



COLLEGE OF ENGINEERING, MATHEMATICS AND PHYSICAL SCIENCES

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

*Submitted by Josef Bicik to the University of Exeter  
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# 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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# TABLE OF CONTENTS

<b>ABSTRACT .....</b>	<b>2</b>
<b>ACKNOWLEDGEMENTS .....</b>	<b>3</b>
<b>TABLE OF CONTENTS .....</b>	<b>4</b>
<b>LIST OF FIGURES.....</b>	<b>8</b>
<b>LIST OF TABLES.....</b>	<b>11</b>
<b>LIST OF ABBREVIATIONS.....</b>	<b>12</b>
<b>CHAPTER 1 INTRODUCTION .....</b>	<b>15</b>
1.1 Motivation and Background.....	15
1.2 Aims and Objectives.....	17
1.3 Thesis Structure .....	18
<b>CHAPTER 2 REVIEW OF LITERATURE .....</b>	<b>20</b>
2.1 Introduction .....	20
2.2 Decision-Making & Decision Support .....	20
2.2.1 Real-Time Decision Support .....	22
2.3 The Concept of Risk and Its Applications.....	23
2.3.1 WDS Reliability Studies.....	24
2.3.2 Applications of Risk .....	24
2.4 Burst Detection and Diagnostics .....	29
2.4.1 Data and Model Driven Anomaly Detection.....	30
2.4.2 Anomaly Diagnostics .....	31
2.5 Failure Impact in WDS.....	34
2.5.1 WDS Modelling Under Failure Conditions.....	38
2.5.2 Pipe Burst Modelling.....	40
2.6 Information Fusion .....	43
2.7 Summary & Conclusions.....	44
<b>CHAPTER 3 RISK-BASED PIPE BURST DIAGNOSTICS .....</b>	<b>48</b>
3.1 Introduction .....	48
3.2 Risk-Based Decision-Making.....	49

---

3.3	Likelihood Component of Risk .....	55
3.3.1	Dempster-Shafer Theory of Evidence .....	56
3.3.2	Information Sources .....	59
3.3.3	Information Fusion .....	63
3.3.4	Independence Assumption.....	68
3.3.5	Dempster-Shafer Model Calibration .....	69
3.4	Impact Component of Risk.....	73
3.4.1	Customer Categories .....	74
3.4.2	Failure Modelling .....	75
3.4.3	Impact Aggregation .....	77
3.4.4	Key Performance Indicators .....	79
3.5	Abnormal Event Prioritisation.....	90
3.5.1	Alarm Ranking .....	92
3.5.2	Diagnostics and Risk Assessment .....	93
3.5.3	Pipe Burst Risk Aggregation .....	93
3.5.4	Overall Risk Aggregation.....	95
3.5.5	Anomaly Ordering.....	98
3.6	Summary.....	100
<b>CHAPTER 4 DSS IMPLEMENTATION.....</b>		<b>102</b>
4.1	Introduction .....	102
4.2	Architecture Overview .....	102
4.3	Database Management System.....	104
4.4	The Back-End .....	106
4.4.1	Alarm Monitor .....	107
4.4.2	Likelihood Evaluator .....	109
4.4.3	Impact Evaluator.....	111
4.4.4	Alarm Ranking .....	117
4.5	The Front-End .....	119
4.5.1	System Overview User Interface.....	119
4.6	External Modules.....	123
4.7	Summary.....	124
<b>CHAPTER 5 CASE STUDIES .....</b>		<b>126</b>

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5.1	Introduction .....	126
5.2	Hydraulic Model Evidence.....	127
5.2.1	Large Burst Flow Simulations (EE1) .....	128
5.2.2	Medium Burst Flow Simulations (EE2) .....	137
5.2.3	Engineered Events in a Typical DMA (EE3) .....	140
5.3	Dempster-Shafer Model: Semi-Real Case Study .....	144
5.3.1	Individual Model Screening .....	146
5.3.2	Dempster-Shafer Model Calibration .....	149
5.3.3	Results and Discussion .....	156
5.3.4	Sensitivity Analysis .....	163
5.3.5	Comparison with Other Methods .....	165
5.4	Impact Model.....	165
5.4.1	Impact Importance Survey.....	166
5.4.2	Questionnaire Survey Analysis Methodology.....	169
5.4.3	Questionnaire Survey Results.....	172
5.5	Alarm Prioritisation Case Study .....	176
5.5.1	Main Results .....	177
5.5.2	Detailed Alarm Prioritisation Results.....	180
5.5.3	Sensitivity Analysis .....	187
5.5.4	Discussion.....	189
5.6	Summary.....	189
<b>CHAPTER 6 CONCLUSIONS.....</b>		<b>192</b>
6.1	Summary.....	192
6.1.1	Summary of the Contributions .....	193
6.2	Main Conclusions .....	194
6.2.1	Risk-Based Pipe Burst Diagnostics .....	194
6.2.2	Dempster-Shafer Model .....	195
6.2.3	Impact Model.....	197
6.2.4	Alarm Prioritisation & Ranking .....	199
6.3	Future Research .....	200
6.3.1	Dempster-Shafer Model .....	200
6.3.2	Impact Model.....	201

---

6.3.3	Alarm Prioritisation & Ranking .....	202
<b>APPENDIX A</b>	<b>EVIDENCE THEORY .....</b>	<b>204</b>
<b>APPENDIX B</b>	<b>FAILURE IMPACT SURVEY .....</b>	<b>214</b>
<b>APPENDIX C</b>	<b>HYDRAULIC MODEL RESULTS .....</b>	<b>218</b>
<b>APPENDIX D</b>	<b>D-S MODEL PERFORMANCE .....</b>	<b>228</b>
<b>GLOSSARY</b> .....		<b>237</b>
<b>BIBLIOGRAPHY</b> .....		<b>239</b>
	Papers Presented by the Candidate .....	239
	List of References .....	240

## LIST OF FIGURES

Figure 3.1 Structure of the risk-based pipe burst diagnostics methodology .....	49
Figure 3.2 A conceptual diagram of the alarm generation process .....	50
Figure 3.3 A high level overview of the risk-based diagnostics methodology .....	51
Figure 3.4 An example risk map of a real pipe burst .....	52
Figure 3.5 A scatter plot showing distribution of risk of two alarms.....	54
Figure 3.6 An example of spatial distribution of Belief and Plausibility.....	56
Figure 3.7 A graphical representation of Belief and Plausibility .....	57
Figure 3.8 Sources of evidence used in the information fusion .....	60
Figure 3.9 Weighed distance from customer contacts to a pipe.....	62
Figure 3.10 Transformation of measurement criteria into BPAs based on Beynon (2005) .....	64
Figure 3.11 A data flow diagram of the information fusion process.....	66
Figure 3.12 An example of a mapping curve .....	69
Figure 3.13 An example of the Rank of the TBL (Link Id 0004G2MM) .....	72
Figure 3.14 An example of a Pareto front .....	72
Figure 3.15 A relationship between pressure and demand of node $j$ .....	76
Figure 3.16 A sample outflow profile from a pressure sensitive burst.....	77
Figure 3.17 A tree of objectives .....	78
Figure 3.18 Measurement of duration of supply interruption and low pressure impact	82
Figure 3.19 A map showing the DISCM KPI after a pipe burst .....	85
Figure 3.20 An example output from the third party damage model .....	90
Figure 3.21 A hierarchical representation of alarms and potential incidents .....	93
Figure 3.22 Distance metric used to represent aggregated risk of a pipe burst.....	95
Figure 3.23 The effect of DM's attitude towards risk $\alpha$ on maximum entropy OWA weights.....	98
Figure 3.24 An alarm state diagram .....	99
Figure 4.1 A simplified overview of DSS architecture .....	103
Figure 4.2 An entity-relationship diagram capturing the main tables used by the DSS	105
Figure 4.3 The interaction of processes involved in anomaly diagnostics.....	107
Figure 4.4 An activity diagram describing the Alarm Monitor module.....	108
Figure 4.5 An activity diagram describing the Likelihood Evaluator module .....	110



---

Figure 4.6 An activity diagram describing the Impact Evaluator module.....	112
Figure 4.7 A database-centric architecture for distributed impact evaluation.....	114
Figure 4.8 Speedup achieved using distributed computing.....	115
Figure 4.9 Speedup achieved using distributed computing on 1 node vs. N nodes .....	116
Figure 4.10 An activity diagram describing the Alarm Ranking module .....	118
Figure 4.11 Table structure of the cache used to store maximum entropy weights .....	119
Figure 4.12 A screen capture of GIS layers projected on top of a background map....	120
Figure 4.13 Online generation of GIS layers from a spatial DB .....	121
Figure 4.14 An example of an alarm list .....	122
Figure 4.15 An interactive trend display .....	123
Figure 5.1 Location of the case study area in the UK .....	127
Figure 5.2 An overview of the case study area for EE1 and EE2 .....	129
Figure 5.3 Erroneous data from sensors 3583 and 3587 .....	130
Figure 5.4 Pressure data of a selected logger for event detection on 6 and 7 August 2008 .....	133
Figure 5.5 Comparison of flow data on 7 August 2008 with an average demand .....	134
Figure 5.6 Corrupt flow data of logger 3276.....	138
Figure 5.7 An overview of the case study area for EE3 .....	141
Figure 5.8 A map showing the most likely location of hydrant opening of EE3 .....	143
Figure 5.9 An overview of DMA E022.....	145
Figure 5.10 A histogram of an average distance of customer contact from a burst location .....	148
Figure 5.11 Illustration of the Proximity function.....	150
Figure 5.12 A 2D View of the 3D Pareto front showing the chosen solution.....	153
Figure 5.13 Mapping functions of the PBPM .....	153
Figure 5.14 Mapping functions of the HM.....	154
Figure 5.15 Mapping functions of the CCM .....	154
Figure 5.16 An example output from the a) PBPM, b) HM, c) CCM and d) the D-S model: $BetP(\{Burst\})$ .....	159
Figure 5.17 Belief and Plausibility maps produced by the D-S model .....	160
Figure 5.18 Distribution of respondents depending on their role within a company ...	169
Figure 5.19 The relative importance of various types of customers .....	174
Figure 5.20 The relative importance of different types of impact.....	174

---

Figure 5.21 The relative importance of different types of Economic impact.....	175
Figure 5.22 An objective tree used in impact aggregation with determined weights ..	175
Figure 5.23 Case study area overview with locations of inlet flow meters and alarms	177
Figure 5.24 An example of ranking based on histogram and an average.....	178
Figure 5.25 A risk map of alarm 8777 .....	180
Figure 5.26 A risk map of alarm 8966 .....	182
Figure 5.27 A risk map of alarm 9030 .....	182
Figure 5.28 A scatter plot of alarms 8966 and 9030 .....	183
Figure 5.29 A risk map of alarm 8802 .....	184
Figure 5.30 A risk map of alarm 8660 .....	185
Figure 5.31 An original (un-filtered) scatter plot of alarms 8854 and 8563 .....	186
Figure 5.32 A filtered scatter plot of alarms 8854 and 8563.....	186
Figure 5.33 Influence of parameter values on distance from a reference solution.....	188
Figure A.1 A relationship between <i>Bel</i> and <i>Pl</i> functions (Agarwal <i>et al.</i> 2004).....	205
Figure A.2 Combination of N independent bodies of evidence .....	207
Figure A.3 A hierarchical structure of evidence.....	207
Figure C.1 The most likely location of hydrant opening for EE1-1.....	219
Figure C.2 The most likely location of hydrant opening for EE1-2.....	220
Figure C.3 The most likely location of hydrant opening for EE1-3.....	221
Figure C.4 The most likely location of hydrant opening for EE1-4.....	222
Figure C.5 The most likely location of hydrant opening for EE1-5.....	223
Figure C.6 The most likely location of hydrant opening for EE2-5.....	224
Figure C.7 The most likely location of hydrant opening for EE2-4.....	225
Figure C.8 The most likely location of hydrant opening for EE2-1.....	226
Figure C.9 The most likely location of hydrant opening for EE2-2.....	227
Figure D.1 a) PBPM, b) HM, c) CCM and d) D-S Model results for case #7080348 .	229
Figure D.2 a) Belief and b) Plausibility of the D-S Model for case #7080348.....	230
Figure D.3 a) PBPM, b) HM, c) CCM and d) D-S Model results for case #8905881 .	231
Figure D.4 a) Belief and b) Plausibility of the D-S Model for case #8905881 .....	232
Figure D.5 a) PBPM, b) HM, c) CCM and d) D-S Model results for case #9315021 .	233
Figure D.6 a) Belief and b) Plausibility of the D-S Model for case #9315021 .....	234
Figure D.7 a) PBPM, b) HM and c) D-S Model results for case #4639990.....	235
Figure D.8 a) Belief and b) Plausibility of the D-S Model for case #4639990.....	236

## LIST OF TABLES

Table 3.1 Structure of a vector of decision variables $\mathbf{z}$ .....	71
Table 3.2 Available types of surfaces, their reclassification and category.....	89
Table 3.3 Types of roads and their sub-category.....	89
Table 4.1 Results of profiling of the distributed Impact Evaluator .....	117
Table 5.1 Difference between pressure measurements and the HM in m of head .....	131
Table 5.2 Detected and actual hydrant opening times of EE1 .....	133
Table 5.3 Summary of times and abnormal flows used by the HM .....	135
Table 5.4 HM hydrant opening results for EE1.....	136
Table 5.5 Time schedule and hydrant flow rate of EE2 .....	138
Table 5.6 HM hydrant opening results for EE2.....	139
Table 5.7 Alarm information provided by a pipe burst detection module .....	142
Table 5.8 Pressure measurement corrections for EE3.....	142
Table 5.9 An average distance of CCs from a burst pipe .....	147
Table 5.10 A histogram showing frequency of CCs per pipe burst .....	147
Table 5.11 Detailed results of the performance of the D-S model.....	156
Table 5.12 An overview of the performance of the D-S model .....	161
Table 5.13 Performance of the D-S model compared with PBPM, HM and CCM based on spatial distribution of the likelihood of potential incidents .....	163
Table 5.14 Results of a global sensitivity analysis (case 9315021) .....	164
Table 5.15 Comparison of the performance of the D-S theory with other combination functions .....	165
Table 5.16 A summary of questions included in the online survey .....	167
Table 5.17 Arithmetic scale used in AHP (adapted from (Saaty (1980)).....	168
Table 5.18 A pairwise comparison matrix $\mathbf{A}$ for Customer importance (Company 1).....	171
Table 5.19 Values of Random Index for a given number of criteria.....	172
Table 5.20 An overview of consistency of the responses.....	173
Table 5.21 A list of 50 alarms considered in this case study.....	178

## 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