

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Need for early prediction of reliability for software systems . . . . .	5
1.2	Motivation of Research . . . . .	6
1.3	Objectives of the present work . . . . .	8
1.3.1	Uncertainty in Markov reliability models . . . . .	8
1.3.2	Uncertainty in input parameters in Markov reliability models and their limitations . . . . .	9
1.3.3	Impact analysis of component reliability on the reliability of a soft- ware system . . . . .	9
1.4	Scope of the Research . . . . .	10
1.5	Thesis Outline . . . . .	10
<b>2</b>	<b>Literature Survey</b>	<b>12</b>
2.1	Introduction . . . . .	12
2.2	Dependability . . . . .	12
2.3	Classification of Computer Based Systems . . . . .	16
2.4	Hardware and Software Reliability . . . . .	17
2.5	Fundamentals of Software Reliability . . . . .	18
2.5.1	Time to failure . . . . .	19
2.5.2	Reliability function . . . . .	19
2.5.3	Hazard Rate . . . . .	20
2.6	Probability Distributions and Reliability Functions . . . . .	23

2.6.1	Exponential Distribution . . . . .	23
2.6.2	Weibull Distribution . . . . .	23
2.6.3	Rayleigh Distribution . . . . .	24
2.7	Classification of Software Reliability Models . . . . .	25
2.7.1	Data-domain models . . . . .	26
2.7.1.1	Fault-seeding models . . . . .	26
2.7.1.2	Input-domain models . . . . .	26
2.7.1.3	Time-domain models . . . . .	27
2.7.1.4	Bayesian software reliability growth models . . . . .	27
2.7.1.5	Other models . . . . .	27
2.8	An Overview of Software Reliability Early Prediction . . . . .	27
2.8.1	Limitations of existing approaches . . . . .	30
2.8.1.1	Modeling Limitations . . . . .	31
2.8.1.2	Analysis Limitations . . . . .	31
2.8.1.3	Parameter Estimation Limitations . . . . .	32
2.8.1.4	Validation Limitations . . . . .	32
2.8.1.5	Optimization Limitations . . . . .	32
<b>3</b>	<b>Problem Formulation and Solution Strategies</b>	<b>33</b>
3.1	Introduction . . . . .	33
3.2	Problem Formulation . . . . .	35
3.2.1	Uncertainty in Markov reliability models . . . . .	35
3.2.2	Uncertainty in input parameters in Markov reliability models and their limitations . . . . .	35
3.2.3	Impact analysis of component reliability on the reliability of a software system for preventive action . . . . .	36
3.2.4	Updation of components reliability during testing / operational phase for corrective action . . . . .	36
3.3	Solution Strategies . . . . .	37
3.3.1	Strategy for dealing with the uncertainty in Markov reliability models	37

3.3.2	Strategy for dealing with the uncertainty in Markov reliability models and their limitations . . . . .	38
3.3.3	Strategy for dealing with impact analysis of component reliability on the reliability of a software system for preventive action . . . . .	38
3.3.4	Strategy for updation of components reliability during testing/operational phase for corrective action . . . . .	39
<b>4</b>	<b>UML Approach to Markov Reliability Modeling</b>	<b>41</b>
4.1	Introduction . . . . .	41
4.2	A Case Study . . . . .	43
4.2.1	Short description of ECCS . . . . .	43
4.2.2	ECCS Instrumentation . . . . .	44
4.2.3	Control logic module . . . . .	45
4.3	Defining attributes into scenario specifications . . . . .	46
4.3.1	Basic Message sequence Chart (BMSC) . . . . .	47
4.3.2	High-level Message Sequence Charts (HMSC) . . . . .	48
4.3.3	Labeled Transition Systems (LTS) . . . . .	48
4.4	A Technique for Early Software Reliability Prediction . . . . .	49
4.4.1	Phase1: Scenario Specification . . . . .	50
4.4.2	Phase2: LTS components identification . . . . .	51
4.4.3	Phase3: Reliability model creation . . . . .	57
4.4.4	Phase4: Reliability prediction . . . . .	58
4.5	Sensitivity Analysis . . . . .	61
4.6	Experimental Validation . . . . .	63
4.7	Conclusion . . . . .	65
<b>5</b>	<b>Transition Probability Prediction in MC</b>	<b>66</b>
5.1	Introduction . . . . .	66
5.2	Related work . . . . .	67
5.3	The proposed method for transition probability prediction . . . . .	68

5.3.1	Phase1: Petri net model creation . . . . .	69
5.3.2	Phase2: Model Parameter assignment . . . . .	69
5.3.3	Phase3: Reachability graph creation . . . . .	69
5.3.4	Phase4: Markov Chain creation . . . . .	70
5.3.5	Phase5: Transition Probability estimation . . . . .	71
5.4	A Case Study . . . . .	72
5.4.1	ECCS Design Requirements . . . . .	72
5.4.2	Test Facility . . . . .	74
5.4.3	Test Facility Architecture . . . . .	75
5.4.4	Communication Module in TF . . . . .	76
5.5	Application of proposed framework for prediction of transition probabilities in Markov reliability model . . . . .	77
5.5.1	Phase 1: Petri net model creation . . . . .	77
5.5.2	Phase2: Model Parameter assignment . . . . .	78
5.5.3	Phase3: Reachability graph creation . . . . .	79
5.5.4	Phase4: Markov Chain creation . . . . .	79
5.5.5	Phase5: Transition Probability estimation . . . . .	81
5.6	Validation of our approach . . . . .	82
5.6.1	Reliability estimation, based on the predicted transition probabilities	82
5.6.2	Reliability estimation, based on the operational profile data . . .	85
5.6.2.1	Phase 1: Data Collection . . . . .	85
5.6.2.2	Phase 2: Data Analysis . . . . .	86
5.6.2.3	Phase 3: Reliability Computation . . . . .	86
5.6.2.4	Phase 4: Reliability Comparison . . . . .	87
5.7	Sensitivity Analysis of Parameter assignment . . . . .	89
5.8	Performance estimation . . . . .	89
5.9	Conclusion . . . . .	91
<b>6</b>	<b>Dynamics in Modeling for Reliability Prediction</b>	<b>97</b>
6.1	Introduction . . . . .	97

6.2	Inference via Bayesian Networks . . . . .	100
6.3	A Case Study . . . . .	101
6.4	Reliability Estimate Updation . . . . .	101
6.5	Experimental Validation . . . . .	105
6.6	Conclusion . . . . .	108
<b>7</b>	<b>Conclusion and Future Research</b>	<b>109</b>
7.1	Uncertainty in Markov reliability models . . . . .	110
7.2	Uncertainty in input parameters in Markov reliability models and their limitations . . . . .	110
7.3	Impact analysis of component reliability on the reliability of a software system for preventive action . . . . .	111
7.4	Updation of components reliability during testing/ operational phase for corrective action . . . . .	112
7.5	Future Work . . . . .	112
<b>Appendices</b>		<b>114</b>
<b>A</b>	<b>Software Reliability Growth Models</b>	<b>115</b>
A.1	Data Domain Models . . . . .	115
A.1.1	Fault-seeding models . . . . .	115
A.1.1.1	Mills's Hypergeometric Model . . . . .	115
A.1.2	Input-domain models . . . . .	117
A.1.2.1	Nelson Input Domain Model . . . . .	117
A.1.2.2	Brown and Lipow Input Domain Model . . . . .	117
A.1.2.3	Ramamoorthy and Bastani Input Domain Model . . . . .	118
A.2	Time-domain models . . . . .	120
A.2.1	Homogeneous Markov Models . . . . .	121
A.2.2	Non-Homogeneous Markov Models . . . . .	121
A.2.3	Semi-Markov Models . . . . .	122
A.2.4	Jelinski-Moranda de-eutrophication model . . . . .	122

A.2.5	Goel-Okumoto Imperfect Debugging Model . . . . .	124
A.2.6	Schick and Wolverton Model . . . . .	125
A.2.7	Finite Failure NHPP Models . . . . .	125
A.2.8	State-space view of NHPP . . . . .	127
A.2.9	Infinite Failure Models . . . . .	131
A.2.9.1	Musa-Okumoto Logarithmic Poisson Execution Time Model	132
A.2.9.2	Duane Model . . . . .	132
A.2.9.3	Log-Power NHPP Model . . . . .	133
A.3	Bayesian software reliability growth models . . . . .	133
A.4	Other Models . . . . .	136
A.4.1	Error Complexity Model . . . . .	136
A.4.2	Littlewood-Verall (LV) Bayesian Model . . . . .	137
A.4.3	Littlewood and Keiller (LK) Bayesian Model . . . . .	138
<b>B</b>	<b>TimeNET TOOL</b>	<b>139</b>
B.1	Introduction . . . . .	139
B.2	System Requirements . . . . .	140
B.3	Downloading TimeNET . . . . .	140
B.4	How to Install the Tool . . . . .	141
B.5	Configure a multi-user installation . . . . .	142
B.6	Starting the Tool . . . . .	142
B.7	Configuring the User Interface . . . . .	142
B.8	Upgrading to TimeNET 4.0 . . . . .	142
B.8.1	Conversion of old Model Files . . . . .	143