	**DG3**	**1GR1**	**1GR2**	**2GR1**	**3GR1**
1	49.6	24.8	5.6	20.15	20.15	20.1	4.5
2	49.6	24.8	5.6	2.1	2.1	2.1	3.7
3	49.6	24.8	5.6	21.7	21.7	21.7	4.9
4	49.6	24.8	5.6	21.7	21.7	21.7	4.9
5	46.5	23.25	5.25	23.25	23.25	23.2	5.2
6	46.5	23.25	5.25	24.8	24.8	24.8	5.6
7	46.5	23.25	5.25	20.15	20.15	20.1	4.5
8	46.5	23.25	5.25	20.15	20.15	20.1	4.5
9	46.5	23.25	5.25	2.1	2.1	2.1	3.7
10	46.5	23.25	5.25	21.7	21.7	21.7	4.9
11	40.3	20.15	5.32	21.7	21.7	21.7	4.9
12	40.3	20.15	5.32	20.15	20.15	20.1	4.5

Actual Values

Predicted Demand

1GR1	1GR2	2GR1	3GR1
16.48	16.55	16.45	4.51
16.48	16.55	16.45	4.51
16.48	16.55	16.45	4.51
16.48	16.55	16.45	4.51
18.87	18.77	18.81	4.74
18.87	18.77	18.81	4.74
18.87	18.77	18.81	4.74
18.87	18.77	18.81	4.74
18.87	18.77	18.81	4.74
18.87	18.77	18.81	4.74
20.99	21.01	21.01	4.70
20.99	21.01	21.01	4.70

Values Predicted by the NN

Table 4 ANN prediction model outcome based on monthly periods

Prediction capability can be improved dramatically if the ANN model were fed by continuous readings from the SCADA system with a small time base period e.g. hour by hour. Through Table 4 the time base for the model was monthly, consequently the predicted outputs seams to be not very close to the real outputs due to adopting average month by month readings. Prediction outcome during for the very small quantities of water demand during the seasonal University holidays between semesters shall be neglected, as we will not need to operate or run the prediction model during students vacation time. More precise curves can be produced such as in Table 5 and Figure 23 below where time base set to be weekly but for one year only:

Annual Water Supply/Demand Log

Week No.	Supply	Real Demand	Predicted Demand
1	83	63	60
2	79	65	61
3	82	64	60
4	78	65	62
5	81	9	60
6	85	12	59
7	80	10	60
8	78	11	62
9	79	72	61
10	82	70	60
11	85	68	59
12	84	73	60
13	79	70	61
14	81	73	60
15	82	74	60
16	82	73	60
17	83	69	60
18	76	72	67
19	77	73	65
20	75	75	69
21	74	76	70
22	76	88	79
23	75	86	80
24	74	83	78
25	73	82	76
26	75	69	69
27	74	64	70
28	76	65	67
29	77	66	65
30	79	63	61
31	74	65	70
32	72	66	69
33	76	67	67
34	75	15	69
35	77	5	65
36	74	10	70
37	78	12	62
38	77	69	65
39	75	72	69
40	75	71	69
41	76	69	67
42	74	72	70
43	78	70	62
44	69	68	67
45	68	72	67
46	65	73	68
47	63	68	69
48	66	66	67
49	65	65	68
50	68	62	67
51	65	65	68
52	64	6	68

N.B. All readings are in m3/h

Table 5: Typical annual water supply/demand log based on weekly average readings

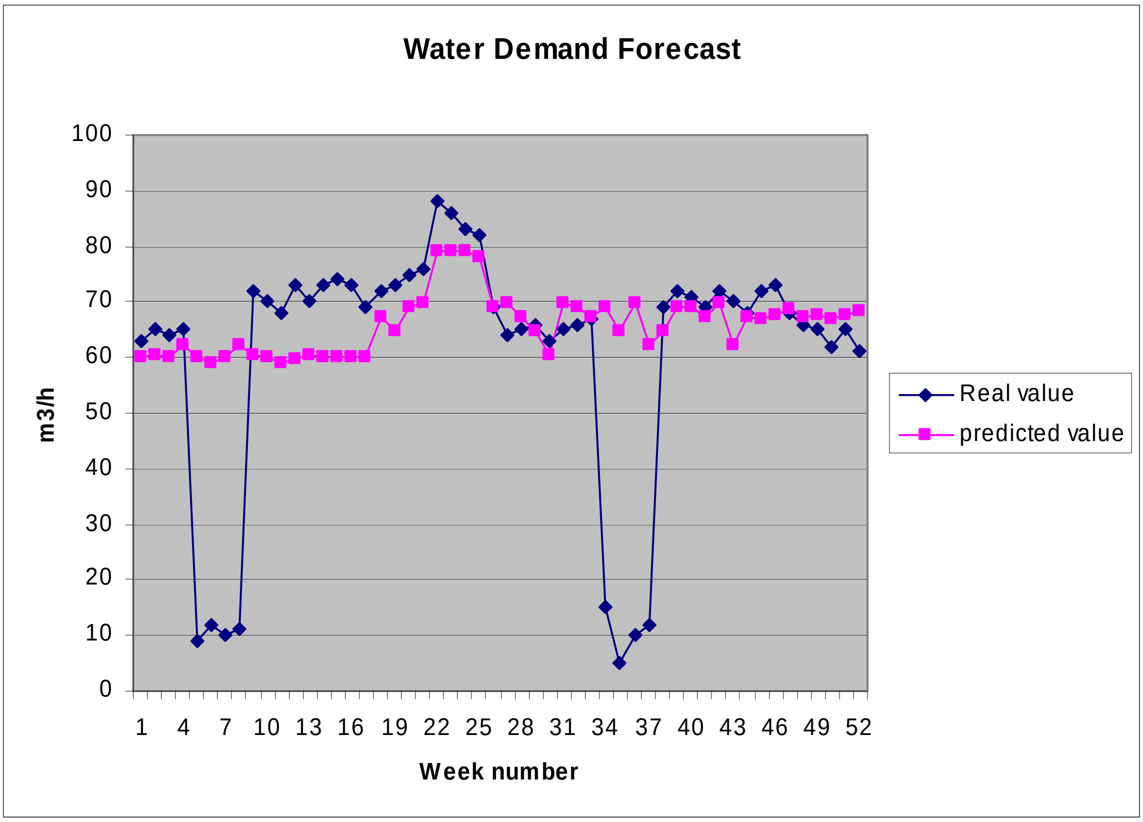


Figure 22: Water demand forecast using neural network, fed by weekly data readings.

The above weekly-based prediction model was not able to predict small quantities of water demand during seasonal holidays between semesters, consequently running prediction function during these two gaps is not recommended and shall be avoided. However, slight improvement can be discerned on the ANN model output upon switching to hourly based data logging. Also upon feeding the model with a big quantity of readings from the field during a time period extending for a couple of years as an example will certainly improve the prediction model precision.

4.2 Planning using transportation problem:

To get the optimal mixed-strategy for water distribution plan along any planning horizon (12 months have been adopted as a typical example), we used the transportation method now to solve this water distribution problem at the level of annual distribution cycle, and based on the availability of demand forecast for each period produced by the ANN model, along with available around-the-hour-service tools (local or from outside the University) to satisfy required demands.

Figure 24 shows a tableau, with each row represents an alternative service or arrangement (local or from outside the University arrangement) for supplying water. In the first row, it is assumed that the amount of stored water inside the university campus is constant to a certain amount. The second row is for regular water distribution process using the University water distribution network during period 1 (January), which can also be used to satisfy demand in any of the twelve periods the plan will cover. The third and fourth rows are for two other water distribution alternatives or arrangements (emergency tank-truck from inside the University and subcontractor from outside the University) in period 1, for meeting demand in any of the twelve periods.

The columns represent the periods that the plan must cover, plus the unused and total capacities available. The box in the upper right-hand corner of each cell shows the cost of producing a unit in one period and, in some cases, carrying the unit in storage reservoirs for distribution in future periods, bearing in mind that supplying backorder water quantities is impossible.

We assume the following notation to be followed when dealing with the transportation tableau:

h = water storage cost per unit per one month

r = cost per unit to distribute water using University water distribution network

e = cost per unit to distribute water using emergency tank (truck) pertinent to the University

s = cost per unit to distribute water using subcontractor from outside the University

u = cost of overhead per one unit of undistributed water

I_o = total stored water units at the beginning of an annual distribution program

I_{12} = the desired total stored water units at the end of an annual distribution program

R_t = regular water distribution capacity through University water distribution network during month number t.

E_t = emergency tank (truck) water distribution capacity pertinent to the University during month number t.

S_t = subcontractor water distribution capacity from outside the University and during month number t.

D_t = forecasted demand on water during month number t.

U = total unused capacity of water units

Figure 24: Transportation method for water distribution planning

Through the solution tableau shown at Figure A.7.2, the following values were set based on actual supply, demand and cost of cubic meter of water:

h = 0 JD/m^3/month

r = 1.25 JD/m^3

e = 1.5 JD/m^3

s = 2.5 JD/m^3

u = 0.001 JD/m^3

I_o = 10 m^3/hour

I_{12} = 10 m^3/hour

R_t = not more than 69 m^3/hour

E_t = up more than 11 m^3/hour

S_t = up to 50 m^3/hour

D_t = According to the monthly quantities mentioned through Figure A.14

According to the above running cost shall be: 68.75 JD/month Jan., 12.5 JD/month Feb., 87.75 JD/month Mar., 87.75 JD/month Apr., 95.25 JD/month May, 107.75 JD/month Jun., 81.25 JD/month Jul., 81.25 JD/month Aug., 12.5 JD/month Sep., 87.75 JD/month Oct., 93.75 JD/month Nov. and 106.25 JD/month Dec.

4.3 Planning using transshipment model:

The transshipment model recognizes that it may be cheaper to ship through intermediate or transient nodes before reaching the final destination. This concept is more general than that mentioned through section 54.2 above (transportation model), where direct shipment is allowed between a source and a destination.

In our case we can solve the problem using the transshipment model, such that we have three main water sources feeding the University from three different points i.e. DG#1, DG#2 and

DG#3. Further we have extra source that can serve any point with in the University campus, this source is via external water subcontractor SC.

Above four sources are linked to four main destinations, i.e, 1GR1, 1GR2, 2GR1 and 3GR1 ground reservoirs by way of two main reservoirs, i.e. 2T1 and 3T1 or directly, according to the network shown in Figure 5.8. The supply amounts at inlet points DG1, DG2, DG3 and SC are considered to be 47 m^3/hour, 23 m^3/hour, 5 m^3/hour and 5 m^3/hour, and the demand amounts at ground reservoirs 1GR1, 1GR2, 2GR1 and 3GR1, are 25 m^3/hour, 25 m^3/hour, 25 m^3/hour and 5 m^3/hour. The shipment cost per m^3 (in JDs as mentioned through the above section) between pairs of nodes is shown on the connecting links or arcs in Figure 25 .

Transshipment occurs in the network in Figure 25 because the entire supply water amount of 80 m^3/hour (=47+23+5+5) from nodes DG1, DG2, DG3 and SC could potentially pass through any node of the network before ultimately reaching their destinations at nodes 1GR1, 1GR2, 2GR1 and 3GR1.

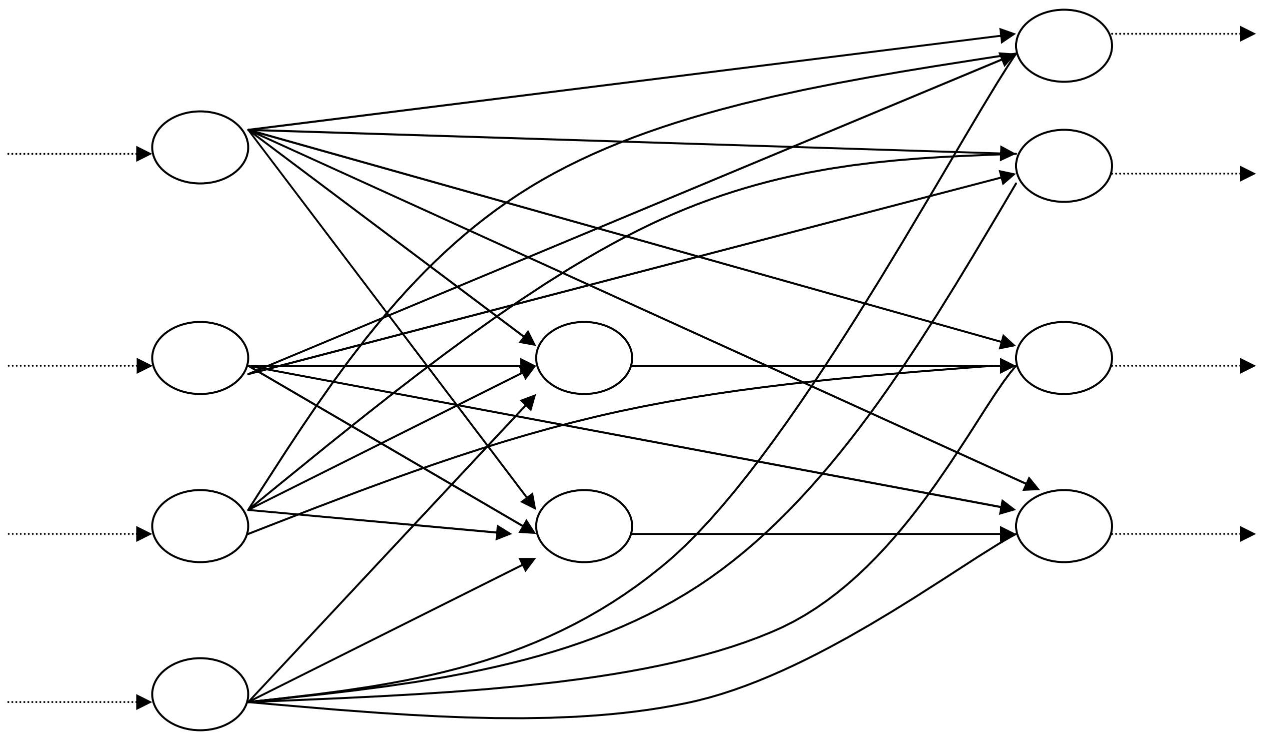


Figure 25: Transshipment network inside the University of Jordan

In this regard, the nodes of the network with both input and output arcs or arrows (2T1 and 3T1) act as both sources and destinations, and are referred to as transshipment nodes. The remaining nodes are either pure supply nodes (DG1, DG2, DG3 and SC) or pure demand nodes (1GR1, 1GR2, 2GR1 and 3GR1). The transshipment model can be converted into a regular transportation model with six sources (DG1, DG2, DG3, SC, 2T1 and 3T1) and other six destinations (2T1, 3T1, 1GR1, 1GR2, 2GR1 and 3GR1). The amount of supply and demand at the different nodes are computed as:

Supply at pure supply node = Original supply

Demand at a pure demand node = Original demand

Supply at a transshipment node = Original supply + Buffer amount

Demand at a transshipment node = Original demand + Buffer amount

The buffer amount should be sufficiently large to allow the entire original supply (or demand) units to pass through any of the transshipment nodes. Let B be the desired buffer amount, then

B = Total supply (or demand)

= 47+25+5+5(or 25+25+25+5)

= 80 m^3/hour

Using the buffer B and the unit shipping costs given in Figure 25, the equivalent regular transportation model is constructed as in Table 6:

Supply \ Demande	2T1	3T1	1GR1	1GR2	2GR1	3GR1	
DG1	1.5	1.5	1.25	1.25	1.5	1.5	47
DG2	0.63	1.5	1.5	1.5	999	1.5	23
DG3	1.5	0.63	1.5	1.5	1.5	999	5
SC	2.5	2.5	2.5	2.5	2.5	2.5	5
2T1	0	1.5	999	999	0.62	999	B
3T1	1.5	0	999	999	999	0.62	B
	B	B	25	25	25	5	

Table 6: Equivalent transportation model

TORA solution of the transportation model is shown in Table A.2 at the Appendix. Figure 26, shown hereunder, displays the optimal routing and quantities for water distribution in case of being forced to use external subcontractor and avoid shortage.

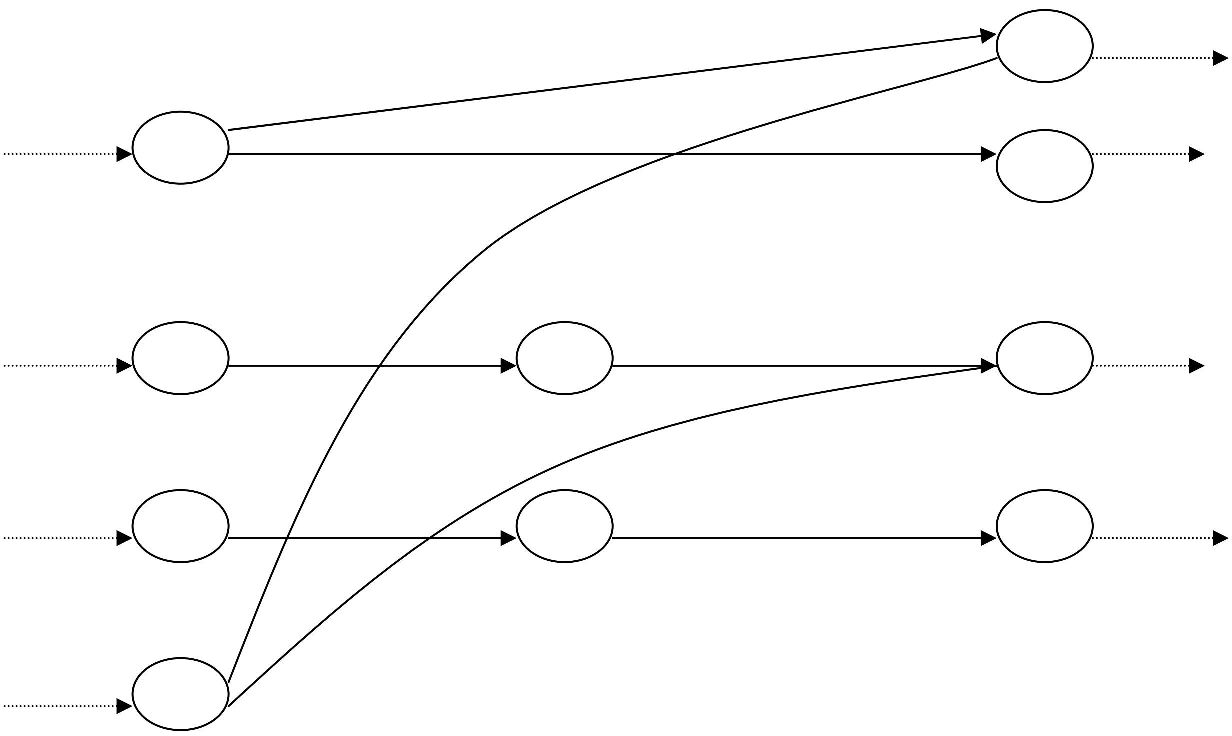


Figure 26: Optimal transshipment network for water distribution

4.4 Development of (Multi-period model) using transshipment concept:

Planning technique mentioned through section 5.4.3, were based on a one time processing method for the problem parameters. (Multi-period model) can be developed and applied at our case study water distribution problem if the time domain was divided in to five different time slots each representing one week within a one distribution cycle for any season – one month. This time division shall be reflected on the water distribution model main physical components such as water feed points readings and ground reservoir demand readings passing through the storage reservoirs in the middle, all adjusted to reflect the proposed time division concept. Table A.2 shows the input data to the TORA transshipment optimization software, Table A.4 shows the output of the TORA

Through this proposed model the transshipment problem can be affected more practically to match with our case study in such a way that more accurate management decisions can be taken. Please have a look at Figure A.19 which shows the proposed water routing for our case study to obtain the least cost water distribution solution along the University campus and to achieve high performance and customer satisfaction level as well by avoiding water shortages by contracting with external water supplier at the minimal necessary level.

5 Performance Measures

5.1 Number of shortages:

It is the total number of shortages counted within one month (4.333 distribution cycles). Each building in the university might suffer number of water shortage events during the successive distribution cycles at any month.

The current status, before installing the proposed SCADA & ANN systems, number of shortages is usually reported to the maintenance and operations department by the inhabitants of the suffering building. Some times complains persist for a long time due to slow communication with maintenance people or the unavailability of water resources in the posses of the last.

It is assumed that the proposed system will provide enough history about the number of shortages and their time and place of occurrence, such that corrective action can be set efficiently to encounter any problem of this type.

5.2 Duration of shortage:

It is the total number of hours per each shortage logged within one month (4.333 distribution cycles). Each building in the university might suffer prolonged period of water shortage during the successive distribution cycles at any month.

It is assumed that the proposed system will provide enough statistics about the average time per each shortage event, such that corrective action can be set to reduce these time durations as much as possible.

Every week (every distribution cycle) basically during Saturday and Friday, the total number of students at university campus decreases to very small number, hence water consumption decreases dramatically. Expected duration of shortage for any distribution group can be calculated along the remaining five days of the week according to the following procedure:

TDQ is
Total Demanded Quantity of water during five days a week =
24hour * 5days * Expected Demand in m^3/h for the concerned group as per demand pattern tables

TSQ is
Total Stored Quantity of water during Sat. & Fri. =
24hour * 2days * Capacity of the network in m^3/h for the concerned group.
Note that TSQ must not exceed the total capacity of the ground reservoirs, also note

TSPQ is
Total Supplied Quantity of water during five days a week =
24hour * 5days * Capacity of the network in m^3/h for the concerned group

Shortage Quantity as a percentage ratio = 100% - Coverage percentage,
Coverage percentage = ((TSQ+TSPQ)/TRQ) * 100%

According to the above formulae, shortage durations have been calculated for each distribution group along the year. Calculations outcome are shown in Table 7:

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1BP1	10%	0%	16%	16%	22%	27%	10%	10%	0%	16%	16%	10%
1MV1	22%	0%	27%	27%	32%	36%	22%	22%	0%	27%	27%	22%
2MV1	2%	0%	10%	10%	16%	21%	2%	2%	0%	10%	10%	2%
3MV1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 7: Shortage duration percentages

1BP1 & 1MV1 are the two main branches within Distribution Group # 1; 2MV1 is the main branch of Distribution Group #2 and 3MV1 is the main branch of Distribution Group #3.

5.3 Observability:

Before installing the proposed SCADA & ANN systems, water distribution process cannot be easily observed under normal conditions, due to the lack of precise and continuous descriptive information about the network different sites conditions.

Upon installing the proposed systems, Observability / controllability shall improve dramatically; hence internal states of the distribution network can be inferred by knowledge of its external outputs.

5.4 Predictability:

Since knowledge of the distribution network past and current states was generally imperfect, predictability will certainly not stay limited upon installing and operating the proposed SCADA & ANN systems for long period of time.

Upon applying abovementioned performance measures at the University water distribution network, we can expect the following main benefits:

1- Better ability of estimating model demands, initial conditions and control settings.

2- Allow precise forecasting for system operations.

3- Gain the ability to calibrate extended-period simulation models.

6 Concluding remarks

One of the primary uses of water distribution system models is to identify problems and evaluate alternative solutions to existing or anticipated problems in water distribution networks. While numerous papers have been written on use of optimization for managing water distribution networks, optimization techniques rarely fit real problems, Waski & Youshock (2002).

Throughout this chapter, ANN is integrated with the SCADA system to participate in generating reliable model fore water demand forecast based on prolonged period of collected data coming from the SCADA system.

But since we are adopting a SCADA as a practical system for data collection, the model to be built by the ANN often has access to more data than can be easily processed. For example, the ANN module may have several weeks of data from which to calibrate an extended-period simulation (EPS) model and must pick a representative day or days to use as the basis for calibration. Selecting the best modeling analysis period from these hundreds of numbers, which may be in several sources, is extremely difficult. Usually, there is no day when all of installed instrumentation is functioning properly, so selecting that day is often based on finding the day with the fewest problems.

This work can be conducted during implementation phase.

Another challenge in working with practical SCADA data is that incorrect readings, time-scale errors, or missing values may not be readily apparent in the mass of raw data.

Fortunately, the ANN module can use a procedure to compile and organize SCADA information into a more usable format, usually in the form of a spreadsheet. The tables and graphs developed using this procedure can then be used directly for a range of applications, including EPS model calibration, forecasting of system operations, and estimating water demands during main seasons.

CONCLUSIONS AND RECOMMENDATIONS

1 Conclusions

In today's environments, major advances arise in utilizing control and communication technologies. In our research these two technologies formed the center-piece of the proposed local area water network management system.

The trend in automating water distribution systems is to use SCADA systems based on PLCs, advanced / reliable radio-communication networks and professional PC-based exploitation software.

SCADA is a broad, divers and valuable part of industry and to a lesser extent science. It allows the remote control of and data acquisition from systems ranging from airports to weather stations, and is the subject of ongoing investment and development.

Throughout this research, a SCADA system with very short update time was developed, in this real time SCADA application, all the parameters of local area water distribution network are monitored and reports generated accordingly. The remote terminal units (RTUs), which are distributed along the University campus, fetch the real time data and send it to the host on which the data is displayed. The host feed the data to man-machine-interface (MMI) screens and provides the operator with a comprehensive overview for the water network.

The primary benefit of the SCADA is to identify and correct problems quickly. By enabling constant monitoring of the condition of the water distribution network, it can often pin-point problems for troubleshooting and necessary corrective actions.

Given the successful implementation of this system, the feasibility of using SCADA for water network monitoring, control and hence management is high.

One might think that water distribution systems would be fertile area to apply some type of optimization. However, this research – based on small case study – illustrated the wide breadth of problems that are faced in just one water network study and highlight the difficulty in developing generalized optimization approaches to manage water distribution networks.

Most of optimization methods presented within this research as well as within literature are based on some of the following assumptions:

- Previous & future demands are currently known in terms of quantity, location and timing.
- Problem can not be isolated i.e. all pipes must be sized simultaneously.
- No understands where the weaknesses in the system are located.
- Any hydraulic capacity in excess of the minimum required to meet operation criteria is to be eliminated.
- No budgetary constraints exist.

As what have been shown and demonstrated throughout this research, very seldom are any of these assumptions valid.

The modeling process in this research did not consist of an author receiving a set of known demands, deciding where problems exist or may occur in the future within the distribution system and then solving those problems. Instead, the process consisted of the author formulating a list of problem areas and meeting with maintenance and operation personnel for a series of brainstorming sessions in which problems were discussed and alternatives were formulated.

Throughout this research, finding the most desirable solution did not involve exhaustively enumerating huge numbers of alternatives, but rather applying teamwork and creativity to solve the problems in cooperation with the University operation and maintenance team. Decisions often hung on tradeoffs between capacity, seasonal demands and supplied quantities from the source.

2 Recommendations for future works

It is recommended to approve and start implementing integrating, installing and maintaining work for the proposed SCADA system at the University water distribution network.

This research has laid the foundations for future work in the University campus, such as to involve and integrate more functions and applications to this central monitoring and control network, as an example, monitoring the status of central heating boilers, fuel tank levels, fire alarm systems and electrical main distribution boards for each building along the University campus, such that maintenance and operation people become fully acquainted about each building real time conditions.

Consequently, similar management and optimization techniques might be developed and applied at these newly introduced monitoring points to achieve perfect monitoring and control system.

References

Wu, Z. Y., Boulos, P. F., Orr, C. H., and Ro, J.E.,(2001), Rehabilitation of Water Distribution Systems Using Genetic Algorithms, **Journal AWWA**.

Thomas, M. Walski, Donald, V. Chase, (2003), **Advanced Water Distribution Modeling And Management**., Haestead Press, 1st, ed, Waterbury, CT.

Boulos, P. F., Wu, Z. Y., Orr, C.H., and Ro, J. J., (2000), Least Cost Design and Rehabilitation of Water Distribution Systems Using Genetic Algorithms. Proceedings of the **AWWA IMTech Conference**, April 16-19, Seattle, WA.

MW SOFT, INC**., (**1999), **H2ONET Scheduler – Users Guide**., Version 1, 300 North Lake Avenue, Suite 1200, Pasadena, CA 91101.

Frank, R., Spellman, (2003), **Handbook of Water & Waste Water Treatment Plant Operations**, Lewrs Publishers CRC press LLC, Florida.

HDR Engineering, Inc., (2001), **Handbook of Public Water Systems**, John Wiley & Sons, 2nd, ed, New York.

L. T. Amy**, (**1993), **Automation Systems for Control and Data Acquisition**. Instruments Society of America, 3rd, ed, Durham - Research Triangle.

Babbitt, H. E., Doland, J. J., and Cleasby, J. L., (1997), **Water Supply Engineering**, McGraw-Hill, 6th, ed, New York.

Twort, A. C., Hoather, R. C., and Law, F. M., (2000), **Water Supply**, Edward Arnold, 5th, ed, London.

Beckerath, A., and Larmann, S., (1992), **Wastewater Measurement and Automation**, Endress + Hauser, Switzerland .

Bateson, R., (1999), **Introduction to Control System Technology**, Printice-Hall Inc., 6th, ed, Newjersy.

Thompson, L. M., (1997), **Industrial Data Communications**, Instrument Society of America, 2nd, ed, Durham - Research Triangle.

Boyer, S. A., (2004), **Supervisory Control And Data Acquisition**, Instrument Society of America, 3rd, ed, Durham - Research Triangle.

Al-Harfi, A. Y., (1997), **Developing a methodology to plan and manage manufacturing automation projects**, Masters Thesis, The University of Jordan.

Bryne, B. Bob., (May1997), SCADA Mailing List, **http://members.iinet.net.au/~ianw/archive/book1.htm**.

Luis, M. Ccamarinha-Matos, and Fernando, J. Martinelli, (1998), **Application of Machine Learning in Water Distribution Networks**, Intelligent Data Analysis Journal, Volume2, Issues 1-4, Pages 311-332.

Manuel Lambert, Bernard Riera, and Gregory Martel, (1999), Application of functional analysis techniquuues to supervisory systems, Reliability **Engineering & System Safety Journal**,Volume 64, Issue 2, Pages 209-224.

Th. H. Gieling, W. Th. M. van Meurs and H. J. Janssen, (1996), A computer network with scada and case tools for on-line process control in greenhousees, **Advances in Space Research Journal**, Volume 18, Issues 1-2, Pages 171-174.

Chrysanthus Chukwuma, (1998), Development and implementation of environmental monitoring and information systems for water resources, **Environmental Management and Health Journal**, Volume 9, Number 4, Pages 153-159.

W. H. Ip, K. C. Lee, and K.L. Yung, (2000), SCADA in an integrated maintenance management system, **Journal of Quality in Maintenance Engineering**, Volume 6 Number 1, Pages 6-19.

Bill Greaves, (1994), SCADA uses radio to bridge the gape, **Sensor Review Journal**, Volume 14, Number 2, Pages 31-34.

Volker Luderitz, (2004), Towards sustainable water resources management, **Management of Environmental Quality Journal**, Volume 15, Number 1, Pages 17-24.

Hamdy Taha, (2003), **Operations Research**, Printshall Education Inc., 7th, ed, Newjersy.

Appendices

I – Tables & Figures:

ملخص

إدارة و أمثلة نظام المياه المحلي
حالة دراسية : ا امعة الأردنية

اعداد

ماهر غازي عبد الله العكش

المشرف

د. زين العابدين طهبوب

تعتبر إدارة تشغيل شبكات المياه بشكل فاعل من أهم التحديات التي يواجهها المسؤولون والعاملون في مجـال خـدمات المياه .
غير أن عدم توفر قاعدة بيانات لمراقبة نظام توزيع المياه ومرافقه الرئيسية بشكل مستمر وفعال إضافة إلى عدم القدرة على التحكم فيه عن بعد يؤدي الى صعوبة التعامل مع الشبكة وإضعاف القدرة على إتخاذ القرار المناسب لمواجهة مـا يطرأ من مشاكل وإدارة شبكة المياه بشكل فاعل.

يقوم هذا البحث بمحاولة حل مسألة إدارة شبكة توزيع المياه المحلية باستخدام نظام جمع معلومات سريع (SCADA System) موزع على جميع مرافق المنطقة المراد مراقبتها والتحكم بها، وقد تم دراسة شبكة المياه المحليـة داخـل حرم الجامعة الأردنية وتبنيها كمثال عملي لتطبيق هذه الفكرة .

وقد تم جمع المعلومات والبيانات عن شبكة توزيع المياه داخل حرم الجامعة وبناءا عليهـا تـم تـصميم نظـام جمـع المعلومات المقترح (SCADA System) كمزود رئيسي لبيانات شبكة المياه على مدار الساعة . تم إقتـراح عـدة نماذج لمعالجة البيانات المجموعة وذلك لمساعدة متخذي القرار في إختيار النموذج الأفـضل للتـشغيل، إلا أن الحـل الرياضي لمثل هذه المسألة غير ممكن بسبب لجوئنا لتبسيط التفاصيل العديدة في شبكة المياه وإهمـال وجـود عوامـل عشوائية كثيرة في المسألة مثل إختلاف ضغط خطوط التوزيع بشكل مستمر ، لذلك تم إدخال البيانات التي جمعت عـن طريق نظام (SCADA) إلى شبكة عصبية (ANN) والإستعانة بها للحصول على الحل الأمثل و مقارنتها بنمـوذج الإستهلاك المتوقع للمياه خلال كل فصل. من ناحية أخرى , تم عمل نموذج رياضي و أخر بإستخدام الشبكات لتـشغيل الشبكة المحلية و تبين منه قدرة الشبكة على تلبية الإحتياجات الحالية. أما النموذج الرياضي, فيمكن الإستعانة به لأمثلة تشغيل الشبكة.