List of Figures

1.1 Single-channel, single-phase 7
1.2 Single-channel, multi-phase 7
1.3 Multiple-channel, single-phase 8
1.4 Multiple-channel, multiple-phase 8
1.5 Tandom machining system 8
1.6 Machining system with buffer 9
1.7 Machine system with spares 10
1.8 A flexible manufacturing system 10
1.9 State transition diagram of machining system 13
1.10 Classification of redundancy 15
1.11 Machine repair problem with spares 16
1.12 Queueing system 17
1.13 Arrivals and departures of customers at the queue 18
1.14 State transition diagram for MRP with standby 31
1.15 State transition diagram for system failure 33
1.16 $K-$out of$-M$:G system 35
1.17 State transition diagram of MRP with N-policy 36
1.18 State transition diagram of MRP with F-policy 36
1.19 Multi-units series system 37
1.20 Multi-units parallel system 37
1.21 Fuzzy arithmetic 41
1.22 State transition diagram of MRP with switching failure ($\Omega_n = M\lambda\,\bar{q}\,q^n, \Psi_n = M\lambda q^{S-n}, \Lambda_n = M\lambda\bar{q} + (S-n)\nu$) 45
1.23 State transition diagram of MRP with common cause failure 45

2.1 The state transition diagram 69
2.2 Reliability of the system $(R_Y(t))$ wrt t for different parameters . . . 88
2.3 Reliability of the system $(R_Y(t))$ wrt t for different parameters . . . 89
2.4 Mean time-to-failure $(MTTF)$ of the system for different parameters 90
2.5 Sensitivity and relative sensitivity of the reliability of the system . . 91
2.6 Failure frequency of the system $(FF(t))$ wrt t for different parameters 92

2.7 Failure frequency of the system $(FF(t))$ wrt t for different parameters . . . 93
2.8 Expected number of the failed units in the system $(E_N(t)$ wrt t for different parameters . . . 94
2.9 Expected number of the failed units in the system $(E_N(t)$ wrt t for different parameters . . . 95
2.10 Expected throughput of the system $(TP(t))$ wrt t for different parameters . . . 96
2.11 Expected throughput of the system $(TP(t))$ wrt t for different parameters . . . 97
2.12 Machining system availiability $(MA(t))$ wrt t for different parameters 98
2.13 Machining system availiability $(MA(t))$ wrt t for different parameters 99

3.1 The state transition diagram . . . 111
3.2 Expected number of failed units in the machining system . . . 127
3.3 The availability of the machining system . . . 128
3.4 The throughput of the machining system . . . 129
3.5 Machine availability . . . 130
3.6 Failure frequency of the machining system . . . 131
3.7 Expected total cost . . . 132
3.8 Contour of expected total cost wrt μ_1 and μ_2 . . . 133

4.1 The state transition diagram . . . 143
4.2 State probability $P_{2,1}$ and availability of the machining system Av wrt μ for different repair time distribution . . . 164
4.3 State probability $P_{2,1}$ and availability of the machining system Av wrt λ for different repair time distribution . . . 164
4.4 State probability $P_{2,1}$ and availability of the machining system Av wrt ν for different repair time distribution . . . 165
4.5 State probability $P_{2,1}$ and availability of the machining system Av wrt β for different repair time distribution . . . 165
4.6 State probability $P_{2,1}$ and availability of the machining system Av wrt σ for different repair time distribution . . . 166
4.7 State probability $P_{2,1}$ and availability of the machining system Av wrt p for different repair time distribution . . . 166
4.8 State probability $P_{2,1}$ and availability of the machining system Av wrt c for different repair time distribution . . . 167
4.9 State probability $P_{2,1}$ and availability of the machining system Av wrt q for different repair time distribution . . . 167

5.1 The State transition diagram 177
5.2 The membership function $(\eta_{\widetilde{L}})$ of the fuzzy expected number of the customers,units, or data in the machining system (L) 197
5.3 The membership function $(\eta_{\widetilde{L_q}})$ of the fuzzy expected number of the customers, units, or data in the queue (L_q) 197
5.4 The membership function $(\eta_{\widetilde{W}})$ of the fuzzy expected waiting time of the customer, unit, or data in the machining system (W) 197
5.5 The membership function $(\eta_{\widetilde{W_q}})$ of the fuzzy expected waiting time of the customer, unit, or data in the queue (W_q) 198
5.6 The membership function $(\eta_{\widetilde{P_0}})$ of the fuzzy probability that there is no customer, unit, or data in the machining system (P_0) 198
5.7 The membership function $(\eta_{\widetilde{\sigma^2}})$ of the fuzzy variance of the state of the machining system (σ^2) 198
5.8 The sensitivity of the membership function $(\eta_{\widetilde{L}})$ wrt to fuzzy machining system parameters 199
5.9 The sensitivity of the membership function $(\eta_{\widetilde{L_q}})$ wrt to fuzzy machining system parameters 200
5.10 The sensitivity of the membership function $(\eta_{\widetilde{W}})$ wrt to fuzzy machining system parameters 201
5.11 The sensitivity of the membership function $(\eta_{\widetilde{W_q}})$ wrt to fuzzy machining system parameters 202
5.12 The sensitivity of the membership function $(\eta_{\widetilde{P_0}})$ wrt to fuzzy machining system parameters 203
5.13 The sensitivity of the membership function $(\eta_{\widetilde{\sigma^2}})$ wrt to fuzzy machining system parameters 204

6.1 The state transition diagram for reliability analysis 212
6.2 The state transition diagram for availability analysis 216
6.3 Membership grade function for reliability characteristics for illustrative example 229
6.4 Membership grade function for reliability characteristics for varied $\widetilde{\lambda}$ 229
6.5 Membership grade function for reliability characteristics for varied $\widetilde{\nu}$ 230
6.6 Membership grade function for reliability characteristics for varied $\widetilde{\mu}$ 230
6.7 Membership grade function for reliability characteristics for varied $\widetilde{\beta}$ 231

List of Tables

1.1 Contributions on MRP with spares 43
1.2 Contributions in MRP with switching failure & common cause failure 46
1.3 Contributions in MRP with imperfect coverage & reboot delay . . . 47
1.4 Contributions in MRP with fuzzy parameters 49
1.5 Contributions in MRP with working vacation & vacation interruption 51
1.6 Contributions in MRP with Newton-quasi method 52
1.7 Contributions in MRP with supplementary variable method 54

2.1 Latent roots of the coefficient matrix 83
2.2 Constants $a_{h,r}$,$b_{h,r}$,$c_{h,r}$ 84
2.3 Transient-state probabilities 84
2.4 Performance measures 85
2.5 Sensitivity and relative sensitivity of the MTTF of the system 85
2.6 System performance measures for different parameters 86
2.7 System performance measures for different parameters 87

3.1 Illustrative example of the Newton-quasi method with initial guess $\mu_1 = 2, \mu_2 = 10$ 123
3.2 Illustrative example of the Newton-quasi method with initial guess $\mu_1 = 6, \mu_2 = 8$ 123
3.3 The optimal repair rates and expected total cost for different system parameters 124
3.4 The optimal repair rates and expected total cost for different system parameters 125
3.5 The optimal repair rates and expected total cost for different system parameters 126

4.1 State probabilities and availability of the machining system 155
4.2 Performance indices corresponding to Fig. (4.2) 156
4.3 Performance indices corresponding to Fig. (4.3) 157
4.4 Performance indices corresponding to Fig. (4.4) 158
4.5 Performance indices corresponding to Fig. (4.5) 159

4.6 Performance indices corresponding to Fig. (4.6) 160
4.7 Performance indices corresponding to Fig. (4.7) 161
4.8 Performance indices corresponding to Fig. (4.8) 162
4.9 Performance indices corresponding to Fig. (4.9) 163

5.1 The trapezoidal fuzzy number of the fuzzy machining system parameters 193
5.2 The support and core of the fuzzy expected number of the customers, units, or data in the machining system $(\widetilde{L})$ 193
5.3 The support and core of the fuzzy expected number of the customers, units, or data in the queue $(\widetilde{L_q})$ 194
5.4 The support and core of the fuzzy expected waiting time of the customer, unit, or data in the machining system $(\widetilde{W})$ 194
5.5 The support and core of the fuzzy expected waiting time of the customer, unit, or data in the queue $(\widetilde{W_q})$ 195
5.6 The support and core of the fuzzy probability that there is no customer, unit, or data in the machining system $(\widetilde{P_0})$ 195
5.7 The support and core of the fuzzy variance of the state of the machining system $(\widetilde{\sigma^2})$ 196

6.1 Fuzzy number for system parameters 226
6.2 Support and core for reliability characteristics for varied $\widetilde{\lambda}$ 226
6.3 Support and Core for reliability characteristics for varied $\widetilde{\nu}$ 227
6.4 Support and core for reliability characteristics for varied $\widetilde{\mu}$ 227
6.5 Support and core for reliability characteristics for varied $\widetilde{\beta}$ 228