UNIVERSITY OF EXETER
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COLLEGE OF ENGINEERING, MATHEMATICS AND PHYSICAL SCIENCES

A Risk-Based Decision Support System for Failure Management in Water Distribution Networks

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Signature: .....

ABSTRACT

The operational management of Water Distribution Systems (WDS), particularly under failure conditions when the behaviour of a WDS is not well understood, is a challenging problem. The research presented in this thesis describes the development of a methodology for risk-based diagnostics of failures in WDS and its application in a near real-time Decision Support System (DSS) for WDS' operation.

In this thesis, the use of evidential reasoning to estimate the likely location of a burst pipe within a WDS by combining outputs of several models is investigated. A novel Dempster-Shafer model is developed, which fuses evidence provided by a pipe burst prediction model, a customer contact model and a hydraulic model to increase confidence in correctly locating a burst pipe.

A new impact model, based on a pressure driven hydraulic solver coupled with a Geographic Information System (GIS) to capture the adverse effects of failures from an operational perspective, is created. A set of Key Performance Indicators used to quantify impact, are aggregated according to the preferences of a Decision Maker (DM) using the Multi-Attribute Value Theory. The potential of distributed computing to deliver a near real-time performance of computationally expensive impact assessment is explored.

A novel methodology to prioritise alarms (i.e., detected abnormal flow events) in a WDS is proposed. The relative significance of an alarm is expressed using a measure of an overall risk represented by a set of all potential incidents (e.g., pipe bursts), which might have caused it. The DM's attitude towards risk is taken into account during the aggregation process.

The implementation of the main constituents of the proposed risk-based pipe burst diagnostics methodology, which forms a key component of the aforementioned DSS prototype, are tested on a number of real life and semi-real case studies. The methodology has the potential to enable more informed decisions to be made in the near real-time failure management in WDS.

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LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
AIJ	Aggregation of Individual Judgements
AIP	Aggregation of Individual Priorities
ANN	Artificial Neural Network
API	Application Programming Interface
AVG	Average
BFOD	Binary Frame Of Discernment
BPA	Basic Probability Assignment
BPBM	Pipe Burst Prediction Model
BST	British Summer Time
CC	Customer Contact
CCM	Customer Contacts Model
CPU	Central Processing Unit
CR	Consistency Ratio
DB	Database
DBMS	Database Management System
DM	Decision Maker
DMA	District Metered Area
DRM	Discolouration Risk Model
D-S	Dempster-Shafer
DSS	Decision Support System
EE	Engineered Event
EM	Eigenvector Method
EPS	Extended Period Simulation

ES	Expert System
FDD	Fraction of Delivered Demand
FIS	Fuzzy Inference System
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode, Effects, and Criticality Analysis
FTP	File Transfer Protocol
GA	Genetic Algorithm
GIS	Geographic Information System
GM	Geometric Mean
GMT	Greenwich Mean Time
HACCP	Hazard Analysis and Critical Control Point
HDA	Head Driven Analysis
HM	Hydraulic Model
HTTP	HyperText Transfer Protocol
KPI	Key Performance Indicator
MAUT	Multi-Attribute Utility Theory
MAVT	Multi-Attribute Value Theory
MCDA	Multi-Criteria Decision Analysis
NP	Non-deterministic Polynomial time
NSGA	Non-dominated Sorting Genetic Algorithm
ODBC	Open Database Connectivity
OFWAT	The Office of Water Services
OGC	Open Geospatial Consortium, Inc.®
OODBMS	Object-Oriented Database Management System
ORDBMS	Object-Relational Database Management System

OWA	Ordered Weighted Averaging
PCR	Proportional Conflict Redistribution
PDD	Pressure Dependent Demand
PHP	Personal Home Page
PNG	Portable Network Graphics
PRV	Pressure Reducing Valve
PVC	Polyvinyl Chloride
RDBMS	Relational Database Management System
RI	Random Index
R-T	Real-Time
SBX	Simulated Binary Crossover
SCADA	Supervisory Control And Data Acquisition
SCEM-UA	Shuffled Complex Evolution Metropolis
SSE	Sum of Squared Errors
TBL	True Burst Location
TBM	Transferable Belief Model
TPD	Third Party Damage
UI	User Interface
UML	Unified Modelling Language
WA	Weighted Average
WDS	Water Distribution System
WFS	Web Feature Service
WMS	Web Map Service
WMSY	Work Management System
WSS	Water Supply System