EXPERT DECISION SYSTEM
FOR
WATER DISTRIBUTION UTILITY

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FOR
WATER DISTRIBUTION UTILITY

by

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CERTIFICATE

This is to certify that the thesis, entitled "**Expert Decision System for Water Distribution Utility"**, being submitted by Mr. Sandeep Kulshrestha to the Indian Institute of Technology Delhi for the award of Doctor of Philosophy, is a record of bonafide research work carried out by him under my supervision. The thesis work, in my opinion has reached the standard, fulfilling the requirements for the said degree. Further, I certify that this submission is Mr. Kulshrestha's own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person which to a substantial extent has been accepted for the award of any other degree or diploma of any University or Institute, except where due acknowledgment has been made in the text.

(Rakesh Khosa)
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ABSTRACT

Present research work describes the development of WAMAN – an Expert System (ES) for management of an existing, and by corollary, an ageing Water Supply System. Hydraulic performance of a typical water supply distribution system is governed by complex and obdurate physics. Often utility managers are faced with situations that require highly specialized levels of understanding and proficiency. In these situations, actions (or interventions) are often based on simple 'thumb rules' based instructions which are often routinely handed down following a change of guard or, alternatively, structural changes that are inevitable in the hierarchical ladder of any organization. Further, typical distribution networks are constantly evolving and, therefore, highly dynamic and, as a consequence, these latter rule of thumb instructions may no longer reflect the current physical reality of the network. Clearly, such decisions are required to be taken without the first hand guidance of qualified and experienced experts and the suggested interventions, therefore, may indeed be wholly inappropriate.

To automate decision processes, researchers have often proposed use of software driven and computer based simulated human expertise that is vested with a semblance of an 'artificial intelligence'. In line with these ideas, researchers have also developed several techniques to transfer human expertise in a form that a computer can understand and amongst these techniques, Artificial Intelligence (AI) based Expert Systems have shown good potential for management of complex systems such as a water distribution network.

The dominant objective of this research work was to develop an Artificial Intelligence based Expert System for Management of a Water Distribution Network that is an effective surrogate and, therefore, a substitute for human expertise. The study sought to achieve this aim by incorporating a validated hydraulic model of the study network in the Expert System that is able to (i) generate, for the network manager, scenarios of consequences and impacts corresponding to any intervention and, thereby, enable evaluation of these proposed interventions for effectiveness; and (ii) enable a priori design of interventions by generation of intelligence for the knowledge base

regarding possible, but hypothetical, eventualities that may occur prospectively during the operational horizon of the distribution system.

For a wider appeal, the present work makes use of public domain software CLIPS (C Language Integrated Production System) developed by National Aeronautics and Space Administration (NASA) of USA. The ES has been designed as a Personal Computer (PC) based application using Visual Studio.Net (VS) platform. The study is based on two case studies namely (i) a hypothetical water distribution network, referred to as Anytown Network, taken from literature (Walski et al., 1987, and Kapelan, 2002,), and (ii) a segment of supply network serving a part of the residential neighbourhood of Vasant Vihar, New Delhi (India). The former network has been used as the basic platform on which all hydraulic modelling related study, including calibration studies, has been based and the latter network has been taken up for study to demonstrate the development of WAMAN Expert System. The choice of Anytown Network was necessitated by the fact that actual observations on hydraulic state variables of pressures and flows was not available and had to be synthetically generated and adopted in the study.

Following are the highlights of the study along with some significant achievements of the research.

1. WAMAN – Experts System has been developed for a water distribution network as an aid to its effective management.
2. WAMAN has a modular structure and also includes modules for Network Calibration, Daily Run Simulation, Daily Diagnostics, Planning, Consumer Complaints and Information amongst others.
3. WAMAN has been designed with a dedicated Calibration Module and various automatic calibration formulations have been developed such as the heuristics based Ant Colony Optimization Algorithm (ACOA) and Genetic Algorithms (GA). The Calibration Algorithm has been developed on MATLAB platform and integrated with Visual Studio using a DLL component and is designed to facilitate the task of obtaining credible estimates of internal roughness values of pipes of an existing network.

4. Novel enhancements of the basic calibration algorithm have been proposed and evaluated. The study demsonstrates a successful, first time adaptation of Ant Colony Optimization technique for a water supply network calibration and is shown to yield a better performance than the widely used Genetic Algorithms based optimization approach at least for the case studies evaluated in the present research.
5. Further enhancements include:
    i. Development of a Hybrid Ant Colony algorithm that also features the local search capability of GAs by using operations that mimic crossover and mutation.
    ii. Development of a novel formulation of Ant Colony Optimization Algorithm designed with a reinforced search capability that enables the Algorithm to accommodate and utilize additional knwoledge of the network which is specified a priori. The proposed algorithm uses an objectively derived, age-based, prior information on the internal pipe roughness values to drive the calibration process.
6. The study establishes that the proposed Hybrid algorithm is more efficient than the Ant Colony Optimization algorithm when used without the local search feature of GAs. Further, the study also establishes that the Ant Colony Algorithm when implemented with Prior Information (PI) has the best search capabilities and surpasses even the Hybrid algorithm.
7. Since calibration algorithm itself requires a large number of iterative solutions of the network solver, an additional, inbuilt network solver based on the improved Gradient Method of Todini and Pilati, 1987, has been developed and incorporated in WAMAN. The Hydraulic Network Solver was developed in MATLAB and has been linked to the Visual Studio platform through its corresponding DLL.
8. WAMAN incorporates a dynamic knowledge acquisition system driven by simulated runs of a hydraulic model, suitably calibrated and validated for the given water utility.
9. In addition, WAMAN has been endowed with Visualization capabilities for graphical display of network model and related

information by enabling capability to handle shape files using public domain Geographical Interface Software (GIS) software, MapWinGIS.

10. WAMAN has been designed with features that include MATLAB based standalone Dynamic Linked Library (DLL) components for computational capabilities.
11. An external Structures Query Language (SQL) based Relational Data Base Management System, (RDBMS), was designed for WAMAN as an added feature and this effectively overcomes the limitation on account of non-availability of a dedicated database system in the expert system shell, CLIPS.
12. Simulation module of WAMAN has been designed to enable simulation studies for general purpose planning, planning of enhancement/upgrades for the network as well solving other network problems. This module has CLIPS rules working at the back end to guide the user to understand implications of any proposed intervention.
13. The planning module of WAMAN estimates Hazen-Williams C-values that are likely over various time horizons of 5, 10, 15, and 20 years and, for each such horizon, additionally computes (i) total energy requirement, (ii) total head loss across the network, (iii) head loss in each individual pipe, and (iv) temporal variation of Hazen- Williams C-values. The module also has the capability to present a graphical depiction of the above information besides populating the databases of WAMAN.
14. The Daily Run Module of WAMAN logs operational attributes in order to be able to offer diagnostic inferences from the logged daily runs. This module has subordinate component sub-modules for the following tasks: (i) retrieve status of the study network on some previous date and time (Sub-Module- I); (ii) generate daily run scenario for a given set of input conditions (Sub-Module-II); and (iii) diagnose specific consumer complaints (Sub-Module-III). CLIPS rule base works on the back end of the module and diagnoses the daily run scenario and issues advice/ suggestions about expected network problems. The Sub-Module-III of the module handles consumer complaints.

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