## Contents

### Chapter 1: Introduction

1.1. Background ................................................................. 1  
1.2. Problem statement ...................................................... 3  
1.3. Research objective ...................................................... 5  
1.4. Thesis outline ............................................................ 5  

### Chapter 2: Literature review

2.1. Review of queuing network based manufacturing models ............... 6  
2.2. Review of lot sizing and lead-time effect on MRP system ................... 8  
2.3. Review of planned lead-time estimation methods .......................... 10  

### Chapter 3: Approach

3.1. General assumptions .................................................... 13  
3.2. Dynamic programming based optimization routine .......................... 13  
3.2.1. General approach ................................................... 14  
3.2.2. Principle of optimality .............................................. 16  
3.3. Queuing network theory based manufacturing system model ............. 19  
3.3.1. Basic elements of queuing model ................................ 19  
3.3.2. Analysis of approximate GI/G/m queues .............................. 20  
3.3.2.1. Basic GI/G/1 open queue network and decomposition analysis .... 21  
3.3.2.2. Notations .......................................................... 23  
3.3.2.3. Mean arrival rates .............................................. 23  
3.3.2.4. Mean values of GI/G/1 queuing system .......................... 24  
3.3.2.5. Output process of GI/G/1 queue system .......................... 25  
3.3.2.6. Traffic and traffic variability equations ......................... 25  
3.3.3. GI/G/m queuing model with interference ................................ 27  
3.3.4. Summary of queuing model discussion .............................. 27
3.3.5. MPX................................................................. 28
3.3.5.1 Theory behind MPX............................................. 28
3.3.5.2. Input parameters of a MPX model....................... 29
3.3.5.3. Limitations of modeling in MPX......................... 29

Chapter 4: Methodology......................................................... 31

4.1. Overcoming the MPX limitations..................................... 33
4.1.1. Unlimited buffer capacity........................................... 33
4.1.2. Introducing time phasing among lots........................... 33
4.1.3. Discussion on using steady state average values .......... 37
4.1.3.1. Determining the arrival rate of a lot......................... 38
4.1.3.2. MPX steady state values vs. simulation results.......... 40
4.1.3.3. Unbiased nature of steady state values................. 43
4.2. Assumptions on lot-sizing problem formulation............... 47
4.3. Notation definition....................................................... 48
4.4. Problem formulation..................................................... 49
4.5. Determination of lot release dates................................... 50
4.6. Lead time estimation in the MPX model......................... 52
4.7. Concept of early starting .............................................. 54
4.8. Algorithm................................................................. 56
4.9. Algorithm execution.................................................... 60
4.10. Approximating MPX results........................................ 61
4.11. Limitations of SLLS algorithm .................................... 62

Chapter 5: Modeling a manufacturing system in MPX............. 63

5.1. Input menu bar.......................................................... 63
5.1.1. General data ......................................................... 63
5.1.2. Labor data........................................................... 64
5.1.3. Equipment data..................................................... 65
5.1.4. Product data......................................................... 66
Chapter 6: Simulation model and methodology

6.1. Modeling logic
6.2. Discussion on different ARENA template modules
6.3. Discussion of the statistical issues
6.4. Estimation procedure and statistical issues
6.4.1. Computation

Chapter 7: Experimental design

7.1. Wagner-Whitin (WW) algorithm
7.2. Lead-time estimation method
7.3. Experiment methodology
7.4. Design of experiments
7.5. Performance measures

Chapter 8: Experiment results and discussion

8.1. Parameter setting
8.2. Results
8.3. Results discussion
8.3.1. Results summary
8.3.2. Effect of number of workstations that parts visit on the percentage of lead-time error
8.3.3. Effect of number of workstations that parts visit on WIP cost
8.4. Effect of safety factor K
8.5. Tractability

Chapter 9: Conclusion

9.1 Future Research

Bibliography
Appendix A: Experiment 7 Results ....................................................... 110
Vita ........................................................................................................... 135
List of Figures

Figure 1: Schematic diagram of the proposed approach ........................................... 12
Figure 2: General schematic diagram of dynamic programming ................................. 15
Figure 3: Schematic diagram of modified dynamic programming
    for lot-sizing model ........................................................................................................ 16
Figure 4: Node representation of the multi period lot-sizing problem ......................... 17
Figure 5: Elementary GI/G/1 queue station ................................................................. 22
Figure 6: Description of the simultaneous lot size and lead-time setting (SLLS)
    methodology .................................................................................................................. 32
Figure 7: Display of time phasing concept in MPX ..................................................... 35
Figure 8: Display of “DELAY” concept in MPX for lot2 ............................................. 35
Figure 9: Display of “DELAY” concept in MPX for lot1 ............................................. 36
Figure 10: Display of “production period” parameter in MPX ................................... 40
Figure 11: Parts routing 1 ............................................................................................. 41
Figure 12: Parts routing 2 ............................................................................................. 44
Figure 13: Node representation of the two-period lot-sizing problem ....................... 44
Figure 14: Description of cumulative time concept ...................................................... 52
Figure 15: Concept of early starting .............................................................................. 55
Figure 16: Display of “General data” submenu in MPX ............................................. 64
Figure 17: Display of “Labor” submenu in MPX ......................................................... 65
Figure 18: Display of “Equipment” submenu in MPX ................................................. 66
Figure 19: Display of “Product” submenu in MPX ....................................................... 67
Figure 20: Display of “Output” menu bar in MPX ....................................................... 68
Figure 21: High-level description of simulation model ................................................. 71
Figure 22: Description of lot n operation-1 module ..................................................... 72
Figure 23: Description of lot n operation-2 module ..................................................... 72
Figure 24: Description of lot n record module .................................................. 73
Figure 25: Description of experiment methodology................................. 80
Figure 26: Routing of parts visiting two workstations................................. 84
Figure 27: Routing of parts visiting four workstations................................. 84
Figure 28: Routing of parts visiting eight workstations............................... 85
Figure 29: Number of workstations that parts visit vs. percentage of lead-time error for the conventional method .............................................................. 94
Figure 30: Number of workstations that parts visit vs. percentage of lead-time error for the SLLS method ................................................................. 95
Figure 31: Comparison of WIP cost with respect to number of workstations that parts visit for demand values at level one ............................................. 96
Figure 32: Comparison of WIP cost with respect to number of workstations that parts visit for demand values at level two ......................................... 97
Figure 33: Comparison of WIP cost with respect to number of workstations that parts visit for demand values at level three ....................................... 98
Figure 34: Comparison of WIP cost with respect to number of workstations that parts visit for demand values at level four ....................................... 98
Figure 35: Comparison of WIP cost with respect to number of workstations that parts visit for demand values at level five ....................................... 99
Figure 36: Safety factor vs. lead-time error estimated for the conventional method .......................................................... 101
Figure 37: Safety factor vs. total cost of the conventional production plan......... 102
Figure 38: Safety factor vs. Number of tardy jobs caused by the conventional production plan .............................................................. 103
Figure 39: The determination of simulation length for Experiment 7............... 134
List of Tables

Table 1: Comparison between MPX and simulation results ........................................ 42
Table 2: Set of demand values and lot size........................................................................ 45
Table 3: Comparison of the decisions made by using both the steady state average values and the simulation results................................................................. 46
Table 4: Description of demand values allotted for each $i^{th}$ level .............................. 82
Table 5: Description of number of machines allotted for each $j^{th}$ level..................... 82
Table 6: Arrangement for a Two-Factor Factorial Design .............................................. 83
Table 7: General arrangement of parameters for different experiments ......................... 88
Table 8: Comparison of lot size estimated by conventional and SLLS methods............. 89
Table 9: Comparison of PLT estimated by conventional and SLLS methods................. 90
Table 10: Comparison of percentage of lead-time error .............................................. 91
Table 11: Comparison of total production cost .............................................................. 92
Table 12: Summary of results ....................................................................................... 93
Table 13: Experiment 7-Conventional - Wagner-Whitin Algorithm............................. 110
Table 14: Experiment 7-Conventional - Wagner-Whitin algorithm results.................... 111
Table 15: Experiment 7-Conventional – Lead estimation (K=2)................................. 111
Table 16: Experiment 7-Conventional – Lot size and PLT .......................................... 111
Table 17: Experiment 7-SLLS - PLT updating.............................................................. 112
Table 18: Experiment 7-SLLS - Lot sizing results......................................................... 112
Table 19: Experiment 7-SLLS – PLT results................................................................... 113
Table 20: Experiment 7-Conventional – % lead-time error estimation......................... 113
Table 21: Experiment 7-Conventional – Holding cost & late penalty........................... 114
Table 22: Experiment 7-Conventional – WIP cost & setup cost.................................... 114
Table 23: Experiment 7-SLLS - % lead-time error estimation...................................... 115
Table 24: Experiment 7-SLLS – Holding cost & late penalty........................................ 115
Table 25: Experiment 7-SLLS – WIP cost & setup cost.........................116