
Contents

1	Introduction	1
1.1	Stochastic Discrete Event Systems	2
1.2	Applications and Goals of Modeling	4
1.3	Overview of Topics	5
1.4	Notation and Selected Background	9

Part I Modeling

2	A Unified Description for Stochastic Discrete Event Systems	17
2.1	Informal Description	18
2.2	Static Model Definition	19
2.3	Dynamic Behavior of Stochastic Discrete Event Systems	23
2.3.1	Rules for a Behavioral Definition	24
2.3.2	The Stochastic Process Defined by an SDES	26
2.4	Measuring the Performance of SDES	36
2.4.1	Reward Variable Specification	37
2.4.2	Derivation of Reward Variables	40
3	Stochastic Timed Automata	45
3.1	Informal Introduction	46
3.2	Model Class Definition	48
3.3	Automata as SDES	49
3.4	UML Statecharts	51
3.5	Transformation of Statecharts into Stochastic Petri Nets	57
3.5.1	States	58
3.5.2	Transitions	59
3.5.3	A Transformation Algorithm	62

4	Queuing Models	65
4.1	Informal Introduction	66
4.2	Model Class Definition	71
4.3	Representing Queuing Networks as SDES	73
5	Simple Petri Nets	79
5.1	Introduction to Stochastic Petri Nets	80
5.2	The Dynamic Behavior of a SPN	88
5.3	A Formal Definition	91
5.4	An SDES description of SPNs	93
6	Colored Petri Nets	99
6.1	Informal Introduction	100
6.1.1	Token Types or Colors	100
6.1.2	Places	101
6.1.3	Arcs and Arc Inscriptions	102
6.1.4	Transitions	104
6.1.5	Model Hierarchy	106
6.1.6	Syntax of Expressions	107
6.1.7	Performance Measures of Colored Petri Nets	108
6.2	On the Dynamic Behavior of Stochastic Colored Petri Nets ...	109
6.3	Model Class Definition	112
6.4	A SDES Description of Colored Petri Nets	115
6.5	Variable-Free Colored Petri Nets	118
6.5.1	An Example	119
6.5.2	Model Class Definition	121
6.5.3	Representing vfSCPNS as SDES.....	122

Part II Evaluation

7	Standard Quantitative Evaluation Methods for SDES	127
7.1	Prerequisites	130
7.2	Next-Event Time Advance Simulation.....	133
7.2.1	Common Functions	135
7.2.2	Estimation of Steady-State Measures	138
7.2.3	Estimation of Transient Measures	141
7.3	Numerical Analysis	143
7.3.1	Reachability Graph Generation	144
7.3.2	Continuous-Time Markov Chain Analysis.....	147
7.3.3	Steady-State Analysis of Non-Markovian Models	151

8	An Iterative Approximation Method	157
8.1	Model Partitioning	159
8.2	MIMO Graph-Based Aggregation	159
8.2.1	The Initial MIMO Graph	160
8.2.2	Aggregation of the MIMO Graph	162
8.2.3	Translation into an Aggregated Petri Net	164
8.2.4	Aggregation of vfSCPN Models	165
8.3	Low-Level Systems and the Basic Skeleton	166
8.4	Iterative Throughput Approximation	166
9	Efficient Simulation of SDES Models	169
9.1	Distributed Simulation of SDES Models	170
9.1.1	Fine-Grained Model Partitioning	173
9.1.2	A Logical Time Scheme for SDES Models with Immediate Actions and Priorities	178
9.1.3	Discussion of Compound Simulation Time	192
9.1.4	A Distributed Simulation Algorithm for SDES	200
9.2	Simulation of Models with Rare Events	213
9.2.1	The RESTART Method	214
9.2.2	RESTART Simulation of SDES Models	218
10	System Optimization	223
10.1	Indirect Optimization	224
10.1.1	Simulated Annealing	226
10.1.2	Avoidance of Recomputations with a Cache	228
10.2	A Two-Phase Optimization Strategy	229
10.2.1	Preliminary Notes on Petri Nets	231
10.2.2	Computation of Performance Bounds	233
10.2.3	Approximate Derivation of Profit Values	240
11	Model-Based Direct Control	245
11.1	A Control Interpretation for Petri Nets	246
11.1.1	An Example	247
11.2	Model-Based Control of SDES	249
11.3	Behavior of a Control-Interpreted SDES	251
12	Software Tool Support	253
12.1	TimeNET	253
12.1.1	Supported Net Classes and Analysis Methods	254
12.1.2	Software Architecture of TimeNET 4.0	257
12.1.3	A Model-Class Generic Graphical User Interface	261
12.2	Software Packages for Stochastic Discrete Event Systems	262

Part III Applications

13 Optimization of a Manufacturing System	269
13.1 Types of Manufacturing Systems	270
13.2 Typical Design and Optimization Issues	271
13.3 Profit Function Elements	273
13.4 A Manufacturing System Example	276
13.5 A Generalized Stochastic Petri Net Model of the Example	277
13.6 Profit Function Approximation Quality.....	279
13.7 Results of the Two-Phase Optimization	283
14 Communication System Performability Evaluation	287
14.1 The Future European Train Control System ETCS	288
14.2 Train Operation with Moving Blocks vs. Fixed Blocks.....	290
14.2.1 Fixed Blocks.....	291
14.2.2 Moving Blocks	292
14.3 An ETCS Train Operation and Communication Model	293
14.3.1 A Communication System Failure Model	294
14.3.2 Alternative UML Statechart Model and its Transformation	297
14.3.3 Derivation of a Condensed Failure Model	300
14.3.4 A Moving Block Operation Model	301
14.4 ETCS Performance Under Failures	302
15 Supply Chain Performance Evaluation and Design	307
15.1 A Supply Chain Logistics Example	308
15.2 Colored Petri Net Model of the Supply Chain Example	309
15.2.1 Customer Model	310
15.2.2 Dealership Model.....	312
15.2.3 Plant Model	312
15.2.4 Vehicle Logistics Model	313
15.3 Order-To-Delivery Time Evaluation and Improvement.....	314
15.3.1 Popular Configuration Storage at the Dealership	315
15.3.2 Order Scheduling at the Plant	318
15.3.3 Truck Transport of Customer-Ordered Vehicles.....	319
16 Model-Based Design and Control of a Production Cell	325
16.1 A Production Cell Application Example	325
16.2 Production Cell Modeling with vfSCP.....	327
16.2.1 Main Hierarchical Model	327
16.2.2 Refined Model of the Rotary Picker Arm	329
16.2.3 Integration of Work Plan Information	330

16.3 Performance Evaluation	332
16.3.1 Partition and Aggregation	333
16.3.2 Performance Evaluation Results	335
16.4 Model-Based Online Control	337
17 Summary and Outlook	341
Symbols and Abbreviations	345
List of Figures	353
List of Algorithms	357
List of Tables	359
References	361
Index	383