Department of Management Science,
Lancaster University Management School (LUMS),
Lancaster University

BRIDGING THE GAP: Refining a Workload Control Concept for Practical Implementation

By

Mark Stevenson

(BSc in Operations Management)

Submitted for the Degree of Doctor of Philosophy

February 2006

BRIDGING THE GAP:

Refining a Workload Control Concept for Practical Implementation

Mark Stevenson

BSc in Operations Management

Submitted for the Degree of Doctor of Philosophy

February 2006

ABSTRACT

Workload Control (WLC) is a Production Planning and Control (PPC) concept designed for complex manufacturing environments such as the job shop, a configuration commonly found in Make-To-Order (MTO) companies. The Lancaster University Management School (LUMS) has been a major contributor to the popularisation of WLC since the early nineteen eighties. This thesis contributes to the further development of a WLC methodology developed at Lancaster, hereafter referred to as the LUMS approach.

The majority of contemporary WLC research is simulation based; as a result, there is a lack of understanding regarding practical elements of the concept. This has created a void between theoretical aspects of WLC and the practice of MTO production. This thesis is case study based and considers two research questions important to improving the feasibility of applying WLC in practice and to the future development of a body of empirical evidence. The first question focuses on bridging the gap between the theory and practice of WLC by refining the LUMS approach. The second centres on identifying the implementation issues surrounding WLC and exploring how these can be addressed in a case study setting.

A three stage process to refine the LUMS approach was undertaken. *Stage One* revisits the literature, identifying areas in which the LUMS approach can be restructured. *Stage Two* focuses on developing a Decision Support System (DSS) based on the LUMS approach, while considering the needs of present day MTO companies. This resulted in changes to key assumptions underpinning the methodology. Through the partial implementation of the DSS in a case study setting, *Stage Three* contributes towards both research questions. This produced inductive refinements to the concept, while issues involved in preparing the company for implementation were also explored, leading to the development of an implementation strategy and framework for WLC.

PUBLICATIONS

Parts of this research have been *published* on the following occasions:

Stevenson, M., 2006, Refining a workload control (WLC) concept: A case study, *International Journal of Production Research,* 44, 4, 767 – 790.

Stevenson, M., and Hendry, L.C., 2006, Aggregate load oriented workload control: A review and a reclassification of a key approach, *International Journal of Production Economics* (Article in Press).

Stevenson, M., Hendry, L.C., and Kingsman, B.G., 2005, A review of production planning and control: The applicability of key concepts to the make to order industry, *International Journal of Production Research*, 43, 5, 869 - 898.

Stevenson, M., (with Hendry, L.C., Land, M.L., and Gaalman, G.,), 2006, Investigating implementation issues for workload control: A comparative case study analysis, *14th International Working Seminar on Production Economics, Innsbruck, Conference Proceedings,* 3, 129 – 142.

Stevenson, M., and Hendry, L.C., 2005, The development of a decision support system (DSS) for workload control (WLC): A case study, *Winds of Change: Production and Operations Management Society (POMS) Conference, Chicago, Conference Proceedings* (Full Paper Available on Conference Compact Disc).

Stevenson, M., Hendry, L.C., and Kingsman, B.G., 2004, Aggregate load oriented workload control, *13th International Working Seminar on Production Economics, Igls, Innsbruck, Conference Proceedings,* 1, 399 - 411.

Stevenson, M., Hendry, L.C., and Kingsman, B.G., 2003, A review of new and established production planning and control (PPC) methods and their applicability to make to order (MTO) companies, *One World? One View of OM?: 1st Joint EUROMA POMS Conference, Lake Como, Conference Proceedings,* 2, 739 - 748.

Parts of this thesis are *planned* for publication:

Stevenson, M., and Hendry, L.C., Improving supply chain integration using a workload control (WLC) concept and web functionality, *Production Planning and Control*, (Submitted for Publication).

Stevenson, M., and Hendry, L.C., Achieving lean in customised b2B supply chains, *Control*, (Submitted for Publication).

ACKNOWLEDGEMENTS

First and foremost, I would like to pay tribute to my two supervisors, Professor Linda Hendry and Professor Brian Kingsman. Professor Hendry has been a source of great support and guidance throughout my research, has always encouraged me to pursue my ideas, and has been of enormous benefit in my research training. Sadly Professor Brian Kingsman died in August 2003, part way through this research project. Professor Kingsman was the inspiration that motivated me to do this research from my days as an undergraduate student in his very entertaining Supply Chain Management lectures. His contribution has been greatly missed although his influence was never far away.

I would also like to thank fellow 'Workload Controllers' that I have had the fortune to meet and share ideas with at conferences over the past three years. In particular, I would like to thank Cristovao Silva from the University of Coimbra and Gerard Gaalman, Martin Land and Peter Henrich from the University of Groningen.

A teaching studentship from the Department of Management of Science was awarded to me for the duration of my studies, and is gratefully acknowledged. I would also like to thank 'Company X' for their collaboration during this research project.

Last but not least, I would like to thank my family: Anne, Arthur, Paul & Sophie, for their constant support throughout my studies.

TABLE OF CONTENTS

PAGE

Abstract i

Publications iii

Acknowledgements iv

Table of Contents v

List of Figures xi

List of Tables xiv

Glossary of Abbreviations xvi

CHAPTER 1: INTRODUCTION

1.1 Overview of Manufacturing 1

1.2 The Make-To-Order (MTO) Industry 3

1.2.1 The Make-To-Order Tendering Stage 8

1.2.2 The Importance of Small and Medium Sized Enterprises (SME's) 8

1.2.3 Job Shop Production 9

1.2.4 Make-To-Order Planning and Control Stages 10

1.3 The Make-To-Order Planning Problem 11

1.4 Gaining Control 13

1.5 Research Objectives: Bridging the Gap Between Theory and Practice 17

1.6 Organisation of the Thesis 20

CHAPTER 2: A REVIEW OF PRODUCTION PLANNING AND CONTROL

2.1 Introduction 22

2.2 The Requirements of the MTO Sector 24

2.2.1 Customisation 24

2.2.2 Shop Configuration 25

2.2.3 Company Size 26

2.2.4 Criteria for Determining Applicability 26

2.3 Material Requirements Planning (MRP) and Beyond 28

PAGE

2.3.1 Assessing the Applicability of MRP and Beyond 33
2.4 Theory of Constraints (TOC) 34
2.4.1 Assessing the Applicability of TOC 36
2.5 Workload Control (WLC) 37
2.5.1 Overview of the LUMS Approach 40
2.5.2 Assessing the Applicability of WLC 44
2.6 Kanban 44
2.6.1 Assessing the Applicability of Kanban 46
2.7 Constant Work-In-Process (CONWIP) 46
2.7.1 Assessing the Applicability of CONWIP 48
2.8 Paired cell Overlapping Loops of Cards with Authorisation (POLCA) 49
2.8.1 Assessing the Applicability of POLCA 50
2.9 Comparison of PPC Methods and Their Applicability 51
2.10 Gaps in the Literature 56

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction 63
3.2 Alternative WLC Methodological Approaches 63
3.2.1 Empirical WLC Research History 65
3.3 Theory Versus Practice: Research Pitfalls and the WLC Paradox 68
3.4 Alternative Empirical Research Methodologies 70
3.4.1 Case Study Research 71
3.4.2 Action Research 74
3.4.3 Differentiating Between Case and Action Research 76
3.4.4 Choosing the Type of Case Study Research 78
3.4.5 Towards Effective Case Study Research 79
3.4.6 Summarising the Approach 86
3.5 Choosing the Case to Study 88
3.5.1 Company X 92
3.5.2 Company Y 92
3.5.3 Company Z 93
3.6 Evolving the Research Methodology: A Three Stage Approach 94

PAGE

3.7 Evaluating the Needs of the Company 100

3.8 Determining Appropriate Performance Measures 102

3.8.1 Delivery Date Adherence 104

3.8.2 Work In Progress 106

3.8.3 Manufacturing and Delivery Lead Times and Lead Time Variability 106

3.8.4 Backlogs and Work Centre Utilisation 107

3.8.5 Company Strike Rate Percentage 107

3.8.6 Feedback and Observations 108

3.9 Conclusion 108

CHAPTER 4: AGGREGATE LOAD ORIENTED WORKLOAD CONTROL – A REVIEW AND A RE-CLASSIFICATION OF A KEY APPROACH

4.1 Introduction 111

4.2 Measure of Indirect Load: A Review 113

4.3 Workload Bounding: A Review 118

4.3.1 Variations on Traditional Approaches to Workload Bounding 121

4.4 The LUMS Approach Updated 123

4.4.1 LUMS Customer Enquiry Management 127

4.4.2 LUMS Order Release Mechanism 131

4.4.3 LUMS Measure of Indirect Load 134

4.4.4 LUMS Workload Bounding 136

4.4.5 LUMS Priority Dispatching 138

4.4.6 LUMS Backlog Length Parameter Setting 139

4.5 Conclusion 141

CHAPTER 5: A DECISION SUPPORT SYSTEM FOR WORKLOAD CONTROL

5.1 Overview of Decision Support Systems 143

5.1.1 Defining a Decision Support System 144

5.2 Development of a DSS 147

5.3 Features of the Proposed Decision Support System 150

5.3.1 The Customer Enquiry Stage 153

5.3.2 Total Backlog Management 153

PAGE

5.3.3 Determining Delivery Dates ... 157
5.3.4 The Job Entry Stage ... 162
5.3.5 Planned Backlog Management ... 163
5.3.6 Backwards Scheduling Procedure ... 164
5.3.7 The Job Release Stage ... 175
5.3.8 Released Backlog Management ... 175
5.3.9 Job Progress Reporting and Feedback Information ... 180
5.3.10 Capacity Management ... 184
5.3.11 Parameter Setting ... 188
5.4 Conclusion ... 189

CHAPTER 6: THE CASE STUDY COMPANY

6.1 Introduction ... 194
6.2 Company Overview ... 195
6.3 Human Resources ... 199
6.4 Machine Resources ... 202
6.5 Customer Enquiries and Setting Delivery Dates ... 207
6.6 MAIS: An Internal Information System ... 210
6.7 End-User Details ... 212
6.8: Organisational Politics ... 214
6.8.1 Political Agendas Within Company X ... 216
6.9 Company Specific PPC Requirements ... 221
6.10 Capacity Management Options ... 224
6.11 Pre-Implementation Data Analysis ... 226
6.11.1 Delivery Date Adherence ... 227
6.11.2 Delivery Lead Time and Lead Time Variation ... 231
6.11.3 Inventory Analysis ... 233
6.11.4 Machine Utilisation and Backlogs ... 234
6.11.5 Company Strike Rate Percentage and Customer Confirmation Time ... 234
6.11.6 Additional Factors ... 238
6.12 Organisational Fit to Workload Control ... 240

PAGE

6.13 Conclusion 243

CHAPTER 7: DEVELOPING AN IMPLEMENTATION STRATEGY FOR WLC

7.1 Introduction 247
7.2 Overview of Implementation Literature 248
7.2.1 General Implementation Issues and Strategies 248
7.2.2 Workload Control Implementation Problem Issues 254
7.2.3 Workload Control Implementation Strategies 255
7.2.4 Summary of Implementation Factors 262
7.3 An Emerging Implementation Strategy for WLC 264
7.4 Applying the Implementation Strategy to Company X 267
7.4.1 Meeting System Data Requirements 267
7.4.2 Grouping Machines into Work Centres 268
7.4.3 Determining Capacities 271
7.4.4 Determining Norms and Parameters 280
7.5 Conclusion 283

CHAPTER 8: OUTCOMES FROM THE CASE STUDY: REFINING THE WLC APPROACH AND THE IMPLEMENTATION STRATEGY

8.1 Introduction 285
8.2 Reflections on the Case Study 286
8.2.1 Towards the Gradual Implementation of Workload Control 289
8.2.2 The Effects of Power and Politics on the Implementation of WLC ... 292
8.2.3 Reflections on the Political Landscape 302
8.3 Refining the LUMS Approach Using Case Study Evidence 303
8.3.1 Data Input at the Customer Enquiry Stage 304
8.3.2 Forwards Scheduling at the Job Entry Stage 308
8.3.3 Part Releasing Jobs at the Job Release Stage 309
8.3.4 The Structure of the Backlog Control Hierarchy 309
8.3.5 Job Reference Numbering System 310
8.4 Refining the Emerging Implementation Strategy 311
8.5 Conclusion 315

PAGE

CHAPTER 9: CONCLUSIONS AND FUTURE RESEARCH POTENTIAL

9.1 Contribution: Building the Bridge from Theory to Practice 317

9.1.1 Refining a WLC Concept 317

9.1.2 Addressing Issues of Implementation 320

9.2 Future Research Scope 325

REFERENCES 327

APPENDIX 1: MEETING THE DATA REQUIREMENTS OF THE DSS

1.1 Importing Data from MAIS: Job Details 357

1.2 Importing Data from MAIS: Employee Details 362

1.3 Saving Data from the DSS: Job Details 365

1.4 Saving Data from the DSS: Work Centre Daily Details 366

1.5 Saving Data from the DSS: Work Centre Assigned Workloads 367

1.6 Saving Data from the DSS: Workload Control Parameters 368

LIST OF FIGURES

PAGE

CHAPTER 1

Figure 1.1: Classification Based on 'Volume vs. Variety' 7

CHAPTER 2

Figure 2.1: Example of Job Routing in the General Flow Shop 26
Figure 2.2: Example of Job Routing in the General Job Shop 26
Figure 2.3: A Variation on the Traditional Application of WLC 39
Figure 2.4: Hierarchical Backlog Control Framework 42
Figure 2.5: Summary of WLC Planning and Control Procedure 43
Figure 2.6: Dual POLCA System for a Job Shop 51
Figure 2.7: System Selection Matrix Presenting PPC Alternatives for the MTO Sector 53

CHAPTER 3

Figure 3.1: Summary of the Case Study Approach Taken in This Research 87
Figure 3.2: Three Stage Research Methodology and Conceptual Refinement Strategy 96
Figure 3.3: Research Timeline 99
Figure 3.4: Research Methodology Milestones 110

CHAPTER 4

Figure 4.1: Measurement of Released Workload Spectrum 118
Figure 4.2: Fluctuation of Backlogs Under an Upper and Lower Bound Release Policy 120
Figure 4.3: Adaptation of the Traditional 'Funnel' and 'Bathtub' Models 131
Figure 4.4: Relationship Between Backlog Lengths and Lead Times 140

CHAPTER 5

Figure 5.1: Development Stages of a Decision Support System 148

PAGE

Figure 5.2: A Typical Workload Control Decision Making Process 152
Figure 5.3: Depreciation of the Backlog Length Over Time 154
Figure 5.4: Customer Enquiry Management Module 160
Figure 5.5: Example of Backwards Scheduling from the Delivery Date 167
Figure 5.6: Job Entry Module with Planned Backlog Table 169
Figure 5.7: Job Entry Module and Job Workload Distribution 171
Figure 5.8: Job Entry Module and Job Gantt Chart 172
Figure 5.9: Job Entry Module and View of Planned Shop Floor Queue 173
Figure 5.10: Job Entry Module and Jobs Currently Beyond Planning Horizon 174
Figure 5.11: Job Release Decision Support Module 179
Figure 5.12: Job Progress Reporting Module and Shop Floor WIP View 181
Figure 5.13: Job Progress Reporting Module and Current Resource Queues 184
Figure 5.14: Capacity Management Module 186
Figure 5.15: Parameter Setting Module 189

CHAPTER 6

Figure 6.1: Distribution of Working Hours for Each Shift Type at a Shop Floor Resource 201
Figure 6.2: Typical Daily Shift Pattern (Between Monday and Thursday) 204
Figure 6.3: Machine-Level View of the Shop Floor 206
Figure 6.4: Pie Chart Showing Sample Delivery Date Adherence of Company X .. 229
Figure 6.5: Summary of Contributory Factors to the Production Planning and Control Problem in Company X 246

CHAPTER 7

Figure 7.1: Factors Influencing the Outcome of an Implementation Project 263
Figure 7.2: Six Step Implementation and Continuous Improvement Strategy 266
Figure 7.3: Operator Distribution and Machine Allocation at a Work Centre 272

CHAPTER 8

Figure 8.1: Example of Job Reference Numbering System 289

PAGE

Figure 8.2: The Gradual Implementation of WLC 291

Figure 8.3: Enhanced (Gradual) Implementation Strategy 313

LIST OF TABLES

PAGE

CHAPTER 1

Table 1.1: MTO Company Characteristics 13

CHAPTER 2

Table 2.1: Summary of Card Based Signalling Systems 52

Table 2.2: Summary of Justification of Preferred Methods in the System Selection Matrix 55

Table 2.3: Summary of Production Planning and Control Literature Reviewed 60

CHAPTER 3

Table 3.1: Summary of Personnel Interviewed at Company X 101

Table 3.2: Summary of WLC Performance Measures from Previous Studies and Those Chosen for This Project 105

CHAPTER 4

Table 4.1: Summary of 'Measure of Indirect Load' Alternatives 117

Table 4.2: Summary of 'Workload Bounding' and its Alternatives 123

Table 4.3: Summary of LUMS WLC Concept, Classified Using the Eight Dimensions Presented by Bergamaschi *et al.* (1997) 126

CHAPTER 5

Table 5.1 Total Backlog Length Example 157

Table 5.2 Released Backlog Length Example 177

Table 5.3: Summary of Key Refinements from the Programming of the DSS 192

CHAPTER 6

Table 6.1: Overview of Company X 198

Table 6.2: Summary of Employee Skills and Working Patterns 203

Table 6.3: Shop Floor Machine Details 205

PAGE

Table 6.4: Delivery Date Adherence Summary 229

Table 6.5: Delivery Date Summary Statistics 230

Table 6.6: Summary of Quoted Delivery Lead Time Statistics 232

Table 6.7: Summary of Achieved Delivery Lead Time Statistics 232

Table 6.8: Monthly Financial Assessment of Inventory 234

Table 6.9: Summary of Customer Confirmation Time Analysis 236

Table 6.10: Distribution of Customer Confirmation Times 237

Table 6.11: Applicability of Company X for WLC (based on Henrich *et al.* 2005) 242

CHAPTER 7

Table 7.1: Summarising the Performance of the Capacity Approximation Measure 277

Table 7.2: Summary of Machine Groupings and Reallocation Possibilities 279

Table 7.3: Summary of WLC Parameters and Planning Stages 282

CHAPTER 8

Table 8.1: Production Planning and Control Development and Implementation Framework 314

CHAPTER 9

Table 9.1: Summarising the Contribution of the Research 324

APPENDIX 1

Table I: Text Files Required by the Decision Support System 357

Table II: Job Details Flat File Format 359

Table III: Machine ID Reference Table 360

Table IV: Job Status Reference Table 360

Table V: Example Operation Details 361

Table VI: Employee Details Flat File Format 364

Table VII: Confirmed Job Details File Format 366

Table VIII: Daily Work Centre Hours 367

Table IX: Assigned Workload File Format 368

GLOSSARY OF ABBREVIATIONS

Abbreviation	Term
ATO	Assemble To Order
B2B	Business To Business
B2C	Business To Consumer
CCT	Customer Confirmation Time
CONWIP	Constant Work In Process
DD	Delivery Date
DLT	Delivery Lead Time
DSS	Decision Support System
ERD	Earliest Release Date
ERP	Enterprise Resource Planning
ETO	Engineer To Order
FGI	Finished Goods Inventory
GFS	General Flow Shop
GJS	General Job Shop
HCA	Hierarchical Control Architecture
I/OC	Input-Output Control
JIT	Just In Time
LRD	Latest Release Date
LUMS	Lancaster University Management School
MLT	Manufacturing Lead Time
MRP	Material Requirements Planning
MRP II	Manufacturing Resource Planning
MTO	Make To Order
MTS	Make To Stock
NOP	Number of Operations
OCD	Operation Completion Date
ORR	Order Review and Release
PB	Planned Backlog
PBL	Planned Backlog Length
POLCA	Paired cell Overlapping Loops of Cards with Authorisation
PPC	Production Planning and Control
QRM	Quick Response Manufacturing
RB	Released Backlog
RBC	Repeat Business Customiser
RBL	Released Backlog Length
SCM	Supply Chain Management
SFTT	Shop Floor Throughput Time
TB	Total Backlog
TBL	Total Backlog Length
TOC	Theory of Constraints
TWC	Total Work Content
VMC	Versatile Manufacturing Company
WIP	Work In Process
WLC	Workload Control

CHAPTER 1: INTRODUCTION

1.1 OVERVIEW OF MANUFACTURING

In recent years, manufacturing companies, such as those in the United Kingdom (UK), have been subjected to increasing competition and progressively more demanding customers (see, for example, Braiden *et al.* 1993; Maffin & Braiden 2001). The growth of the Internet within business (e-business / e-commerce), for example, has contributed to the changing face of manufacturing, providing a globalised marketplace in which firms must compete in order to survive. Such advancements as the Internet, and its integration within Supply Chain Management (SCM), serve to break down barriers to trade and increase competition by providing suppliers with access to new markets and by providing customers with greater transparency and comparability, thus creating a more 'level playing field' (see, for example, Kehoe & Boughton (2001a and 2001b) and Bruun & Mefford (2004)). This competitive environment has been further intensified by the emergence of China within the global market place (see, for example, Brown & Qi 2000) and a slowdown in the world economy. In addition, the growth of the European Union (EU) has arguably increased competition from low cost producers in Eastern Europe; with cheap and transferable labour skills, goods and services, whilst also providing new opportunities for existing EU members (see, for example, Nahuis 2004).

Globalisation has resulted in many manufacturers shifting their supply chain sourcing overseas (CBI 2000). As a result, many manufacturing companies in the UK, no longer able to compete on price alone, have struggled in the current, highly competitive, manufacturing climate. While there have been a number of well publicised takeovers, mergers and closures (such as in pharmaceuticals and ship building), there is also a trend towards 'off-shoring', in other words, relocating manufacturing facilities and jobs to low cost labour countries. Despite this, the manufacturing industry remains an important contributor within the UK economy, with a reputation for World Class Manufacturing (WCM) in areas such as aerospace, engineering and the automotive industry. Three of Europe's eight most productive car plants can be found in the UK, while the UK aerospace industry is the second largest in the world with a turnover exceeding £17.5bn and a workforce of over 150,000 people (CBI 2000). Over 374,000 people in the UK are employed in engineering alone, with total sales in 2001 reaching £37,880m (see Ukplc 2002).

According to a survey by the Confederation of British Industry (CBI 2000), manufactured products account for over 60% of the UK's exports and a total of approximately four million people are directly employed in manufacturing in the UK. The report also finds that manufacturing contributes £150bn to the Gross Domestic Product (GDP) of the UK each year, accounting for approximately 20% of the total GDP of the UK. Although growth in the service sector means that it now contributes more to employment than manufacturing, the report claims that approximately 2.4 million jobs in service industries depend on manufacturing. In addition, recent forecasts predict growth in manufacturing and engineering in forthcoming years (EEF 2004), even if this growth cannot keep pace with that in the service economy. Hence, manufacturing remains the backbone of British industry, an argument likely to be equally valid in other traditionally strong manufacturing countries in Europe, such as in Germany and The Netherlands.

1.2 THE MAKE-TO-ORDER (MTO) INDUSTRY

With increased competition and shifts in buying trends, purchasers in Business to Consumer (B2C) and Business to Business (B2B) relationships, have a great deal of power in a buyers market, often demanding shorter lead times, greater customisation and personalised products and services. This demand provides an opportunity for companies to gain competitive advantage through manufacturing versatility or flexibility, Delivery Date (DD) competitiveness and DD reliability. The capability of offering a greater degree of customisation is an important strategic objective for many companies (Spring & Dalrymple 2000; Hendry *et al.* 2003).

To highlight the importance of these companies, Brown & Bessant (2003) refer to Ford (1990), explaining that the degree to which customisation is required within industrial markets is now greater than before. As a result, there has been large growth in the number of companies offering customers an element of customisation, thus increasing competition. Even in the manufacture of a relatively standardised product, issues such as diversification and shorter production cycle times encourage manufacturers to shift their production from Make-To-Stock (MTS) to Make-To-Order (MTO) or an intermediate production system (Kuroda & Takeda 1998).

However, providing the flexibility to cater for specialised demand comes at a cost. For example, due to unstable demand and the customised nature of production, companies are unable to keep a Finished Goods Inventory (FGI) from which to satisfy requirements. As a result, a product, and its requirements (such as raw materials), must be directly attributed to a specific order from the moment the customer enquires (the customer enquiry stage).

Such companies, aiming to capitalise on the individualised nature of customer requirements, range from mass customisers (see, for example, Hendry *et al.* 2003) to producers of bespoke one-off items; all of which can be considered as producers on a MTO basis. As a result, there are a number of different definitions of MTO production companies, making it important to specify what is meant by MTO in the context of this thesis. It is insufficient to merely make a distinction between MTO and MTS production as, for example, Assemble-To-Order (ATO), Engineer-To-Order (ETO), Design-To-Order (DTO) and Make-To-Print (MTP) types must also be considered in defining terminology.

Definitions range from grouping MTO, ETO and DTO producers together under a broad definition, to distinguishing between a number of different types of MTO Company with varying characteristics: MTO1, MTO2, MTO3 and so on (see Amaro *et al.* 1999). Tobin *et al.* (1988) categorise MTO companies based on the type of production and whether this is geared towards a product or a process, distinguishing between the capital goods and subcontracting industries.

Companies that do not satisfy demand from a FGI have also been referred to broadly as non-MTS companies (see Amaro *et al.* 1999; Muda 2001). Amaro *et al.* (1999) present a new taxonomy for 'non-MTS' companies based on the level of work carried out after an order has been placed and the nature of customisation. Hendry

(2005) also categorises different types of MTO production by identifying the point at which the customer order is received and the type of customisation offered at that point, according to Mintzberg (1988), in other words pure, tailored or standardised customisation. According to Amaro *et al.* (1999), in the case of a MTO company, when an order is placed, the basic design is available and the remainder of the work is in manufacturing and assembly. However, for the purposes of this thesis, the definition of a MTO company incorporates the design stage, if required by the customer. In other words, companies have the capability to offer pure customisation.

Perhaps the closest definition to the one used in this thesis is provided by Hill (2000). The author states that:

> "*MTO businesses are usually involved in the provision of special (that is, will not be repeated) products and services. In addition, some companies decide to meet demand for standard (that is, repeat) items only on a MTO basis. Either way, a MTO response means that inventory will not be held either as part finished or finished items. What may be held in stock are the materials and components that form all or part of an item*".

(Hill 2000, Page 379)

This thesis concentrates on the companies that are involved in the provision of 'special products' not manufactured on a regular basis. Thus, hereafter, the term MTO is used in a broad sense, encapsulating companies that other researchers have referred to as ETO and DTO. Here, the definition simply refers to products for which (1) design and/or production does not take place until after the customer order confirmation stage and (2) for which products are manufactured to the individual requirements of each customer order. This is considered a sufficient distinction, as it is these characteristics that make the topic of this thesis, the planning and control of operations, so difficult. Such specialist companies represent a sector of manufacturing companies concentrating on meeting the specific personalised requirements of customers and are able to produce a wide variety of products, often in small volumes, and varying in processing and material requirements, with few, if any, standard products. Products manufactured by such MTO companies include specialised small parts for aeroplanes, cars and construction equipment.

The thesis also classifies the MTO or 'highly customised' industry into two types: Repeat Business Customisers (RBC) and Versatile Manufacturing Companies (VMC), as discussed by Amaro *et al.* (1999), although it is acknowledged that complexity within each category is not uniform. A RBC provides customised products on a continuous basis over the length of a contract. Goods are customised but may be made more than once permitting a small degree of predictability. The VMC market is more complex requiring more sophisticated solutions where each order is competed for individually and a high variety of products with variable demand are manufactured in small batches with little repetition. Both types allow customisation, but the RBC is able to establish more stability by enticing customers into a more predictable and committed relationship.

Figure 1.1 illustrates the position of the RBC and VMC categories on the traditional volume/variety spectrum, in relation to the ATO and MTS categories. For clarification, MTS companies are often able to purchase and produce in large batches, operate continuous production methods, maintain low set up times and accumulate a finished goods inventory from which to rapidly satisfy demand. Companies employing an ATO strategy part-finish an item prior to a customer order, and then on receipt of an order the item is completed (see Hill 2000). Under such ATO production, components and subassemblies are made to stock (see Hill 1993).

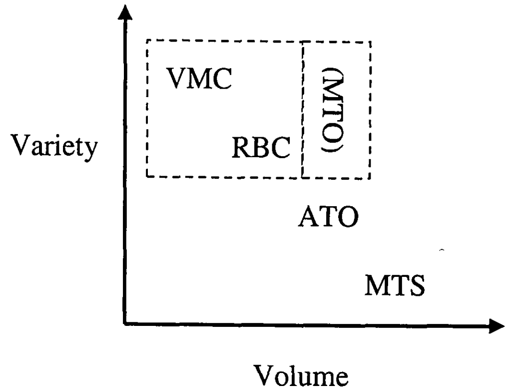


Figure 1.1: Classification Based on 'Volume vs. Variety'

Although an ATO company could be considered a mass customiser in certain settings, this research is focussed upon less standardised production problems. Brown & Bessant (2003) refer to Davis (1987) in explaining that mass customisation describes the ability to both produce and distribute what are perceived to be customised goods and services within a high volume or mass market. Meanwhile, Russell & Taylor (2003) define mass customisation as the mass production of customised products. Brown & Bessant (2003) add that a large part of the volume is achieved through the aggregate variety produced around a single product or similar products. Krajewski & Ritzman (1998) explain that mass customisers attempt to provide the variety inherent in an ATO strategy but often focus on relatively high volume markets. Therefore, given this discussion, it seems reasonable to conclude that producers of mass customisation do not typically provide the degree of production variety to satisfy the MTO definition used in this thesis.

MTO companies have an earlier Order Penetration Point (OPP) than ATO and MTS producers: the stage at which a product is linked to a specific customer order (see Olhager 2003). Therefore, delivery lead times are inevitably longer for MTO companies than, for example, MTS companies (for a comparison, see Hill 1995), as materials cannot be ordered or production started until after the customer has confirmed the order (demand cannot be supplied or assembled from existing stocks).

1.2.1 The Make-To-Order Tendering Stage

Unless involved in partnerships with downstream elements of the supply chain, MTO companies generally have to compete against a number of other companies for each order that they receive and each job that they produce. This bidding or tendering stage may consist of quoting a DD, or Delivery Lead Time (DLT), and a price to a prospective customer, or even a series of prices and lead times for different order quantities. Such a procedure requires (internal) vertical integration and a close link between production and marketing decisions, although other factors can also play a part in a successful bid (see, for example, Kingsman *et al.* 1993). The demands of customers and the nature of production make lead times and delivery date determinations a troublesome, but strategically important, issue for MTO companies. The significance of the customer enquiry stage for MTO manufacturing is also further explored by Hendry & Kingsman (1989), Easton & Moodie (1999), Calosso *et al.* (2003) and Olhager (2003).

1.2.2 The Importance of Small and Medium Sized Enterprises (SME's)

Small and Medium sized Enterprises (SME's) represent a large and important sector of the MTO industry (see Tobin *et al.* 1988; Muda 2001). A SME can be commonly defined based on the number of people employed and size of annual turnover, while, for example, the European Commission also considers the actual monetary values reported in the balance sheet and the independence of the company when determining if a company warrants SME status (see Keynote 2002). A Small Enterprise may have less than fifty employees or a turnover of less than or equal to ten million Euros, while a medium sized company has less than 250 employees or a turnover of less than or equal to fifty million Euros (see EUROPA 2003). Note that a company with less than ten employees can also be considered a micro enterprise.

SME's are extremely important to supply chains and the economy as a whole; such companies often act as suppliers to larger national or multinational companies that have previously followed trends in outsourcing non-core competencies. However, although large firms rely on SME's for raw materials and subcontracting, large firms dominate in terms of total turnover and employment and often have a major influence on SME's. It is estimated that there are 3.7 million SME's in the UK alone and this could rise to 4 million by 2006 (Keynote 2002). Based on figures produced by the Department of Trade and Industry (DTI 1999), approximately 99% of all businesses in the UK employ less than 250 people and of the small companies, 9% are based in the manufacturing industry (Keynote 2002).

1.2.3 Job Shop Production

MTO companies often operate job shop production with flexible machines and operators (see Muda & Hendry 2003). This configuration provides the company with the agility and versatility required to produce pure customised products. However, the random routing sequences prevalent in job shop production make it difficult to track the progress of jobs resulting in tardiness and a high degree of WIP. For a review of problems and approaches associated with job shop scheduling, see, for example, Blazewicz *et al.* (1996) and Jain & Meeran (1999).

1.2.4 Make-To-Order Planning and Control Stages

To summarise, the cycle through which a manufactured MTO product must be planned and controlled can be broken down into a number of steps:

(1) *Customer Enquiry Stage*: At the customer enquiry stage, a prospective customer will invite a number of potential suppliers to provide a tender for a particular job specification, perhaps including the design process.

(2) *Job Entry Stage*: If the customer accepts the tender the company can start to plan production, finalising processing requirements (including job routings) and ordering the necessary materials. More detailed planning for the workload of the job and the available capacity of the machines it will visit can also take place.

(3) *Job Release Stage*: At this stage the company must decide when a job is to be released onto the shop floor and the start of production is to be signalled. Once released, the job can be considered as Work-In-Progress (WIP). Clearly every company must release jobs onto the shop floor, whether this is as soon as materials are available or based on more sophisticated criteria, thus making order release a strategic decision.

(4) *Priority Dispatching*: This relates to the way jobs are sequenced at machines on the shop floor, such as according to a simple First-In-First-Out (FIFO) policy. The job remains part of the WIP of the shop until it is completed, before finally being delivered to the customer.

1.3 THE MAKE-TO-ORDER PLANNING PROBLEM

The description above highlights the supply chain uncertainty to consider when quoting delivery dates and planning production. A company may have very few regular customers, thus it is difficult to foresee when customers will make an enquiry (forecast demand) or whether a particular tender will be successful. Hence, it is difficult to know how many tenders to make at once, considering the capacity of the shop, a wish to prevent resources from overloading and a natural tendency to avoid rejecting jobs that are offered. With such prolonged tendering and negotiation stages it can also be difficult to know when a customer will confirm or reject a tender (customer confirmation time), or if they will formally notify the company of this decision at all. On the other hand, accepting an infeasible mix of processing requirements and delivery dates can result in a workload imbalance, late deliveries and a loss of goodwill and reputation with valuable customers.

With such diverse customer needs, MTO companies are likely to have a wide supplier base with materials only ordered when a job is confirmed; this is inevitable given that the material and production requirements of a job may be vastly different to those of other jobs in the factory. This increases the degree of uncertainty at the job entry stage; as, for example, it may be difficult to be confident of material arrival dates from a non-preferred supplier. It is also difficult to accurately estimate the Total Work Content (TWC) of a job that is significantly different to those that have been previously processed. Furthermore, with such variable job routings and lead times within job shops, it can be difficult to foresee how long a job will have to queue at machines or work centres before being operated upon, and therefore when to start production (job release). Hence, a lack of parts commonality and variable job routings add to the difficulties of planning and control.

Although it could be argued that starting production as early as possible, and effectively forward scheduling, could produce the best delivery date adherence, companies have a limited cash flow and do not want to have too much capital tied up in WIP. In addition, changes to quantity and design specifications, common when dealing with large, influential and demanding customers, can also be more easily accommodated prior to the job release stage, while jobs can also be re-scheduled more easily if production has not yet commenced. Beginning production as soon as possible would also go directly against the philosophy of lean production, contributing towards the lead time syndrome (see Mather & Plossl 1978). The lead time syndrome relates to the detrimental impact of lead time variation throughout the supply chain caused by overloaded resources, emphasising the importance of controlling lead times and capacity requirements in order to meet delivery dates. As a result, striking a balance between starting a job as late as possible and ensuring the job will be completed by the delivery date, is considered a key planning problem.

Companies are under increasing pressure to quote short lead times, in order to gain a competitive advantage and gain work for the shop resources. However, unless delivery dates are realistic and reliable, based on current capacity and workload constraints, this will not result in long-term success. If a company regularly fails to meet delivery dates this will result in both internal and external repercussions. Externally, a poor DD adherence record will affect the reputation and future sales of the company, while internally it may indicate an unrealistic DD determination policy and an unbalanced shop leaving some machines idle and others overloaded. However, without the insurance of a FGI, lead times are inevitably longer than for MTS companies. Determining delivery dates, and therefore planning aggregate machine capacities and workloads, is very important. However, considering the individuality of jobs and routing sophistication, accurate planning in the MTO industry is evidently a complex process.

In summary, the (problematic) characteristics of a MTO company, as defined for the purposes of this research, are presented in Table 1.1 below:

Company Characteristics
Unpredictable demand
Products are highly customised
High proportion of 'first-off' items produced
In-house process may include a design stage
Companies have to compete for every new order
Variable material requirements
Large supplier base
High shop floor routing variability (job shop is typical)
Variable processing times and delivery lead times
Versatile machinery and workforce required
Work often subcontracted from larger companies

Table 1.1: MTO Company Characteristics

1.4 GAINING CONTROL

Production Planning and Control (PPC) Systems are important tools for meeting increasingly high customer demands and expectations in the present manufacturing climate. An effective PPC approach is crucial if competitive and reliable delivery dates are to be quoted to customers and achieved in practice. Typical functions of a PPC System include planning material requirements, demand management, capacity planning and the scheduling and sequencing of jobs. The key purposes of such functions include reducing WIP, minimising Shop Floor Throughput Times (SFTT's) and lead times, lower stockholding costs, improving responsiveness to changes in demand, and improving DD adherence (see Zäpfel & Missbauer 1993). However, it is also clear that the planning requirements for MTO companies are particularly complex, and differ greatly from the needs of MTS companies (see Hendry & Kingsman 1989).

Many manufacturers use 'legacy PPC systems', such as Material Requirements Planning (MRP) systems (see Sower & Abshire 2003), or an ad-hoc and old-fashioned paper based approach to planning production on the shop floor. SME's particularly lag behind in the use of new technologies (see, for example, Quayle 2002); however, through time and as a company grows, such ad-hoc or old-fashioned approaches are likely to become unmanageable. The large number of SME's (with limited financial resources), the importance of them within British industry (such as within the MTO sector) and the growth in demand for customised products means that there is a great need for cost effective PPC concepts designed for the MTO industry.

One PPC approach that can cater for the needs of MTO companies and job shops is Workload Control (WLC). The approach originates from the concept of Input-Output Control (I/OC), see Wight (1970), and uses a pre-shop pool to reduce shop floor queues and congestion, maintaining a stable level of WIP through emphasising the importance of the job release stage of production planning. The aim is to stabilise lead times and provide a more predictable throughput time in an attempt to ensure that delivery dates are more reliable (subsequent chapters provide a complete description). WLC works particularly well in the job shop environment and can lead to the reduction of SFTT and WIP (Land & Gaalman 1996). This can also be a relatively simple and cost effective approach, making it a particularly appealing alternative for SME's with financial constraints and an aversion to risk.

Despite the apparent advantages of WLC, few empirical studies have been presented in the literature and it has been noted that further practical research regarding WLC is required (see, for example, Bertrand & Wortmann 1981; Bechte 1988; Kingsman & Hendry 2002; Bertrand & Van Ooijen 2002). Most of the limited number of empirical WLC studies that have been conducted (see Bertrand & Wortmann 1981; Fry & Smith 1987; Bechte 1988; Hendry *et al.* 1993; Bechte 1994; Wiendahl 1995; Park *et al.* 1999) tend to focus on the results of implementation rather than the actual process of implementation required by this concept in practice. The majority of research in the field of WLC is focussed on simulation experiments; however, in many respects these simulations tend to underestimate the complexities of real life job shops (see Perona & Miragliotta 2000). It is therefore not surprising that a number of attempts to implement WLC in practice have failed (see, for example, Hendry *et al.* 1993). As a result, the process of implementation remains a 'black box', surrounded by uncertainty, with a void existing between the extensive theoretical aspects of WLC and the limited practical perspective.

Some previous empirical studies have also assumed accurate DD's have already been quoted at the customer enquiry stage and that an appropriate mix of jobs have been accepted at the job entry stage. Hence, such research has begun the planning process with the job entry stage or the job release decision; thus simplifying the requirements for implementation. Although the order pool and job release function can help in an isolated (and decentralised) job shop scheduling problem, this fails to cater for the customer enquiry / delivery date determination and job entry stages that are so important to gaining control in highly customised MTO companies. By failing to control the customer enquiry stage, such approaches provoke comparisons with alternative PPC concepts; such as Kanban, Constant Work-In-Process (CONWIP) and Paired cell Overlapping Loops of Cards with Authorisation (POLCA) (see Chapter 2). On the contrary, contemporary simulation research has demonstrated the benefits of providing I/OC at the higher customer enquiry and job entry planning levels as a complementary control mechanism to job release (see, Kingsman & Hendry 2002).

There appears to be some awareness regarding the use of both a pre-shop pool and a simple order release mechanism in manufacturing practice. However, this often relates to a partial and informal implementation of the WLC concept and has not been explicitly documented. Bechte (1994), for example, states that Load Oriented Manufacturing Control (LOMC), a particular branch of Workload Control methodology, has been implemented in numerous factories, although this is not reflected in the volume of detailed published accounts.

The uncertainty surrounding the process of implementing WLC in practice, the time required to produce publishable results and a number of failed implementation projects are likely to have been major contributing factors to this gap in knowledge. Therefore, more empirical research is required for two reasons. Firstly, it is needed in order to validate existing theory and advance the theoretical development of the WLC concept. Secondly, it is required in order to improve the understanding of the WLC implementation process.

1.5 RESEARCH OBJECTIVES: Bridging the Gap Between Theory and Practice

The Lancaster University Management School (LUMS) has been a long-standing contributor to the popularisation of WLC, and a particular branch of WLC known as the Aggregate Load Approach. The methodology developed at LUMS is hereafter referred to as the LUMS approach. The LUMS approach originates from the doctoral work of Tatsiopoulos (1983) and Hendry (1989), and has also been documented in a number of journal papers; see, for example, Hendry & Kingsman (1989 and 1991), Kingsman (2000) and Kingsman & Hendry (2002). It is this approach to the concept of WLC that is the topic of this thesis. Unlike many other WLC concepts, the LUMS approach has been specifically designed for the particular needs of MTO companies. However, despite a significant contribution to this field of research, the LUMS approach has not been fully applied in practice and at the commencement of this research project, did not exist in the form of a contemporary integrated Windows based software package that would enable such research to take place. Hence, very little is known about the exact requirements for implementing the approach in practice. More contemporary research than is currently available from previous projects is required when the fast moving and increasingly competitive environments in which companies operate and for which WLC is designed are considered.

Since the conception of the LUMS approach, the amount of research in the field of WLC and MTO production has increased greatly, perhaps the most notable contemporary contributors are at the University of Groningen (see, for example, Land & Gaalman 1996 and 1998; Henrich *et al.* 2002), the University of Eindhoven (see, for example, Van Ooijen 1996; Bertrand & Van Ooijen 2002) and Hanover University (see, for example, Bechte 1994; Wiendahl 1995). Hence, a first major element of this research was to consider whether the LUMS approach needs to be updated in the light of such research.

Therefore, a process of re-evaluation and refinement of the LUMS approach was required in order to facilitate future empirical results. For research rigour, this process must begin with an in-depth exploration of both the MTO industry and of applicable PPC approaches for this sector before further conceptual development of the LUMS approach is considered. As described, researchers and practitioners would also benefit from learning more about the implementation process and how this can be eased.

While a great deal of past research has been invaluable to the development of the concept, it is only by examining the application of the methodology in practice that researchers will learn more about the needs and complexities of MTO companies and what is required to allow WLC to be implemented in practice. Based on this discussion, a second major element of this research project was to conduct a case study analysis of the LUMS approach, refining the concept for practical use, developing a contemporary Decision Support System (DSS) based on the approach and advancing knowledge of the implementation process by applying the concept to the company. It was anticipated that the process of implementation would present a number of issues that have been overlooked in theoretical work and which warrant further exploration. This aimed to bridge the gap between the theory of WLC and practice of MTO companies, advancing the methodology of WLC with regards to both theoretical / conceptual development and practical application.

Given the discussion presented here and the subsequent literature review in Chapter 2 indicating a further need to research WLC, the remainder of this research is motivated by the following two questions:

> *(1) How can theoretical aspects of the LUMS approach be refined to facilitate practical implementation of the Workload Control concept, thus bridging the gap between theory and practice?*
>
> *(2) What Workload Control implementation issues can be identified, and how can they be addressed in practice?*

In order to contribute towards answering these research questions, this thesis sets out to achieve the following accompanying objectives:

(a) Identify the most appropriate PPC approaches for the MTO industry.

(b) Re-evaluate and validate the applicability of the LUMS approach to WLC.

(c) Enhance the LUMS approach for MTO companies, refining the existing methodology.

(d) Develop the methodology of the LUMS approach into a contemporary Windows based Decision Support System (DSS) to assist PPC through the full spectrum of planning and control stages applicable to MTO companies.

(e) Identify a suitable company for case study research and attempt to implement the DSS.

(f) Learn from and reflect on experiences of the implementation process, considering how the concept must be refined in the light of case study findings.

1.6 ORGANISATION OF THE THESIS

The remainder of this thesis is organised as follows. Chapter 2 provides a literature review, examining the existing PPC alternatives available to practitioners and assessing the applicability of these techniques to MTO companies. This is achieved by comparing the methodologies against a detailed criterion and analysing the insights into the performance of the approaches presented in the literature. The motivation behind this is to establish whether Workload Control remains a leading option for MTO companies, in order to validate continuing with the intended research direction.

Chapter 3 outlines the research methodologies applied during this project, covering a range of approaches, such as an exploratory literature review and case study research (including semi-structured interviews and observational techniques). The chapter also describes some of the different types of research methodologies conducted in the field of WLC.

Chapter 4 then provides a detailed description of the concept of WLC and the different branches of WLC research. This includes revisiting the existing LUMS approach, evaluating its continued applicability and classifying it against an established criterion (see Bergamaschi *et al.* 1997).

Chapter 5 describes the development of the DSS, programmed using Borland Delphi (object oriented Pascal). Chapter 6 provides a description of the case study company to be used as a test bed for the DSS and implementation process. The applicability of the company to the concept of WLC is also evaluated using a framework presented by Henrich *et al.* (2005).

Chapter 7 highlights a number of implementation issues presented in the literature. This chapter develops an implementation strategy for WLC and describes how this was applied to the case study company. The outcomes of the implementation process are described in Chapter 8. By applying the DSS to the company, the research seeks to refine the concept and implementation strategy in line with the practical requirements of MTO companies. Final conclusions and future research directions are highlighted in Chapter 9.

CHAPTER 2: A REVIEW OF PRODUCTION PLANNING AND CONTROL - THE APPLICABILITY OF KEY CONCEPTS TO THE MTO INDUSTRY

2.1 INTRODUCTION

The importance of an appropriate PPC system has been highlighted in Chapter 1; hence choosing the right PPC system for a particular company can be a crucial strategic decision. However, determining the applicability of PPC approaches is a complex process due to the increasing number of alternative concepts and the inclination of many software producers to suggest that an approach is universally appropriate. Often the latter is implied by a lack of indication of the type of company that could hope to benefit from a particular PPC system and thus an intention to gain wide applicability. However, through aiming for such wide applicability it is inevitable that industry-specific planning and control needs are not adequately met given that manufacturing environments are diverse in terms of characteristics such as shop floor configuration, levels of customisation offered and so on. Hence, the choice of a PPC technique is often an ill-informed decision based on superficial software features rather than on the selection of features that are designed for a specific industry.

The need to address the specific requirements of the MTO sector has been increasingly acknowledged in recent research literature. Thus, contemporary literature presents a number of concepts that claim to cater for complex production settings such as the job shop. However, further guidance is required to determine when each approach should be practically applied. As a result, a critical assessment of PPC methodologies from a MTO viewpoint is necessary to aid this system selection process for practitioners.

Zäpfel & Missbauer (1993) present the most notable review of production planning and control methodologies (see also Gelders & Van Wassenhove 1981). However this does not focus primarily on MTO production. The authors review Manufacturing Resource Planning (MRP II), Optimised Production Technology (OPT), Workload Control (WLC), Kanban / Just In Time (JIT), briefly highlighting both Constant Work In Process (CONWIP) and the Progressive Figures Approach. Since this important review, further approaches have emerged, such as Paired cell Overlapping Loop of Cards with Authorisation (POLCA), part of the Quick Response Manufacturing (QRM) philosophy, and Enterprise Resource Planning (ERP). In addition, there are also trends towards web or e-based Supply Chain Management (e-SCM) tools, while further contemporary research has emerged for existing approaches, such as CONWIP and WLC. The growth and importance of MTO industries, coupled with this influx of new planning and control methodologies, contribute to this need to undertake a critical assessment from a MTO perspective. In the context of this thesis, reviewing and determining the applicability of the PPC approaches presented in the literature to the MTO industry formed a key part of the process of assessing whether this research project should continue in the field of Workload Control or switch to an alternative concept.

The chapter continues by discussing the requirements of the MTO industry and proposing criteria to be used to determine the applicability of each PPC system to the MTO sector. The chapter reviews the approaches presented in the literature contrasting 'classic methods' with a 'new breed' of approaches often hybrid in design. In Section 2.9, the chapter evaluates and categorises the applicability of the approaches reviewed in the previous sections in order to assist practitioners in the choice of PPC approach and ensure the validity of the research direction pursued in this thesis. Section 2.10 summarises the literature covered in the earlier sections in tabular form and highlights some broad areas in need of further research.

2.2 THE REQUIREMENTS OF THE MTO SECTOR

When reviewing the PPC approaches presented in the literature, it is important to consider the characteristics and particular planning requirements of MTO companies in order to determine the applicability of the concepts. Three important features are briefly discussed before the criteria for determining applicability are presented.

2.2.1 Customisation

The high degree of customisation offered by MTO companies invariably leads to non-standard product routings on the shop floor and longer lead times. As a result, the ability to accommodate customisation is a key test of the applicability of the PPC approaches reviewed in this chapter to the MTO industry.

2.2.2 Shop Configuration

Shop floor configuration is a major determining factor of PPC applicability. The review considers the Pure Flow Shop (PFS), the General Flow Shop (GFS), the General Job Shop (GJS) and the Pure Job Shop (PJS). However, shop configuration is unlikely to lie at one of the extremes (Portioli 2002). The key difference between the job shop and the flow shop is the direction of material flow. In a pure flow shop, work travels in one direction through a sequence of work centres in a strict order, unlikely in a MTO company. In a general flow shop work still travels in one direction but jobs are allowed to visit a subset of work centres, permitting limited customisation, relevant to a RBC. Pure job shop routing sequences are random; jobs can start and finish at any work centre allowing complete freedom and customisation. The job shop is still an appropriate configuration for many MTO Companies (Muda & Hendry 2003); as a result much of the literature has concentrated on this. However, there is doubt whether the pure job shop can be found: in reality a dominant flow direction usually exists (Oosterman *et al.* 2000). Enns (1995) meanwhile argues that the real life job shop has more in common with the theoretical general flow shop. The general job shop is defined as providing for multi-directional routing, but with a dominant flow direction, relevant to both VMC and RBC groups. Hence, this discussion examines the general flow shop but with particular focus on the general job shop.

The degree of customisation offered by a company is linked to shop configuration and flexibility. However, it is possible for MTS companies to operate as a job shop. To illustrate the distinction between GFS and GJS, Figures 2.1 and 2.2, respectively, show the typical routing of a job in the general flow and general job shop.

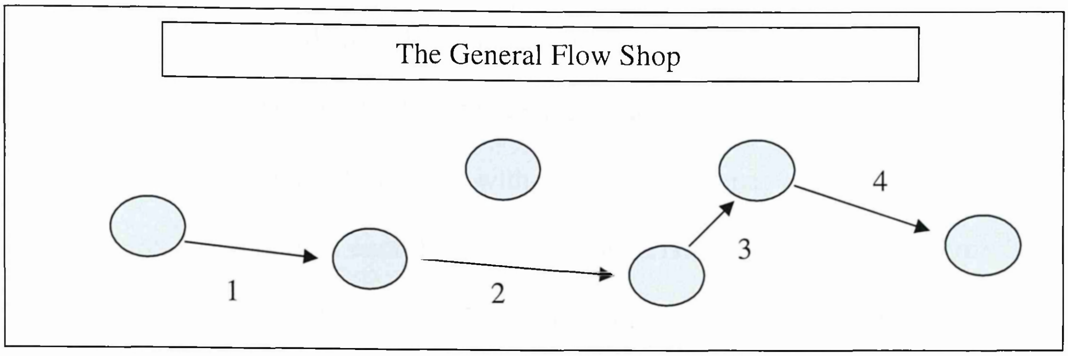


Figure 2.1: Example of Job Routing in the General Flow Shop

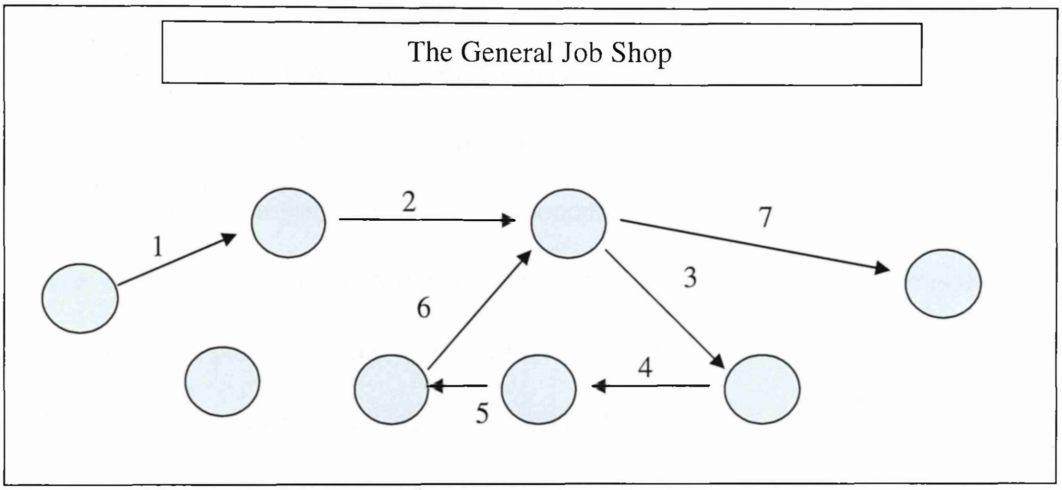


Figure 2.2: Example of Job Routing in the General Job Shop

2.2.3 Company Size

Where possible, the review also considers the impact of organisational size, with particular interest in SME's. The high proportion of SME's in customised industries means that accessibility to companies with more limited resources is an important factor in the applicability of PPC approaches to many MTO companies.

2.2.4 Criteria for Determining Applicability

Soman *et al.* (2004) explain that the main operational issues for MTO companies are capacity planning, order acceptance/rejection and attaining high due date adherence.

Capacity planning should be addressed at several levels including the stage at which orders are first considered and thus the customer enquiry stage is of particular importance to the MTO sector. Further capacity planning should be carried out at each of the four stages outlined in Chapter 1, with due date adherence as a major criterion for lower level planning and control decisions. For MTO applicability an approach must cope with high levels of customisation, which entails many end products, variable routing and numerous set ups. It is noted that once a RBC has established a contract with a customer it needs less control over the customer enquiry stage, but a VMC must go through the whole process for every order.

Soman *et al.* (2004) also explain that the competitive priority is often shorter delivery lead times. Kingsman *et al.* (1996) concur that the bid a company makes in response to a customer enquiry must contain realistic and currently competitive delivery dates and prices although other factors such as the reputation of the company and the financing package may also be important in winning an order. Thus, the ability of a PPC system to assist in the calculation of competitively short and realistic delivery dates at the customer enquiry stage is also important.

Therefore, in summary, the following criteria are proposed as the main requirements of a PPC system in the MTO sector:

(1) Inclusion of the Customer Enquiry Stage for delivery date determinations and capacity planning.

(2) Inclusion of the Job Entry and Job Release stages, focusing on due date adherence.

(3) Ability to cope with non-repeat production, i.e. highly customised products.

(4) Ability to provide planning and control when shop floor routings are variable, i.e. general flow and job shops.

(5) Applicability to Small and Medium sized Enterprises.

The chapter now reviews the literature relating to six PPC concepts, and uses these criteria to evaluate the applicability of the concepts to MTO companies.

2.3 MATERIAL REQUIREMENTS PLANNING (MRP) AND BEYOND

Material Requirements Planning (MRP) is a periodic push-based system designed for complex production planning environments. MRP can provide significant benefits such as improved customer service, better production scheduling and reduced manufacturing costs. Despite being labelled a 'legacy system', MRP is still an important PPC approach; Sower & Abshire (2003) found that one third of manufacturing companies studied use packages such as MRP. Manufacturing Resource Planning (MRP II) offers greater functionality than MRP, integrating a wider number of modules and company operations. For a complete description of MRP/MRP II, see Vollmann *et al.* (1997).

However, the reasons for the importance of MRP/MRP II need to be questioned. Bertrand & Muntslag (1993) explain that the choice of a MRP II system is often based on its wide availability. In addition, MRP/MRP II vendors have tended to adopt a universalistic approach, rather than gearing the associated software to any particular industrial sector. However, there is evidence that this approach has tended to better suit the larger organisations with lower levels of variety. For example, Petroni (2002) is critical of the low implementation success rate of MRP, especially amongst SME's. In addition, Bertrand & Muntslag (1993) suggest many ETO firms have tried to implement MRP II without success. It is acknowledged that implementation problems are not always the result of system functionality; as argued by Petroni (2002), other factors can also be important, such as the level of management support, degree of functional integration and data accuracy. However, in this case it is argued that functionality is often the cause.

To understand the problematic issues regarding the functionality of MRP/MRP II, it is necessary to explore the underlying assumptions of the approach. Bertrand & Muntslag (1993) explain that the concept assumes the production of standard products with well known Bill of Materials (BOM) and product routings, and that MRP II also assumes that it is possible to forecast the future demand of these standard products as a basis for the Master Production Schedule (MPS). As a result MRP does not always generate feasible plans, and as Kanet (1988a) explains, can lead to high WIP and long cycle times. Hence, the changeable environment and variation in design and production in MTO environments may severely affect the applicability of this approach. However, despite this criticism, the authors acknowledge that attempts have been made to address these concerns. Vollmann *et al.* (1997) examine MRP design issues, the inadequacies of MRP and system nervousness before discussing ways to overcome issues such as these, highlighting the role of, for example, Rough Cut Capacity Planning (RCCP), Capacity Resource Planning (CRP) and the use of a two-level master production scheduling system. However, this does not specifically address the customer enquiry stage, nor adequately consider capacity decisions at the point of job entry and job release. Thus key decision support needs are not fully addressed by this approach.

MRP has led to further Advanced Manufacturing Technology (AMT) such as Enterprise Resource Planning (ERP), Advance Planning and Scheduling (APS) Systems and Workflow Management Systems. Kehoe & Boughton (2001a) remark that the current manufacturing planning and control research mindset is dominated by the industrial progression from MRP II to Enterprise Resource Planning (ERP) through products such as SAP, Baan and Oracle. ERP systems, as defined by Muscatello *et al.* (2003), are comprised of a suite of software modules, with each module typically responsible for a separate business function, or a group of separate business functions. New software capabilities increase functionality; however, the core planning and control assumptions underpinning these packages have developed less rapidly. Consequently, similar issues regarding the underlying assumptions of MRP also apply to these more advanced systems.

Hong & Kim (2002) explain that, similarly to MRP, ERP projects also report an unusually high failure rate, sometimes jeopardising core operations. Motwani *et al.* (2002) list a cautious and evolutionary implementation process backed by careful change management and cultural readiness as important factors for successful implementation. Schniederjans & Kim (2003) suggest that success depends on how an organisation prepares itself for integration; change methods such as Business Process Reengineering (BPR) and catalyst for change methods such as Total Quality Management (TQM) can help support the implementation of ERP. Meanwhile, Ash & Burn (2003) present a framework for managing ERP enabled e-business change (see also Mabert *et al.* (2003)). Based on case study findings, Muscatello *et al.* (2003) suggest that ERP implementation problems experienced are similar to those previously reported for MRP II and Computer Integrated Manufacturing (CIM), similarly the approach shares the same secrets to successful implementation. Yusuf *et* *al.* (2004) present a case study of ERP implementation, grouping difficulties into three areas: cultural, business and technical. Further ERP case studies are presented by, for example, Bhattacherjee (2000), Sarker & Lee (2003) and Mandal & Gunasekaran (2003). These recent ERP case studies further illustrate the particular implementation difficulties of this approach. However, overcoming these issues will not be enough to make the method more applicable to the MTO sector.

Muscatello *et al.* (2003) explain how, using ERP, customers and suppliers can access information through an external communication interface. Kehoe & Boughton (2001a) encourage a network-based approach by suggesting that through the use of Internet based technologies, a mindset closer to Supply chain Resource Planning (SRP) can emerge. Thus web or e-based Supply Chain Management (e-SCM) technology is a major growth area, with the lead taken by large companies. However, Cagliano *et al.* (2003) suggest that the Internet is also feasible for SME's and identify 'e-purchasing' as an area where SME's use these capabilities, but that companies can draw benefits from the use of Internet tools only by defining a clear e-business strategy. Quayle (2002) considers e-commerce strategy to be missing from SME business plans, but agrees that SME's could benefit from e-commerce, both as a strategic business tool and to facilitate purchasing consortia. Hunter *et al.* (2004) acknowledge that the use and benefits to be gained from e-business vary with buying circumstances. The degree of customisation present in the MTO industry means that customers cannot take full advantage of e-purchasing at the customer enquiry stage, only by, for example, confirming previous tenders at the job entry level.

Cagliano *et al.* (2003) acknowledge a close link between the use of Internet tools and the level of integration with customers and suppliers. Kehoe & Boughton (2001b) explain the benefits that companies can gain from the use of internet based

SCM, as it provides the opportunity for demand data and supply capacity data to be visible to all companies within a manufacturing supply chain allowing companies to anticipate demand fluctuations and respond accordingly. However, Calosso *et al.* (2003) state that only 30% of European SME output goes to the consumer market implying the focus should be on Business to Business (B2B) rather than Business to Consumer (B2C) relations. Based on case study findings, Quayle (2002) reports that only 34% of SME's trade electronically and 50% of those have been 'forced' to do so by major purchasers. Although SME's have been slower to adopt this technology, it is becoming more prominent in PPC, hence web-based functionality may be a key criteria in future 'system selection' decision making.

Despite slow growth in some areas, the use of Electronic Data Interchange (EDI) in supply chain management can help to improve the flow of information. For example, Machuca & Barajas (2004) explain that EDI can reduce ordering costs, allowing more frequent ordering in smaller batches, reducing the distortions in demand information in the supply chain that create the bullwhip effect (see Forrester 1961; Lee *et al.* 1997). However, Kehoe & Boughton (2001a) suggest that in order for improvements to be realised from e-business, a radical overhaul of the current planning and control mechanisms, practices and systems is required.

Despite the ERP market being dominated by larger companies, the SME segment is recognised as the biggest untapped IT market in the European economies (EITO 2000). Muscatello *et al.* (2003) suggest that ERP vendors are turning their marketing sights on SME's and hence, ERP may emerge as a more viable 'system selection' possibility for MTO practitioners in the future.

2.3.1 Assessing the Applicability of MRP and Beyond

Partly due to its universalistic approach, MRP is very widely used. However, this does not mean wide applicability. There is a clear progression in concept design and increased functionality from MRP to ERP, with large companies setting the pace in the implementation of these concepts. However, this evolutionary process does not seem to have eased the problem of integration and implementation, eased data requirements nor tackled the key characteristics of the MTO industry that differentiate it from more repetitive manufacturing environments, such as the strategic importance of accurate and competitive delivery date quotations at the customer enquiry stage. Thus there are reservations for the first four criteria listed in Section 2.2.4 regarding the use of MRP based systems in the MTO industry.

Company size has been identified as important in implementation strategy and success. It may be possible, to an extent, to tailor the design of MRP systems to the needs of MTO companies; however this would further add to the expense. The capital investment and the impact on SME's of a failed ERP implementation strategy may be a barrier to entry for ERP into some SME dominated markets. However, as the use of e-based supply chains becomes common practice in larger companies through packages such as ERP, web-based solutions may gradually become an order qualifier for SME's in order to maintain their relationships. The future importance of e-active MTO manufacturing is clear; however, the development of MTO specific solutions is required.

Having stated these reservations regarding the applicability to MTO companies, it is acknowledged that the issue of wide availability remains. Consequently, ERP based approaches are likely to continue as a system selection option for both RBC and VMC companies whatever the shop floor configuration.

Hence ERP may continue to be seen as a potential solution for at least some of the concerns of the MTO sector, particularly those related to e-based supply chains.

2.4 THEORY OF CONSTRAINTS (TOC)

The Theory of Constraints (TOC) is a bottleneck-oriented concept. The approach developed from Optimised Production Technology (OPT), as is commonly attributed to the work of Goldratt (see, for example, Goldratt & Cox 1984; Goldratt 1990a), and is now more commonly known as the Drum-Buffer-Rope (DBR) approach. Under the TOC philosophy, the production process is scheduled to run in accordance with the needs of the bottleneck(s), as the bottleneck (constraint resource) determines the performance of the whole production system. Mabin & Balderstone (2003) explain that although the approach was conceived in the 1970's in a manufacturing context as a scheduling algorithm, TOC has been developed into a management theory of theoretical frameworks, methodologies, techniques and tools.

Based on analysis of, mainly manufacturing based, applications of TOC, Mabin & Balderstone (2003) show companies benefit from, for example, lead-time reduction, cycle time reduction and increased revenue. TOC can be used in a job shop (Spearman *et al.* 1989) and within small organisations, demonstrating its apparent applicability to the MTO industry. Wahlers & Cox (1994) discuss the use of TOC in an ETO organisation, further highlighting its applicability to highly customised industries, where the company was able to reduce lead times and improve delivery performance. Duclos & Spencer (1995) compare MRP scheduling with that of DBR scheduling in a flow shop, where it was concluded that DBR performed better, with the constraint buffer used in DBR useful in increasing system output. Hence, it has been shown that TOC can have a beneficial impact on performance in both the flow and job shop scenarios, confirming its relevance to both the RBC and VMC sectors of MTO industries.

However, TOC has received a large amount of criticism in the literature. Early criticisms focus on a lack of disclosure of the full details of TOC (see, for example, Duclos & Spencer 1995; Wiendahl 1995) and claims of optimality (see, for example, Wiendahl 1995); however, it is acknowledged that explanations have shown that TOC is not an optimal approach (see, for example, Goldratt 1990b). Duclos & Spencer (1995) are also sceptical of the achievements of TOC, highlighting the confusion resulting from a TOC performance measurement system with distinct differences to traditional Operations Management (OM) performance measurement systems; hence making comparisons and objectivity difficult. TOC has a poor start up rate in Japan, where it is associated with finite loading and continual rescheduling (Matsuura *et al.* 1995). Despite attempts to accommodate the 'wandering bottleneck' problem (see, for example, the discussion of multiple constraint scheduling by Simons & Simpson (1997)), there must also still be doubt regarding the applicability of a method so bottleneck oriented to complex MTO environments. Although in the general flow shop it is likely that bottlenecks will remain relatively stationary and deterministic, as configuration approaches the pure job shop, routing variation becomes more random meaning bottlenecks can regularly move and occur anywhere.

Rahman (1998) presents a thorough review and classification of research in this field. Perez (1997) discusses extending the principle and application of TOC from in-house to the constraints and bottlenecks of global supply chains. Comparisons of TOC with alternatives suggest TOC will outperform MRP when there is a dominant bottleneck, but that MRP performs better when there are highly customised products, and that the TOC system is more complete than the JIT system (see Plenert & Best (1986), Rahman (1998) and Plenert (1999)). This further suggests that it is important to determine bottleneck resources for TOC, and given the problems with MRP highlighted in Section 2.3, casts further doubt over the performance of TOC when production is made to order / demand is customised. However, with reference to simulated comparisons by Ramsay (1990), Neely & Byrne (1992) and Cook (1994), Rahman (1998) states that it is difficult to conclude that one system is better than the other. See also, for example, Radovilsky (1998) for a discussion of the calculation of an optimal time buffer for TOC.

2.4.1 Assessing the Applicability of TOC

The discussion has highlighted the use of TOC in MTO production scenarios such as the job shop where variable routings and non-repeat production exist, including use in SME's. However, the stationary positioning of bottleneck resources may be a requirement for effective use, a more realistic assumption in the pure flow (MTS production) and general flow shops than in the job shop. In addition, as with MRP, TOC does not directly cater for the importance of planning and control at the customer enquiry and job entry stages in make to order production. Despite this, it could be argued that these planning processes are simplified as, providing non-constraint resources are maintained, the workload need only be estimated for constraint resources. This may be of particular benefit in highly customised industries where estimating required processing times in advance can be difficult. As described above, TOC continues to be an option widely considered by practitioners and has been used effectively in ETO and highly customised environments.

2.5 WORKLOAD CONTROL (WLC)

As briefly described in Chapter 1, Workload Control (WLC) is a sophisticated PPC solution specifically designed for the needs of complex planning problems. There are many methodologies that can be termed as WLC concepts, designed for a variety of situations. This section begins by discussing the typical features of WLC, before Section 2.5.1 provides an overview of the LUMS approach.

WLC uses a pre-shop pool of orders to reduce shop floor congestion, making the shop floor more manageable, consisting of a series of short queues. Thus this approach stabilises the performance of the shop and makes it independent of variations in the incoming order stream (Bertrand & Van Ooijen 2002). For most WLC concepts, jobs are only released onto the shop floor if released workload levels will not exceed preset maximum limits, whilst ensuring jobs do not stay in the pool too long in order to reduce lead times and meet DD objectives. Whilst jobs remain in the pool, unexpected changes to quantity and design specifications can be accommodated at less inconvenience. Land & Gaalman (1998) suggest that the procedure to release jobs is basically the same in each WLC concept. As the performance of release increases, the impact of shop floor dispatching rules diminishes (Wein 1988). Henrich *et al.* (2002) consider the decision of job release to be the main control point crucial to the simplification of the remaining process. Hence, with a release method in place, only a simple shop floor dispatching rule such as First-in-System-First-Served (FSFS) or First-at-Work-centre-First-Served (FWFS) is needed (Kingsman 2000).

Releasing mechanisms have a significant effect on the performance of the production system, reducing WIP and lead times (Hendry & Wong 1994).

Tatsiopoulos (1997) states that the key to the successful use of an order pool is the availability of a good mechanism to select orders for release. However, the customer enquiry stage and order acceptance point (job entry) may be better as the main control point. For example, it has been shown that job entry can reduce WIP and lead times with the same workload (Haskose *et al.* 2002). Without control at the customer enquiry and job entry stages, power will have been lost before reaching the job release or shop floor dispatching stages, causing pre-shop pool times to escalate. These stages are the least elaborated areas (Land & Gaalman 1996), but have received attention recently (see, Enns & Prongue Costa 2002; Kingsman & Hendry 2002). At these stages, input control such as adjusting job start dates or delivery dates, and output control such as reallocating operators, can be used together coping with the same workload but with lower lead times (Kingsman & Hendry 2002). Although when customers enquire cannot be determined, this research shows that when WLC is employed at the customer enquiry stage, DD quotations can be made with confidence by stabilising lead times and controlling workloads. All three levels, customer enquiry, job entry and job release, have been addressed by some WLC systems.

There are a wide range of WLC concepts (see for example, the review and classification of Order Review and Release (ORR) methods by Philipoom *et al.* (1993), Bergamaschi *et al.* (1997) and Sabuncuoglu & Karapinar (1999)), where the common principle is the use of a pre-shop pool. However, the reduction of congestion, lead times and improved delivery date performance does not rely on the pool being placed before the first in-house activity. A recent research project by the author, with a repeat business MTO steel fabricator, led to a recommendation of a pool being placed between two value adding shop floor work centres, as illustrated in Figure 2.3. For the economic use of steel, to act against any in-house manufacturing errors and to gain from some of the advantages of a MTS company, 'pre-pool' jobs required some batching and 'over production'. However, this previously led to over and early delivery, excess purchasing of raw materials, and high levels of WIP and FGI due to intermittent demand. Activities after the pool did not require safety production; as a result the pool was able to act as a means to control and coordinate production from the critical resource onwards, satisfying individual daily demands. While Cox & Spencer (1998) explain that the selection of a bottleneck for TOC can be more a management decision than an issue of capacity, similarly, this example illustrates that the positioning of the job pool, for WLC, can be a strategic decision.

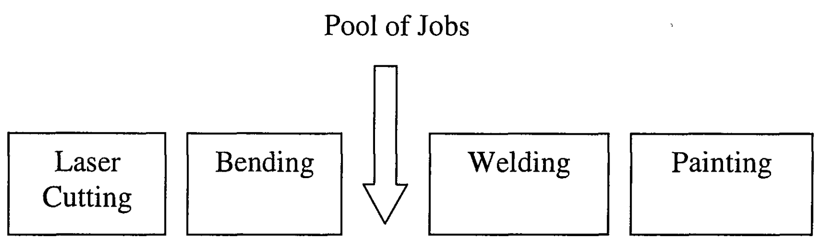


Figure 2.3: A Variation on the Traditional Application of WLC

The main three branches of WLC are covered by Bechte (Load Oriented Manufacturing Control: LOMC), Bertrand and the Lancaster School (see Land & Gaalman 1996); see also the discussion of the Time Bucket (for example Bobrowski 1989), Probabilistic (for example, Bechte 1988, 1994; Wiendahl 1995), Atemporal (for example, Glassey & Resende 1988) and the General Bucket approaches by Portioli (2002). WLC concepts differ with respect to workload accounting over time; whether they include work queuing at a centre, work upstream, or the work downstream in the measurement of indirect load; the more complicated the flow of work, the more work it may be necessary to consider. This important measure is further explored in Chapter 4. At the order release stage, concepts also vary in their approach to workload bounding, with some adopting a workload balancing philosophy (see Cigolini & Portioli 2002). The majority of WLC concepts use periodic release, where the period length must be less than the smallest slack of the jobs in the pool to avoid lateness. The upper centralised planning level performs the sophisticated part allowing shop floor supervisors to make simple decentralised shop floor scheduling decisions. Hence WLC concepts can vary in sophistication in order to cater for a range of shop configurations from the general flow shop towards the pure job shop. Oosterman *et al.* (2000) consider a number of Workload Control concepts and show that the performance of each varies depending on shop configuration. However, in general, as variability increases and configuration approaches the job shop, WLC becomes more applicable (see Henrich *et al.* 2002). In fact, WLC works particularly well in the job shop environment and can lead to the reduction of SFTT and WIP (Land & Gaalman 1996). Bechte (1988) documents how LOMC, a job shop specific solution, can cut lead times and converge planned and actual lead times, while Wiendahl (1995) compares Load Oriented Manufacturing Control (LOMC) with five other PPC methods. For a more complete description of WLC, see Land & Gaalman (1996), Bergamaschi *et al.* (1997) and Kingsman (2000).

2.5.1 Overview of the LUMS Approach

The LUMS approach is built around the control of workloads through a hierarchy of backlogs beginning when a prospective customer first enquires, and hence accommodates the customisation offered by MTO companies in the design of the PPC concept. This is considered a complementary technique to job entry and job release control. In the case of the shop as a whole, the hierarchy of backlogs incorporated in the LUMS approach is as follows, where each is a subset of the backlog below. For a more complete description of the LUMS approach, see, for example, Hendry & Kingsman (1989 and 1991), Kingsman (2000) and Chapters 4 and 5.

(1) *Released Backlog*: The total work content of jobs on the shop floor.

(2) *Planned Backlog*: The total work content of jobs awaiting materials, in the pre-shop pool and on the shop floor.

(3) *Total Backlog*: A proportion of the total work content of unconfirmed jobs, in addition to the total work content of all accepted jobs.

Figure 2.4 below summarises the hierarchical control framework provided by the LUMS approach. The figure highlights the key production stages to control (before allowing the shop floor supervisor to take decentralised control of the shop floor), examples of the decisions to be made at each stage and the appropriate backlogs to regulate. Figure 2.5 accompanies Figure 2.4 to further illustrate the integration of the hierarchical backlog control framework in the delivery lead time of a job.

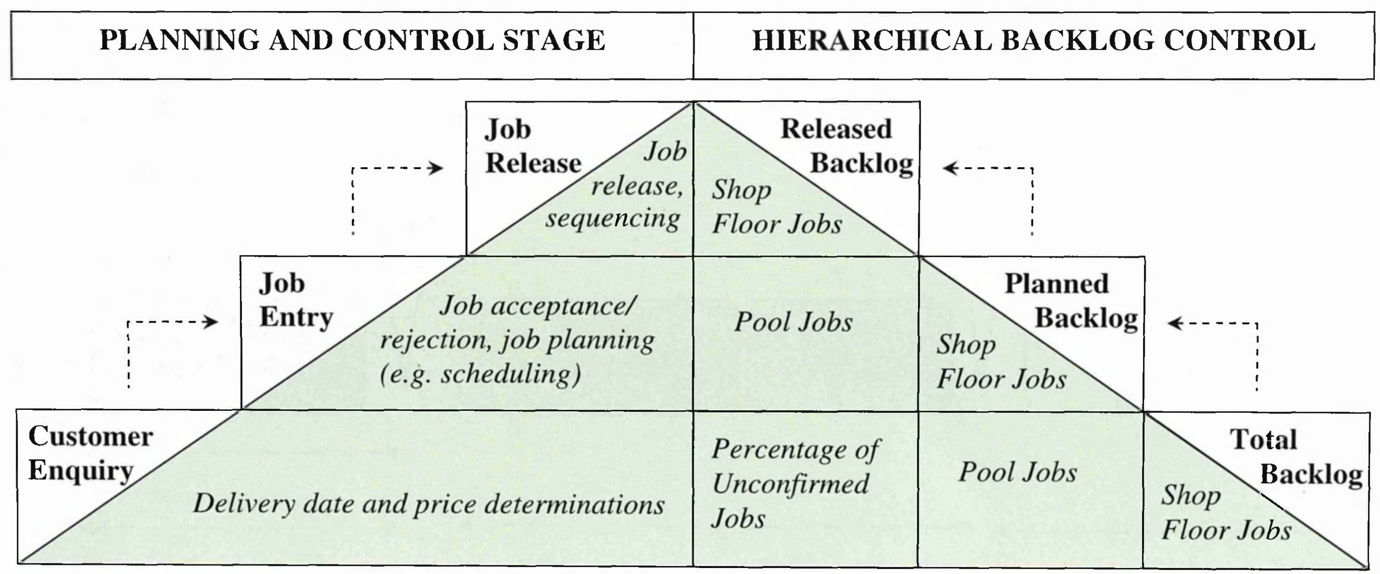


Figure 2.4: Hierarchical Backlog Control Framework

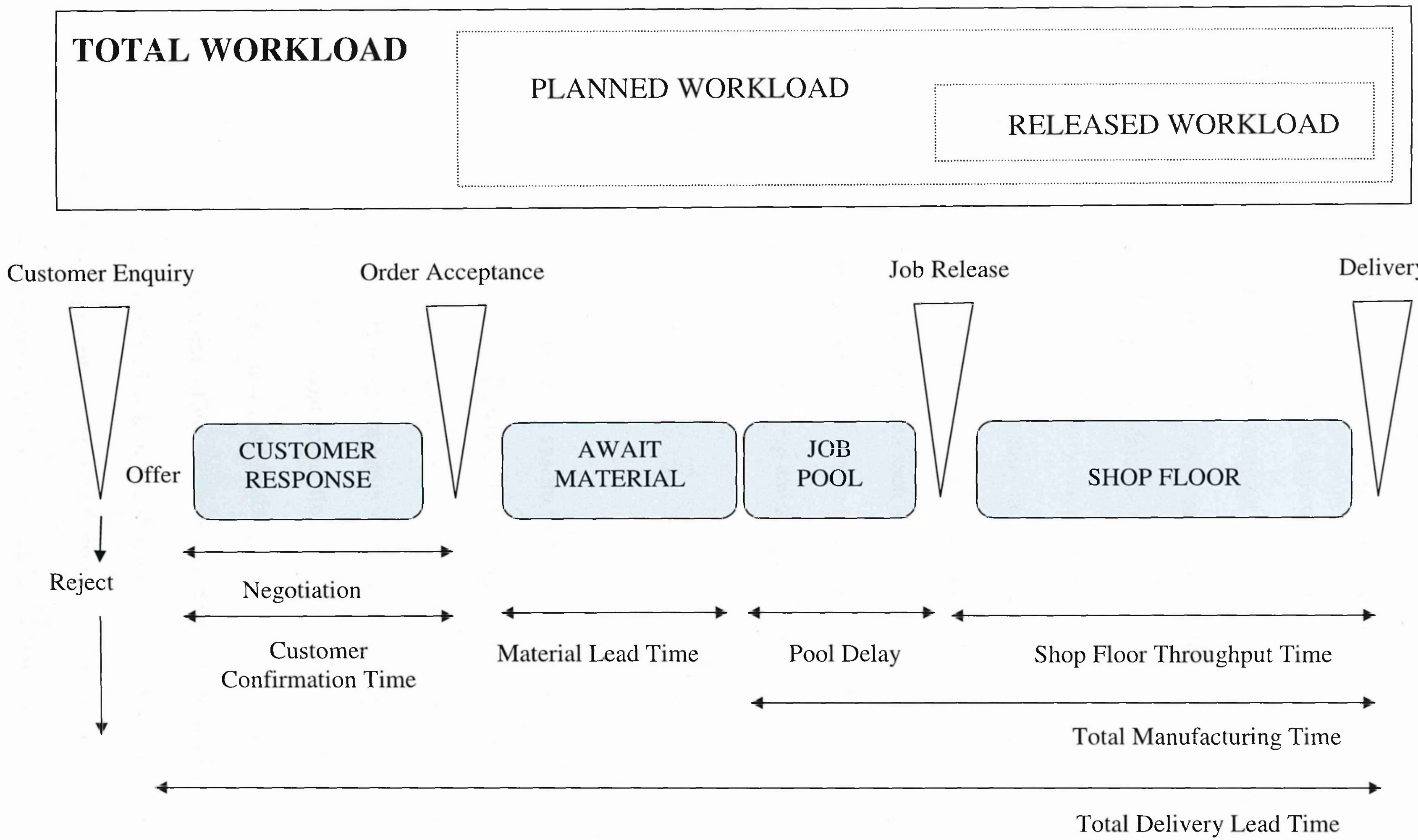


Figure 2.5: Summary of WLC Planning and Control Procedure

2.5.2 Assessing the Applicability of WLC

WLC is designed for MTO type production environments like the job shop and can be an effective method of reducing WIP and controlling lead times, accommodating non-repeat production and variable routings. This has been demonstrated through simulation and empirical research. As illustrated in the description of the LUMS approach, WLC can also accommodate the customer enquiry stage by considering the total backlog of the shop in delivery date determinations. It also enables capacity planning at the lower levels of job entry and job release. In addition to its effects on delivery date adherence, the lower cost of the approach also makes it more practical to implement for SME's than packages such as ERP. As discussed in the literature, the sophistication of the methodology can be varied to allow WLC to be an effective concept for both the general flow shop and the general job shop.

2.6 KANBAN

Kanban is a card-based production system that aims to cut inventory and flow times, where the start of one job is signalled by the completion of another. There are many variations but, in its simplest form, cards are 'part number specific'. Determining the number of Kanban cards is an important decision, balancing WIP, flow times and utilisation. Kanban needs a continuous flow or large batches, a limited number of parts, few set ups and low demand variability to be an effective system, making it suited to repetitive manufacturing. However Kanban has been highlighted in this review because it can be used as a simple shop floor signal in conjunction with more sophisticated MTO applicable approaches involving centralised planning, and has been a catalyst for the development of other card-based systems.

Kanban relies on the use of Just in Time (JIT), which does require advanced planning, a rare commodity in the MTO sector. JIT is a major factor in the popularisation of pull systems (Tardif & Maaseidvaag 2001); however, Zäpfel & Missbauer (1993) question whether reported improvements are a direct result of the use of Kanbans or the necessary adoption of JIT involving reform and reorganisation of the manufacturing process. Implementation of JIT requires a reduction in set up time and lot sizes and the use of cellular manufacturing. Abdul–Nour *et al.* (1998) commented that when small firms try to implement JIT they struggle with a lack of materials, high up front costs and a lack of much needed influence over suppliers. Also note that Japan (i.e., Japanese Manufacturing) is not completely happy with JIT, and is looking for improvement to attain a 'Post-JIT' level (Matsuura *et al.* 1995), while Plenert (1999) does not consider JIT to be an effective solution for the job shop. Fowler *et al.* (2002) explain that Kanban was difficult to implement at best; hence some enterprises evolved a derivative suitable for their environment and others abandoned it.

The Kanban approach described in this section is well known to PPC researchers; as a result, further details of this approach are not supplied. For a more complete description, see Schonberger (1983), Karmarkar (1989) and the review of Kanban production control systems by Singh & Brar (1992). Variations on the Kanban include the Adaptive Kanban (Tardif & Maaseidvaag 2001); see also Dallery and Liberopoulos (2000), Karaesmen & Dallery (2000), Axsater & Rosling (1999) and the discussion by Gaury *et al.* (2000).

2.6.1 Assessing the Applicability of Kanban

It is clear from this discussion that the 'traditional' Kanban system cannot cater for the routing variability and lack of repetition predominant in MTO manufacturing. In isolation, the Kanban is a de-centralised shop floor signalling system and lacks control at the customer enquiry, job entry and job release stages. Despite this, it may be possible to use Kanban on the shop floor in conjunction with a higher level planning tool such as WLC; however, this would still need a way to accommodate product variation, while the WLC job release function means that the shop floor can be controlled through simple priority dispatching without the need for Kanban signals. However, in the example illustrated in Figure 2.3, where a pool is placed between two shop floor resources, a Kanban system could be used for the more repetitive front end (pre-pool operations) and the supervisor can be allowed to control the back end (i.e. control jobs after they are released from the pool).

Although Kanban cannot adequately plan and control in a non-MTS environment, aspects of the JIT philosophy and lean thinking approach, such as attitude towards waste and stockholding, could be adopted. However, the discussion has also highlighted the practical difficulties that SME's encounter with JIT production. Hence, reservations exist regarding the use of Kanban against all five criteria. Generalised card based systems, of greater applicability originating from the Kanban approach, are described in Sections 2.7 and 2.8.

2.7 CONSTANT WORK-IN-PROCESS (CONWIP)

Constant Work in Process (CONWIP) is a continuous shop floor release method. Cards regulate the flow of work, but are not 'part number specific'; instead they are 'job number specific' staying with a product or batch through the whole length of the process, making it a more manageable method when there is high variety. Fowler *et al.* (2002) consider Kanban to be throughput control oriented while CONWIP is naturally more focussed on WIP. Nevertheless, CONWIP can provide a greater throughput than Kanban (Spearman & Zazanis 1992). Spearman *et al.* (1989) explain that CONWIP is part of a Hierarchical Control Architecture (HCA) bringing the hierarchical and JIT approaches together providing a JIT environment whilst accommodating a changing product mix, more set ups, and short production runs. In comparing CONWIP with push alternatives, Spearman *et al.* (1989) conclude that the stability of CONWIP is preferred at the expense of a slightly higher average level of WIP, since WIP in the push system fluctuates erratically and its performance deteriorates more quickly when control is reduced.

Gaury *et al.* (2000) consider modelling and optimisation to be much easier for CONWIP than for Kanban. CONWIP only requires the determination of one parameter (Tardif & Maaseidvaag 2001), since a single level of WIP is set for the whole system. Statistical Throughput Control (STC) (Hopp & Roof 1998) is used to change the number of cards and regulate the level of WIP (or throughput). However, this requires accurate feedback data, difficult to provide in a complex manufacturing environment where it may also result in too many card changes. Under CONWIP, some standardisation of products is needed because if the number of cards is to regulate the level of WIP, the workload represented by each card will have to be similar. Gaury *et al.* (2000) concede that a disadvantage of CONWIP is that inventory levels inside the system are not controlled individually; high inventories can appear in front of slow machines and when a machine breaks down.

There have been some attempts to adapt CONWIP to the specific needs of the semi-conductor industry. Rose (1999) criticises CONWIP and WLC in relation to the individualistic semiconductor industry for not tracking the current load situation of the shop accurately enough, while Rupp & Ristic (2000) describe semi-conductor manufacturing as a dynamic environment for which MRP II is not sufficiently flexible. Rose (1999) developed Constant Load (CONLOAD), a hybrid system based on adapting CONWIP and WLC specifically for the semiconductor industry. However, it is difficult to generalise CONLOAD, as the semiconductor industry is a 'special case scenario'. Jain *et al.* (2003) include re-entrant process flows (or re-circulation) as a characteristic of this environment, a characteristic that has drawn comparisons with the job shop. However, Fowler *et al.* (2002) remark that comparisons made between semi-conductor manufacturing and the job shop are unfounded; insiders know that routings are fixed and similar across product families, just as they are in flow or even assembly lines. Fowler *et al.* (2002) also remark that some authors consider the semiconductor wafer fab to be the most difficult of all manufacturing environments. There is a wealth of research in the semi-conductor wafer fabrication area, see for example, Starvation Avoidance (Glassey & Resende 1988), and Chang *et al.* (2003) who examine Production Activity Control (PAC) methods for a hybrid MTO/MTS semi-conductor manufacturing company. See Anavi-Isakow & Golany (2003) for an adaptation of the CONWIP principle to project management.

2.7.1 Assessing the Applicability of CONWIP

This discussion has highlighted CONWIP as an approach of greater applicability to the MTO industry than Kanban. However, it is again questionable whether the hierarchical control system can provide the necessary control at the customer enquiry, job entry and job release stages. In addition, HCA needs end items to be grouped into families of common routings, restricting customisation possibilities and applicability. In the MTO industry there are only limited opportunities to batch, and even if such opportunities are found it tends to lead to delays and poor DD adherence.

For practitioners choosing between Kanban and CONWIP, Kanban is most useful for the pure flow shop, while CONWIP may be of more relevance in the general flow shop. If a practitioner is unsure of the exact flow shop configuration, CONWIP may offer the safest solution as Kanban would struggle if the actual shop configuration emerged to be closer to the general flow shop. Although CONWIP is a generalisation of Kanban, it is not a suitable option for the job shop and hence in a VMC setting. For a more complete overview of CONWIP, see also Spearman *et al.* (1990) and Hopp & Spearman (1996).

2.8 PAIRED CELL OVERLAPPING LOOPS OF CARDS WITH AUTHORISATION (POLCA)

POLCA is a hybrid push–pull card based signalling system emphasising the reduction of lead times, cutting product costs, increasing DD adherence, and cutting scrap and rework. It is aimed at highly engineered production, small batches and high product variety (Suri 1999). The card system is aided by the company-wide ‘mindset’ of Quick Response Manufacturing (QRM) focussed on operating at 70–80% capacity. Suri (1999) warns that utilisation any higher will lead to a false sense of security and see lead times increase, whilst also suggesting that JIT is too waste reduction oriented to fully utilise the potential for lead-time reduction. Despite this, QRM is a complementary technique to lean manufacturing (Suri 1999). Cards are ‘cell specific’; operating between pairs of cells staying with a job on its journey between them. Cards can belong to more than one fixed pairing, allowing routing flexibility. Suri (1999) explains that the cards bring back information signalling the capacity at the partner cell so the destination cell will always have capacity. POLCA links MRP with the shop floor, thus the reservations described earlier regarding MRP apply here too, although without higher level planning its applicability would be limited.

Documentation of this approach is in its infancy, resulting in cautious conclusions requiring further research for wider generalisation, although it is acknowledged that Tubino & Suri (2000) explain that a large number of projects have been conducted. For a successful implementation strategy it is important for the project to be championed by securing management support, which is not always a trouble-free process. Despite a number of successful QRM projects, Tubino & Suri (2000) comment that in many cases managers are sceptical that a QRM policy would lead to any benefits at all.

2.8.1 Assessing the Applicability of POLCA

This limited discussion suggests that POLCA may be of relevance to the MTO industry based on its allowance for non-repeat production. However, it is difficult to draw decisive conclusions until further research in this area has been conducted. However, as with other production signalling methods, POLCA relies on assistance at the higher planning levels to determine delivery dates based on workloads and capacities at the customer enquiry stage. Similarly, it needs to be incorporated with other methods if it is to address job entry and job release.

Using the POLCA philosophy, cards are placed in pairings where jobs travel in one-direction and information returns in the other. To be useful in a job shop, the system has to accommodate high routing variability, including upstream travel. To allow multi-directional flow and variable routing, it may be possible to place two cards between a pair of cells to allow work and feedback data to travel in both directions (as illustrated in Figure 2.6 below). However, research is needed to ascertain whether this is feasible. It is therefore concluded that this method appears to be more suited to the flow shop rather than the job shop and hence is only a solution for a RBC company with that particular shop floor configuration.

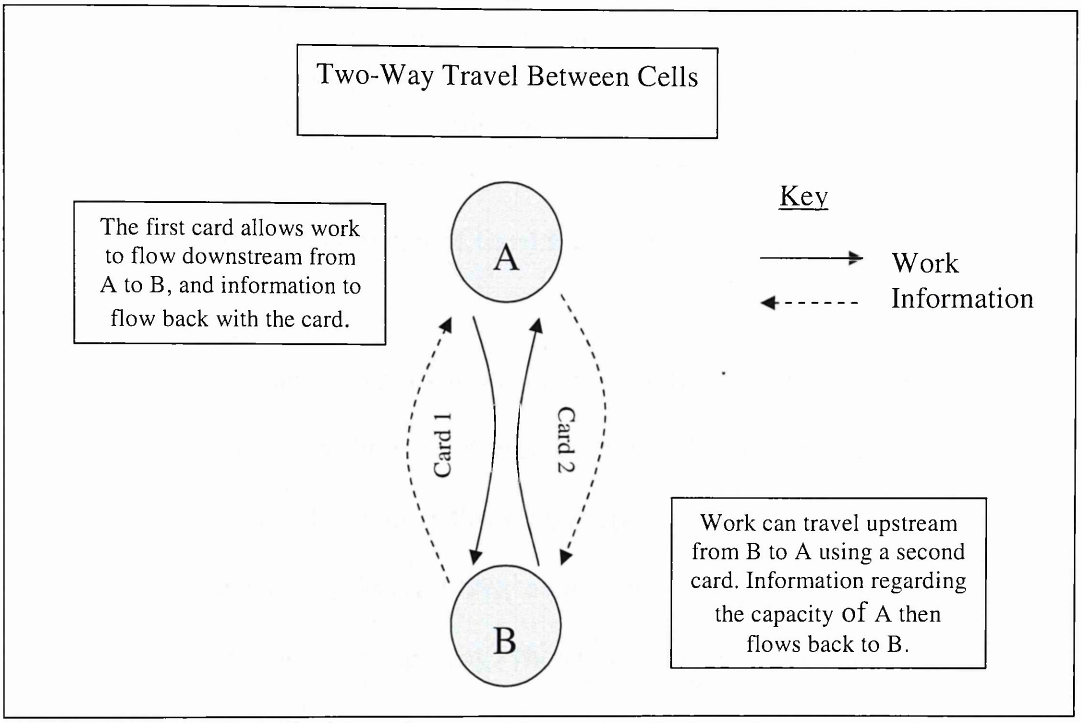


Figure 2.6: Dual POLCA System for a Job Shop

2.9 COMPARISON OF PPC METHODS AND THEIR APPLICABILITY

Table 2.1 compares and summarises the three card based signalling systems reviewed in Sections 2.6 to 2.8 above. In isolation they are purely shop floor production control mechanisms and require a higher-level coordination to be used in the MTO industry. MRP and TOC have been used as enhancements in conjunction with these approaches (see 'Collaboration' in Table 2.1), but whether HCA and QRM can provide the necessary customer enquiry and job entry control may determine their success in the MTO industry.

Card System	'Philosophy'	Emphasis	Collaboration (e.g.)	Push/Pull
Kanban	JIT	Throughput Control	MRP	Pull
CONWIP	HCA	WIP Regulation	TOC	Hybrid
POLCA	QRM	Utilisation	MRP	Hybrid

Table 2.1: Summary of Card Based Signalling Systems

All the PPC approaches discussed in this chapter can be effective under the right shop conditions; however, the concepts are provided to aid decision-making, and are not 'expert systems'. In addition, there is no perfect production control system that will fit for all situations (Plenert 1999); as a result, applicability depends on the individual characteristics of a company. Therefore managers must still play a large role by 'championing' the project, giving their specialist opinion, setting parameters and easing implementation through facilitating organisational change. Where possible, this chapter has critically reviewed the PPC literature from the perspective of the MTO industry, considering shop configuration, company size, customisation and provisions for the customer enquiry, job entry and job release stage. The complex demands of this criterion mean that the more sophisticated PPC approaches are required.

Figure 2.7 attempts to present a PPC system selection matrix summarising what the author considers to be the most applicable PPC options for companies in the MTO sector, where the most appropriate concepts are underlined, providing a useful guide for researchers and practitioners. If it is difficult to determine configuration, the more widely applicable approach should be chosen; however, it could be argued that wider applicability is gained at the expense of accuracy, and the use of a sophisticated PPC approach, where not required, will lead to unnecessary excess computation and scheduling time. Note that the matrix includes the MTS industry with a pure flow shop configuration for reference, thus indicating the appropriate positioning of the Kanban approach. Table 2.2 summarises the reasons given for the preferred approach in each case. The matrix also demonstrates that for the PPC concepts covered, whether a MTO company, with a general job shop configuration, is a RBC or a VMC, PPC concept applicability seems alike. ERP is considered to be applicable to all company types in Figure 2.7, but as discussed earlier this is due to its wide availability and its inclusion of general facilities such as those addressing e-purchasing.

	MTS
Pure Flow Shop	Kanban CONWIP ERP TOC

	MTO (RBC)	MTO (VMC)
General Flow Shop	WLC CONWIP ERP POLCA TOC	Not Applicable
General Job Shop	WLC ERP TOC	WLC ERP TOC

Figure 2.7: System Selection Matrix Presenting PPC Alternatives for the MTO Sector

Table 2.2 highlights Workload Control as being the most appropriate PPC approach for MTO companies, both for general job shop and for general flow shop production, and hence for both the RBC and VMC scenario. Hence, the chapter validates the continued research emphasis of this thesis on WLC as an effective PPC solution for MTO companies. However, within the WLC literature there are a wide range of concepts that vary in performance with shop conditions (see Oosterman *et al.* 2000) and there is no Workload Control method that performs better than the others under all tested conditions (Cigolini & Portioli 2002). Hence, although WLC is considered the most applicable approach, a generic WLC concept does not exist. However, it is considered that in practice managers would prefer the simplicity of aggregate or atemporal approaches to workload measurement and control, such as the LUMS approach. The robustness of a WLC concept to different environments is an important factor, especially when it is difficult to evaluate and generalise with confidence which PPC concept is the most appropriate, when it is difficult to determine the shop structure and when conditions are variable. Attempts to determine this can be made using a robustness index (see Cigolini & Portioli 2002).

Rahman (1998), referring to Ptak (1991) and Neely & Byrne (1992), concludes that an organisation needs a combination of production control methods in order to take advantage of the strengths of each system, although acknowledges that several studies had argued that TOC, JIT and MRP are mutually exclusive (see Grunwald *et al.* 1989). Indeed, PPC approaches do not have to be mutually exclusive; and at times can be hard to isolate. Most practical systems seem to consist of both push and pull elements. Many of the emerging approaches are hybrid methods based on established concepts. In addition there is increasing attention being focussed on hybrid production environments, such as the MTO-MTS sector (see Chang *et al.* 2003; Soman *et al.* 2004).

MTO Company Type and Configuration	Possible PPC Methods	Reasons for Preferred Methods
RBC General Flow Shop	WLC	WLC addresses the PPC levels required by a RBC, with some methods particularly effective in the flow shop, while WLC is likely to be cheaper than ERP;
	CONWIP	CONWIP is designed for the flow shop, but does not address all PPC levels and needs some standardisation of products, a RBC may not have enough standardisation for CONWIP to work well;
	TOC	The bottleneck(s) in a general flow shop are likely to be relatively deterministic with lower routing variation and customisation than the general job shop allowing TOC to be effective; however, not all PPC levels are addressed;
	ERP	ERP is based on MRP and persistent issues for MTO companies apply, for example, a lack of capacity planning whilst determining DD quotations at the customer enquiry stage;
	POLCA	POLCA is for high routing variability, but it only addresses the shop floor and further research may be required to determine its wider applicability to the general job shop.
RBC General Job Shop	WLC	WLC addresses the PPC levels required by a RBC; in the job shop it will be superior to CONWIP as it can accommodate greater routing variability; in addition, some WLC methodologies are designed specifically for the job shop;
	TOC	TOC buffers the bottleneck, and may be less effective in the general job shop than in the general flow shop, but routing variability is likely to be lower for a RBC than a VMC;
	ERP	ERP is based on MRP and persistent issues apply, for example the lack of capacity planning whilst determining DD quotations at the customer enquiry stage.
VMC General Job Shop	WLC	WLC addresses the PPC levels required by a VMC; in the job shop it will be superior to CONWIP as it can accommodate greater routing variability; in addition, there are job shop specific WLC methods applicable to both RBC's and VMC's;
	TOC	TOC buffers the bottleneck, although this can be applied, it is considered that, for a VMC, TOC is likely to be adversely effected by 'wandering bottlenecks';
	ERP	ERP is based on MRP and persistent issues apply, for example the lack of capacity planning whilst determining DD quotations at the customer enquiry stage; also, given that many VMC job shops are SME's, this PPC method may be prohibitively costly.

Table 2.2: Summary of Justification of Preferred Methods in the System Selection Matrix

Thus, although the approaches have been reviewed individually, it is clear that they are not always employed in this fashion. If a system does not cover all of the required PPC levels it relies upon the simultaneous adoption of complementary approaches for effective use in a MTO environment. Emerging solutions tend to embrace established classic methods, particularly MRP, attempting to gain wider applicability and an improved adoption rate. TOC can be integrated with WLC to enhance its application (Riezebos *et al.* 2002), see also Fry *et al.* (1991) for the use of Input-Output Control within the DBR approach. CONWIP can benefit from TOC (Spearman *et al.* 1989) while MRP and Kanban can be used together (see, for example, Ding & Yuen 1991). Smet & Gelders (1998) evaluate the feasibility of introducing a Kanban subsystem into a MRP system. The authors conclude that, for such a scenario, Kanban control is only a good idea for fast moving parts (see also Vollmann *et al.* (1997) for a discussion of how it can be important to integrate JIT into a MRP system). In addition, some Japanese companies want to integrate MRP with JIT (Matsuura *et al.* 1995), while there is now a trend to integrate ERP and APS so the material related functions of ERP are retained. The progressive figures approach, as described by Zäpfel & Missbauer (1993), can be interpreted as a kind of combination of MRP and Kanban; however, the authors explain that this approach is best suited to large series production, such as in the automobile industry.

2.10 GAPS IN THE LITERATURE

The chapter has reviewed a wide range of key PPC methodologies and trends, highlighting reviews and simulation studies for researchers and empirical work of particular interest to practitioners. The chapter has also highlighted the growth of e-based SCM solutions. Table 2.3 presents a summary of the literature reviewed. The papers have been categorised based on key contributions, with some classified under more than one heading.

Through this review and evaluation process a number of under-researched areas have emerged. In conclusion, several key areas of further research are briefly outlined below.

(1) *Integration:* Further research is required to determine the compatibility of integrating different PPC methodologies at different levels of the planning hierarchy under varying production environments. For example, the feasibility of integrating appropriate ERP functions in collaboration with WLC, or the relative performance improvement of adding an adapted Kanban to a 'Workload Controlled' shop floor.

(2) *Robustness:* Further research is required to evaluate and improve the robustness of planning and control approaches across varying manufacturing conditions, to allow greater confidence during the system selection and implementation phases. It is also particularly important that an approach is robust in the job shop, where conditions are highly changeable.

(3) *Applicability:* Emerging approaches, such as POLCA, are in their relative infancy and are in need of further research to confirm their applicability and performance in appropriate production environments, both empirically and through simulation.

(4) *Implementation:* Implementation frameworks for new approaches, such as POLCA, must also be clearly defined and made accessible. However, as

described, implementation is a problem common to many methodologies and similar issues may arise.

(5) *Sustainability:* Beyond implementation strategy, a key research issue is how the performance improvements reported from the use of the PPC concepts described in this chapter can be sustained over time, once the initial hype and emphasis has reduced. This is crucial to practitioners and is a key indicator of the true impact on company performance of a planning and control technique, but due to research budget and time constraints, is an area that continues to receive less attention.

(6) *Practical Guidance:* Further assistance with parameter setting common in most approaches would be of great benefit to practitioners, reduce the length of the implementation process and start up period, while improving the success rate. For example, the number of Kanban cards, the desired level of WIP (CONWIP) and the maximum accepted / released workloads in WLC.

(7) *Empirical Evidence:* The review has highlighted a need for further case study, or empirical, research in conjunction with a number of 'classic' and 'infant' PPC methodologies. For example, further contemporary Workload Control case study research is required in order to verify the performance improvements that have been demonstrated in simulations.

(8) *Technological Innovation:* e-SCM trends have been noted in this chapter. Future research should further address the application of web technology to enhance PPC in a MTO environment. The Internet presents opportunities for all types of companies; however, some existing methods such as e-purchasing cannot be fully applied to companies producing highly customised products. However, the web can be used to improve supply chain integration in other ways, such as

allowing customers access to the status of their orders prior to delivery, although this requires much further research. Lessons can also be learnt from ERP regarding the benefits of enhancing B2B relationships through improving the external flow of information in the supply chain.

(9) *Company Size:* The implications of company size on system applicability have been more adequately addressed for some concepts, such as MRP, than for others, for example, WLC. Hence, the issue of applicability and many of the other above further research avenues should also be considered in the specific context of company size, with particular emphasis on SME's.

It is concluded that Workload Control remains an important approach for the MTO sector and hence it is this approach to planning and control which is the topic for the remainder of this thesis. In particular, the thesis will seek to add to the issue of implementation: this is achieved in three ways. Firstly, by collaborating with a local precision engineering company, the research seeks to provide an original empirical contribution, providing a detailed, first-hand account of the obstacles encountered to the implementation of Workload Control. Secondly, by refining an appropriate Workload Control concept, the research seeks to facilitate greater implementation of the concept in practice. Finally, the thesis provides a starting point for the development of an implementation framework for Workload Control.

Approach	Topic	Methodology	Author(s)	Example(s)
Production Planning and Control (PPC) – Multiple Approaches	Overview of PPC approaches	*Literature Review*	Gelders & Van Wassenhove (1981); Zäpfel & Missbauer (1993)	Review of new PPC concepts.
	Comparing (at least two) PPC Approaches	*Various e.g. simulation and reviews*	Plenert & Best (1986); Ovrin (1990); Ramsay (1990); Ptak (1991); Spearman & Zazanis (1992); Neely & Byrne (1992); Cook (1994); Duclos & Spencer (1995); Matsuura *et al.* (1995); Wiendahl (1995); Karaesmen & Dallery (2000); Rahman (1998); Plenert (1999); Suri (1999); Gaury *et al.* (2000)	Comparing LOMC with alternative PPC approaches. Performance of different pull-type mechanisms. Evaluating alternatives to MRP.
	Integrating PPC Concepts	*Various e.g. theory*	Ptak (1991); Ding & Yuen (1991); Smet & Gelders (1998); Rose (1999); Riezebos *et al.* (2002); Schniederjans & Kim (2003)	Integrating MRP and Kanban. Enhancing TOC with WLC.
	PPC for Semi-conductor Wafer Fabrication	*Theoretical*	Rose (1999)	Combining CONWIP and WLC for the semi-conductor industry.
		Case Study	Rupp & Ristic (2000)	Case study of PPC in semi-conductor manufacturing.
		Simulation	Glassey & Resende (1988); Wein (1988); Rose (1999); Fowler *et al.* (2002); Jain *et al.* (2003)	Scheduling and job release methods.
Material Requirements Planning (MRP), Manufacturing Resource Planning (MRPII) and Enterprise Resource Planning (ERP)	Implementation insights, problems, frameworks, and practical use	*Theoretical*	Bertrand & Muntslag (1993)	Problems of MRPII for ETO sector.
		Case Study and Surveys	Bhattacherjee (2000); Hong & Kim (2002); Motwani *et al.* (2002); Petroni (2002); Ash & Burn (2003); Mabert *et al.* (2003); Mandal & Gunasekaran (2003); Muscatello *et al.* (2003); Sarker & Lee (2003); Yusuf *et al.* (2004)	Case study highlighting ERP implementation difficulties. Investigating critical factors for ERP success.
	e-business, Web-based SCM and PPC	*Various e.g. theory and reviews*	Kehoe & Boughton (2001a); Kehoe & Boughton (2001b); Quayle (2002); Cagliano *et al.* (2003); Calosso *et al.* (2003); Machuca & Barajas (2004)	eSCM for planning and control. eSCM strategy.

Theory of Constraints (TOC)	Overview of TOC methodology	*Theoretical*	Goldratt & Cox (1984); Goldratt (1990a); Goldratt (1990b)	Introduction to TOC methodology.
		Literature Review	Rahman (1998); Mabin & Balderstone (2003)	Review of TOC literature.
	Application of TOC	*Case Study and Surveys*	Wahlers & Cox (1994); Mabin & Balderstone (2003)	Performance evaluation of TOC in practice.
	Analysing performance of aspects of TOC	*Simulation*	Radovilsky (1998)	Determination of TOC time buffer.
	Extensions of TOC	*Theoretical*	Perez (1997)	Applying the TOC philosophy to the whole supply chain.
Workload Control (WLC)	WLC Methodology	*Theoretical*	Bechte (1988); Wiendahl (1995); Land & Gaalman (1996); Land & Gaalman (1998); Kingsman (2000); Oosterman *et al.* (2000); Breithaupt *et al.* (2002); Fowler *et al.* (2002); Henrich *et al.* (2002); Portioli (2002)	Outline of the probabilistic WLC approach. Adjusting the traditional aggregate load methodology.
	Overview of Order Review and Release (ORR) Methods	*Literature Review*	Philipoom *et al.* (1993); Bergamaschi *et al.* (1997); Sabuncuoglu & Karapinar (1999)	Classification of ORR concepts in the literature.
	Performance of WLC in practice	*Case Study*	Bechte (1988); Bechte (1994); Wiendahl (1995); Park *et al.* (1999)	WLC in a plastic leaves factory.
	Analysing the performance of aspects of WLC concepts and methodologies	*Simulation*	Hendry & Wong (1994); Bergamaschi *et al.* (1997); Land & Gaalman (1998); Sabuncuoglu & Karapinar (1999); Oosterman *et al.* (2000); Bertrand & Van Ooijen (2002); Cigolini & Portioli (2002); Haskose *et al.* (2002); Kingsman & Hendry (2002); Portioli (2002); Henrich *et al.* (2003)	Comparing performance of order release mechanisms. Comparing workload bounding and balancing strategies. Evaluating the impact of input and output control.

Kanban and Just In Time (JIT)	Overview of Kanban and JIT	*Literature Review*	Schonberger (1983); Singh & Brar (1992)	Overview of use of Kanbans and JIT philosophy.
	JIT in practice	*Case Study*	Abdul-Nour *et al.* (1998)	Case study application of JIT.
	Introducing and Evaluating Adapted and Generalised Kanbans	*Various*	Axsater & Rosling (1999); Dallery & Liberopoulos (2000); Karaesmen & Dallery (2000); Tardif & Maaseidvaag (2001)	Introducing an adapted Kanban approach.
Constant Work In Process (CONWIP) and Hierarchical Control Architecture (HCA)	Concept Overview and Development	*Theoretical*	Spearman *et al.* (1989); Hopp & Spearman (1996); Hopp & Roof (1998)	Introducing and outlining this generalised Kanban method.
	Testing and Developing Aspects of CONWIP Methodology	*Simulation*	Spearman *et al.* (1990); Hopp & Roof (1998)	Setting WIP levels.
	New applications or extensions of CONWIP	*Various*	Rose (1999); Anavi-Isakow & Golany (2003)	Applying CONWIP to project management.
POLCA and Quick Response Manufacturing (QRM)	Concept Overview	*Theoretical*	Suri (1999)	Describing the POLCA system and QRM philosophy.
		Case Study Surveys	Tubino & Suri (2000)	Highlighting problems and success stories from the use of QRM in practice.

Table 2.3: Summary of Production Planning and Control Literature Reviewed

CHAPTER 3:
RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter examines previous research approaches taken in the field of WLC and draws on insights available from the management research literature in order to develop a clear research strategy for this study. The results of any study will be affected by the research approach chosen (Saunders *et al.* 1997); hence it is important that the strategy developed in this chapter is rigorous and uses an appropriate framework in order to contribute towards answering the research questions outlined in Chapter 1.

3.2 ALTERNATIVE WLC METHODOLOGICAL APPROACHES

For the purposes of this discussion, previous WLC research can be categorised under one of the following three headings, or a combination of (1) and (2):

(1) Theoretical Development (conceptual)

(2) Simulation Based Research (experimental)

(3) Empirical Research (case study)

Research relating to theoretical development is focussed on outlining new WLC concepts or improving existing methodologies. One such example of theoretical development being the adaptation of the Aggregate Load Approach, known as the Adjusted Load Method, described by Land & Gaalman (1996). To validate the new or enhanced methodology, theoretical development has often been followed by a series of comparative simulation experiments, such as comparing different WLC concepts under varying shop conditions. Cooper & Schindler (2003) explain that to simulate is to replicate the essence of a system or process; simulations are increasingly used in research, especially in Operational Research. As a result, a large proportion of contemporary WLC research has been simulation based. Such experiments can be performed quickly and replicated time and again. For example, simulations involving the Adjusted Load Method are presented by Oosterman *et al.* (2000) and Henrich *et al.* (2004). Empirical research, on the other hand, involves learning from the use of WLC concepts in practice, and is less commonly undertaken, see, Park *et al.* (1999) for the most recent example. Also note that an empirical research project is currently being undertaken at the University of Coimbra, Portugal (see Silva & Magalhaes (2003) for initial details).

The growing trend in simulation-based WLC research includes the determination of workload norms and parameters (Perona & Portioli 1998; Land 2004a), testing the ability of different approaches to balance workloads across work centres (Cigolini & Portioli 2002), evaluating the impact of the number of shop floor information feedback points on WLC (Henrich *et al.* 2003), assessing the effectiveness of various ORR mechanisms (Cigolini *et al.* 1998; Sabuncuoglu & Karapinar 1999), evaluating the impact of input control on performance under different WLC concepts (see Enns & Prongue Costa 2002), determining the relative contributions of input and output control to the control of workloads (Kingsman & Hendry 2002) and assessing the impact of grouping machines on the effectiveness of WLC (see Henrich *et al.* 2004). This emphasis on simulation studies is understandable, as empirical research has certain risks associated with it; for example, it can take a long time to complete and has no guarantee of success.

On the other hand, empirical research is also considered very valuable and can allow the researcher to explore issues that cannot be investigated through simulation. By reflecting on the experiences gained from practical work, it is possible to direct conceptual development, thus provoking further simulation research. Furthermore, empirical research can increase the awareness of practitioners towards the benefits of WLC in industry and attempt to popularise the use of the technique, whilst highlighting the implementation issues particular to the use of WLC in practice.

3.2.1 Empirical WLC Research History

The first reported case study involving the use of a 'WLC concept' in practice was presented by Bertrand & Wortmann (1981). Bertrand & Wortmann (1981) developed an aggregated production control theory and information system and applied this to the diffusion department of a semiconductor plant producing integrated circuits. Although this is an important piece of research, the planning and control requirements of the semiconductor industry are rather unique: for example, the industry is renowned for a process of re-circulation (see Fowler *et al.* 2002; Jain *et al.* 2003), making it difficult to generalise these results. The authors concluded that developing a body of theory about aggregation should be a main production control research topic during the next decade, despite this; empirical research in the field has only sporadically emerged. Since the work of Bertrand & Wortmann (1981), a wealth of further research has emerged in the field of semiconductor manufacturing, see, for example, Glassey & Resende (1988), Uzsoy *et al.* (1992 and 1994), Rose (1999), Fowler *et al.* (2002) and Jain *et al.* (2003). However, although attention has been paid to the semiconductor industry, there is very little contemporary research regarding the use of aggregate load oriented WLC methods in practice.

Fry & Smith (1987) presented a restricted case study implementation of a bottleneck-oriented input/output control method for a tool manufacturing job shop, focusing on job release. The paper describes how the approach was used on one product line (pliers), representing 40% of total sales. However, other product lines may have different routings and bottlenecks. Although the method was shown to work in a job shop, products do not seem to be customised, with an element of MTS production. For such standardised production, the importance of the customer enquiry stage is greatly diminished, thus reducing the complexity of planning and control requirements. Park *et al.* (1999) present a second bottleneck-oriented case study, developing a WLC-based DSS to aid delivery date determinations for a large rotating machinery shop, hence catering for the customer enquiry stage. The DSS monitors the workload of the bottleneck operation in line with the principles of the Theory of Constraints (TOC) (see Chapter 2) and similar to the Bottleneck Load Oriented Release WLC concept (see, Enns & Prongue Costa 2002). However, in a job shop, it is considered important to control the workload balance across all resources.

The WLC methodology used by Bechte (1988 and 1994) and by Wiendahl (1995), known as LOMC, with a subsequent Load Oriented Order Release (LOOR) mechanism, determines the indirect load of a work centre based on the probability of a job arriving at a downstream work centre in the corresponding planning period (see Chapter 2 and Breithaupt *et al.* (2002) for a further description). Wiendahl (1995) is one of very few researchers to document a methodology in enough detail for the reader to gain a detailed understanding. However, this is a complex approach and, in practice, managers are likely to prefer simplicity.

An aggregate load oriented WLC method is perhaps a less sophisticated representation of workload; however it can be an effective means to control and improve shop performance and is considered relatively generic to MTO companies (see Hendry *et al.* 1993). Hendry *et al.* (1993) present a case study where this approach to WLC is partially used in an artist's studio to successfully control lead times. However, again this is considered an unusual or uncharacteristic company, making it particularly difficult to generalise the results or learn from the implementation procedure. The authors explain that further research is required to fully implement the concept. The authors also consider such research to be of more benefit when conducted within more 'traditional' (or characteristically typical) MTO companies.

All of these studies report favourable results, with an improvement in shop performance; however, these cases are too few and far between to allow more generalised conclusions to be drawn or to drive current theoretical development. Hence, research needs to build a body of case studies and use contemporary evidence to move the field forwards.

3.3 THEORY VERSUS PRACTICE: Research Pitfalls and the WLC Paradox

The 'Workload Control Paradox' highlights the differing performance of WLC in theory and practice, and is a phenomenon that continues to frustrate academics in this field. Therefore, it is important to be aware of this when conducting research in the field of WLC. The paradox arises as despite the limited number of successful implementations (as described above), some simulations have shown an increase in lead times when a pre-shop pool is used. In addition, Bertrand & Van Ooijen (2002) remark that empirical research reports reductions in total work order throughput time of 40-50%, while theoretical research reports reductions of only a few percent or even an increase in total order throughput time. Meanwhile, in the context of favourable simulation results, Kingsman & Hendry (2002) remark that further case study research is required to confirm that observed simulation results hold when many of the assumptions are removed.

Many researchers have contributed to this debate over the years in an attempt to explain and resolve the WLC Paradox. Consider the following examples:

- *Job shop dynamics*: Differences exist between the job shop dynamics found in practice and those that are simulated (the theoretical job shop). Land & Gaalman (1998) explain that some studies have tried to resolve the WLC Paradox by introducing other elements of the PPC system into simulation models.
- *Simplistic simulation models*: Simulation studies have generally focussed on less advanced release methods (see Breithaupt *et al.* 2002); hence it is inevitable that results have suffered.

- *Human aspects of WLC*: In a human operated system there is likely to be an optimum level of workload at which to maximise productivity (see Bertrand & Van Ooijen 2002; Van Ooijen & Bertrand 2003). However, these human aspects have not been modelled in simulations (see Land & Gaalman 1998). Humans are also likely to have greater schedule visibility beyond the work queuing at a work centre; hence supervisors will use rules of thumb and satisfy their natural tendency to batch reducing symmetry between the real life and simulated shop.
- *Pooling effect*: Kanet (1988b) argues that while ORR strategies may reduce the time an order spends on the shop floor, when the time the order spends in the pre-shop pool is considered, the overall system flow time will not be reduced. This suggests the problem is merely relocated from the shop floor to the pre-shop pool and does not explain practical implemented success.
- *Isolating the impact of WLC*: While simulations struggle to replicate shop conditions, empirical studies can find it difficult to isolate and evaluate the impact of applying a particular PPC technique on the shop.
- *Case study selection process*: The dramatic improvements observed in practice may be explained by the suggestion that the companies most receptive to collaboration are those that are currently having difficulties with PPC. Hence, dramatic improvements in case studies can be achieved as the initial state of the company is more 'out-of-control' than those replicated in simulation experiments.
- *Theoretical assumptions*: Simulations should, in some respects, outperform practical implementations. For example, capacity can be more flexible in simulation (see Bergamaschi *et al.* 1997), while simulations also often assume

the immediate feedback of information from the shop floor (see Henrich *et al.* 2003).

- *Shop conditions*: Oosterman *et al.* (2000) find that the performance of WLC concepts varies with shop conditions. Hence, some negative simulation results can be explained by the application of WLC to an inappropriate simulation environment.

In the light of this discussion, the research questions proposed in Chapter 1 and the research gaps highlighted in Chapter 2, this research maintains a strong empirical focus, considered the best way to address implementation issues for WLC. Hence, this research seeks to add to the case study end of the WLC Paradox debate. For a further insight into the WLC Paradox, see Melnyk & Ragatz (1989), Perona & Miragliotta (2000) and Land (2004b).

3.4 ALTERNATIVE EMPIRICAL RESEARCH METHODOLOGIES

It could be argued that it is impossible to fully understand and develop a WLC approach, or envisage all the implementation requirements of a company, until an attempt is made to apply the concept in practice. This view is supported by Meredith (1998) who argues that for theory building, case and field research are preferred to the more traditional rationalist methods of optimisation, simulation and statistical modelling. In addition, Westbrook (1995) argues that the principal research methods of production and operations management should be the various types of empirical research. Meanwhile, as justification of further empirical research, several authors have also pointed to the fact that many of the recent developments in Operations

Management have come from field research and developments in industry (McCutcheon & Meredith 1993; Westbrook 1995; Voss *et al.* 2002). Therefore, the best way to achieve the objectives of this study is considered to be through empirical research.

With reference to Flynn *et al.* (1990), Scudder & Hill (1998) define empirical research as research that makes use of data derived from naturally occurring field-based observations, taken from industry. The two most appropriate forms of empirical research for this project are the case study research method (for typical accounts, see Easton 1992; Stake 1995; Yin 2003) and action research (see, for example, Stringer 1999; McNiff 2000; Costello 2003). By reviewing these two methodological approaches, the discussion focuses on debating what the most appropriate form of field research for this project is and ultimately what measures can be taken to ensure that the approach taken herein is both rigorous and valid.

3.4.1 Case Study Research

Defining Case Study Research

Many definitions of case study research can be found in the literature; four example definitions are provided below to introduce the topic. Firstly, Meredith (1998) explains that the case study is an example of an alternative research paradigm known as interpretivism and uses both *quantitative* and *qualitative* methodologies to help understand a phenomenon. Example data sources include financial data, interviews, memoranda, business plans, organisation charts, questionnaires and observations of managerial or employee actions and interactions. Secondly, Benbasat *et al.* (2002) similarly explains that a case study examines a *phenomenon* in its natural setting, employing multiple methods of data collection to gather information from one or a few entities (people, groups or organisations). A third definition comes from McCutcheon & Meredith (1993) who explain that case study research is based on the observations and assessments of an *objective* outside party and is credited with being able to stop theories becoming detached from reality. Finally, Hussey & Hussey (1997) define case study research as *observational* and concerned with gathering information about a unit of analysis, such as a group of workers, a company, an event, a process or even an individual.

Common themes run throughout the definitions, such as a focus on taking a multi-disciplinary approach, where the researcher's presence is primarily observational. Therefore, for the purposes of this thesis, case study research is described as research that examines a phenomenon or focuses on a particular event (or set of events) in its natural setting (i.e., situational), where the key sources of data collection are interviews, observations and archival data. Such research should concentrate on maintaining objectivity and the researcher's presence is considered to be primarily observational.

Advantages of Case Study Research

Voss *et al.* (2002) explain that case studies can be used for different types of research purposes such as exploration, theory building, theory testing and theory extension / refinement. However, a key role for case study research lies in theoretical development. Stuart *et al.* (2002) argue that case studies should not be seen as a methodology appropriate only for understanding and the preliminary stages of theory development; because of their observational richness, case studies also provide a means of refutation of, or extensions to, existing concepts. Westbrook (1995) argues that the real value of case study research is in building theory from the observation of practice. Likewise, Saunders *et al.* (1997) refer to Emory & Cooper (1991) when noting that the case study method can enable the researcher to challenge an existing theory and provide a source of new hypothesis. Cooper & Schindler (2003) argue that a single well-designed case study can provide a major challenge to a theory and provide a source of new hypotheses and constructs simultaneously. For a further discussion of theory driven empirical research, see Melnyk & Handfield (1998).

A second advantage of the case study is the practical and dynamic nature of the research. Yin (2003) explains that the case study method can be used when the researcher wants to deliberately cover contextual conditions. By using the case study method, this research can observe the cultural dynamics found in practical production environments that interact with each other and contribute to influence the adoption of WLC in practice. Referring to Benbasat *et al.* (1987), Meredith (1998) clarifies this by explaining that case study research allows a phenomena to be studied in its natural setting, allows the researcher to ask 'why', not just 'what' and 'how', and allows for investigation even when a phenomenon is not fully understood (such as the implementation requirements of WLC). McCutcheon & Meredith (1993) support this by suggesting that case study research may be the best way of examining highly varied implementation situations, adding that case study research will make the individual researcher and the field in general, richer and better prepared to solve real problems. Similarly, Stuart *et al.* (2002) also outline some of the areas where case study research could have potential within Operations Management; these include theory extensions and implementation (such as with MRP and ERP). Given that the focus of this thesis is on both theoretical development (refining existing WLC theory towards greater practical applicability) and an investigation of implementation issues, this discussion emphasises the applicability of the case study research methodology to this project.

3.4.2 Action Research

Defining Action Research

Like the case study research method, action research is considered to be a multi-disciplinary approach; however, definitions of action research focus on the interventionist and 'hands-on' (*participatory*) nature of the approach.

The notion of action research is largely attributed to the work of Lewin (1946, 1947 and 1951), and is described as a 'live' case study (see Coughlan & Coghlan 2002). Action research projects have a grounded, iterative and interventionist nature (Westbrook 1995), where the research output results from an involvement with members of an organisation over a matter which is of genuine concern to them (see Eden & Huxham 1996). One of the ideas behind the emergence of action research is the belief that the best way to learn about an organisation is to try to change it, i.e., learning in, and from, action. In an action research project, the researcher is seen as an agent of change, i.e., an outside agent who acts as a facilitator (Coughlan & Coghlan 2002). Similarly, Gummesson (2000) describes action research as participation with active intervention.

Besides participation and intervention, one of the key characteristics of action research is the integration of theory and practice and of industry and academia. Baskerville & Wood-Harper (1996) explain that action research requires close collaboration of researchers and practitioners. Meanwhile, Eden & Huxham (1996) describe a two way relationship where the researcher becomes involved in and contributes to the practitioner's world, and the practitioner is involved in and contributes to the research output. With reference to Susman (1983), Baskerville & Wood-Harper (1996) support this by explaining that action research attempts to link theory and practice, thinking and doing, achieving both practical and research objectives.

Therefore, for the purposes of this thesis, action research is considered to be research that is characterised by involvement in change and intervention, where the researcher's presence is primarily participatory.

Advantages of Action Research

One of the key advantages of action research is that it allows certain types of data to be captured that cannot be so through other means. For example, Westbrook (1995) explains that (traditional) scientific methods cannot always permit the capture or interpretation of the richness of human activity in organisations. He adds that, above all, action research provides insight. Coughlan & Coghlan (2002) support this by explaining that not all questions of interest to managers and operations management researchers can be answered by surveys, case studies or participant observation. Action research can increase a researcher's understanding of a complex problem, improve practice and extend theory.

Referring to Argyris & Schon (1974), Eden & Huxham (1996) explain that an action research setting increases the chance of getting at a participants 'theory in use' rather than their 'espoused theory'. Referring to Eden (1994), the authors clarify this by explaining that one of the most persuasive reasons for using action research is to counter the unreliability of research where subjects do not have to commit to real life action and to creating a future which they will inhabit. Much conceptual research can be criticised for becoming detached from reality; for example, it could be argued that the sophistication of shop floor sequencing rules used in simulation is far beyond those that will ever be effectively used in practice. By its very nature, action research has real world relevance as it takes place in the real world.

Ottosson (2003) explains the motivation behind action research and the importance of participation: the closest a researcher can come to a project or a process, in order to be aware of as many small important daily steps and 'information quanta' as possible, is to manage the project or process himself / herself. The author explains that action research provides the advantages of access, feedback, deep understanding, knowledge transfer, the forming of relationships, and the discovery of 'unspoken needs'. In the context of information systems, action research is described as an increasingly popular research methodology ideally suited to the study of technology in its human context and places information systems researchers in a 'helping-role' (see Baskerville & Wood-Harper 1996). Hence, action research is an important methodology and, like case study research, has relevance to the objectives of this project.

3.4.3 Differentiating Between Case and Action Research

From the descriptions presented above, it is clear that there are strong similarities between the two approaches. Indeed, action research is commonly referred to as a variant of case study research (see, for example, Westbrook 1995). Both involve research within organisations, apply techniques such as observation and interviewing and are commonly driven by theory. The key difference between the two lies in the role of the researcher within the organisation and whether the primary objective is one of participation or observation.

Action research takes the more participatory approach, emphasising practical problem solving by first understanding and evaluating a situation and then attempting to change it. Westbrook (1995) argues that while the case study researcher is an independent observer, an action researcher is a participant in the implementation of the system. The author also refers to Benbasat *et al.* (1987) in explaining that the action researcher is not an independent observer, the researcher becomes a participant, and the process of change becomes the subject of research. Similarly, Coughlan & Coghlan (2002) explain that action research can be seen as research and knowledge in action, rather than research about action (recording the existing situation). McCutcheon & Meredith (1993) explain that in case study research, the researcher usually has little or no capability of manipulating events, in contrast, the action researcher is involved as a participant and director of events in a natural setting.

The project described in this thesis focussed on working towards applying the WLC approach to an organisation and studying the effects of the implementation process, leading to future adjustments and modifications to the concept and the development of an implementation strategy. The primary role of the researcher was one of observation, to gather data on the effects of WLC on performance in practice, and to observe the implementation process. Whilst the researcher worked with the company to ensure the WLC system is appropriate to their setting, this work was mostly completed before the implementation process commenced. The major participatory task of driving the implementation process forward was delegated to a member of the organisation. Thus it was not intended that the researcher would participate in any of the managerial tasks involved in instigating change. Whilst it is acknowledged that there are aspects of participation in a project of this type, it is argued that the primary role of the researcher was such that the label of 'case study' research is the most appropriate label for this project. Thus it is this approach that is discussed in further detail below.

3.4.4 Choosing the Type of Case Study Research

Case study research can take the form of a single or multiple study and can be cross-sectional or longitudinal (Robson 1993; Saunders *et al.* 1997; Voss *et al.* 2002). A single case study is likely to be an in depth longitudinal study, where one company is studied over a period of time, with a full contextual analysis of a few events or conditions and their interrelations. In a multiple case study approach, a broad cross-sectional study may be chosen, where a 'snapshot' of a number of companies at one moment in time is taken and analysed. The longitudinal study can be more time consuming; hence, it can be difficult to commit to multiple cases. Longitudinal studies allow the researcher to study and understand how an organisation changes and develops through time (such as in preparation for the implementation of WLC). In order to examine cases in sufficient detail (refining the methodology and developing the DSS from the beginning), there was only time available to study one company and attempt one implementation project.

Yin (2003) identifies five occasions when a single case study can be justified; these are the *critical* case, the *extreme* (or unique) case, the *representative* (or *typical*) case, the *revelatory* case and the *longitudinal* case. This research project can be viewed and justified from three of these perspectives. Firstly, the study is to some extent being used in conjunction with testing a formulated theory, and hence can be considered a *critical* case. Secondly, it is acknowledged that, in taking a single case approach, the choice of company is important in order to maximise the benefits of this project. For example, issues regarding the implementation of WLC encountered with 'the average or typical' company are likely to reappear with other companies. Therefore, although there are many different MTO companies, the company chosen is intended to be fairly representative of MTO companies and appropriate for WLC (see Section 3.5 and Chapter 6), and hence could be considered a relatively *typical* case. This can be a very important issue for rigour and validity; Saunders *et al.* (1997) explain that concerns regarding generalising the results of a study are particularly pertinent if the organisation is sufficiently 'different' in some way. Thirdly, the company will also be involved in the project from concept re-evaluation and development to DSS programming and implementation, hence, the company can be observed in great detail over a period of time as it develops, and thus can also be considered a *longitudinal* case.

3.4.5 Towards Effective Case Study Research

Despite concluding that the research is to be labelled as a single longitudinal case study, given that (1) action research and case studies share many of the same characteristics; (2) the approaches have received similar criticisms from the traditional scientific research community and (3) share many of the same techniques for maintaining rigour and validity, this section seeks to learn from both sources of literature, where relevant. It summarises the key issues relating to research rigour, which have been addressed whilst undertaking the research described in this thesis.

Preparation: Preparation is a key part of a good research project. It is important to be clear on the objectives of the study before commencing, to choose the right organisation(s) and to have an appropriate set of research questions, i.e., do not let the study descend into a fishing expedition (see Voss *et al.* 2002). The objectives and research questions of this study are outlined in Chapter 1 while Section 3.5 of this chapter details the case study selection process. To ensure the researcher is well prepared, Voss *et al.* (2002) also advise using a pilot case to test research protocols or to use pilot interviews to test out questions. In the context of this research, experience with case study research was gained through a project completed with a separate company prior to the research described in this thesis.

The Role of the Researcher and Maintaining Objectivity: Action research has been heavily criticised for being subjective; however, any form of field based research could fall into the trap of becoming too immersed in an organisation, becoming too close to the subjects, or momentarily forgetting the main objectives of the research. In response, Baskerville & Wood-Harper (1996) advise the researcher not to become so involved in the immediate practical effects of the research that they neglect the scientific discipline. Similarly, Eden & Huxham (1996) remind the researcher not to allow a study to become consultancy, while Baskerville & Wood-Harper (1996) emphasise the importance of not losing sight of the goals of the project, both of the research and to help the organisation. Voss *et al.* (2002) warn that case study research is not an excuse for industrial tourism. In other words, it is important to remember what the purpose of the study is and how to go about achieving it. This was achieved in this project by continually writing up the findings in parallel to conducting the field research, thus taking a 'working thesis' approach to the process.

It is also important to keep an open mind during the project and avoid observer-bias. For example, Westbrook (1995) encourages the researcher not to pre-specify the solution (grounded theory). To maintain validity over proceedings, Baskerville & Wood-Harper (1996) suggest that the research could employ an independent disassociated 'watcher'. In this project, this role is incorporated within research supervision.

Data Recording and Reflection: Field research is a multi-disciplinary approach covering quantitative and qualitative data and hence relies upon a variety of data recording techniques. One of the key tools that can differentiate field research from other types is the use of a diary or journal. It is important to remember that the journey involved in field research may be more important than the final destination (Westbrook 1995); hence journal keeping and writing up any findings during the project is very important. This can play an important role; Coughlan & Coghlan (2002) advocate the use of journal keeping for reflective skills, imposing a discipline on the researcher and capturing key events close to when they happen. Similarly, Eden & Huxham (1996) emphasise the important role of reflection in action research. Stuart *et al.* (2002) explain that case based research is often seen as simply a collection of anecdotes and 'war stories'. Hence, while a diary can be a useful approach, it is important to consider the implications of the findings of the research beyond the confines of the organisation and supplement this with other forms of data. For a more in depth discussion of the use of diaries for field research, see Symon (1998).

To supplement the above techniques, Baskerville & Pries-Heje (1999) suggest that grounded theory techniques, such as memos and diagrams for diagnosis and coding for evaluation and learning, can dramatically improve the rigour and reliability of the theory and improve the generalisability of the findings. Baskerville & Wood-Harper (1996) list various data collection methods, including audio-taped observations, interviews, action experiments, participant written cases, diaries and group diaries. Voss *et al.* (2002) acknowledge that there are divided views on whether tape recorders should be used in interviews. The authors explain that this may inhibit interviewees and be seen as a substitute for listening. Given this advice, tape recorders were not used in this project; instead findings were noted and reflected on shortly after the event. Notes were made during semi-structured interviews and when technical details are being explained. However, it is important to do this discreetly and to use judgement to decide when it is appropriate to record data. It is important to maintain trust, a sense of being part of the team and to ensure the interviewee is relaxed, so as to be able to extract the most information from the situation.

Flexibility: With reference to Bechhofer (1974) and Gill & Johnson (1991), Croom (2002) warns that the research process is not a clear cut sequence of procedures following a neat pattern, but a messy interaction between the conceptual and empirical world, with deduction and induction occurring at the same time. Hence, flexibility and the ability to adapt to change are key skills for a field researcher. Similarly, Coughlan & Coghlan (2002) include the ability to cope with the uncertainty of the unfolding story as one of the key skills required by an action researcher. McCutcheon & Meredith (1993) also advise the researcher to be flexible in case study research; the scope of the project can change, focus can shift and other sources of data may have to be found. Developing contingency plans is another useful way to cope with change and maintain flexibility. In this project, issues such as data availability, led to a need to retain an appropriate level of flexibility. The evolving nature of this project is described in more detail in Section 3.6.

Personal Skills and Forming Collaborative Relationships: Forming relationships within the organisation(s) is a particularly important part of field research. The extent to which the researcher is able to forge good relationships will inevitably impact upon the quality of the information yielded from interviews. This can be particularly important in SME's where access to only a small group of actors may be possible.

Westbrook (1995) explains that it can be important to make the right frequency of visits in order to maintain momentum without becoming a nuisance and to agree what is to be achieved before the next meeting so that evidence of progress can be seen (see Westbrook 1995). Hill & Wright (2001) advise that the field researcher should stay in the field until no new data is being yielded or until data collection is reaching saturation point.

Baskerville & Wood-Harper (1996) emphasise the importance of nurturing collaboration with subjects in the organisation. The authors explain that for action research to succeed, there have to be expected benefits for the researcher and the organisation, active participation and a cyclical process linking theory and practice. If the goals of the research and client differ drastically there will be tension. Conflicts may be inevitable; Eden & Huxham (1996) warn that action research leads to organisational change and to challenging the status quo, and that this will not be welcomed by everyone. This is also relevant to this project, given that the introduction of a new planning and control system leads to changes in working practices and there was hence a need to be aware of these issues.

Eden & Huxham (1996) stress the importance of being credible; although research is not consultancy, it can be important to develop a competent consultancy style and process, whilst being aware what must be included in the consultancy process to achieve the research aims. Voss *et al.* (2002) stress the importance of finding the principal informant, i.e., the best person to inform the researcher on a topic, and warn that this may not be the prime contact for the project. McCutcheon & Meredith (1993) advise that case study research takes time to conduct (needs patience), the researcher must have good interview skills and an ability to see patterns that may be distorted by perceptions and politics. Finally, Cooper & Schindler (2003) outline a number of characteristics required from the observer:

(1) Concentration: Ability to function in a setting full of distractions

(2) Detail-Oriented: Ability to remember details of an experience

(3) Unobtrusive: Ability to blend with the setting and not be distinctive

(4) Experience level: Ability to extract the most from an observational study

Generality and Triangulation: A key criticism of context based research is the lack of generality that emerges from the work. However, some researchers argue that triangulation and cautious generality can be achieved from action and case study research. Baskerville & Wood-Harper (1996) claim that tentative causal links can be claimed and reliability can be gained through the consistency of observations. Coughlan & Coghlan (2002) argue that it is important to extrapolate to other situations and to identify how an action research project could inform like organisations. Eden & Huxham (1996) claim that triangulation is as important as in other research approaches, but has a different significance. Likewise, Meredith (1998) also argues that case study research requires close and detailed observations, triangulation and logical inference. Thus it is concluded that generality can be achieved, but through different means than for more traditional methodologies.

Useful techniques to achieve generality and triangulation in a case study setting include seeking a convergence of views within the organisation, taking a thorough and consistent approach, acknowledging any differences as examples are accumulated, and the triangulation of a single person's views at different stages of the project. Triangulation can also be achieved by checking the claims of interviewees against any available data, whilst remembering that opinions are also data (Westbrook 1995). It can also help to get the representatives from the company to check write-ups to ensure that what has been recorded is an accurate understanding; the reader may even add to the insight (see Westbrook 1995). If work is disseminated, future research has the opportunity to confirm or refute the findings (Baskerville & Wood-Harper 1996). Cooper & Schindler (2003) also suggest that in a single case study approach, generalisation of results is more valid with a negative (rather than positive) result; important scientific propositions have the form of universals, and a universal can be falsified by a single counter-instance. Hence, arguably a negative result could be generalised. For the origins of falsification within research, see Popper (1959).

In this project, the key methods of triangulation were the comparison of viewpoints of a number of different members of staff and the triangulation of viewpoints over time. Details were confirmed orally in future interviews rather than through written documents, given the time limitations of the interviewees. It is also argued that while in isolation this will represent a single case study approach, other cases are also being conducted at the University of Groningen (The Netherlands) and the University of Coimbra (Portugal). Therefore, triangulation and generalisation is also possible through an emerging collaborative (multiple and comparative) longitudinal case study approach. However, this level of triangulation is beyond the scope of this thesis.

3.4.6 Summarising the Approach

The research primarily takes an observational stance, and hence has been described above as a (single longitudinal) case study. However, it is acknowledged that there was also a small degree of participation in the project, which is the primary characteristic of the action research approach. Therefore, this section has drawn on applicable parts of both the case study and action research literature in order to take a rigorous approach to the research. Figure 3.1 summarises the research approach taken in this thesis and emphasises the importance of the case study research methodology.

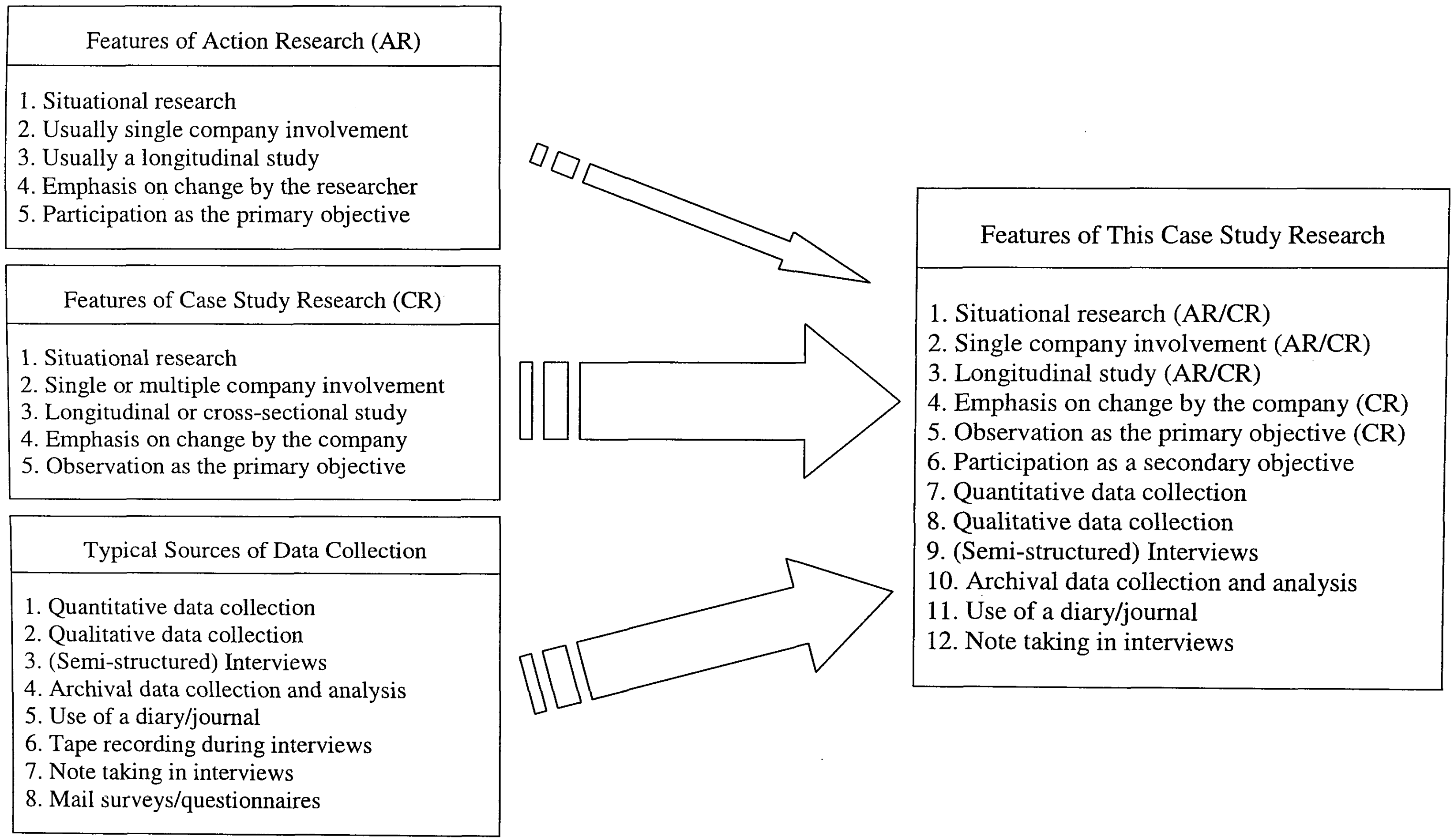


Figure 3.1: Summary of the Case Study Approach Taken in This Research

3.5 CHOOSING THE CASE TO STUDY

To validate the findings of this research and to ensure that as much information as possible can be learnt about the implementation of WLC in practice, it is important to ensure that the company chosen from those available is the one that best meets the requirements of the project. Due to the diverse nature of markets, it may be unrealistic to expect to find a company that is typical of all MTO companies. However, a company can be found that has typical characteristics of a sector of MTO companies. By doing so, the research is able to maintain an element of universal appeal and wider relevance, while it is important to acknowledge localised aspects that make the company different from others where WLC may be applied. Hence, an appropriate case for this research agenda will show evidence of the following characteristics. The first four criteria relate to company features as discussed in Chapter 2, the remainder relate to safeguarding the success of the project. In addition, the appropriateness of the chosen company to WLC is assessed in more detail in Chapter 6.

The company should:

(1) Manufacture highly customised products from unstable demand, i.e., Make-To-Order (MTO) production

(2) Be involved in competitive bidding at the customer enquiry stage, i.e., have an element of VMC production, and not merely MTO production on a repeat basis

(3) Operate a General Flow Shop or General / Pure Job Shop configuration

(4) Be a Small or Medium sized Enterprise (SME)

(5) Have no formal planning system or be dissatisfied with the current one

(6) Be able to supply the necessary data requirements, or have the means for these to be collected

(7) Have the necessary computer hardware infrastructure

(8) Be keen to collaborate / are committed to the project for the duration of the case study research

Note that, although the needs of SME's can be considered different to those of larger companies (see, Hsu & Chen 2000; Knight 2000) and that (4) specifies that the company be a SME, it is not suggested that WLC cannot be used in larger companies (see Park *et al.* 1999). However, in order to find a representative MTO company, maximise access to key employees and data, and in order to most appropriately embark on investigating the implementation of the LUMS approach, it is considered that a SME should be targeted. Future research could see the DSS implemented within larger organisations.

In addition to the above criteria, the following are desirable qualities for a case study company, deduced from the work of Hendry (1989):

(9) The computing facilities available within the company must be fast so as not to deter users from using the system fully; similar to (6) above

(10) The current workload within the company must be either 'normal' or greater than normal, i.e. the company must not be in a period of prolonged under-load, where production planning can be more easily controlled, although this would have its advantages during the start-up period

(11) It is essential that the computer program(s) developed are seen to be of importance by all employees and there is a commitment to the fast installation of the system

It was also important to be aware of the pitfalls of case study research, in an attempt to avoid such eventualities reoccurring and in order to develop contingency plans should problems develop in the project, for example, the case study company may:

(a) Lose interest
(b) Ultimately not meet the criteria for an appropriate production environment for WLC (i.e., the company appears to satisfy the criteria, but on closer inspection does not)
(c) Misuse or neglect the system, invalidating the results
(d) Ultimately not meet the software or hardware requirements

In fact, contingency planning and taking an evolutionary approach to the research design played major roles in this project. At the start of this research the intention was to collaborate with Company A. Company A is a MTO company engineering largely subcontract sheet metal fabricated jobs, and currently employs approximately ninety people. The company manufacture a wide range of products; by using CAD/CAM technology the process often begins at the design stage, meaning that for some jobs the company could be classified as an Engineer-To-Order (ETO) company. Hence, the customer enquiry stage may be a very complex and timely process, where the LUMS approach could be of great benefit.

This was considered an appropriate company with management, who already had a well-established relationship with LUMS. Management of the company had also previously provided a written statement committing itself to work with LUMS in the future. As a result the project began with a definite company in mind. Therefore, two of the initial steps taken consisted of learning to program in an appropriate language (Microsoft Visual Basic 6.0) and developing the DSS for Company A. However, part way through the project, the company had a change of management, with the new management team having its own agenda and a reluctance to honour previous agreements. As a result, the new managing director was unable to provide any guarantees that would safeguard the long term future of the project. Hence, the research had fallen into pitfall (a); continuing with the project would arguably have also led to pitfall (c). With regards to the eleven desirable qualities of a case study company, Company A now failed in relation to (8) and (11). As a result, it was necessary to find a new company for the project.

In the process of obtaining a new and equally suitable case study, a number of alternative companies were considered, the most promising of which are described below (Company X, Y and Z). During this selection process, visits were made to Company X and Z, where tours of the companies and discussions with key members of staff took place. In the case of Company Y, the company was assessed via its website and through discussions with members of staff at Lancaster University who had close links to the company and a good understanding of the types of products it produces.

3.5.1 Company X

Company X is a small MTO precision engineering company employing approximately 30 people with customers throughout the UK. The company produce small components for larger companies in, for example, the aerospace, automotive and defence industries. The company relies on an ad-hoc and informal approach to production planning without the use of a formalised planning software package; however, management appreciates that the lack of such a system may be contributing to poor delivery date adherence. The company has consulted a number of ERP vendors to determine the costs and implementation process of such a system. Deterred by price and perceptions of high risk involved in implementing ERP type packages, the company has since begun developing an Information System (known as MAIS) using the Borland Delphi programming language. Although this would not provide any direct PPC support, it will incorporate a database of customer and job details that would provide the job information requirements from which a custom built PPC system, such as a WLC DSS, could benefit. Although it is not necessary in programming terms, in order for MAIS and the WLC DSS to interact, the company requested that the DSS be developed in the same programming language as the MAIS, i.e., Borland Delphi. Such a provision would require a change from the programming language used in the initial development phase of the WLC DSS (Microsoft Visual Basic). However, the company sufficiently satisfies the criteria outlined above.

3.5.2 Company Y

Company Y produces custom made furniture both in high volumes for large companies and individually for households. Products typically include desks, cabinets and other office furniture. This is a small but progressive company looking to improve its approach to production planning as it begins to grow. However, there were concerns regarding the degree of customisation offered by the company. It seems likely that several products are made from the same raw materials and hence can be grouped into product families, reducing the complexity of the customer enquiry stage, raw material ordering policy and job release stages. The actual degree of customisation the company permits suggests more of an assemble to order strategy without the required level of variety in shop floor routings and processing requirements to stretch this research project or the WLC concept. Therefore, Company Y fails to satisfy point (1) of the above criteria for an appropriate case to study.

3.5.3 Company Z

Company Z is a MTO company in the steel fabrication industry, and has approximately 100 employees. The company typically produce small components for the automotive and construction vehicle industries, with customers in the UK and mainland Europe. The company currently operates a dated MRP system; the MRP system is version 3 of a package currently available in version 8. It is acknowledged that it is possible that the PPC methodology underpinning versions 3 and 8 may be very similar, with the differences between the two relating to additional integrated functions available in the later version, the processing speed of the system and the user interface. Nonetheless, Company Z is considering upgrading this software, but is also interested in pursuing other, less costly, alternatives (such as WLC). The company has recently employed a new operations manager keen to follow his own ideas, and may therefore be undergoing a transitional period and be less receptive to adopting an unproven WLC system. Hence, similar to Company A, Company Z may fail points (8) and (11) and may lead the project into pitfalls (a) and (c).

In the light of this analysis, Company X has been chosen as the case study company. Chapter 6 provides a more complete description of the company and compares the company against an existing WLC framework, presented by Henrich *et al.* (2005). This company was chosen as it appeared as appropriate as Company A, but was able to provide greater assurances of data access and its long-term commitment to the project; qualities outweighing the disadvantage of having to restart the DSS programming process. This did however mean that it was also necessary to begin by learning a new programming language (Borland Delphi 8.0) and recoding the progress made with the Microsoft Visual Basic version of the DSS.

3.6 EVOLVING THE RESEARCH METHODOLOGY: A Three Stage Approach

As is common in projects of this nature and duration, the research has encountered a number of setbacks. The initial aim was to gain empirical results regarding the performance of WLC in practice. However, it became clear that this would not be possible within the scope of this study, due to factors outside of the control of the project, namely delays with the implementation of MAIS. As a result of this initial focus, considerable time was spent determining performance measures and collecting historical data to compare against the post-implementation performance of the company. While ultimately these measures are not used, they are included as a guide for fellow researchers and to reflect the complete research process undertaken (see Section 3.8 and Chapter 6 of this thesis). This setback also led to changes to the research methodology, resulting in the research questions and objectives outlined in

Chapter 1. These problems are also described in later chapters of this thesis and contribute to the development of an implementation strategy for WLC.

Through this evolution of the research methodology, a three stage strategy focussed on conceptual refinement of the LUMS approach towards implementation emerges. With reference to Blaikie (2000), Baker (2003) explains that there are four distinct research strategy alternatives: inductive, deductive, retroductive and abductive. The emerging strategy contains both deductive and inductive elements, and is summarised in Figure 3.2. Deductive research is concerned with testable predictions from an existing general theory; Jankowicz (2000) describes it as a scientific method involving theory, measurement and verification. On the other hand, inductive research is based on observation and analysis to produce scientific discoveries and tentative theories (see Blaikie 2000; Baker 2003). Maylor & Blackmon (2005) highlight the distinction between the two by explaining that deductive research involves existing theory, while inductive research involves generating theory.

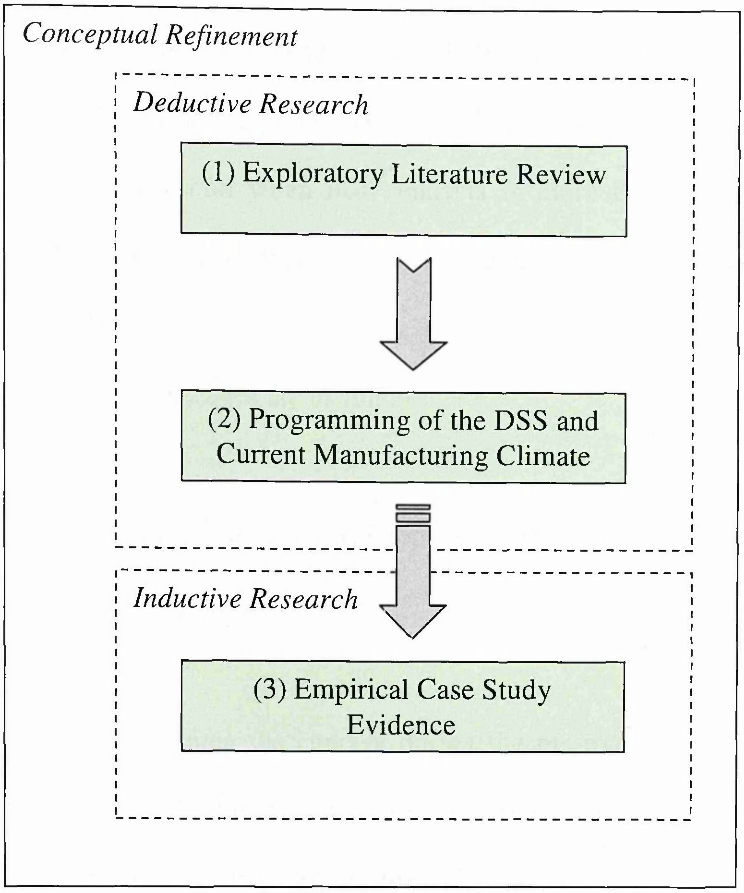


Figure 3.2: Three Stage Research Methodology and Conceptual Refinement Strategy

The initial research phase (Stages 1 and 2) involves verifying a theoretical framework using findings in the literature, considering the needs of the current manufacturing climate and through the programming of the DSS. In this sense it can be described as deductive research. Stage 3 involves reanalysing the framework inductively, using empirical case study evidence to generate new theory / enhance existing theory. This is likely to reveal issues that are less prominent in the deductive stages of analysis. Investigating the process of implementation and the cultural issues relating to this can also be viewed from a phenomenological perspective (see Easterby-Smith *et al.* 1991; Saunders *et al.* 1997). This allows the researcher to consider how and why events happen by understanding the social processes involved, and can be particularly useful when data analysis is more difficult. Management research often consists of a deductive and inductive element, for examples; see Saunders *et al.* (1997).

To clarify, the three stages are as follows:

Stage 1: This involves revisiting the LUMS approach and evaluating the methodology in the light of contemporary literature.

Stage 2: This involves refining the concept during the programming of the DSS to improve functionality, make the system more user-friendly and give the concept a more practical focus. While programming the DSS, the research also considers the needs of present day manufacturing companies, thus bringing the concept up to date with current requirements.

Stage 3: This involves inductively refining the concept in the light of evidence gained from the case study company, in order to facilitate the implementation of WLC in practice.

This discussion has illustrated how the strategy has evolved during this research project in order to contribute towards the research questions outlined in this thesis and prepare for future empirical research. Based on the categorisation of WLC research presented at the beginning of Section 3.2, the resulting approach consists of a combination of (1) theoretical / conceptual development and (3) empirical / case study research. In summary, Figure 3.3 provides a timeline of the research undertaken in this study.

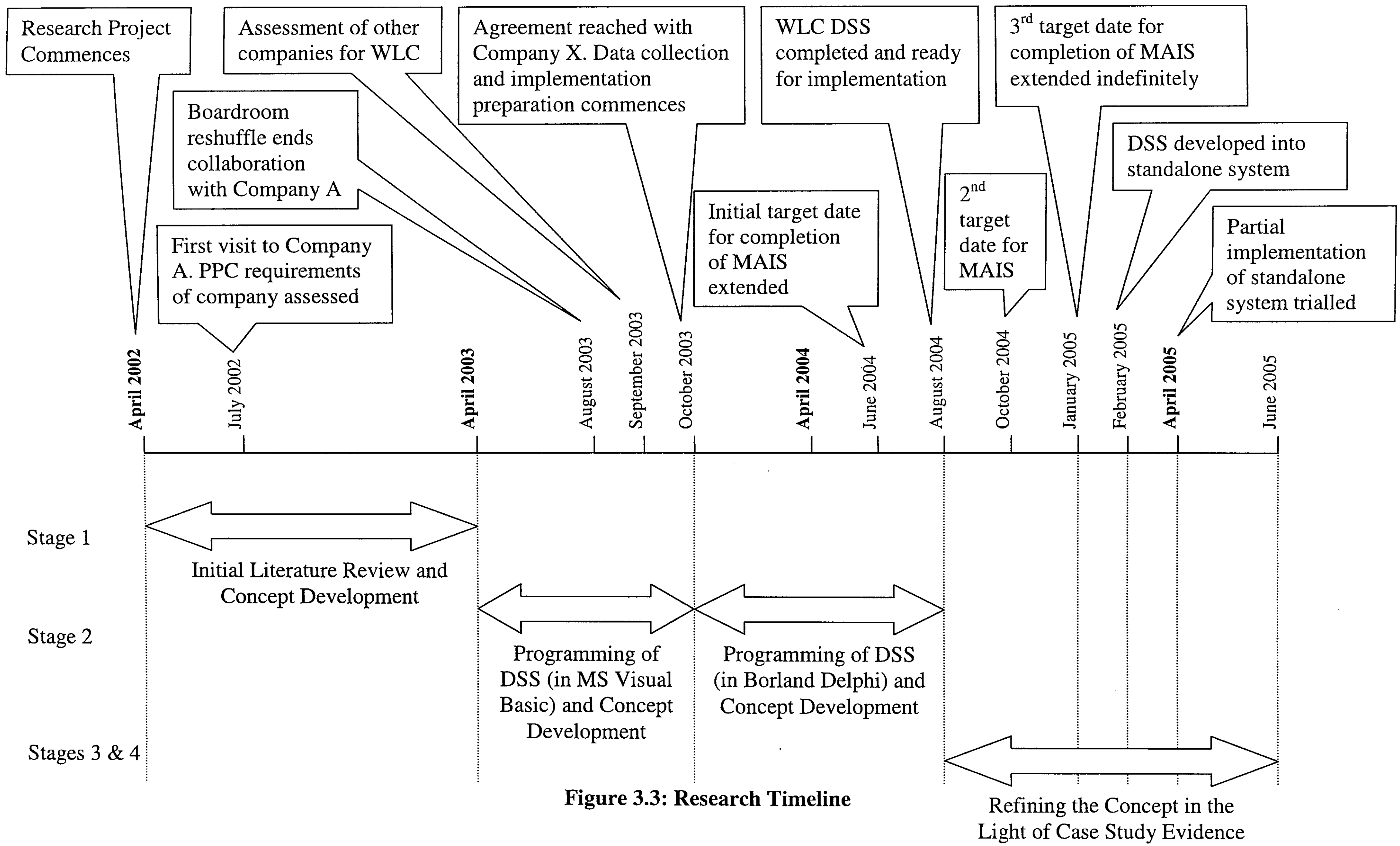


Figure 3.3: Research Timeline

3.7 EVALUATING THE NEEDS OF THE COMPANY

During the case study selection process, an initial evaluation of the needs of the company took place. However, once the company was finally chosen, it was necessary to perform a more in depth investigation. This includes semi-structured face-to-face interviews to determine the exact nature of the production environment and the complexity of production.

Meeting the individual requirements of the company will include factors outside of WLC, and relevant to the development and implementation of any information system. It may be important to determine the perceptions of the user, for example, if they are accustomed to using Windows based packages this is the minimum they will expect from the system. If they are familiar with modern ERP systems, they may expect the system to have web-enabled functionality. Failing to meet the expectations of the user may result in a lack of respect for the DSS, undermining the system. Over the course of this period, discussions took place with five key personnel to determine, for example, current in-house procedures, data availability, user requirements and shop floor characteristics. This is summarised in Table 3.1 below:

Personnel	Frequency of Discussions (Approx)	Examples
Operations Manager	> 30	Interviews, emails, telephone conversations, factory tours.
Shop Floor Supervisor	> 5	Supplied information, demonstration of tasks.
Contracted Software Developer	> 10	Interviews, demonstration of software, discussions of data availability.
Estimator	> 5	Demonstration of quotation procedure.
Administrative Staff	> 5	Demonstration of administrative tasks.

Table 3.1: Summary of Personnel Interviewed at Company X

Criteria for evaluating the needs of the company, and the user, at this stage of the research project included the following:

(1) Determine any specific company requirements from the system, such as user interfaces

(2) (Ensure hardware availability and) Assess the current software within the company

(3) Determine the extent to which data requirements can be met

(4) Determine the nature of production, such as the use of sub-assemblies, and routing complexity / shop configuration

(5) Gain an accurate list of machines and machine capabilities ('interchangeability')

(6) Gain an accurate list of the workforce and the machining capabilities of the employees, such as the amount of multi-skilling / reallocation options

(7) Determine how machines can be grouped and how capacities can be calculated (see Chapter 7)

(8) Ensure an end user has been allocated, determine (and assist in further developing) their understanding and expectations for the system

3.8 DETERMINING APPROPRIATE PERFORMANCE MEASURES

This section discusses performance measures that could be used for assessing the impact of the LUMS approach in practice. Although post-implementation data will not be collected during this project, this discussion provides a useful starting point for future research, both with this and other companies, and a useful guide for other researchers and practitioners. The collection of pre-implementation data is described in Chapter 6.

When gauging the impact of WLC in practice, it is important to have data regarding the performance of the case study company prior to implementation. In addition it is also important to acknowledge additional uncontrollable factors that could also impact upon the performance of the system, such as current initiatives within the company, new machinery (increasing capacity), or simply the impact on decisions and productivity of a researcher being present within the organisation (the Hawthorne Affect). Reviewing some of the outcomes of previous studies will propose a set of expected benefits from the project, and hence a set of performance measures that need to be quantified prior to implementation. It is also important to observe and be aware of non-quantitative effects.

Fry & Smith (1987) report a reduction in WIP and backlogs, improved customer service and a decrease in lead times. Bechte (1988 and 1994) reports a reduction in lead times and inventories, with actual lead times kept on a planned level, an improvement in delivery date adherence and the ability to maintain an appropriate work centre utilisation. Wiendahl (1995) takes a more cost-based-analysis approach to evaluating LOMC, for example, by analysing the amount of capital tied up in the throughput of an order. The author considers the change in inventory, such as space savings and amount of stock on hand (interest and stockholding cost savings), and changes in lead times, for example, reliability of lead times and volume of alterations (to delivery dates). The reliability of lead times is also assessed by considering the cost savings resulting from fewer penalties or as a result of late delivery. The author also considers improvements in market share, overtime costs and reductions in computing time. Park *et al.* (1999) observe an increase in the rate of meeting promised delivery dates (or improved delivery date adherence), a reduction in the processing times of customer enquiries, a reduction in manufacturing costs (through workload smoothing) and greater integration of production and marketing. Park *et al.* (1999) also list a number of measures that they consider to be traditional measures of delivery date assignment policies, including tardiness, queue lengths, waiting times and throughput times.

From this and the initial objectives of this research (including an additional emphasis on the customer enquiry stage), a list of performance measures emerge, as summarised in Table 3.2, with further details provided in Sections 3.8.1 to 3.8.6 below. When collecting data it is important to ensure that this is representative of the company and provides a useful comparison for post-implementation performance. For example, it may be best to take a large sample over a relatively long period of time. If a small period is chosen, this may represent a particularly good or poor period for the company, at the same time the data should be relatively contemporary in order to reflect the current performance of the company and limit the impact of 'uncontrollable factors' on the data. In addition to the quantitative performance measures discussed in this section, the main desirable outcome of this particular study is to learn how the company is able to prepare for the implementation of WLC.

3.8.1 Delivery Date Adherence

It is anticipated that the use of the LUMS approach will improve DD adherence through more accurate and realistic delivery dates being quoted and through stabilising lead times and WIP. Although these are considered complementary techniques that contribute to PPC, this complicates matters. For example, it raises the question as to whether it is the delivery dates quoted at the customer enquiry stage or the shop floor control at the job entry and job release stages that produces any recorded improvements.

The case study company chosen for the research has a database of historical information, including planned and actual delivery dates. A sample of these archival records, taken over a number of months, can be analysed, considering, for example, the mean tardiness and standard deviation of lateness. This can be used to gain an insight into the current performance of the company prior to implementation.

Performance Measurement	Previous WLC Research	Anticipated Outcome	Data Availability	Further Comments	Chosen Measures
Delivery Date Adherence	Fry & Smith (1987); Bechte (1988 and 1994); Wiendahl (1995); Park *et al.* (1999)	By aiding decisions from the customer enquiry stage to job release, DD adherence is likely to improve.	Historical data available.	Currently, Company X does not consider available capacity when setting DD's.	*DD Adherence / On Time Deliveries*
Work-In-Progress / Inventory	Fry & Smith (1987); Bechte (1988 and 1994); Wiendahl (1995)	By stabilising the input of work and controlling job release, both WIP and FGI should reduce.	Financial summary information of WIP available.	Insight into WIP levels also available from shop floor supervisor.	*WIP*
Lead Time (LT) (and LT Variability)	Bechte (1988 and 1994); Wiendahl (1995)	The variability of delivery LT's should reduce, allowing more predictable DD determinations. Closely linked to DD adherence.	Data on past quotes includes Delivery & Manufacturing LT's (DLT & MLT).	DLT may not reduce, but given the pool delay, MLT's should shorten.	*Manufacturing & Delivery LT's (Length & Variability)*
Backlogs / Work Centre Utilisation	Fry & Smith (1987); Bechte (1988 and 1994); Park *et al.* (1999)	WLC will reduce and regulate released backlogs. Use of minimum backlogs can avoid idleness.	Difficult to acquire past data, use insight from supervisor.	Use workload smoothing for high work centre utilisation.	*Backlogs & Work Centre Utilisation*
Market Share	Wiendahl (1995)	If company continue to quote for the same number of jobs, market share likely to increase through sustained use of WLC over time.	Sensitive information. Market share likely to be small. Difficult to pinpoint competitors.	Linked to strike rate of company (very important to LUMS approach).	*Strike Rate*
Integration of Production and Marketing	Park *et al.* (1999)	Consideration of capacities and workloads in DD and pricing decisions.	Difficult to assess level of integration.	Both roles performed by one person in Company X (SME).	
Time to Process Customer Enquiries / Computation Time	Wiendahl (1995); Park *et al.* (1999)	Previous results suggest time to process enquiries and PPC computation time reduced.	Can be assessed based on feedback from estimator / user.	Time may increase, currently little planning at customer enquiry stage.	*User Feedback, e.g. functionality, time savings*
Other Financial Impacts	Wiendahl (1995)	Less storage/inventory holding costs, less overtime and subcontracting. Increased DD adherence implies less lateness penalty costs.	Financial summary information, including valuation of WIP (£).	Some of this information is sensitive. An indication can be gained from management.	*Observations*
Also note: Uncontrollable Factors	*It is important to be aware of other factors that will impact the performance measures, such as project hype helping to reduce DD's, other company initiatives (e.g. new machinery) and the actions of customers (e.g. pressurising the company).*				

Table 3.2: Summary of WLC Performance Measures from Previous Studies and Those Chosen for This Project

3.8.2 Work In Progress

The LUMS approach aims to reduce shop floor queues and congestion as a central theme of the approach, using a set of maximum released backlog limits across work centres. As a result, it is anticipated that the use of WLC will not only stabilise WIP, but also reduce levels of WIP in the case study company.

A limited amount of historical data relating to WIP is available within the case study company; this is largely aggregate weekly and monthly data regarding the value of WIP (£ 000's). The main source of this data is the monthly financial accounts of capital tied up in WIP. A further insight into WIP can also be gained through shop floor observations and discussions with the Operations Manager and Shop Floor Supervisor.

3.8.3 Manufacturing and Delivery Lead Times and Lead Time Variability

The LUMS approach delays the release of jobs in a pre-shop pool in accordance with backlog limits and latest release dates. Hence, a previous criticism (as described in Section 3.3) has been that when the time the job spends in the pool is added to the manufacturing lead-time, the total delivery lead-time of the job will not have been reduced. However, it is anticipated that more accurate delivery date quotations will reduce the variation between planned and actual lead times, as previously observed by Bechte (1988 and 1994), creating greater lead-time stability.

Current delivery lead-times can also be obtained from an analysis of delivery data within the company, while manufacturing lead-time information may prove more difficult to collect. As jobs currently have little slack, the current time between the delivery lead time and the manufacturing lead time is likely to be minimal. However, a further insight can be gained from the Supervisor and Operations Manager.

3.8.4 Backlogs and Work Centre Utilisation

Backlogs can be measured on three levels (total, planned and released), and an important measure of the approach will be how the user respects the backlog limits when quoting delivery dates, when scheduling production and when releasing jobs. If the company quote unrealistic delivery dates, this will be highlighted in the total backlog length of the company. The shop is currently considered overloaded, hence, current released backlogs are considered large, and by delaying the release of jobs in a pool, released backlogs will be reduced.

Relating delivery dates to capacities and workloads in a more direct manner will reduce these backlogs further. By releasing an appropriate mix of jobs, the company will be able to smooth workloads across work centres, utilising work centres more effectively without leaving machines unnecessarily idle. The initial backlogs of each machine and work centre can be determined from the current mix of jobs and processing and routing information. However, it is also acknowledged that, in a job shop environment, this is constantly changing over time and would therefore only represent a snapshot in time of the load of the shop.

3.8.5 Company Strike Rate Percentage

By improving the accuracy of delivery dates that the company can offer to prospective customers it is anticipated that the overall strike rate of the company will increase, in other words, the percentage of bids that become firm orders. Conversely, it could be argued that the delivery dates that the company currently quote are too ambitious, and hence, at first it may be necessary to increase delivery lead times to gain control, and 'grasp the tap' (see Land 2004b). Hence, it is suggested that an improvement in the strike rate can be achieved through a long-term strategy of improving the reputation of the company, creating an image of reliability and good delivery date adherence. Pre-implementation data, regarding the strike rate of the company, can be obtained from records of quotations and confirmed jobs. This includes an analysis of quoted delivery lead times at the customer enquiry stage.

3.8.6 Feedback and Observations

It is important to gain feedback from the user on the use of the system and how the DSS can be improved. User feedback can be gained during the implementation of the DSS, leading to improvements to the functionality and user friendliness of the system. This may provide individual user preferences; however, this may also guide more generalised future research. Observations can be recorded in a diary as evidence, for example, the impact of the system on daily routines and shop floor morale. Possible results include positive feedback regarding the assistance the DSS provides when determining what jobs to work on and improved morale on the shop floor due to fewer urgent / rush jobs. Clearly, pre-implementation data cannot be collected objectively for these criteria.

3.9 CONCLUSION

A simulation can be an invaluable tool in theoretical development; however, the ultimate test of a PPC concept comes from attempting to apply the method in practice. The single case study approach used in this project will enable a great deal to be learnt about WLC in practice. In order to maximise the potential of this project, the case to study has been chosen carefully and every precaution has been taken to protect the reliability of the research findings. Whilst a full implementation, with post-implementation data collection, has not been possible, insights can be gained into practical issues such as how machines are grouped into work centres and how accurate estimates of capacity can be determined. These are two critical issues important to the successful implementation of PPC concepts such as WLC. Delays to the project can also be noted so that future research can attempt to avoid these.

In the long term, once the concept is implemented the project can be assessed through completing a post-implementation data collection and analysis procedure, including the quantitative and qualitative factors described in Section 3.8. The performance measurement data can be collected on a weekly basis to monitor progress; a task that will be made easier by the greater detail of information that the company will now possess. At this stage it will also be important to validate the results. In interpreting the results it will be important to again acknowledge variables that have had an impact on the performance of the system since the initial data was collected, and how these may have affected performance. Hence, the impact of WLC may only be determined by revisiting the company, perhaps a year later, and assessing the sustainability and longevity of the system.

In summary, Figure 3.4 presents the key stages of the project, the objectives (as listed in Section 1.5 of Chapter 1) that each stage contributes towards, and the relevant chapter where the phase is discussed. The main objective to emphasise is Objective E: issues surrounding the implementation of the DSS. The thesis continues with Chapter 4, by re-evaluating the LUMS approach in the context of contemporary WLC research trends and findings.

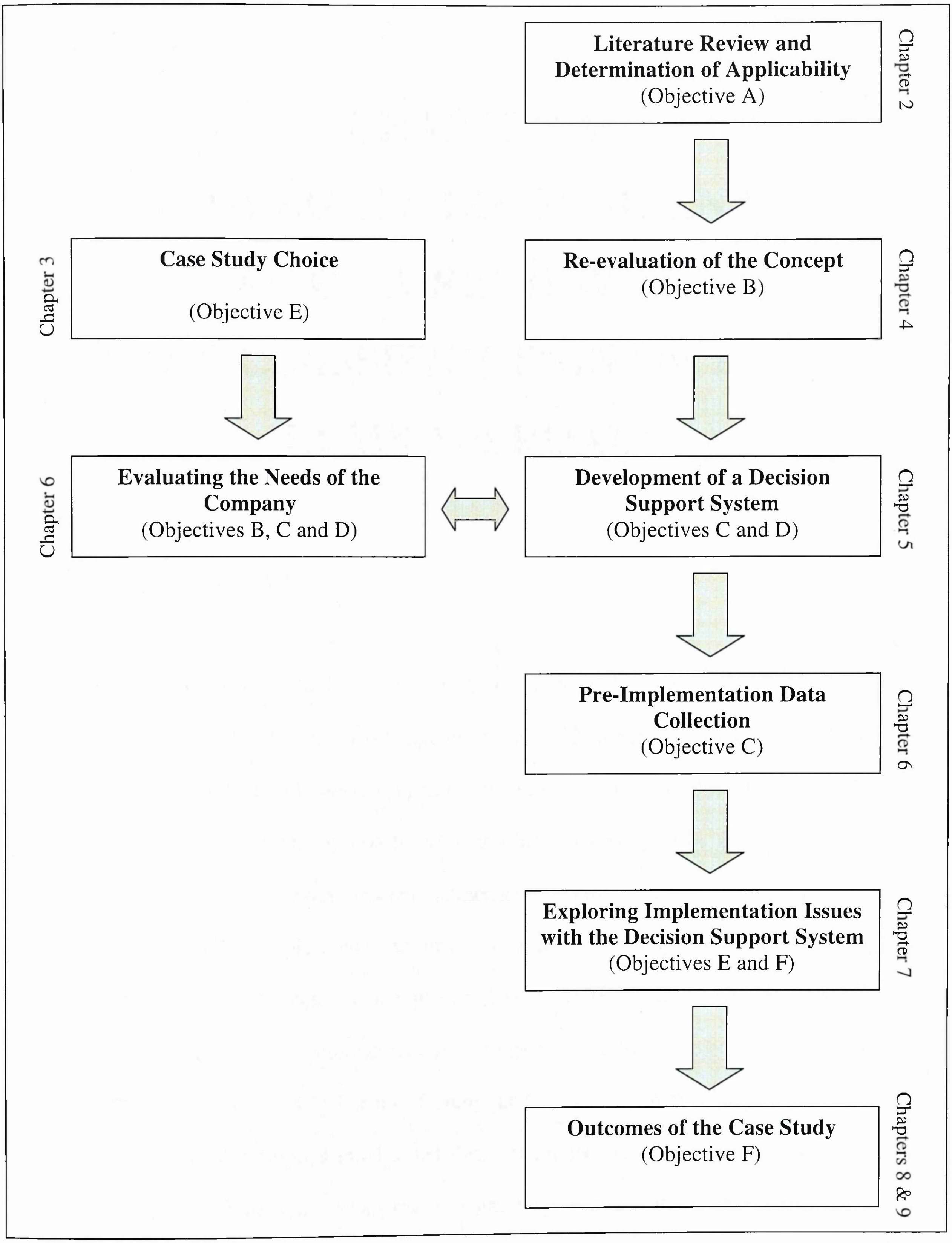


Figure 3.4: Research Process Milestones

CHAPTER 4: AGGREGATE LOAD ORIENTED WLC – A REVIEW AND RE-CLASSIFICATION OF THE LUMS APPROACH

4.1 INTRODUCTION

This chapter pursues the following objectives: (1) to further narrow the focus of the thesis from WLC to the LUMS approach; (2) to summarise the current thinking underpinning the LUMS approach *prior* to the research undertaken in this project; (3) to classify the LUMS approach *prior* to this research project using the eight dimensions of order review and release mechanisms presented by Bergamaschi *et al.* (1997) and (4) to explore potential refinements to the existing LUMS methodology using contemporary literature as a precursor to the development of the methodology and to conducting the empirical research. Regarding the fourth objective, it was felt necessary to explore whether any features of the existing methodology have been found to be outperformed in all tested shop conditions, and if so to make permanent and generic changes to the approach. Thus, the emphasis of this chapter is upon deductive research, using insights from the literature to investigate potential refinements to the existing LUMS approach.

The reason for using the classification presented by Bergamaschi *et al.* (1997) is that it incorporates the majority of the key elements that make up the alternative approaches to WLC and included a classification of the LUMS approach based on a paper by Hendry & Kingsman (1991). It is acknowledged that this is not the only paper that reviews and classifies order review and release methods; see for example, Philipoom *et al.* (1993) and the extension of this by Sabuncuoglu & Karapinar (1999). However, the classification by Bergamaschi *et al.* (1997) is arguably the most commonly referred to in the WLC literature and is the most comprehensive in terms of the characteristics of aggregate approaches to WLC. Given that the LUMS approach can be best described as an aggregate load oriented approach, the characteristics within the Bergamaschi *et al.* (1997) classification are hence the most appropriate to the aims of this chapter.

The two key aspects of WLC concepts that this chapter focuses on initially are the varying approaches presented in the literature to 'workload bounding' and the 'measure of indirect load' (or aggregation of workload measure). For most WLC concepts, jobs are only released onto the shop floor if released workload levels will not exceed pre-set maximum limits, a form of 'Workload Bounding'. There are several approaches to workload bounding, as well as some alternative approaches that aim instead to balance the workload across the shop. WLC concepts also differ in their approach to the 'Measurement of Indirect Load' of a work centre. The latter is usually defined as the load in transit between the pre-shop pool and a particular work centre that will process the job in the future (upstream work); however, some methods also include work already processed at a work centre, but still positioned on the shop floor (downstream work) in the workload measure.

The remainder of this chapter is organised as follows. Sections 4.2 and 4.3 review the two important research areas of 'measurement of indirect load' and 'workload bounding', respectively. In Section 4.4, the existing LUMS approach is described in detail. The classification of Order Review and Release mechanisms presented by Bergamaschi *et al.* (1997) is recalled as a means to summarise the ideas underpinning much of the LUMS approach. Also in Section 4.4, the existing LUMS approach is re-classified, indicating why re-classification was necessary, for example, due to a misinterpretation of the methodology (i.e., a mistake in the original classification) or due to advances in knowledge between 1991 and the start of this project. Finally, conclusions are drawn in Section 4.5.

4.2 MEASURE OF INDIRECT LOAD: A REVIEW

When a job is being considered for release, it is very difficult to foresee when it will arrive at a downstream work centre, and hence it is difficult to determine when resources will be required. As a result of such issues, a number of approaches to calculate and account for the indirect load (load in transit) of a work centre have emerged. Aggregate load oriented workload control methods, such as the LUMS approach, attribute the workload of a job to the backlog of each work centre that processes it at the moment of job release. Thus it is attributed to the work centre that will process it first, second and so on, irrespective of the routing of a job prior to arrival at a work centre. The backlog at a work centre hence includes indirect load and load on hand without distinguishing between the two. An aggregate load method is perhaps a less sophisticated representation of the workload than some other WLC concepts; however, it can be an effective means to control and improve shop performance (see, for example, Hendry & Wong (1994)).

An alternative to this system is Load Oriented Manufacturing Control (LOMC), (see, Bechte 1988 and 1994; Wiendahl 1995). This is a Probabilistic approach, in which a percentage of the workload of a job is added to the backlog of its corresponding work centres at the moment of job release, based on the probability of the job reaching the work centre in the planning period. Thus this is more sophisticated in attempting to represent the current backlog of a work centre. The more simplistic measure used by the aggregate load approach has received criticism for having difficulty in providing sufficient control in job shop simulations. Perona & Portioli (1998) suggest that LOMC yields better results, but only if the right value for the planning period is chosen; a condition not always easy to satisfy. Meanwhile, Oosterman *et al.* (2000) criticise aggregate load methods in the context of the job shop for not appropriately indicating the future flow of work to a workstation. However, as described, there is a lack of previous empirical research regarding aggregate load methods (since Bertrand & Wortmann 1981), and more research is needed to determine whether the disadvantages of its simplicity are outweighed by the advantages. In addition, it seems reasonable to suggest that the smaller the manufacturing lead time, the less need there is to estimate the arrival times at work centres after release, as jobs remain part of the backlog of work centres for less time. Given the increasing importance of shorter lead times in the current manufacturing climate, this further substantiates the need for further empirical research into the effectiveness of the aggregate load approach.

WLC concepts can vary in their depreciation of the workload over time and hence their value of the released backlog of work centres. Measures comprising the work upstream and work queuing at a work centre will attempt to reduce the backlog of work centres after each operation, thus ensuring that the indirect load of a work centre does not contain a downstream element. However, this assumes that the WLC system receives accurate and up to date feedback information regarding the progress of jobs; this is not always possible in practice (see Henrich *et al.* 2003 and Chapter 7). Others that include downstream work (such as Tatsiopoulos 1983) may only need to do this when all work is completed on a job, meaning the workload of a job contributes to the backlog of all work centres that process it until the moment of job completion. Land & Gaalman (1996) criticise that such a concept does not consider the position of a work centre in a job's routing. Yet, the position of a workstation in the routing of a job is an important factor, particularly if downstream work is included. If a work centre is towards the start of the routing, it must include work it has already completed for a long period and if it is towards the end it must include work that it is unlikely to process in the near future. Thus including the downstream element in the measure of indirect load may lead to inappropriate job acceptance or job release decisions, risking unnecessarily idle work centres in some cases. Oosterman *et al.* (2000) suggest that it might be better to exclude the measure of direct load altogether and to focus on the quantities upstream of a work centre, but further research is required to verify this. However, Cigolini & Portioli (2002) suggest that the behaviour of WLC concepts does not depend very much on the workload accounting over time (measurement of the workload) approach; although the paper did not cover the inclusion of downstream work, having done so may have led to different conclusions.

Enns & Prongue Costa (2002) discuss Bottleneck Load Oriented Release, a method based on the philosophy that the flow of work to the bottleneck is the key to the performance of the system. As a result the approach only controls the workload that is routed through the bottleneck. Any jobs that do not visit the bottleneck work centre are free to be released immediately. However, as a result Enns & Prongue Costa (2002) concede that queues at non-bottleneck work centres are likely to be higher than under aggregate load control. Queuing priority is given to jobs that are still to visit the bottleneck work centre; if there are two jobs still to visit the bottleneck then priority is given to the one with the highest remaining processing time at the constraint resource. This will be the philosophy at all work centres except the bottleneck, where jobs will be merely sequenced in order of largest bottleneck resource processing time. The authors compare, through simulation, an aggregate load method based on 'total shop load' with the Bottleneck Load Oriented Release method based on feeding the requirements of the bottleneck resource. Results suggest that the aggregate load method is the best performer in a flow shop, but that the bottleneck method is better in less structured situations. The method can lead to a significant reduction of bottleneck queues at the expense of an increase in non-bottleneck queues, performing better the more severe the bottleneck. However in a job shop with no bottleneck, the aggregate method performs just as well. Enns & Prongue Costa (2002) also suggest that giving bottleneck jobs dispatching priority improves performance for both bottleneck load oriented and aggregate load oriented workload control strategies, although variability increases. Note that Park *et al.* (1999) implement a WLC oriented DSS in a large MTO company similar to this philosophy, where only the workload of the bottleneck resource is monitored.

Land & Gaalman (1996) acknowledge the importance of control and regulation at the bottleneck, suggesting loads of potential bottlenecks should be kept close to a norm level. However, it may be difficult to cater for the wandering bottleneck problem and multiple bottlenecks found in complex manufacturing situations, requiring constant updating, although this type of problem has recently been addressed in the context of the Theory of Constraints (see Chapter 2). Oosterman *et al.* (2000) present an adapted aggregated load method differing in its initial measure of the indirect load known as the 'Adjusted Aggregate Load method'. The paper suggests an alteration to the calculation of the load in transit, similar to Bechte (1988 and 1994) and Wiendahl (1995). However, rather than assigning a percentage of the future load based on the probability of arriving at the downstream work centre, a simple proportion based on the number of work centres the job must visit before arriving downstream is used, calculated as processing time divided by the position of a work centre in the routing of a job. This means that a downstream work centre is not burdened with a large load that it is unlikely to process in the near future, and the method maintains its relatively simplistic nature. To summarise, Table 4.1 presents the key 'Measure of Indirect Load' concepts discussed in this section.

Category	**Aggregate Load Approach**	**Alternatives**
Methods Discussed	Upstream, Downstream and Load on Hand; Upstream and Load on Hand.	Adjusted Load Method; Load Oriented Manufacturing Control; Bottleneck Load Oriented Release.

Table 4.1: Summary of 'Measure of Indirect Load' Alternatives

Figure 4.1 below presents a representation of the released backlogs of a resource under four of the approaches described in this section. In addition, if the resource were a bottleneck, the bottleneck load oriented method would be similar to the 'upstream' aggregate load method. Whether the released load of the adjusted method is greater than the released load under the LOMC approach depends on the average position of the resource in the routing of a job compared with the percentage calculated for the probability of jobs arriving at the resource in the current planning period. Obviously, the larger the planning period and the smaller the routing length, the greater the probability of arriving. As emphasised in this section, it is essentially the way that the load is accounted for when a job is released from the pool and how it is reduced over time that provides the distinction between the methods. The varying approaches also mean that the restrictions on released workloads must be determined differently under each measure.

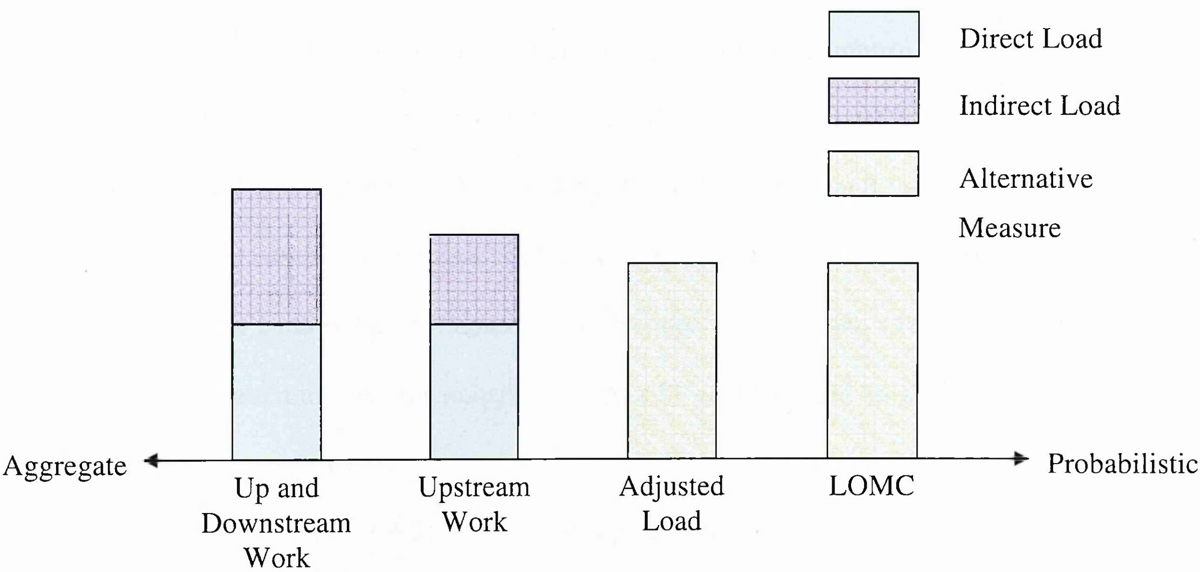


Figure 4.1: Measurement of Released Workload Spectrum

4.3 WORKLOAD BOUNDING: A REVIEW

In order to stabilise the workloads of shop floor resources, WLC concepts commonly place limits on the backlogs of work centres, referred to here as workload bounding. This can help, for example, to stabilise the level of WIP and help to ensure that a company does not accept, or release, an inappropriate mix of jobs, where, for example, some work centres are overloaded and others are left idle unnecessarily. This is another aspect through which WLC concepts vary, with some contemporary concepts completely opposing the use of rigid limits (for example, workload balancing). Workload Bounding can refer to the use of maximum and/or minimum workload restrictions at the backlog levels. For example, the amount of work on the shop floor that will visit a particular work centre (released backlog) or the amount of scheduled work, either in the pre-shop pool, or on the shop floor (planned backlog). Breithaupt *et al.* (2002) explain that workload norms provide a convenient means to communicate at the interface between overall planning and shop floor control. Breithaupt *et al.* (2002) continue to explain that many job shop control methods risk the occurrence of the 'lead time syndrome' (see Mather & Plossl 1978), but that the use of fixed WLC norms avoids this problem. The use of upper and lower bounding of the workload can help to prevent bottlenecks and reduce the threat of starvation at individual work centres but, as identified by Hendry & Kingsman (1991), this has received little attention by researchers, a point still equally valid in the context of more contemporary research.

Land & Gaalman (1998) explain that tight norms seem to hinder the release of some urgent jobs, but loose norms seem to act more as an upper bound than as a predictable mean. In addition, Land & Gaalman (1998) suggest that it is difficult to determine suitable levels for aggregate loads, hence it is difficult to determine released workload bounds, also stating that the tighter the workload norms, the poorer the delivery date performance. Enns & Prongue Costa (2002) advise that a control level set too high is ineffective but that too low a level provides inadequate throughput. Land & Gaalman (1998) conclude that at low levels of WIP, performance seems to be very sensitive to small changes of workload norms. Therefore, if a lower limit is to be used in conjunction with an upper limit, the width between them must not be too narrow. If the bounds are tighter than the largest workload contribution of jobs in the pool, a job may never be released. Cigolini & Portioli (2002) comment that adding a lower workload bound leads to a worsening of almost all performance measures regardless of the measure of indirect load policy considered. For example, rigid upper and lower bounds that are not tight, coupled with a periodic release mechanism (such as every seven days) could lead to wide fluctuations in released backlog lengths (see Figure 4.2 for a simplified example). In addition, there is little guidance for managers in setting workload limits and so having to set both upper and lower limits may increase errors and start up time requirements. However, Land (2004a) shows that although tightening workload norms hinders the timing of job release, queues on the shop floor fluctuate less, while the difficulties experienced by jobs with long routings and / or long processing times when norms are tight can be compensated for by increasing job priority.

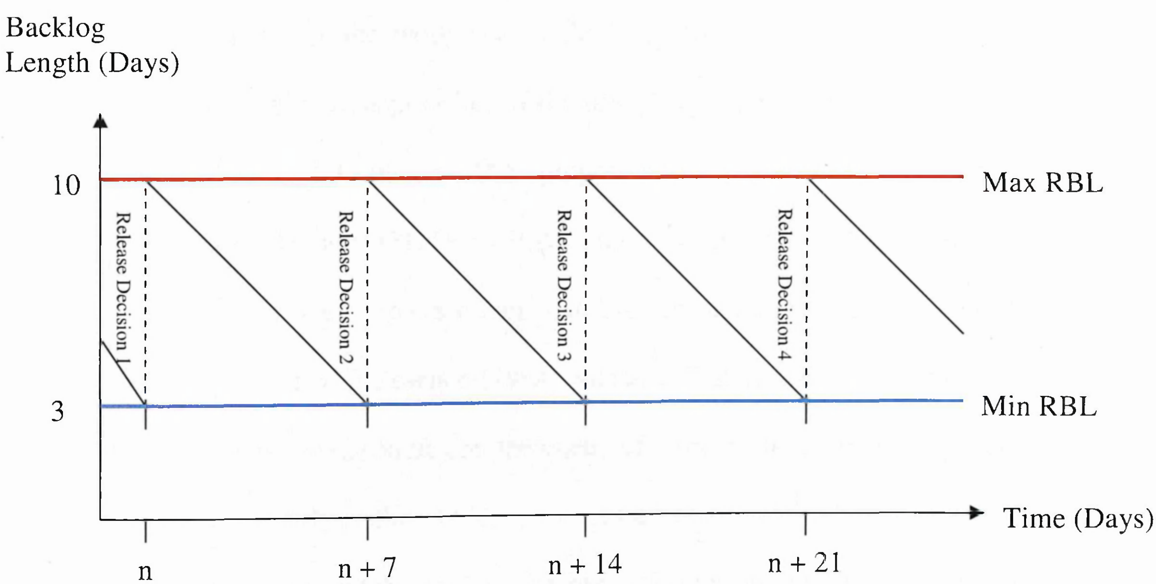


Figure 4.2: Fluctuation of Backlogs Under an Upper and Lower Bound Release Policy

The key criticism of the aggregate load approach is that the indirect element of the approach means that machines are in danger of being under-loaded because a work centre at its backlog limit may consist entirely of jobs queuing elsewhere. This is particularly true if the indirect load includes downstream work that has already visited a work centre. The arguments documented here illustrate the diversity of viewpoints regarding the issue of workload bounding. For example, Bergamaschi *et al.* (1997) classify Bechte (1988) as using an upper bound only, Glassey & Resende (1988) as using a lower bound only and Hendry & Kingsman (1991) as using both upper and lower bounds. This diversity of opinion is further highlighted by shifts away from the use of rigid workload bounds by several researchers (see Section 4.3.1 below).

4.3.1 Variations on Traditional Approaches to Workload Bounding

Land & Gaalman (1996) comment that a good timing of job release may conflict with realising the norms for the workload on the shop floor; as a result, the section examines three alternative approaches to the use of rigid upper and lower workload bounds. Firstly, Land & Gaalman (1998) propose an alternative entitled Superfluous Load Avoidance Release (SLAR). SLAR follows the principle of Starvation Avoidance for wafer fabrication (see Jain *et al.* 2003 for a description of the industry), as presented by Glassey & Resende (1988). Glassey & Resende (1988) explain that Starvation Avoidance concentrates on the queue of work at the bottleneck, setting an acceptable level of risk of the bottleneck running out of work. New work is only started just-in-time to avoid the bottleneck workstation becoming idle, balancing high bottleneck resource utilisation with maintaining low levels of WIP. Breithaupt *et al.*

(2002) describe SLAR as a starting point for the control of workloads without the need to determine norms. The method centres on the direct load, which is replenished either from upstream work centres, or from the pool. Employees on the shop floor are authorised to determine the moment of release rather than reviewing released workloads at periodic intervals. Urgent and non-urgent priority levels are assigned in the pool, where urgent jobs are those with negative slack. Work is released from the pre-shop pool according to priority if the direct load of a work centre falls to zero, reducing variance (Land & Gaalman 1998), and thus improving the stability and transparency of the shop floor. Also, if the direct load consists purely of non-urgent jobs, urgent jobs, defined as those where the first destination is the work centre in question, are released.

Cigolini & Portioli (2002) discuss the second alternative: Workload Balancing. Their Workload Balancing approach is based upon striking a balance between improving the situation at an under-loaded work centre in danger of starvation at the expense of overload elsewhere. Individual work centres can be overloaded as long as the overall workload balance across all shop work centres is improved. The method relaxes the upper bound method and aims to minimise the sum of the deviations between work centres, where a penalty is assigned to under and overloading. A penalty for under-loading suggests the use of a lower limit, although this penalty could alternatively be set equal to zero. If the improvement at the under-loaded work centre is greater than the impact on overloaded work centres, the job can be released to the shop floor. Land (2004a) explains that increasing the time between job release decisions can also increase the opportunities for workload balancing, although this is at the expense of a larger pool delay.

Finally, Land & Gaalman (1998) explain that the LOMC concept presented by Bechte (1988) compensates at the release stage for large jobs. When the load limit is reached, the consideration of jobs is continued for one additional job, with the next job that would visit the fully loaded work centre released to the shop floor. This allows very large jobs to be released that would otherwise need the load at work centres to be very low before they could fit within the limit, providing a useful relaxation of rigid workload bounding towards a more balancing oriented approach. To summarise, Table 4.2 presents the key 'Workload Bounding' concepts reviewed in this chapter.

Category	Workload Bounding	Alternatives
Methods Discussed	Upper Bound Only; Upper and Lower Bound; Lower Bound Only.	Starvation Avoidance; Superfluous Load Avoidance Release; Workload Balancing.

Table 4.2: Summary of 'Workload Bounding' and its Alternatives

4.4 CHARACTERISTICS OF THE INITIAL LUMS APPROACH

Bergamaschi *et al.* (1997) classify a wide range of WLC strategies (or Order Review and Release methods) based on eight dimensions: Order Release Mechanism, Timing Convention, Workload Measure, Aggregation of Workload Measure, Workload Accounting Over time (referred to above as the measure of indirect load), Workload Control (referred to above as workload bounding), Capacity Planning and Schedule Visibility. The LUMS approach was included in this initial classification, based upon their interpretation of the concept presented by Hendry & Kingsman (1991). This classification of the LUMS approach is presented in Table 4.3 along with definitions of the above criteria. This set of criteria has proved very useful in re-evaluating the LUMS approach during the initial phases of this research. Table 4.3 also indicates a revised classification of the existing LUMS approach prior to this study. The re-classification is justified in sub-sections 4.4.1 to 4.4.6 below, indicating why reclassification is needed for 5 of the 8 criteria. These sub-sections are organised around key characteristics of the LUMS approach, rather than the eight criteria, in order to more clearly describe this approach. Note that due to the hybrid nature of some of the re-classified aspects of the LUMS concept, the options provided by Bergamaschi *et al.* (1997) have also been elaborated upon where appropriate in Table 4.3.

For the record, the most recent review of this ilk by Sabuncuoglu & Karapinar (1999) splits Order Review and Release methods into four groups with sub-categories within each group. The LUMS concept, also based on Hendry & Kingsman (1991), is categorised as a load limited order release method, but rather than being aggregate, Sabuncuoglu & Karapinar (1999) classify the approach as using 'Work centre Information Based Loading' (WIBL), which the authors suggest utilises more detailed information than the aggregate method. Sabuncuoglu & Karapinar (1999) conclude that load oriented release methods such as aggregate loading and WIBL outperform due date oriented release methods for the mean tardiness and the proportion tardiness measures. Despite this, the authors criticised load limited order release methods for not utilising due date information. However, as will be discussed in detail in sub-sections 4.4.1 to 4.4.6 below, the LUMS concept is more than just an order review and release mechanism, as it can determine delivery dates at the customer enquiry stage, provide scheduling at the job entry stage and aid job release decisions. When required, due date information can be used by supervisors during informal shop floor dispatching. It could equally be argued that the LUMS approach would be in need of reclassification using the criteria discussed by Sabuncuoglu & Karapinar (1999), as the LUMS concept shows traits of Order Review and Release methods in other branches of their classification. For example, the contemporary LUMS concept could arguably be placed in the group that relates to release mechanisms that consider both the workload level in the shop and the due dates of jobs. However, for the purposes of this chapter, this method of classification is not discussed in further detail.

Dimension	Options	Definition	Original LUMS Classification	Contemporary LUMS Classification
Order Release Mechanism	Load Limited Time Phased	The mechanism can be either based upon a predetermined **time phased** release date or to satisfy shop floor **load limited** constraints.	Load Limited	Load Limited
Timing Convention	Continuous Discrete	Decides when an order can be released, either at **discrete** time set intervals or **continuously** at any appropriate time.	Discrete	**Hybrid**
Workload Measure	Number of Jobs Work Quantity	A measure of the workload of the shop or company as a whole, where if job specifications vary it may be necessary to consider **work quantity** in hours of work and not merely the **number of jobs**.	Work Quantity	Work Quantity
Aggregation of Workload Measure	Total Shop Load Bottleneck Load Load by each work centre	How workload is calculated and whether it represents **load by each work centre**, in the **total shop** or at **bottleneck** resources. As routing and processing times vary, the need to move away from total shop load may increase.	Load by each Work Centre	**Load by each Work Centre, including Load on Hand and Load Upstream**
Workload Accounting Over Time	Atemporal (also called aggregate load) Time Bucketing Probabilistic	An indication of how the workload is distributed over time, based on varying assumptions about the load in transit, using an **atemporal**, **probabilistic** or **time bucketing** approach.	Atemporal	**Atemporal (or Aggregate) with Probabilistic Element**
Workload Control	Upper Bound Only Lower Bound Only Upper and Lower Bounds Workload Balancing	The method by which the released workload is regulated on the shop floor, based on **balancing** workloads across work centres, or using **upper, lower** or **upper and lower workload bounds**.	Upper and Lower Bounds	**Upper Bound with Unenforced Lower Bound and Optional Balancing by Supervisors**
Capacity Planning	Active Passive	The ability to make capacity adjustments within the planning horizon, beyond the customer enquiry stage varies from **'passive'** to **'active'** participation.	Active	Active
Schedule Visibility	Limited Extended	The ability to look beyond the current planning period, considering future time period capacity requirements and customer orders. Aims vary from long-term shop performance (**extended visibility**) to a short-term present planning period perspective (**limited visibility**).	Limited	**Hybrid**

Table 4.3: Summary of LUMS WLC Concept, Classified Using the Eight Dimensions Presented by Bergamaschi *et al.* (1997).

4.4.1 LUMS Customer Enquiry Management

After capacity management and delivery date considerations, if a bid is to be placed in response to a customer enquiry, it is important that the total backlog of the company reflects this, to ensure that the company do not create an imbalance in the mix of future jobs. However, there is a degree of uncertainty regarding whether the potential customer will accept the offer, particularly in very competitive industries. Kingsman & Mercer (1997) explain that poor delivery performance or capacity utilisation is not necessarily due to bad production scheduling, but to imbalances in the factory created because of the mix of contracts won by the marketing function, while Kingsman *et al.* (1993) describe the need to integrate the production and marketing functions. As a result, the strike rate of the company, based on historical data, can be incorporated within the design of a WLC concept, particularly important when the concept is to be applied to a MTO company, such as Company X. The strike rate relates to the percentage of bids or tenders that a company makes that lead to firm orders. This can be a simplified percentage or a complex probability matrix based on a variety of factors, such as the size of a job, the customer, previous history with a customer or the profit margin.

Kingsman *et al.* (1993) observe that the strike rate of a company can vary from 3 to 100%. In a case study of a company producing aluminium moulds for the plastic injection industry, Silva & Magalhaes (2003) report an overall strike rate of only 6%. Kingsman & Mercer (1997) explain that it is usual for management to have prior beliefs about strike rates before a tendering system is introduced; in fact Company X estimated their overall strike rate to be approximately 15%. Company X conducts a large amount of business with the aerospace and defence industries. Kingsman & Mercer (1997) discuss the case of a manufacturer of sophisticated components for military equipment, where the overall strike rate is 16%. However, the authors explain that the defence industry is subject to sudden political changes that can impact the strike rate, an element that may have a cyclical effect on the workload distribution of Company X.

The initial groundwork for the strike rate within a WLC concept is presented by Tatsiopoulos (1983). However, this was not formally incorporated and it has since been suggested that this could be developed into a much more sophisticated probability matrix. For example, Kingsman & Mercer (1997) discuss a weighted approach, as it is anticipated that management are likely to place greater emphasis on the result of the most recent tenders, while the authors also explain that as more results are obtained, clear differences in the strike rate are likely to emerge for different groupings (for example, according to customer characteristics). Shop load may also have a significant impact on the outcome of a quotation; for example, if a company is experiencing an under-load situation they may reduce the mark up placed on an order or put more effort into the negotiation process with a customer, while an under-load may also temporarily ease delivery date adherence problems, perhaps invalidating empirical results. There are therefore several ways of calculating the strike rate, varying in sophistication; however, it may be useful to begin by experimenting with one overall percentage. This percentage is then multiplied by the total work content of the quotation to give an 'expected value' for the workload of the job. The sum of the expected values of unconfirmed jobs can be added to the planned backlog of the company to create the 'total backlog', in an attempt to prevent a company from bidding for more jobs than it can cope with, a common problem when companies expand too quickly. Inevitably, this strike rate approach will lead to problems if all jobs are confirmed; however, it is considered better to use the expected value rather than considering future quotations on the basis that either all or no jobs will be confirmed. Silva & Magalhaes (2003) decide to exclude the use of the strike rate from their model due to a small tender to job acceptance ratio and hence a small contribution to the total backlog; however, if the percentage improves the importance of accounting for unconfirmed jobs will also increase in this case.

The total backlog of the company must be updated as soon as a customer confirms an order, as discussed by Kingsman (2000). If a tender is rejected, the total backlog can be reduced; however, if the job is accepted, the total backlog for the company must be increased to represent the whole workload of the job. It must be acknowledged that some customers may never reply to a quotation, with either a positive or negative response; hence after a set period of time, such tenders can be assumed to have been rejected by the potential customer. In either case, the historical data used to calculate the strike rate can be updated to reflect the outcome of this bid. If the customer confirmation time delay was unusually long it may be necessary to check and adjust the delivery date. The backlogs of the individual work centres must also be checked to ensure that they can process the required work, using backward scheduling to generate operation completion dates. Extra capacity may be required in the form of overtime or through the reallocation of operators from under-loaded to overloaded work centres. In addition, extra capacity can be provided from an external source through subcontracting to provide further active capacity scheduling. Once materials are available the job can be placed into the pre-shop pool and can be added to the planned backlog.

The strike rate introduces a probability element to the workload accounting over time approach used by the LUMS approach until the customer confirmation stage and ensures that the workload reflects the anticipated future load of the shop.

However, it is acknowledged that there is no probabilistic element at the more detailed released and planned backlog levels. It is therefore concluded that the current method of 'workload accounting over time' as defined by Bergamaschi *et al.* (1997), is atemporal, or aggregate, with a probabilistic element, rather than simply atemporal. Attempting to represent the future load of the shop in this manner also demonstrates an attempt to consider beyond the current planning horizon and capacity requirements to provide a less limited degree of schedule visibility. Thus the schedule visibility criterion is also adjusted in Table 4.3, becoming hybrid, to include extended as well as limited schedule visibility. The theory behind incorporating the strike rate within the LUMS approach dates back to before 1991; however, the emphasis placed upon this aspect has increased in recent years (see, for example, Kingsman 2000).

The inclusion of the strike rate and hence greater schedule visibility is regarded to be of general importance to the MTO sector, as well as of particular relevance to Company X. If the strike rate is 15%, as predicted by management, this would be too high to be ignored when considering further potential orders. This issue will be further explored in Chapter 6. In summary, Figure 4.3 presents an adaptation of the traditional *'funnel'* and *'bathtub'* models, as discussed by Bechte (1988) and Land (2004b), to illustrate the additional control supplied by the incorporation of support prior to the job entry stage.

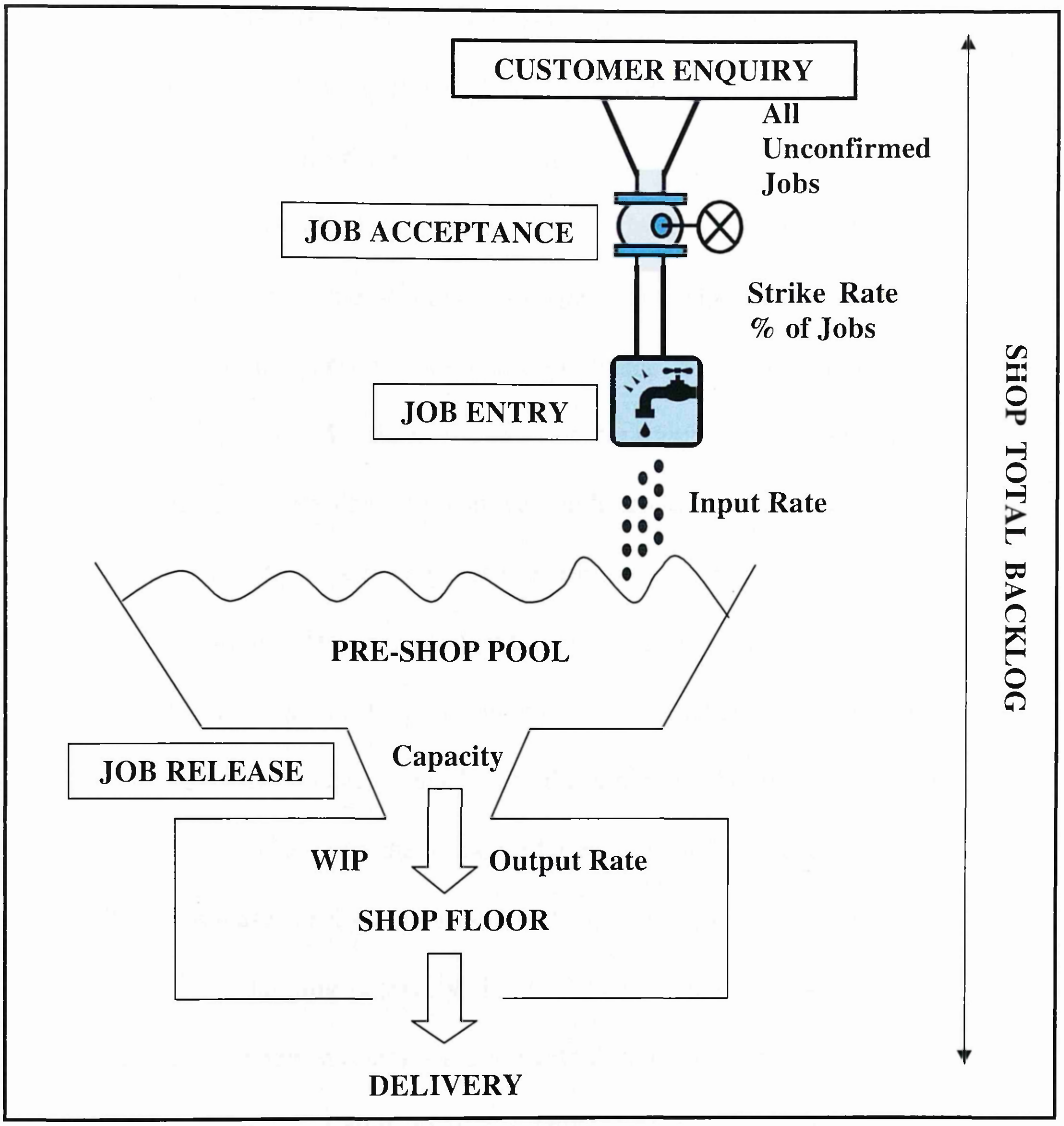


Figure 4.3: Adaptation of the Traditional 'Funnel' and 'Bathtub' Models

4.4.2 LUMS Order Release Mechanism

On entry to the pre-shop pool, jobs are assigned a Latest Release Date (LRD), the date by which a job must be released if it is to satisfy its delivery date. This date may be brought forwards by giving a job 'Pool Priority', thus reducing the expected pool delay. Alternatively, the expected shop floor throughput time of a job may be reduced by giving a job 'Shop Priority', thus reducing the expected shop floor queuing times. Note that 'Hot Priority' jobs can be assigned, referring to those jobs given both pre-shop 'Pool Priority' and 'Shop Priority' on the shop floor. The number of jobs given priority must be limited if prioritisation is to have the desired effect of expediting jobs and the effect on 'Normal' jobs is to be minimised. Jobs in the pool will be considered for release according to the shortest remaining total slack criteria, deducting the current date from the latest release date and hence taking into consideration the relative processing times, due dates and work centre routings of all jobs in the pool.

The main release decision can be made on a periodic basis, where it is essential to consider the risk of work centres running out of work in determining the release period interval. The maximum interval between releases can be set equal to the smallest slack of jobs in the pool, otherwise a job that is not released one period will be late, or have negative slack, by the time of the next release decision. Bergamaschi *et al.* (1997) comment that Order Review and Release policies based on a time phased release mechanism have a reduced conception of workload and only consider capacity planning passively. Land (2004a) explains that the choice of an appropriate period between releases is a delicate decision and argues that non-periodic release methods should be embedded and emphasised within future research. In the LUMS approach, the periodic release decision is supplemented by two further options: Intermediate Pull Release and Force Release. Hence, between periodic releases, jobs that would improve the workload balance and avoid work centres from starving, whilst satisfying workload bounds, can be 'pulled' from the pre-shop pool, using an 'Intermediate Pull Release' option between periodic releases, allowing supervisors to maintain control of both order release and the shop floor. As lead times reduce, it has become important to adopt a more continuous review and release policy if delivery dates are to be adhered to. Thus it is concluded in Table 4.3 that the LUMS approach has a hybrid timing convention with both discrete and continuous release options available. The inclusion of this characteristic will be relevant to any case study setting, including Company X.

Using the second option, if a supervisor requires certain jobs between periodic releases but pull releasing them would break workload limits, supervisors can choose to 'Force Release' jobs onto the shop floor, providing the control and flexibility of both the workload bounding and workload balancing philosophies. This is important for jobs that have developed negative slack and would otherwise be refused entry to the shop floor and inevitably delivered late to the customer as a result of exceeding workload bounds. It also gives this WLC concept greater schedule visibility. Land & Gaalman (1998) comment that SLAR provides the opportunity to let empowered people on the shop floor determine the moment of release, while Wiendahl (1995) claims that a LOMC system helps the experienced operator rather than ruling them. Similarly, the LUMS order release options are presented as an aid to decision making, with pull and force release options giving employees the freedom and responsibility to respond to ever-changing shop conditions and requirements. However, these supplementary options should not undermine the main release decision and control of the workload, hence, restrictions in the form of an advised maximum allowance can be placed upon the use of Pull and particularly Force Release decisions. The use of these inter-period options means that the hybrid LUMS approach bridges the gap between the periodic and continuous timing convention release methods providing a flexible and dynamic planning and control environment. This re-classification reflects the increasing competitiveness within manufacturing sectors in recent times.

4.4.3 LUMS Measure of Indirect Load

At the job release stage, the Released Backlog Length (RBL) of each work centre that a job will visit is compared to its pre-set limit. The RBL of a work centre is the amount of time, usually measured in days or weeks, required to process the proportion of work on the shop floor (direct and indirect load) that will visit a particular work centre, given the current capacity constraints. Where appropriate, the same approach can be used to calculate the planned and total backlog lengths. If adding the job to the RBL will not exceed the limits for each work centre and the shop overall, the job can be released onto the shop floor, updating the RBL for each work centre and the shop. Hence load on hand and load in transit are accounted for in the same way and the aggregation of workload measure is based simply upon the work at a work centre and upstream. Downstream work is not included in the backlog lengths as the processing time at a work centre is deducted from the relevant RBL, Planned Backlog Length (PBL) and Total Backlog Length (TBL) for the work centre and shop as a whole as soon as the associated job operation is complete. The LUMS approach has previously included upstream and downstream work in its measure of indirect workload (see Tatsiopoulos 1983) but later removed the downstream element (see Hendry 1989). Oosterman *et al.* (2000) acknowledge the LUMS shift in philosophy to including only work upstream and on hand in its aggregated measure and show that an aggregate load method based on load on hand and load upstream outperforms the aggregate load method based on load on hand, load upstream and load downstream. Note that Tatsiopoulos (1997) now defines the released backlog as consisting of upstream work and that currently queuing at a work centre, with no mention of downstream work.

Measuring the indirect load in this manner requires regular and accurate feedback information regarding the position of jobs on the shop floor, for example, through the use of bar coding, shop floor computer terminals or traditional routing cards. It is important to note that the moment of operation completion is not necessarily equal to the moment of information feedback (see Henrich *et al.* 2003); however, the disadvantages of the alternative are too great. Tatsiopoulos (1997) describes a method that caters for the need to know information regarding the input and output of work centres at the moment they happen by a connected data collection and monitoring system. In documenting the LOMC concept, Wiendahl (1995) explains that complete and up to date information is required at the moments when work is released and allocated only. However, Henrich *et al.* (2003) observe that IT supported information feedback within Small and Medium sized Enterprises (SME's) is often not successful or not tried out at all.

Using simulation, Land & Gaalman (1998) demonstrate that such an aggregate load based method performs worse than Bechte's LOMC concept in a pure job shop. However, Enns (1995) states that real life job shops have most in common with the theoretical general flow shop, suggesting that in practice a concept such as the LUMS approach would compare favourably. Oosterman *et al.* (2000) show that the Adjusted (or Corrected) Aggregate Load method can perform better than the LUMS approach in a pure and 'restricted job shop'; however, in the general flow shop the LUMS approach outperforms this release mechanism. In the pure flow shop, it seems that there is little to choose between the two alternatives. Note that Oosterman *et al.* (2000) report that the approach of Bechte (1988) outperforms both methods in the pure job shop; however, in the pure flow shop, Bechte's concept allows work centres to starve too often, demonstrating that the further from the theoretical job shop the case study company used in the empirical research project is, the less need there is to consider sophisticated probabilistic elements of LOMC. However, the LOMC release procedure discussed warrants further consideration in future development of the LUMS approach. For example, releasing the first job after released backlog limits have been reached is likely to be the type of ad-hoc / rule of thumb approach used in practice. In conclusion, no single method is proven to outperform all others and it is argued that all of the methods, including the LUMS approach, warrant further research in their appropriate production environments. Company X has a general job shop layout; therefore this is an appropriate production environment in which to further investigate the existing LUMS methodology.

4.4.4 LUMS Workload Bounding

The LUMS concept is currently based upon an upper bounded workload restriction method, documented as outperforming the use of an upper and a lower bounded method (see Section 4.3). However, this is supplemented by a non-enforced lower bound as a further aid to decision making. If a job will exceed the bounds of any of its work centres, it cannot be released onto the shop floor until the situation changes, without resorting to the Force Release option. The non-enforced lower bound is provided as a guide to supervisors, empowering them to decide whether to try to improve the workload balance or wait until the next planning period, assessing the risk and impact of work centres starving, and hence the use of the intermediate pull release option. If a work centre is approaching its lower limit, the release of jobs is not automatically triggered from the pre-shop pool; however, it is advisable to pull release jobs that would visit the aforementioned work centre first. This concept provides a Workload Control structure that strikes a balance between the advantages of a lower limit and the greater performance (under all tested shop configurations) of an upper bound only. Force Release also arguably offers the system user some additional balancing qualities.

Simulations conducted by Cigolini & Portioli (2002) suggest Workload Balancing is able to enhance the atemporal WLC approach, although the percentage of tardy jobs gets worse. The paper shows that the upper bound method performs better than the workload balancing procedure, but that workload balancing is more robust, while the use of an enforced upper and lower bound is the worst performer under the tested conditions. It is important to provide a balanced workload; however, the LUMS approach can do this and can cater for unexpected idleness between periodic releases by relaxing the bounding method to allow jobs to be 'pulled' from the pool, not only if workload limits are satisfied, but if the supervisor wants to Force Release a job. The difference between this and Workload Balancing is that one relies on quantifying the impact of under-loading and overloading and the other leaves this to the experience and preference of the supervisor, arguably a more realistic solution in a practical situation. Thus, the current LUMS 'Workload Control' characteristic, as defined by Bergamaschi *et al.* (1997), is described in Table 4.3 as having an upper bound with a non-enforced lower bound. This re-classification is required in order to emphasise the subtlety that the lower bound is not enforced (as previously interpreted by Bergamaschi *et al.* 1997); it is only provided as guidance for the user. The non-enforced lower bound could perhaps be set equal to the periodic release interval in an attempt to avoid work centres starving unnecessarily between periodic releases or to avoid overuse of the Intermediate Pull Release option. This characteristic is thought to be of general relevance rather than linked to a specific type of production environment or particular issues for Company X.

4.4.5 LUMS Priority Dispatching

The use of WLC reduces the complexity of shop floor dispatching; as a result, the LUMS approach considers it sufficient to allow supervisors to determine the order in which the released subset of jobs are processed, based on their experience and informal ad-hoc approaches, or by using simple non due date based rules such as First-In-First-Out, a philosophy supported by, for example, Land & Gaalman (1998). Sabuncuoglu & Karapinar (1999) also support the LUMS approach in this manner by concluding that due date based release methods, as used in the LUMS approach, tend to improve the due date performance of non due date dispatching rules, for example, Shortest Processing Time and First-Come-First-Served. In addition, under the LUMS approach, altering priority changes the latest release date and individual operation completion dates of a job, reducing slack and hence increasing urgency. Prioritising jobs can also aid the release function and it is anticipated to assist supervisors in their informal shop floor planning and dispatching decisions. If the number of Hot jobs is too great, the time a normal job spends queuing will quickly escalate meaning that in theory it may never get processed, therefore management must set limits for the number of Hot jobs and hence Pool and Shop jobs.

However, there has been much research into more complex dispatching rules. For example, Missbauer (1997) argues that sequence dependent set up times should influence the structure of the sequencing rule at the detailed scheduling level, and highlights the importance of lot sizing rules (Missbauer 2002). Meanwhile, Enns & Prongue Costa (2002) suggest that giving bottleneck jobs dispatching priority improves performance for both bottleneck load and aggregate load oriented strategies, although variability increases. While it is important to acknowledge these alternatives, it is considered important to maintain simplicity in dispatching decisions, allowing them to remain decentralised and ad-hoc, one of the advantages a WLC concept can provide. As a result, no changes to this part of the methodology have been made since the Hendry & Kingsman (1991) paper, while shop floor dispatching is understandably not further considered in a classification of order review and release methods.

4.4.6 LUMS Backlog Length Parameter Setting

The use of rigid workload norms and parameters has been criticised in the literature, particularly in the light of difficulties in setting appropriate workload bounds and subsequently in implementing WLC in practice. Fry & Smith (1987) explain that in setting maximum inventory levels between work stations, supervisors should be consulted regarding how much inventory they need in order to ensure that work centres do not starve. Although the importance of expert opinion is acknowledged, the WLC research field can be criticised for offering few advancements on this in the proceeding years, notable exceptions include Perona & Portioli (1998) and Land (2004a). However, the problem of parameter setting is not isolated to WLC; estimates are required for most PPC techniques and hence, in many respects, this can be considered a common problem. For example, Material Requirements Planning (MRP) has previously been criticised for requiring accurate estimates of capacity, while CONWIP relies on accurate feedback data in order to regulate throughput (see Chapter 2).

As a result of the shortcomings of much of the WLC literature, Figure 4.4 provides a simple guide for practitioners implementing WLC, illustrating the relationship between the total backlog length and delivery lead time, the planned backlog length and material lead time and the released backlog length and SFTT.

When setting norms it is also worth considering the interaction between the different levels of the hierarchy. For example, the difference between the material lead time and the SFTT indicates how long a job may spend in the pool.

Work centre RBL limits can all be set equally or determined individually. There may be advantages to be gained from setting some limits higher than others; for example, resources that feed the bottleneck work centre(s) could be allowed to have higher workloads to ensure that the bottleneck does not starve. However, a great deal depends on the individual situation, the objectives of the company and the skill and experience of managers. It may be necessary to run simulations or use ad-hoc trial and error to aid this process.

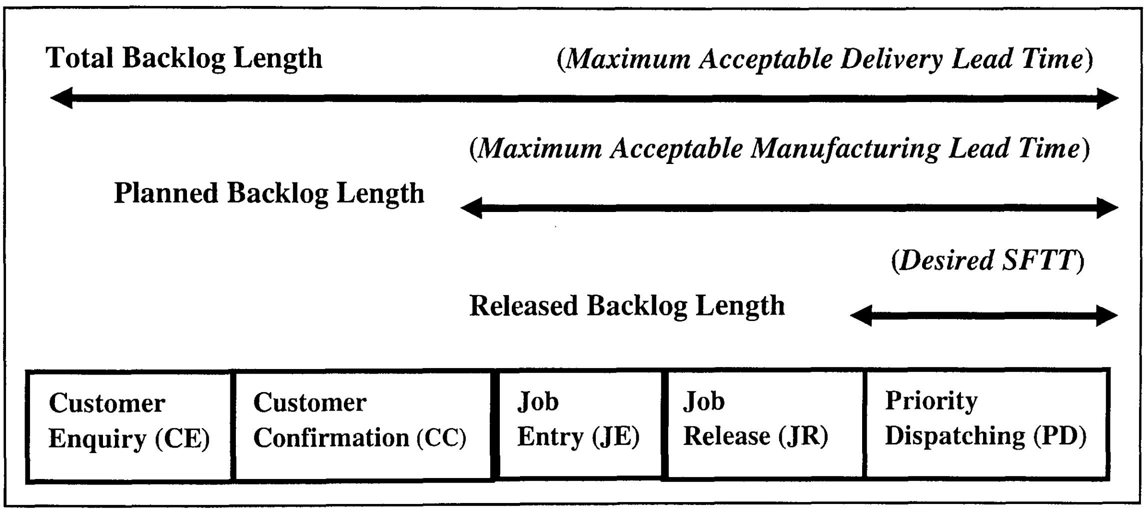


Figure 4.4: Relationship Between Backlog Lengths and Lead Times

The planning horizon over which jobs are considered must also be determined. It is assumed that the customer will require a potential job as soon as possible, and the job would therefore correspond to the current planning period, a factor to consider when setting the length of the period. However, some orders may have fixed delivery dates for far into the future; this may be particularly true for Repeat Business Customisers. In such cases it is assumed that few jobs will have been accepted for this time period and that this delivery date can be achieved. It is important to consider and acknowledge such jobs in order to see beyond the current planning horizon and increase schedule visibility, planning material and capacity requirements in advance. Developments such as the inclusion of the strike rate enable the LUMS approach to consider the shop and pool load for time periods beyond the current planning horizon, perhaps a skill also requiring human interaction and foresight. This discussion highlights that schedule visibility has arguably increased (or is greater than was interpreted by Bergamaschi *et al.* 1997); however, it is acknowledged that further improvement may be required. This further explains why it is claimed in Table 4.3 that the schedule visibility in the current LUMS approach is considered to have characteristics of both limited and extended schedule visibility. Among other measures, the delivery lead time analysis of Company X in Chapter 6 will prove valuable when setting norms for the company in the future.

4.5 CONCLUSION

This chapter has highlighted that there is a wealth of alternative characteristics within the various WLC systems presented in the literature. In particular, at the job release level there are many alternative measures of indirect load and of workload bounding, some of which could be considered more sophisticated than the methods used in the existing LUMS approach. It is argued that these developments should not be incorporated into the design of the LUMS approach at present, as it is not yet clear that simpler methods work less well in practice or that the alternative methods provide generic improvements. Given that many managers prefer simplicity, it is suggested that it is better to first carry out empirical research to validate simulation results of the

LUMS approach. For example, the probabilistic approach used to measure indirect load has already been demonstrated to work, as documented by Bechte (1988 and 1994) and by Wiendahl (1995), arguably suggesting that other forms of WLC are in more need of empirical research. In addition, although aggregate load methods have been criticised, it is unknown what further benefits the additional control provided by the LUMS approach at the customer enquiry stage will have on performance in practice.

As configuration complexity increases, the validity of incorporating ideas from the literature into the more simplistic aggregate load model described increases, and may benefit practical implementation, requiring a further reclassification. For example, the presence of bottlenecks would increase bottleneck load oriented release applicability. This evaluation has been an important stage, acting as a precursor, to the conceptual refinement / development process. It is important for researchers and practitioners to be aware of the WLC contingency options. As a result, progressive development of the LUMS approach may lead to the incorporation of some of the techniques reviewed in this chapter.

Chapter 2 confirmed the applicability of WLC to the MTO industry; this chapter has narrowed the focus further upon the LUMS approach to WLC. It is concluded that the LUMS approach remains a key approach to explore through empirical research. Therefore it is this approach to Workload Control that is developed into a decision support system, as described in the following chapter.

CHAPTER 5:
A DECISION SUPPORT SYSTEM (DSS) FOR WORKLOAD CONTROL (WLC)

5.1 OVERVIEW OF DECISION SUPPORT SYSTEMS

Before describing details of the WLC methodology developed in this thesis, the chapter begins by explaining the purpose of a Decision Support System (DSS). The intention of this opening discussion is not to provide a full review of the DSS literature, but to look at how researchers define information systems while highlighting a number of key issues that it is important to consider when structuring a DSS. In an industry as fast moving as the information technology market, it is particularly important to examine some of the contemporary literature in order to determine current trends and technological capabilities. For a description of the origins of the concept of decision support, see, for example, Keen & Scott Morton (1978). Beginning in Section 5.3, the chapter describes the DSS developed during this project. This systems development process has contributed significantly to the refinement of the WLC methodology underpinning the program.

5.1.1 Defining a Decision Support System

There are many textbook definitions of a DSS (see, for example, Keen & Scott Morton 1978; Sprague & Carlson 1982; Freyenfeld 1984; O'Brien 1994; Turban & Aronson 2001; Laudon & Laudon 2002); however, it is also acknowledged that there has been a lack of agreement over an acceptable definition of what constitutes a DSS, its characteristics and components (see, for example, Er 1988; Pearson & Shim 1995). Definitions of decision support systems seem to have evolved as the technology that the systems are founded upon becomes more powerful. In general, a DSS can be seen as a particular type of an Information Processing System (IPS). Laudon & Laudon (2002) describe six types of IPS: Executive Support Systems (ESS); Decision Support Systems (DSS); Management Information Systems (MIS); Knowledge Work Systems (KWS); Office Systems (OS) and Transaction Processing Systems (TPS). The authors describe how a DSS can help to make decisions that are unique, rapidly changing, and not easily specified in advance. A DSS tends to use internal information from TPS and MIS, but can also incorporate information from external sources. A DSS can analyse large amounts of data, creating a form easily interpreted by decision makers. The authors give examples of DSS, such as flight scheduling, supply chain management, customer relationship management, and group DSS.

In general, Decision Support Systems are computer technology solutions that can be used to support complex decision-making and problem solving (Shim *et al.* 2002). A computer system can be developed to deal with the structured portion of a DSS problem, but the judgement of the decision maker is utilised on the unstructured part, hence constituting a human-machine problem solving system (Gorry & Scott Morton 1971). Klein & Methlie (1990) define Decision Support Systems as computer information systems that provide information in a given domain of application by means of analytical decision models and access to databases, in order to support a decision maker in making decisions effectively in complex and ill structured (non-programmable) tasks. A DSS usually consists of the following subsystems: data management, model management, knowledge subsystem and user interface (see De Souza 1995; Turban 1995). A DSS can help to provide faster decision-making based on more complete information, with improved accuracy and efficiency. For further details, Finlay & Forghani (1998) present a review of the classifications of Decision Support Systems.

In addition to IPS, Laudon & Laudon (2002) also explain that businesses are interested in Expert Systems (ES), considered Artificial Intelligence (AI). In other words, programs that are built to 'think'. A DSS assists a human operator in making decisions whilst an expert system typically replicates the actions of a human advisor. Expert systems are not subject to fatigue or worry, they can do jobs that do not satisfy humans and they can store large amounts of information. However, the authors point out that expert systems lack the breadth of knowledge and the understanding of the fundamental principles of a human expert. For a further discussion of expert systems, see, for example, Bidgoli (1989) and Klein & Methlie (1990).

As will be demonstrated, the system developed in this thesis is intended to support and assist in improving the decisions made by the operations manager; the system does not make the decisions for the user. The user can override any of the suggestions made by the system using expert knowledge and, for example, must choose the jobs to release to the shop floor, perhaps taking advantage of foresight (extending schedule visibility) that the system could not fully possess in isolation. However, at the same time, the system supports this decision by suggesting the order the jobs should be released in and by demonstrating the effect the jobs would have on the shop floor. Hence, the complexities and degree of uncertainty involved in the decisions mean that the system can be most appropriately classified as a Decision Support System.

Some researchers have broken down definitions of decision support systems into sub-categories. For example, De Souza (1995) explains how a DSS can be classified based on implications for the outcome of the DSS (see Alter 1980), decision situations where the DSS applies (see Meador *et al.* 1984) and in relation to the user of the DSS (see Turban 1995). Through questionnaire analysis, Pearson & Shim (1995) were able to encapsulate a number of these issues, classifying types of DSS into five categories. The five types of DSS differ with regard to, for example, the management and decision levels involved, database interaction, problem definition, number of users supported and the level of expertise required from the user. The authors conclude that the results show that distinct decision support system structures and unique combinations of environmental factors exist for the five structures.

The DSS developed in this chapter demonstrates qualities associated with a number of these types of DSS; hence it is not surprising that the definitions of a DSS have struggled to converge. For example, the DSS interacts (in a restricted manner) with an existing database, supports semi-structured problems and supports the decisions of a range of management levels. It is therefore clear from this small sample of literature that there are many ways to categorise the WLC system that is developed in this chapter. However, in general the DSS can be described as containing the following characteristics:

(1) The ability to support decisions that will be made on a regular basis but where, given the customised nature of jobs and variability of the job shop, each decision will be different.

(2) The capability to make some decisions for the user, therefore including elements of artificial intelligence in order to reduce user input requirements. However, ultimately the user maintains control and can intervene and interact at any stage.

(3) The ability to simplify and speed up decision making processes at a number of decision levels, including procedures involving the estimator, operations manager and supervisor (therefore potentially incorporating multiple users / experienced operatives).

5.2 DEVELOPMENT OF A DSS

Alavi & Joachimsthaler (1992) explain that although the number of decision support systems used in practice has grown, the expected benefits of the systems are frequently unrealised, and the overall picture regarding the most appropriate development route for decision support systems remains unclear. Hence, it is important to structure the design, programming and implementation process for each DSS in order to achieve the intended results. In many ways this remains a unique process, although describing this development stage will be of benefit to future research in the field of WLC. Laudon & Laudon (2002) provide a basic introduction to Information Systems design, presenting the traditional methodology of systems development in formal stages and milestones, as illustrated in Figure 5.1 below. In one sense, the opening chapters of the thesis have described the first three stages of this process, for example, Project Definition (Chapter 1), Existing Systems Study (Chapter

2) and Concept Design (beginning with Chapter 4). This chapter describes the functionality of the system incorporated at the 'Programming' stage, while further contributing to conceptual design / refinement.

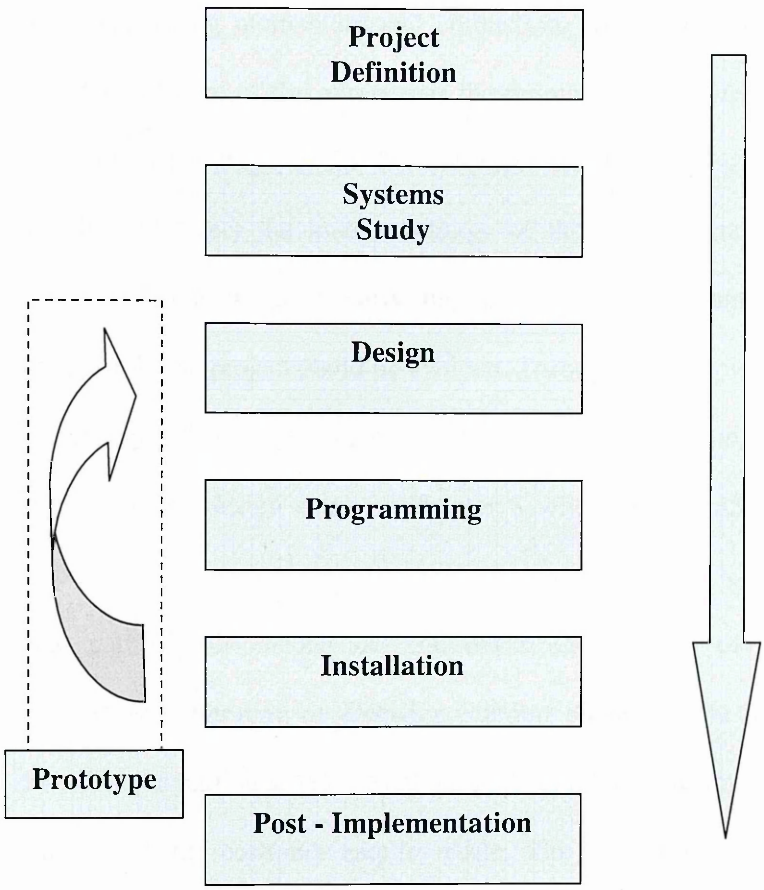


Figure 5.1: Development Stages of a Decision Support System

Although this may be considered as part of programming and installation, it is important to acknowledge the role of prototyping. For example, a prototype may be installed, and then in response to the initial reaction of the users, the project may have to revisit the design and programming stages. In addition, during such a prototype phase, further important factors currently missing from the model may become evident, thus creating a more rigorous approach to conceptual development. The arrow on the left of the diagram has been added to illustrate this important stage.

In this project, screen shots and a functional prototype were presented to Company X. This proved to be a valuable exercise, and led to further additions to tailor the generic DSS to the needs and data availability of the individual company. This process also allowed the user to see the benefits of the system before implementation, maintaining momentum and enthusiasm for the project within the company. The main outcome of this phase was the requirement for greater schedule flexibility at the job entry stage of the DSS. Hence, these additions were largely superficial and did not affect the inner workings of the WLC system. However, discovering these requirements at an early step in the process meant that greater delays at a later point in the project could be avoided. Through part implementation of the DSS, this thesis arguably covers the prototype stage a second time, leading to a further re-visitation of the design stage in Chapter 8 when the LUMS approach is applied to Company X.

The first part of this chapter has introduced the concept of Information Processing Systems, concentrating on Decision Support Systems. The remainder of this chapter describes the particular features of the DSS developed during this research project, beginning with the customer enquiry stage. The DSS aims to provide the functionality particular to the LUMS approach, whilst providing a software package that meets the planning needs of MTO companies. It was also important to maintain an element of simplicity to ensure that decisions could be made quickly, given the wide range of roles and responsibilities incorporated within the job design of managers of SME's. The DSS aims to encompass the four planning and control levels, in order to provide a fully integrated WLC concept across a hierarchy of backlogs in a single software package. This is achieved by aiding decision making at the Customer

Enquiry Management, Job Entry and Job Release stages, and allowing simple Priority Dispatching at the decentralised shop floor level.

5.3 FEATURES OF THE PROPOSED DECISION SUPPORT SYSTEM

An existing computer system from previous research involving the LUMS approach is now considered too old in terms of both software and conceptual development to be of relevance to modern day MTO companies. Hence, the DSS has been developed from a 'blank canvas' using Borland Delphi 8.0 (Object Pascal). Programming tools such as Delphi, allow the researcher / developer to build user-friendly packages with interfaces that mirror those of any commonly used Windows package. Such superficial factors are considered likely to increase user confidence in the decision-making suggestions the package provides. The DSS encourages the user to think more carefully about delivery dates and the way production is planned and controlled, and increases awareness regarding the importance of delivery date adherence. A number of the key features of the DSS are described individually in the following subsections. However, although these are described individually, it will become apparent that in such an integrated approach, each planning level is affected by decisions made at other levels of the hierarchy. In addition, insights from initial case study company visits (as described in Sections 6.1 and 6.2) helped to focus and structure this programming and design process to provide a system that will not only work in theory, but is feasible enough to be effective in practice.

Also note that previous versions of the LUMS approach have used weekly estimates of workloads and capacities. Due to the short delivery lead times offered by modern day MTO companies, it is necessary to plan workload and capacity requirements on a daily basis. Hence, the current manufacturing climate has played a major role in the development of the DSS.

Before describing the DSS in detail, it is important to have a clear understanding of the concept of a Planning Horizon. The Planning Horizon is the immediate schedule visibility of the planning and control system, given here in terms of a set number of days. The horizon constantly readjusts from day to day so that the user is always at the start of the horizon and can always see the same length of time into the future. For example, if the majority of jobs are started three weeks (21 days) before the delivery date, the user will need to see and plan at least this far into the immediate future. In such a case, the DSS would constantly update the planning horizon each day so that the current date is always 'Day 1' of the current planning period and the user can see workload and capacity details over the next 21 days. When determining the size of the planning horizon it is important to determine competitive delivery lead times for the largest jobs that the company anticipate producing.

By developing the DSS from the start, every ingredient of a WLC concept has to be scrutinised and manually programmed. This process has led to extensive refinements to the methodology and changes to the assumptions underlying the LUMS approach. Before describing the DSS, the typical decision making structure / process for a job is summarised in a flow diagram, see Figure 5.2 below.

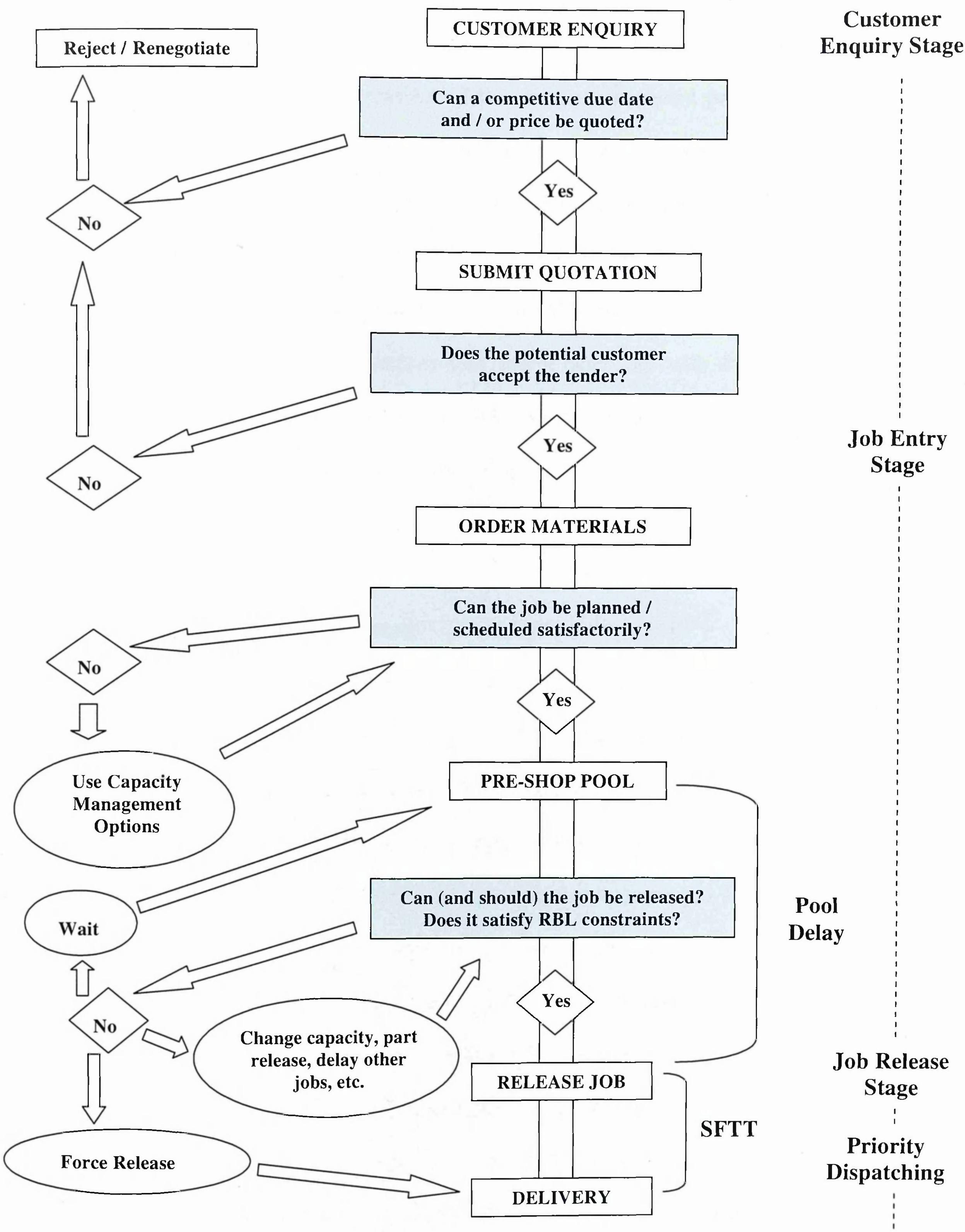


Figure 5.2: A Typical Workload Control Decision Making Process

5.3.1 The Customer Enquiry Stage

Providing control at the customer enquiry stage can help the user to directly consider the current workloads and capacities of the shop, the expected pool delay and the anticipated queuing times at shop floor resources when quoting delivery dates. However, at the same time, it is important that this high level planning is not performed in a precise manner, as there is a great deal of uncertainty and potential change between the time a quotation is made and the time that a prospective customer responds. For example, the company may accept other jobs with shorter lead times requiring a change to the current planned schedule of the shop. Hence, at this stage the DSS must maintain control of the whole shop whilst remaining flexible with regards to when the work is carried out.

5.3.2 Total Backlog Management

The DSS incorporates a simplified strike rate percentage at the customer enquiry stage in the determination of the total backlog of the shop in order for delivery date determinations to reflect the anticipated future load of the shop, as described in the re-evaluation of the LUMS approach in Chapter 4. Hence, in addition to the aggregate workload of confirmed jobs, the workload of an unconfirmed job multiplied by the strike rate of the company contributes to the total backlog. The DSS incorporates this in an attempt to avoid the company bidding for more work than it can process in time to meet delivery dates, given current workload and capacity constraints.

The total backlog can be determined for any day during the current planning horizon by considering the delivery dates of the current mix of confirmed and unconfirmed jobs, and the impact these jobs will have on the total backlog on a given day. The total backlog of the shop on a given day should not include jobs that are expected to be completed prior to that date. For example, a job with a delivery date of 20th April will affect the backlog length of the 19th April; however by the 21st April it is expected that the job will have been completed, and hence the job will not contribute to the total backlog of the shop on this date. As a result, the backlog of the shop should 'step down' towards the end of the planning period (see also Hendry & Kingsman 1993); the DSS also reflects this stepping down procedure in the backlog length limits, as shown in Figure 5.3. The figure shows a planning horizon of 'p' days and a maximum backlog length of ten days (simplified example). At 'p – 10' days, the limit begins to step down by a day at a time until the end of the planning horizon. This is provided to ensure throughput times remain competitive, so that the resources are not constantly fully loaded in future time periods, and the requirements of future jobs can be accommodated, thus maintaining medium term flexibility for the shop.

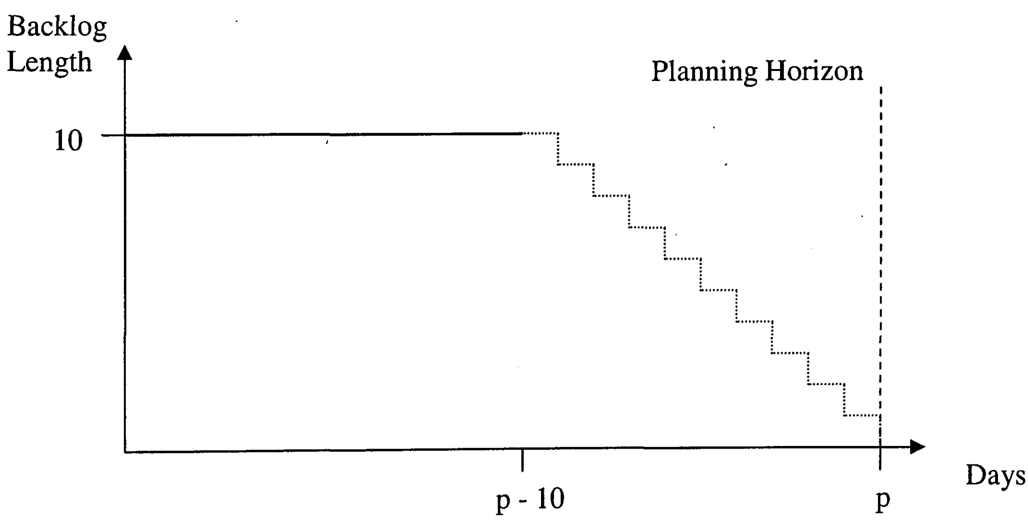


Figure 5.3: Depreciation of the Backlog Length Over Time

As a result, the total backlog of the shop on day '*d*' (TB_d) can be calculated using equations (1) and (2) below, where the jobs used in the calculation have a delivery date greater than or equal to the current date (*d*). Previous development of the

LUMS approach presented an instantaneous total backlog. While this is also incorporated into the design of this DSS, by also looking at the distributions of workloads and delivery dates through time, the approach adds a time phased element to the total backlog and extends schedule visibility beyond that of previous editions of the LUMS approach.

$$\mathrm{TWC}_i = \sum_{w=1}^{W} [(\mathrm{Q}_i \times \mathrm{PT}_{iw}) + \mathrm{ST}_{iw}] \qquad (1)$$

where,

TWC_i = Total work content of job i.

Q_i = Quantity of job i.

PT_{iw} = Unit Processing time for job i at machine / work centre w.

ST_{iw} = Set up time for job i at machine / work centre w.

$$\mathrm{TB}_d = \sum_{i=1}^{I} [\mathrm{SR} \times \mathrm{TWC}_i] + \sum_{j=1}^{J} \mathrm{TWC}_j \qquad (2)$$

where,

SR = Overall strike rate of the company.

TWC_i = Total work content of unconfirmed job i with DD greater than or equal to d.

TWC_j = Total work content of confirmed job j with DD greater than or equal to d (calculated as in (1) above).

Using the total backlog of the shop, the DSS calculates the total backlog length for each day of the current planning horizon, 'stepping down' towards the end of the planning period. The backlog lengths are determined by the workload and the capacity, in other words the input and output rates of shop floor resources. The total backlog length on a given day is calculated by determining the number of days it will take for the shop to complete the current mix of jobs, by incrementing the total backlog length by a day at a time and reducing the total backlog by the capacity of the shop on that particular day. In its simplest form, a backlog of 100 hours and a constant daily capacity of 10 hours would represent a backlog length of 10 days. It is considered adequate at this top level planning stage to determine this length in total days, and not at further discrete time intervals (such as, 'part-days' or hours). The DSS calculates the total backlog length over time for the shop as a whole, and individual resources, where possible. However, it may be undesirable to determine the backlogs of machines, as delaying the final allocation decision until a later stage maintains routing flexibility. There may also be some uncertainty at this stage as to exactly which machines will be required.

Consider the following small example:

(1) A company has a strike rate of 20%.

(2) The total work content of all unconfirmed jobs (with delivery dates greater than or equal to day *d*) is equal to 2000 hours.

(3) The total work content of all confirmed jobs (with delivery dates greater than or equal to day *d*) is equal to 800 hours.

(4) The total backlog of the shop on day *d* is therefore: [20% x 2000] + 800

= 1200 hours.

(5) Therefore, the total backlog length on day *d* can be found to be equal to 14 days, see Table 5.1 below.

Opening Total Backlog (Hours)	Daily Shop Capacity (Hours)	Closing Total Backlog (Hours)	Total Backlog Length (Days)
1200	100	1100	1
1100	120	980	2
980	110	870	3
870	90	780	4
780	80	700	5
700	30	670	6
670	10	660	7
660	100	560	8
560	120	440	9
440	110	330	10
330	100	230	11
230	100	130	12
130	80	50	13
50	50	0	14

Table 5.1 Total Backlog Length Example

5.3.3 Determining Delivery Dates

The advised delivery date that the DSS provides to the user at the customer enquiry stage for a given job is based on the anticipated customer confirmation time and the expected delivery lead time for the job. The customer confirmation time requires flexibility and expert knowledge, as it is likely that customers, with differing agendas, and at different stages of production and planning cycles will take different lengths of time over choosing a supplier. For example, if an estimator knows the job is urgent, it may be reasonable to assume that the customer will respond almost immediately.

Once this earliest advised delivery date has been found (as described later in this section), the DSS considers the capacity of the shop. If adding the whole of the total work content of the job to the total backlog of the shop does not exceed the maximum limits then the delivery date can be quoted, and the strike rate percentage incorporated in the TBL. If the delivery date is considered unsuitable, the delivery date is incremented by a day at a time until the TBL remains within limits and a suitable delivery date is found. If the user considers the delivery date to be unacceptable / uncompetitive, the user can use the capacity management module of the DSS to change the capacity of certain constraint resources on appropriate dates, thus increasing the total daily capacity and reducing the TBL of the shop. Hence, the system goes beyond rough-cut capacity planning at the customer enquiry stage by providing flexible input-output control and a capacity management support tool (see Section 5.3.10 for further details). This facility is available throughout the hierarchy of backlogs, and changing the capacity will impact the lower planning levels. Hence, this must be performed with caution and an understanding of the effect on the planned and released backlog lengths. In addition, pool delay and queuing time constants determined in theory will only be realised in practice if the job release function is used as intended (or as described below). Once the delivery date has been determined, the DSS can include the workload of a job in the backlog of the company during the appropriate interval of the planning horizon. If the customer accepts the offer, the delivery date can be rechecked to ensure that this can be met.

As an example, the anticipated Delivery Lead Time for job i (DLT_i), can be calculated using the formula in (3) below. This formula provides a significant refinement to the LUMS approach, by allowing the user to vary the expected queuing times for each shop floor resource, rather than having a single norm used for all resources; this is more likely to mirror the characteristics of real life job shop queues and increases the level of flexibility available to the user.

$$\mathrm{DLT}_i = \mathrm{MatLT}_i + \mathrm{PD}_p + \mathrm{TWC}_i + \sum_{w=1}^{W} \mathrm{QT}_{pw} \qquad (3)$$

where,

MatLT_i = Expected material lead time for job *i*.

PD_p = Expected pool delay constant for a job of priority level '*p*'.

TWC_i = Total work content of job *i*.

QT_{pw} = Expected queuing time constant for a job of priority level '*p*' at work centre *w*. Only resources that the job will visit are considered in the calculation.

Hence, provided that the maximum total backlog length of the shop will not be exceeded, the advised minimum Delivery Date to quote at the customer enquiry stage for job *i* (DD_i) is calculated using the formula in (4) below:

$$\text{DD}_i = \text{ED}_i + \text{CCT}_i + \text{DLT}_i \qquad (4)$$

where,

ED_i = Enquiry date for job *i*.

CCT_i = Estimate of customer confirmation time for job *i*.

Formula (3) and (4) also illustrate that, by changing the priority of a job, by varying the expected material arrival date and the customer confirmation time, the user can experiment with different delivery dates in this module of the DSS when negotiating with potential customers.

Figure 5.4, below, shows the customer enquiry management module of the DSS, where the unconfirmed jobs in the list are sorted according to the earliest delivery date determined by the estimator or required by the customer. The advised delivery date proposed by the DSS is shown in the job details part of the module. Note that although many of the company names used in the screenshots are real, the data is fictional.

where,

TWC = Total Work Content (Hours)

NOP = Number of Operations

MLT = Anticipated Material Lead Time (Days)

CCT = Anticipated Customer Confirmation Time (Days)

DLT = Delivery Lead Time (Days)

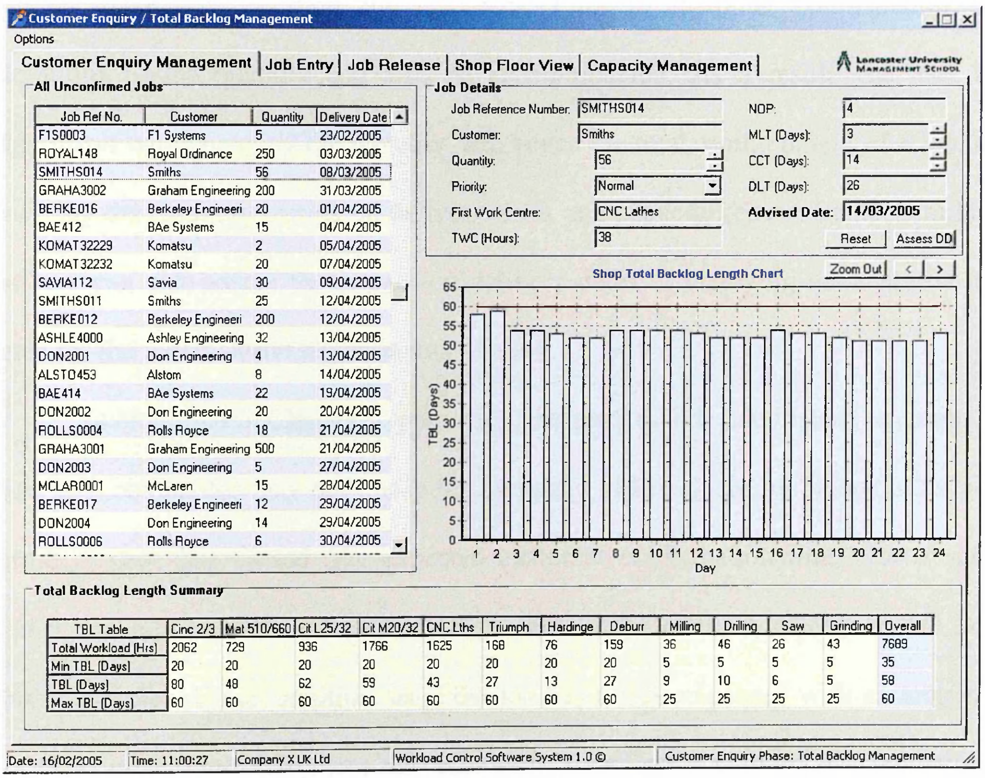


Figure 5.4: Customer Enquiry Management Module

Amongst other details, the form shows the expected delivery lead time for each job, the advised earliest possible delivery date (see top right of Figure 5.4), and displays all the jobs for which quotations are being produced or that are currently under consideration by prospective customers (see left hand table in Figure 5.4). Together with the delivery lead time and advised earliest delivery date, the time phased Total Backlog chart provides the user with a visual aid for delivery date determinations and negotiations with customers by indicating the distribution of workloads through time. The chart shows days 1 to 24 in the planning horizon. However, the user can also view any other part or the whole of the horizon, and by positioning the cursor over each bar / day, can find the corresponding calendar dates represented by the day numbers in the horizon. The summary table in the customer enquiry module (see bottom of Figure 5.4) indicates the instantaneous (or immediate) backlog details of the shop and resources. Prior to customer confirmation, any alterations to the quantity can also be accommodated. As a result, the user can experiment with changing the quantity, and hence the total work content of a job, and assessing the resulting impact on delivery dates and capacity requirements. Similarly, the user can also assess the impact on delivery dates of changing the material lead times for the raw material requirements of a job.

As identified in Chapter 4, potential customers that decide instead to award the order to a competitor may not notify the company of this decision. Hence, after a set period of time has passed (the expected customer confirmation time plus a safety factor), the job can be removed from the total backlog of the company by the DSS. This is a reasonable assumption, as if the job has not been placed with a competitor and the company return to place the order some time later it is likely that the delivery date would have to be renegotiated due to the lengthy customer confirmation time, while the availability of raw materials may also mean that the price has to be re-evaluated.

5.3.4 The Job Entry Stage

The job entry stage is the point at which the customer returns to the supplier with a response to the quotation. Jobs accepted at the job entry stage are intended to provide a stable level of work for shop floor resources, with delivery dates staggered throughout the planning period. If the customer has accepted the quotation, then the company can decide whether to go ahead with production or reject the job after all. If the job is accepted by both parties, the company can order any necessary materials required for the job.

The job entry stage of some jobs may be immediately after the customer enquiry stage; while for other jobs it may be some weeks later. Therefore, if the customer accepts the quotation, it may also be necessary to re-evaluate the delivery date to ensure that the company can still achieve this before the remaining work content of the job is reintegrated into the TBL and added to the PBL. For example, if the customer confirmation delay was much larger than anticipated, the delivery date may be unrealistic and in need of renegotiation. In addition, if the company has accepted a number of unanticipated urgent jobs from an important customer, there may be insufficient capacity available to meet the delivery date of the job. Through making use of the accompanying customer enquiry module, it is anticipated that fewer changes would be suggested at this stage, while small changes could also be absorbed without affecting the delivery date.

At the job entry level it is important to plan and control the job at a more detailed level in order to ensure that capacity can be made available at corresponding resources at the right time. As a result, in addition to the total backlog, the DSS considers the time phased (and instantaneous) planned backlog of the shop and resources.

5.3.5 Planned Backlog Management

The DSS attempts to schedule jobs using daily capacities and workloads of shop floor resources by applying a backwards scheduling method, as described in the following subsection. In addition, the total work content of the job can be added to the planned backlog of corresponding resources and the shop as a whole between the job entry date and the delivery date. The planned backlog of the shop for a given day d (PB_d) contains a subset of the total backlog of the shop, as it only considers the total work content of accepted jobs with a delivery date equal to or beyond the current backlog day, as shown in (5) below.

$$PB_d = \sum_{i=1}^{I} TWC_i \tag{5}$$

where,

TWC_i = Total work content of confirmed job i (with a delivery date equal to or beyond day d).

The DSS also calculates and regulates the planned backlog lengths for individual resources through time, where the Planned Backlog of machine / work centre w on day d (PB_{wd}) is given in (6) below:

$$PB_{wd} = \sum_{i=1}^{I} [\,(Q_i \times PT_{iw}) + ST_{iw}\,] \tag{6}$$

where,

i = A confirmed job with a corresponding OCD equal to or beyond day d.

Q_i = Quantity of confirmed job i

PT_{iw} = Unit Processing time for confirmed job i at machine / work centre w.

ST_{iw} = Set up time for confirmed job i at machine / work centre w.

Using the planned backlogs of a resource, the DSS can calculate the planned backlog lengths for individual resources and the shop as a whole. Although these are calculated for the shop as a whole, the lower the level in the planning hierarchy, the greater the importance of considering the impact of jobs on individual machines or groups of machines. These values are calculated in the same way as the total backlog; however, in the case of an individual resource, capacity relates to the daily capacity of individual machines, and not the collective total daily capacity of the shop.

If the job cannot be scheduled effectively or the maximum planned backlog lengths of the shop or a resource that the job must visit will be exceeded, the job is flagged and the user must consider the capacity management options available in order to reduce the backlog length and provide additional capacity at the appropriate resources so that the job can be appropriately scheduled. The user can also consider the option of rejecting the job or renegotiating the delivery date if additional capacity (an increase in the output rate) cannot be provided for the job. If a job is accepted, the DSS also adds the remaining proportion of the job to the total backlog of the shop. Alternatively, if the job is rejected, the DSS reduces the total backlog accordingly.

5.3.6 Backwards Scheduling Procedure

When the user runs the DSS, all newly accepted jobs are scheduled based on job routing information, daily capacity constraints and current daily workload constraints, starting with the job(s) with the earliest delivery date. The backwards scheduling procedure produces a set of operation completion dates for each job, and hence a latest release date, based on the delivery date, and from comparing daily capacity with currently planned daily and total workloads. An earliest release date is also set. This is the date on which the job first becomes eligible for release to the shop floor, and is usually equal to the material arrival date.

From the delivery date, working backwards, the final destination of the job is first considered, and the current date is reduced by a day at a time until sufficient available capacity has been found for the job (perhaps accumulated over a number of days), the process then moves onto the penultimate resource beginning with the next day in the shop calendar. If the job can be scheduled successfully, with a latest release date greater than or equal to the current date and the ERD, the operation completion dates of the job are set. The LRD generated by the DSS is the latest date by which the job can be released under the current shop conditions if it is going to meet the delivery date. If the company is able to provide details of shift patterns, the system is also able to automatically account for reduced capacities at weekends in the scheduling procedure, where available capacity is likely to be relatively low.

If a job cannot be scheduled, the job is highlighted and the user is advised to change the capacity of certain resources before rescheduling the job. The planned input and output of workloads over time can be studied to ensure that capacity requirements can be accommodated. The user can also choose to change the OCD's manually to provide greater flexibility, or choose to reschedule one or all jobs having made appropriate capacity adjustments. This maintains a degree of versatility, essential for realistic job shop scheduling. At this planning level and the subsequent job release stage, the user can also assess the impact of changing the priority of a job on operation completion dates and the latest release date from the pool.

To demonstrate the backward scheduling rule applied at the planned backlog level, consider the following example for 'Job A' (as illustrated in Figure 5.5):

(1) Job A has a delivery date of 10^{th} December 2004.

(2) The current date is 10^{th} November 2004.

(3) Job A visits four resources (R1, R2, R3, and R4).

(4) The routing and work content of Job A is as follows: R1 (10 hours), R2 (12 hours), R3 (5 hours) and R4 (10 hours).

(5) Therefore, by backwards scheduling from the delivery date:

R4: 8 hours can be scheduled on 9^{th} December and the remaining 2 hours on 8^{th} December.

R3: 2 hours can be allocated on the 7^{th} of December, 2 hours on the 6^{th} of December and the final hour on the 4^{th} December.

R2: 6 hours can be scheduled on the 3^{rd} December and the remaining 6 hours on the 2^{nd} December.

R1: 5 hours can be scheduled on the 1^{st} December, 4 hours on the 30^{th} November and the remaining hour on the 29^{th} December.

(6) Therefore, in order to meet the delivery date, the latest release date of Job A is 29^{th} November 2004, and hence the job currently has a slack of 19 days in the pool.

Resource: R4

(Delivery Date)

OCD 4

Date	27/11	28/11	29/11	30/11	01/12	02/12	03/12	04/12	05/12	06/12	07/12	08/12	09/12	10/12
Capacity (Hours)	10	5	20	20	20	20	15	10	5	18	20	20	20	12
Workload (Hours)	10	5	20	20	16	12	10	9	5	16	18	10	12	12

Resource: R3

OCD 3

Date	27/11	28/11	29/11	30/11	01/12	02/12	03/12	04/12	05/12	06/12	07/12	08/12	09/12	10/12
Capacity (Hours)	5	0	16	16	16	16	8	5	0	16	20	20	16	10
Workload (Hours)	5	0	15	16	16	12	7	4	0	14	18	20	15	10

Resource: R2

OCD 2

Date	27/11	28/11	29/11	30/11	01/12	02/12	03/12	04/12	05/12	06/12	07/12	08/12	09/12	10/12
Capacity (Hours)	12	4	24	24	24	24	16	12	4	24	24	24	24	16
Workload (Hours)	10	4	18	20	20	18	10	12	3	16	14	12	10	8

Resource: R1

(LRD)

OCD 1

Date	27/11	28/11	29/11	30/11	01/12	02/12	03/12	04/12	05/12	06/12	07/12	08/12	09/12	10/12
Capacity (Hours)	12	0	26	26	26	26	24	12	0	26	18	18	26	20
Workload (Hours)	8	0	20	22	21	26	22	10	0	18	14	14	18	18

Figure 5.5: Example of Backwards Scheduling from the Delivery Date

This procedure provides a major conceptual change and simplification to the LUMS approach at the programming stage of the refinement process. Previous development of the LUMS approach, using weekly capacities and workloads, utilised queuing norms at the job entry level in conjunction with an overly complex algebraic method of calculating OCD's (see Hendry 1989). This is replaced by detailed backwards scheduling using a daily capacity and workload approach. This provides a new dimension to the approach and supplies additional functionality that can help the supervisor to ensure that delivery dates are achieved in practice. Although it is acknowledged that detailed scheduling in such a dynamic and ever changing job shop environment is unlikely to be strictly followed in practice, the schedule provides the user with a helpful tool to aid the main decision of job release. If the job is not processed on the specific date, it is likely that other jobs will be available and the machine in question will not be left idle. In addition, this adaptation means that queuing norms are only utilised at the customer enquiry stage, reducing the importance of accurately determining such parameters.

However, it is acknowledged that this is not a precise scheduling method, particularly if machines were to be grouped into work centres. Although the available capacity of a work centre may indicate that a job can be processed in time to meet a specific date, at the shop floor level this available capacity may consist of small pockets of time on different machines. However, in practice it is likely that management will want a job to run continuously on one machine in order to minimise set up times. Although programs can be devised to schedule jobs on individual machines to exact start and finish times during a day, discrete scheduling such as this is beyond the objectives of aggregate planning and release methods. This is not considered a feasible solution in the job shop where it may lead to continuous rescheduling and excess computation time (see, for example, Sotskov *et al.* 1997). It is considered sufficient to allow supervisors to perform the day to day sequencing and scheduling of workload requirements, a key advantage provided by a WLC concept.

The job entry module of the DSS is shown in Figure 5.6 below.

where,

MAD = (Anticipated) Material Arrival Date

ERD = Earliest Release Date

LRD = Latest Release Date

DD = Delivery Date

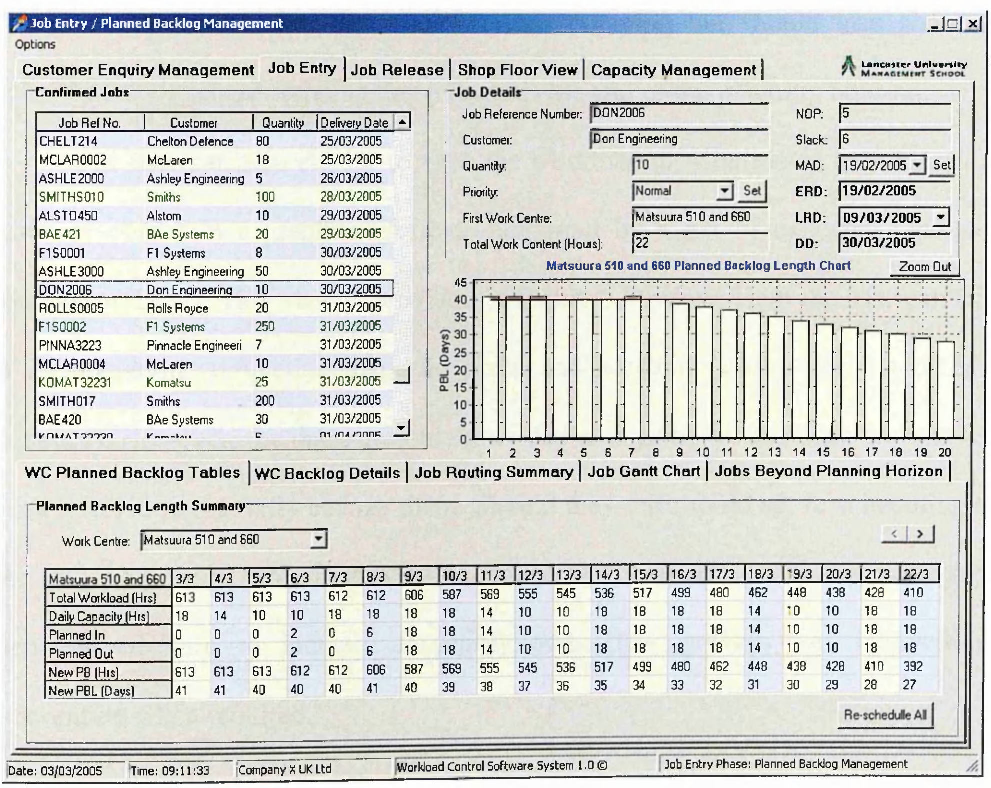


Figure 5.6: Job Entry Module with Planned Backlog Table

The form shows the planned backlog charts and tables for each shop floor resource in addition to a list of confirmed jobs for the current planning horizon (listed in order of earliest delivery date). In the upper half of the form the user can adjust job details, such as job priority and material arrival dates. In the lower half, the user can choose a number of different views by clicking on the various tabs. Figure 5.6 shows the planned backlog tables of each shop floor resource illustrating the planned input and output for the resource on each day. This can be used to determine where extra capacity is needed. The table shows the input and output rates over the first twenty days of the planning horizon, but the user can also scroll through the remaining planning period using the arrow buttons. Similarly, in the time phased PBL chart (and previously in the TBL chart of the customer enquiry stage module), the user can zoom in and view small intervals within the planning horizon, or zoom out to view the workload distribution over the whole period. Zooming out should also show the planned backlog length stepping down towards the end of the planning horizon.

The user can also choose to view the workload distribution of individual jobs across resources in a graphical format, supported by a list of expected Operation Completion Dates. This view is provided in Figure 5.7 below. Here the user can click on an operation completion date and make an alteration (whilst keeping dates in sequence). However, the dates are only provided as a guide for the user, and the user is not advised to regularly change them. Should they wish to do so, re-scheduling the jobs may be a more appropriate way to change job plans. However, the concept has been refined here to increase flexibility and allow greater user interaction / intervention when required.

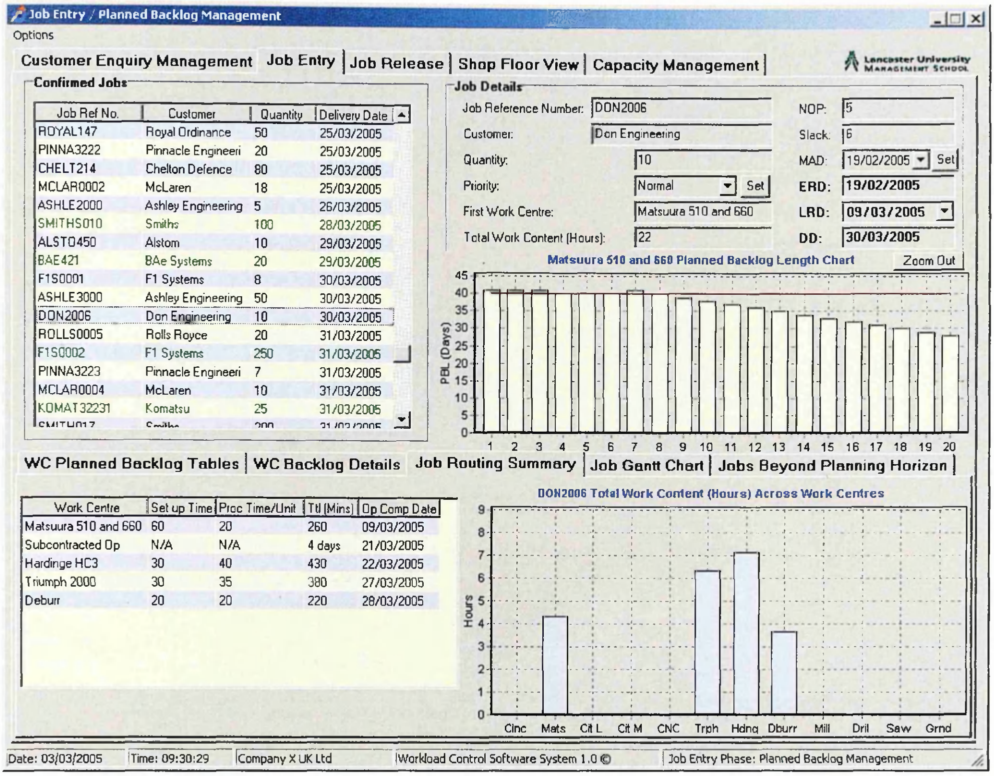


Figure 5.7: Job Entry Module and Job Workload Distribution

Similarly, the user can view the Gantt chart of any job, based on the expected operation completion dates of the job, as shown in Figure 5.8. This provides even greater guidance for the supervisor in a user-friendly format.

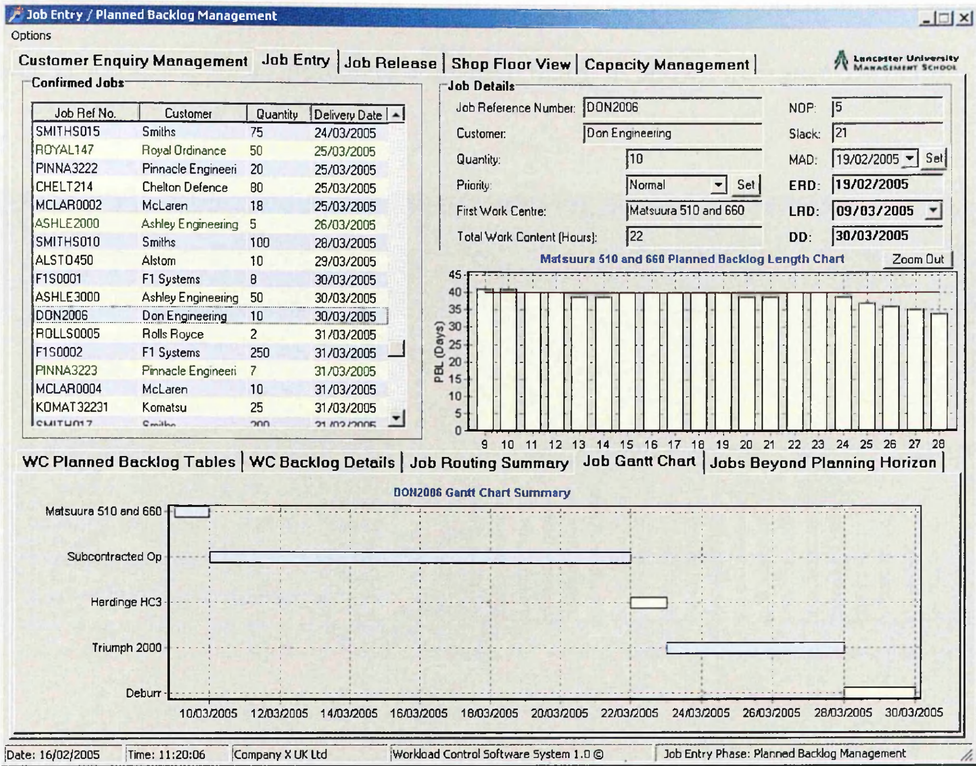


Figure 5.8: Job Entry Module and Job Gantt Chart

The job entry form also allows the user to view the planned queue at any resource on a given day or in a given week, based on expected operation completion dates. This is duplicated in the shop floor control module, but is provided here for user friendliness and because it utilises information calculated at the job entry level. If the operation completion date of the previous operation of a job (or the latest release date, if this is the first destination for a job) is prior to the chosen date and the operation completion date of the current operation is equal to or beyond the current date, the job will be displayed as part of the planned queue of a resource. This helps to regulate the levels of WIP by showing the user exactly what should be queuing at a resource in a given time period (daily or weekly) and which jobs are contributing to the input of a resource in the planned backlog table; this again gives the concept a greater practical focus over previous versions of the LUMS approach. Jobs are sorted in the planned queue according to their operation completion dates, as shown in Figure 5.9 below.

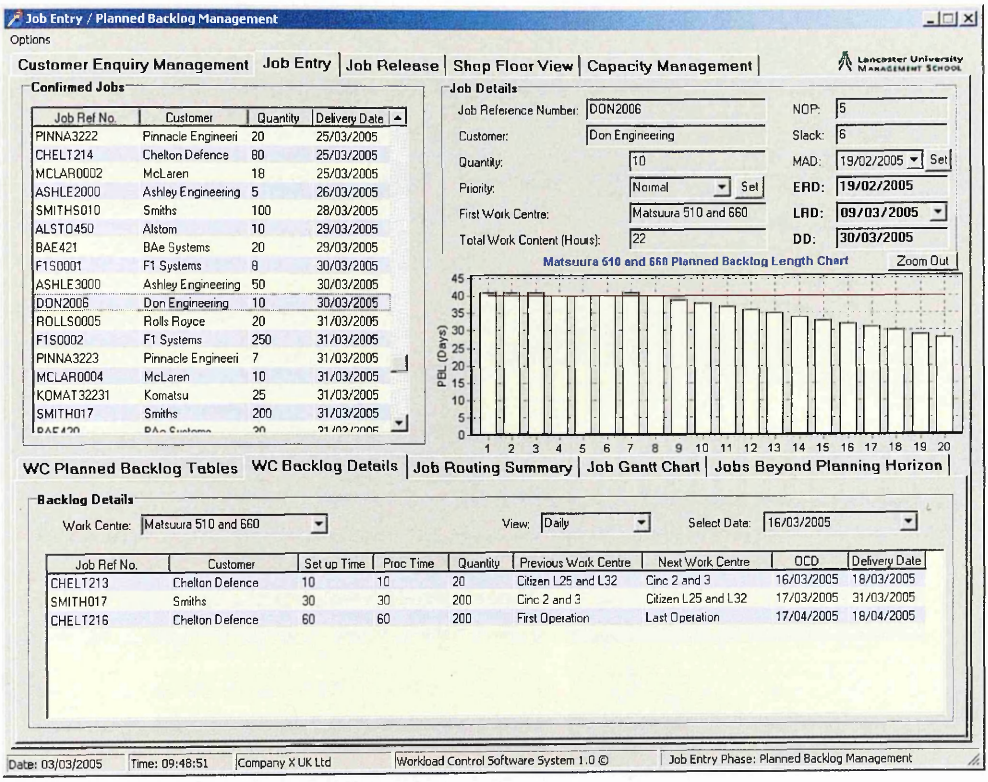


Figure 5.9: Job Entry Module and View of Planned Shop Floor Queue

Most of the jobs that a customer requests are likely to be for as soon as possible, and hence will fall into the current planning period. However, some may be for far into the future. Hence, the company does not need to plan production for such jobs at present. The company can also choose to accept these jobs with confidence as the accepted workload beyond the current planning horizon should be low. Alternatively, if the confirmed workload beyond the current planning horizon is large, the size of the planning period should be reviewed. Figure 5.10 demonstrates a form where the user can view jobs that are beyond the current planning period, thus improving scheduling visibility and foresight. When the delivery date of the job enters the planning horizon of the DSS, it can be added to the appropriate backlogs and scheduled for release, hence each job beyond the planning horizon is allocated a Schedule (or horizon) Entry Date (SED).

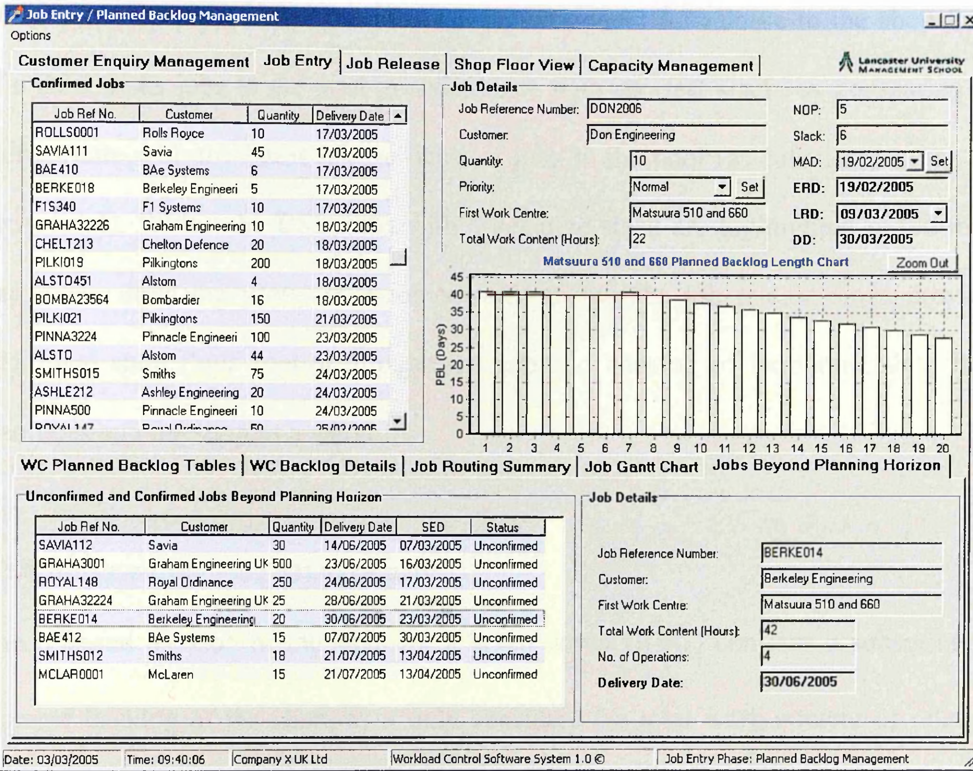


Figure 5.10: Job Entry Module and Jobs Currently Beyond Planning Horizon

The schedule entry date of job i (SED_i), with a delivery date beyond the current planning horizon, is calculated using the equation in (7) below. This is a further measure that has been added to the LUMS approach to increase schedule visibility and provision for jobs with long lead times.

$$SED_i = DD_i - PH \tag{7}$$

where,

DD_i = Delivery date of job i

PH = Length of the planning horizon (Days)

5.3.7 The Job Release Stage

When jobs have been accepted and materials made available, the DSS transfers them to the pre-shop pool, where the jobs can be considered for release to the shop floor. The DSS ranks jobs in the pool in accordance with shortest slack, by comparing the current date with the latest release dates of jobs in the pool (as calculated at the job entry level). Within the DSS, jobs with a negative slack are highlighted in red in an attempt to draw the users' attention towards them. The job release stage provides additional shop floor control through the released backlog of individual shop floor resources and the shop as a whole.

5.3.8 Released Backlog Management

The released backlog of the shop for a given day d (RB_d) contains a subset of the planned backlog of the shop, as it only considers the total work content of released jobs with a delivery date equal to or beyond the current backlog day (d), as shown in (8) below.

$$RB_d = \sum_{i=1}^{I} TWC_i \qquad (8)$$

where,

TWC_i = Total work content of job i with a delivery date equal to or beyond day d.

The Released Backlog of work centre (or machine) w on day d (RB_{wd}) is given in (9) below:

$$RB_{wd} = \sum_{i=1}^{I} [(Q_i \text{ x } PT_{iw}) + ST_{iw}] \qquad (9)$$

where,

i = A released job with a delivery date equal to or beyond day d.

Q_i = Quantity of confirmed job i.

PT_{iw} = Unit Processing time for confirmed job i at machine / work centre w.

ST_{iw} = Set up time for confirmed job i at machine / work centre w.

Using the released backlog values, the DSS calculates the released backlog lengths for individual resources and the shop as a whole. This is performed similarly to the planned backlog length, but with the released subset of the workload. In addition, due to the smaller time frames and the precision required at this more short term level, it is considered insufficient to calculate the RBL in whole days. Adding a job to the shop floor may result in a small contribution to the RBL of a shop floor resource, and so to accurately find the new RBL a more precise approach is required. Previous development of the LUMS approach involved calculating the RBL in weeks, and then for the last week in which capacity is required, the number of days is calculated (see Hendry 1989). In the present manufacturing climate and with the planning horizon split into days, part day requirements are calculated in this DSS for the last day on which capacity is required. Therefore, when the backlog is less than the capacity of a day, the contribution to the backlog length is calculated by dividing the backlog by the daily capacity value.

Consider the following simplified example:

(1) The current released backlog of a resource is equal to 80 hours

(2) Prior to the release of a new job, the RBL is equal to 4.0 days.

(3) The workload contribution to the resource of a job chosen from the pool is equal to 4 hours.

(4) Hence the RBL after the job has been released is equal to 4.25 days, calculated as follows:

Opening Backlog (Hours)	Daily Capacity (Hours)	Closing Backlog (Hours)	Released Backlog Length (Days)
84 [80 + 4]	20	64	1
64	24	40	2
40	20	20	3
20	16	4	4
4	16	0	4.25 [4 + 4/16]

Table 5.2 Released Backlog Length Example

The released backlog length is arguably the most important backlog in the hierarchy, as it is used to control the levels of WIP on the shop floor; as a result when the DSS initially opens, the user is automatically presented with the job release module, see Figure 5.11 below. In this module, jobs can be chosen and dragged from the pool into a 'release enclosure', where the impact of the chosen jobs on the released backlog lengths of resources can be assessed, using RBL charts and tables, and taking into consideration the maximum released backlog lengths, to avoid excess congestion, and minimum released backlog lengths, to avoid unnecessary machine idleness and starvation. The user is advised to consider priority, the slack of jobs and the backlog limits in choosing jobs for release. The user can choose varying mixes of jobs from the pool, assessing the relative impact on the shop floor, before making the final choice of which jobs to release to the shop floor. The user may choose to release the most urgent jobs first, in other words, as ranked by the DSS in the pool. Alternatively, the user may attempt to balance the released backlog lengths across shop floor resources. Providing an opportunity to assess the impact of multiple jobs on shop floor resources allows the user to see the cumulative effect that jobs have before making any decisions / releasing any jobs. Previous versions of the LUMS approach restricted the user to assessing and releasing each job individually without this capability. This is a refinement that could have major practical advantages, especially if several jobs in the pool are components that form part of an assembly operation or if several jobs have very similar shop floor routings.

Although the aggregate method attributes the whole workload of a job at the moment of release, inevitably, the user is likely to pay particular attention to the immediate impact of the job on shop floor queues, especially if processing or queuing times are long. Hence, this may be an important factor in the release decision; as a result, the DSS clearly indicates the first resource that a job will visit. Once the user has made their final decision, they can choose to release the selected jobs onto the shop floor and the DSS updates the released backlogs.

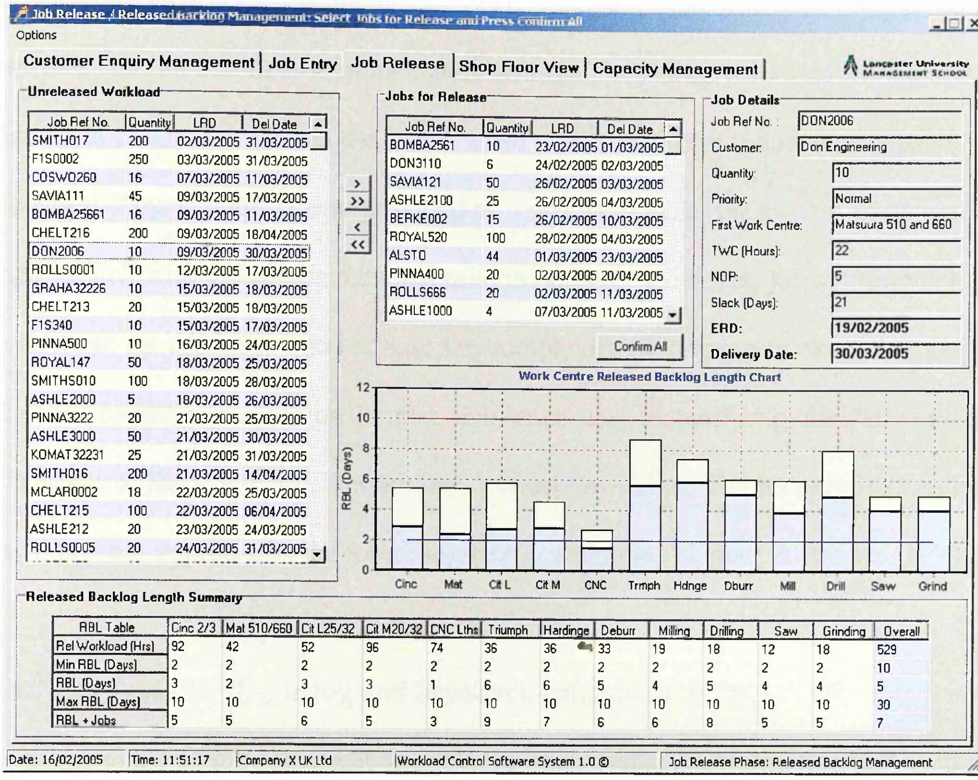


Figure 5.11: Job Release Decision Support Module

The LUMS approach has previously proposed the use of an Intermediate Pull Release option between periodic releases; however, as lead times reduce, the need for a more continuous review policy of the job release function increases. The short lead times prevalent in today's highly competitive manufacturing environment mean that, in order to avoid jobs becoming behind schedule, the interval between periodic releases would have to be very small. Therefore, the user can choose to pull jobs from the pool at any time, and can also force jobs onto the shop floor that will break workload restrictions at one or more resources. This should be performed with caution; and the user is presented with a warning message to remind them of the implications of overuse of the force release function. However, if force releasing was not permitted it may make the system too restrictive, particularly in the early stages of implementation, when backlog limits may be initially unrealistic.

The system also aids the release decision by allowing orders to be split, so that part of a job can be released immediately without exceeding workload limits, and the remainder can be released in the future when workloads have reduced or capacity has increased. This is a refinement provided as a means to make the system more realistic and in touch with the ad-hoc methods used in practice. However, job splitting is likely to increase set up times, and increase the complexity of keeping track of the progress of jobs, potentially resulting in part deliveries and jeopardising the delivery date adherence of the whole job. Despite this, it is acknowledged that lot splitting can be an advantageous approach in the job shop, see, for example, Wagner & Ragatz (1994).

5.3.9 Job Progress Reporting and Feedback Information

At the moment of job release, it is important that feedback information and therefore the released backlog lengths of resources are up to date, or a job may contribute to the backlog of resources for longer than it needs to, adversely affecting the release of other jobs. Arguably, this is particularly important as lead times become shorter; the shorter the lead times, the smaller the likely interval between job releases, and hence the more continuous feedback information must be. If jobs are released periodically, then the user may choose to update the position of jobs on the shop floor before releasing further jobs; however, if this is a continuous review process, this relies on the user being more vigilant.

It is acknowledged that it can be unrealistic to assume the automatic feedback of information; however, on the other hand, it would also be unrealistic in a dynamic job shop to automatically depreciate backlogs (assuming work is completed by the scheduled operation completion dates), as in reality, jobs will inevitably fall behind schedule on occasions. If backlogs were automatically depreciated when the operation completion date of a job had passed, this may cause problems as, for example, jobs may be chosen for release that would not otherwise have been chosen if the decision was based on real time information. In addition, the user and supervisor may overlook jobs that are behind schedule, failing to expedite them and thus leading to late delivery. To combat this, the DSS provides a manual, but rapid and user-friendly, way of updating the position of jobs on the shop floor to enhance the LUMS approach (see top right hand corner of Figure 5.12). If data is regularly recorded, this will ensure that backlogs are up to date when jobs are released from the pool, while the process forces the user to think about the position of jobs on the shop floor.

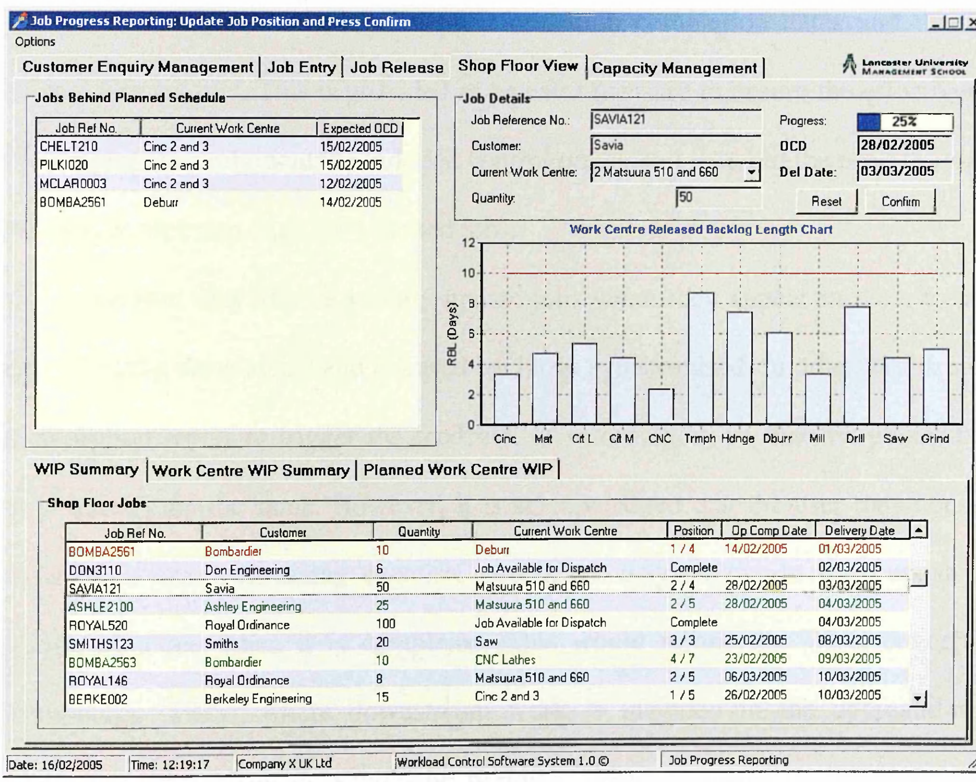


Figure 5.12: Job Progress Reporting Module and Shop Floor WIP View

This however still requires a disciplined approach to supplying information. As a result, in addition to relying on the vigilance of the user, jobs that are behind schedule are highlighted by the system and brought to the attention of the user in a daily 'exception report' (see top left hand corner of Figure 5.12), in an attempt to ensure that workload information is as up to date as possible. The DSS presents the user with a catalogue of jobs that are 'behind schedule'. This is based on the expected OCD of a job at its current location and the current date. Therefore, if the OCD of a job at the current location (according to feedback information) is prior to the current date, the job will be considered to be behind schedule. The user can then present this report to the supervisor and update the position of jobs before the next release decision, if they have been overlooked in the data recording process. On the other hand, the supervisor can 'chase' jobs that are genuinely behind schedule on the shop floor in an attempt to ensure subsequent operation completion dates and the final delivery date are met. This is provided as an extra measure to ensure the effectiveness of the aggregate load oriented workload control policy and to avoid the need to re-plan operation completion dates for released jobs.

The user may choose to only update jobs when they appear in the exception report, keeping the planned and released backlogs synchronised. In other words, using the exception report to trigger the feedback of information, so that the planned and actual queues are the same. However, it is acknowledged that the user may consider this to be a time consuming exercise, and hence may choose to only update the position of a job when it is completed. This would mirror the WLC concept of Tatsiopoulos (1983), where downstream work is included in the aggregation of workload. Such a decision should be performed cautiously and requires the RBL limits of resources to be subsequently increased to compensate for this increased workload representation. Although it is acknowledged that the user may want as little manual input as possible beyond job planning and release, without an investment in technology on the shop floor (such as bar coding equipment or localised computer terminals), some intervention is inevitable for the system to run effectively.

The module also provides the user with a number of different views in the lower half of the screen. The user can view the overall WIP for the shop as a whole, sorted by earliest delivery date, as shown in the lower half of Figure 5.12. From here the user can see the current position of all jobs on the shop floor (including their previous and subsequent destinations). Alternatively, the user can view the current queue at each resource, ordered by operation completion dates, as shown in Figure 5.13. Hence, the jobs that have the smallest slack (or negative slack) are at the top of the list. As is the case throughout the DSS, jobs are colour coded to highlight those with priority and those behind schedule / unscheduled. However, this again inevitably relies on up to date information from the user. The module also allows the user to compare the actual queues at each resource with the expected queues at each resource, based on the expected schedule calculated at the job entry level. Also note that although the planned schedule of each job is calculated at the job entry level, this can be reconfigured at any time.

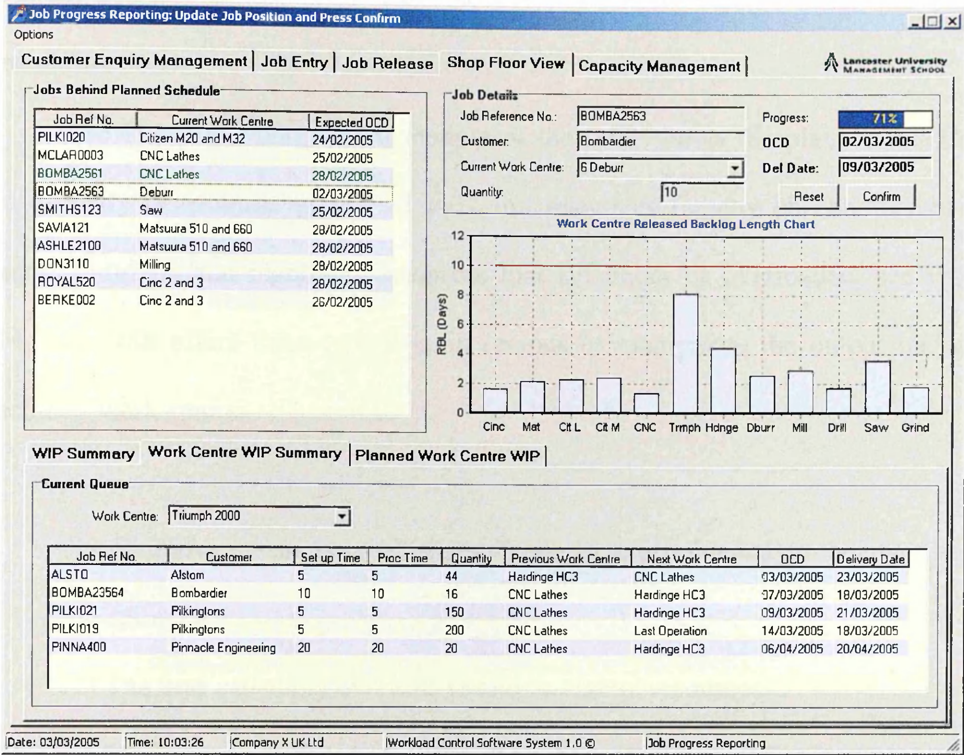


Figure 5.13: Job Progress Reporting Module and Current Resource Queues

5.3.10 Capacity Management

A change to the capacity of resources has an impact throughout the full hierarchy of backlogs, influencing the total, planned and released backlog lengths, as a result the capacity management module of the DSS can be accessed for input-output control purposes at the customer enquiry, job entry and job release stages. Hence, changes to the capacity of each machine / work centre influence the delivery dates the company can quote at the customer enquiry stage, the operation completion dates scheduled at the job entry stage and the mix of jobs that can be released at the job release stage. For example, if the RBL of a shop floor resource is at the maximum advised level, and the user wishes to release further work without force releasing, then either the user must wait until the backlog has reduced or the user must increase the capacity of the resource, in other words, manipulate the backlog length through input and output control functions.

The Capacity Management module of the DSS shows the planned workload and capacity distribution across all jobs and resources on any chosen day in the planning horizon and highlights resources that are under or overloaded, see Figure 5.14. The DSS offers three typical main options to manipulate the output rate of a machine / work centre:

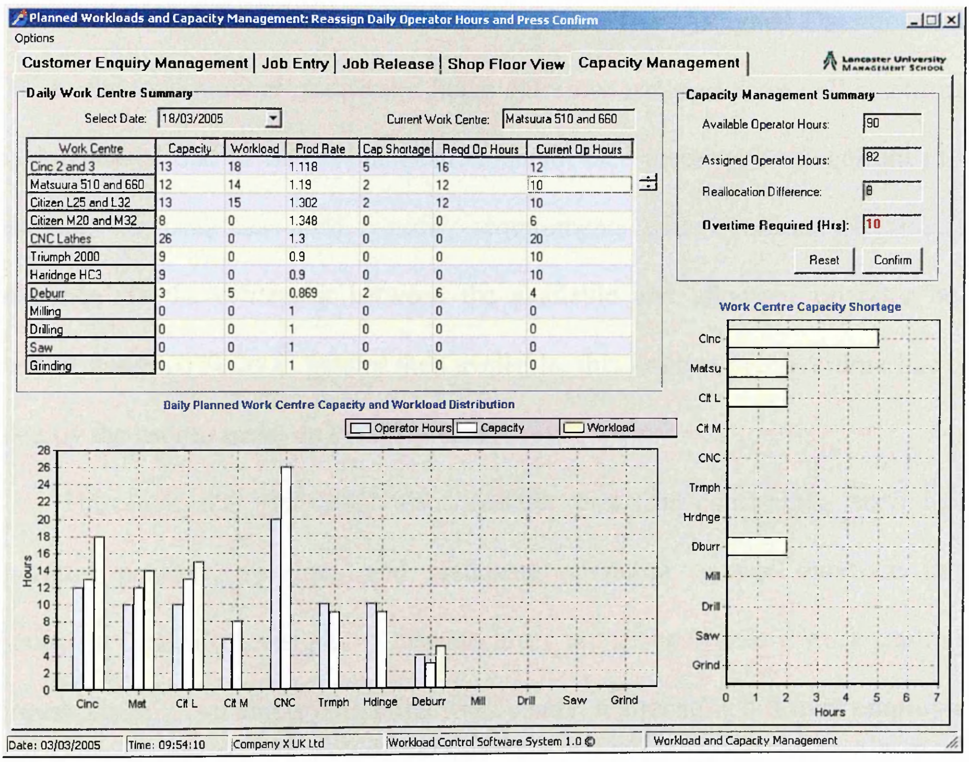
(1) Employees can be reallocated from an under-loaded to an overloaded resource.

(2) The user can apply overtime to one or several resources.

(3) The user can subcontract part or the whole of a job.

For example, the system indicates the number of additional hours required in order to release a job, allowing the user to attempt to provide this using the options listed above. It is considered infeasible to make capacity decisions without user input, as there may be many considerations outside the model that cannot be accounted for automatically. For example, the DSS cannot be expected to know that, wherever possible, Operator X and Operator Y are kept apart as they tend to be less productive than when paired with other operators. As a result, the DSS can only aid this decision making process.

Any subcontracting required should be planned as early as possible, usually at the job entry level, before materials have been ordered. By providing the decision support previously described at the customer enquiry and job entry stages, it is anticipated that the number of jobs a company subcontracts at the last minute due to insufficient capacity can be reduced. It is also foreseen that such operations can be performed in-house at less cost. This reduction in subcontracting is achieved by accounting for the amount of work currently being considered by prospective customers when quoting delivery dates. It may also be reduced through improved synchronicity between the workload and capacity of resources at the planned backlog level, and through stabilising lead times and WIP, such as through the use of the job release function and maximum RBL limits.



Work Centre	Capacity	Workload	Prod Rate	Cap Shortage	Reqd Op Hours	Current Op Hours
Cinc 2 and 3	13	18	1.118	5	16	12
Matsuura 510 and 660	12	14	1.19	2	12	10
Citizen L25 and L32	13	15	1.302	2	12	10
Citizen M20 and M32	8	0	1.348	0	0	6
CNC Lathes	26	0	1.3	0	0	20
Triumph 2000	9	0	0.9	0	0	10
Haridnge HC3	9	0	0.9	0	0	10
Deburr	3	5	0.869	2	6	4
Milling	0	0	1	0	0	0
Drilling	0	0	1	0	0	0
Saw	0	0	1	0	0	0
Grinding	0	0	1	0	0	0

Figure 5.14: Capacity Management Module

In addition, the user can also try to expedite a job by releasing part of the job ahead of the remaining quantity or by increasing the priority of the job. The priority of the job can be increased in order to reduce the expected queuing time of the job in the pool and / or on the shop floor. The DSS highlights jobs that have been given priority. For example, a job with pool priority would be highlighted green in the pool, a job with shop priority highlighted green on the shop floor, and a hot job highlighted both in the pool and on the shop floor. However, the use of WLC reduces the complexity of shop floor dispatching, allowing supervisors to determine the order in which the released subset of jobs are processed based on their experience and informal ad-hoc approaches, reducing the need for shop floor priorities.

The user can reallocate operators from one work centre to another, while the DSS indicates the remaining hours required at each work centre based on the current allocation of operators. 'Available Operator Hours' refers to the total daily operator hours, based on shift patterns and before overtime. The 'Assigned Operator Hours' refers to the total number of operator hours currently assigned across all resources. If it is considered that sufficient reallocation cannot take place with the current mix of operators, the user can fulfil capacity requirements with overtime. 'Reallocation Difference' is the difference between the available and allocated operator hours, hence, if assigned hours is greater than available, this implies that overtime has been added by the user to make up the difference.

However, the user must also consider practical constraints, such as the maximum possible overtime, and reallocate operators or use overtime at the appropriate time. For example, if two machines are grouped into a work centre and there are already two employees at the work centre, reallocating a further employee to the work centre will have no impact on the capacity. Hence, the user must consider the maximum operator hours per day for each work centre and the maximum number of operators at any one time. The user can also use the capacity management module to reduce capacity, for example, when a bank holiday enters the planning horizon of the schedule. To maintain flexibility, this is left to the user to determine at this stage of development. Hence, although this module provides helpful support, a greater level of user participation is required than at other planning stages, as making this process more automatic would rely on making too many assumptions.

5.3.11 Parameter Setting

Parameter setting is required for all PPC concepts presented in the literature. In the context of WLC, for example, parameters are required for the expected pool delay of jobs in the pool, expected shop floor queuing times and the backlog length limits of shop floor resources.

To aid this process, the DSS has been developed to provide a user-friendly module where parameters can be set and easily changed after implementation, as shown in Figure 5.15 below. This includes pool delays, queuing times, the strike rate percentage and backlog length restrictions. The backlogs of all resources can be set equally or varied to reflect, for example, provisions for bottlenecks. The user is also shown a number of these parameters in graphical format to aid this decision making process. For example, with the aid of a bar chart, the user can directly compare the expected queuing time norms at each machine on the shop floor. In addition to the parameters set in this module, for user friendliness, certain parameters are changeable in the main modules of the DSS. For example, the Customer Confirmation Time is likely to change from one job to another; hence although a default is set, if necessary this can be directly changed for each delivery date quotation within the customer enquiry management module.

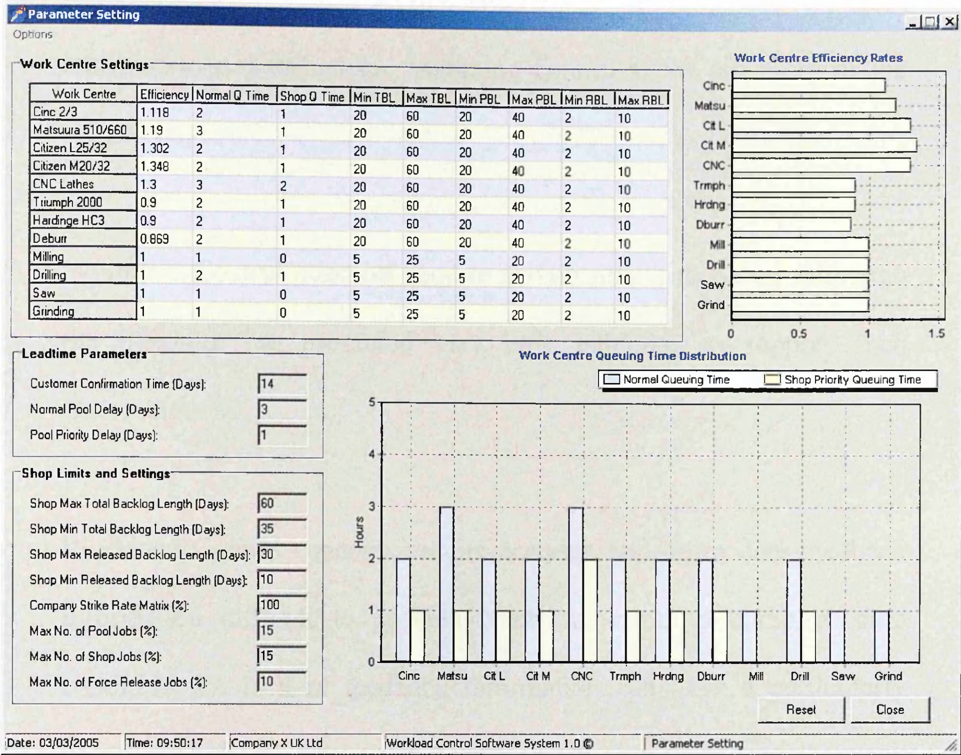


Figure 5.15: Parameter Setting Module

5.4 CONCLUSION

This chapter has described the refinement of an aggregate load oriented WLC concept for MTO companies through a systems development approach. Through deductive refinements and simplifications to the WLC methodology underpinning the DSS, the chapter provides theoretical development and a step towards a concept of greater practical relevance. The refinements to the methodology attempt to overcome the perceived problems of WLC concepts, and in particular aggregate load methods. These criticisms have been touched upon in earlier chapters and are summarised below:

(a) Workload Control concepts often assume a given mix of delivery dates and workload distributions, beginning control at the job entry or job release stage.

(b) Workload Control concepts require certain norms to be set, although the literature has presented very little guidance to support such determinations.

(c) Workload Control concepts require accurate and up to date feedback information difficult to provide when subjected to complex shop conditions. A lack of feedback information can have a particularly detrimental effect on aggregate load methods.

(d) Aggregate load methods do not attempt to represent or reflect the future load of the shop, such as at the job release stage.

In response to criticism (a), the methodology already aids the determination of delivery dates and incorporates the strike rate in the determination of the total backlog of the shop, and hence already begins to provide workload control from the customer enquiry stage onwards, as required by MTO companies. While this therefore does not represent significant theoretical development, the LUMS methodology has been further developed at the customer enquiry stage so that queuing norms can vary across work centres, thus improving flexibility and the fit between the methodology and real-life job shops. In response to criticism (b), a backwards scheduling approach is used with daily capacity and workload constraints to provide Operation Completion Dates at a relatively discrete scheduling level. This represents a significant refinement and simplification to the methodology from the overly complex approach described in Hendry (1989). This also means that the LUMS approach now only uses expected queuing norms and pool delay parameters at the customer enquiry stage, thus reducing some of the burden of parameter setting for WLC. Perhaps the only parameters considered critical to determine are the backlog lengths for the shop as a whole and for individual / groups of shop floor resources.

In response to criticism (c), the DSS presents the user with a user-friendly module through which to rapidly update the positions of jobs on the shop floor; taking such steps to improve the provision of information is important for effective use of the methodology in practice. The module highlights jobs that are behind the expected schedule; hence, if the user has limited time available, they can choose only to update the positions of those jobs that are behind schedule. Therefore, the response to this criticism was not to change the underlying theory behind the LUMS approach, but to design the DSS in such a way as to minimise the impact of this issue.

In response to criticism (d), the LUMS approach is enhanced to allow the planner to consider the future load of resources. At the moment of job release, the whole of a job is added to the backlog of machines / work centres; however, the user can also consider the anticipated downstream arrival times by viewing the planned queues of shop floor resources. Hence, the user can differentiate between the direct and indirect load of a resource at any given time, and consider this in the release decision; this is a step towards overcoming a key criticism of aggregate load oriented WLC methodologies. In conclusion, Table 5.3 below summarises the key contribution made in this chapter to the refinement of the LUMS approach at each planning level.

Planning Level	Key Refinements
Customer Enquiry Stage	Allowing norm queuing times to vary across shop floor resources to reflect the characteristics of job shops in practice; Providing a time phased representation of the TBL to illustrate the distribution of delivery dates over time; Incorporating jobs beyond the planning horizon and calculating a schedule entry date for each, in order to increase visibility.
Job Entry Stage	Providing discrete backwards scheduling for greater guidance and a reduced parameter setting burden; Increasing emphasis on practical aspects of interest to users, such as, planned shop floor queues and Gantt charts.
Job Release Stage	Promoting a continuous, rather than periodic, review policy to compensate for short delivery lead times; Calculating the RBL in days and part days for increased accuracy; Providing an option to release part of a job / lot split to increase flexibility and reflect the ad-hoc decisions made in practice; Allowing the user to assess the cumulative impact of jobs on the shop floor before releasing jobs.
Shop Floor Control / Priority Dispatching	Promoting up to date feedback information from the shop floor through an exception report and user friendly data input system to improve the effectiveness of the aggregate load methodology.
General Aspects	Calculating the total, planned and released backlogs in days, rather than weeks, to reflect the competitiveness of the MTO industry; Simplifying the use of job routing data through the hierarchy of backlogs; Greater capacity management and parameter setting assistance to improve practical applicability.

Table 5.3: Summary of Key Refinements from the Programming of the DSS

The research now focuses on how the methodology can be applied to the case study company. The following chapter examines Company X in more detail, identifying contextual considerations while giving a measure of the current performance of the company, before Chapter 7 looks at implementation issues and

Chapter 8 examines the outcomes of a partial implementation of the system. These three chapters form the third stage of the process, designed to ensure the practical relevance of the LUMS approach and explore how the approach can be further refined, completing the bridge between the theory and practice of WLC.

CHAPTER 6: THE CASE STUDY COMPANY

6.1 INTRODUCTION

This chapter describes and analyses the case study company in detail in order to put the research presented in the following three chapters into context. This research explores the specific needs of Company X and seeks to determine how the DSS described in the previous chapter can be applied to the organisation. While the case study research further contributes to the refinement of the WLC concept, this chapter also begins the process of contributing to the second research question and the phenomenological issue of implementation.

When investigating (non-positivist) phenomena, it can be necessary for data collection to be more open-ended than would be the case for positivist research; see, for example, Remenyi *et al.* (1998). Hence, the chapter uses a variety of sources to build a chain of evidence surrounding the company. For example, the investigation began with a number of informal and semi-structured meetings with management. At this stage, relatively little was known about the company, and hence an open, rather than closed-ended, questioning approach was appropriate (see, for example, Van der

Velde *et al.* 2004). This also involved a great deal of active listening, focussing on both the content and intention behind what the interviewees were explaining. At later stages, when the research had a greater understanding of the company, questions became more directed, but maintained a rather informal nature. This ensured that interviewees were at ease when collaborating with the research. As the anonymity of the company and the confidentiality of the information were assured from an early stage, a sense of trust was also promoted in the relationship with the company, and this helped the research to gain greater insight and data access.

The chapter looks at a wide range of issues, such as those relating to human and machine resources within Company X. These two factors increase the complexity of PPC, affect the flexibility of the company and will become very important in the implementation process. Subject to data availability, the chapter also provides an overview of the pre-implementation data analysis that has been conducted, using many of the performance measures identified in Chapter 3. This also provides an insight into the difficulties of data mining in SME's. At the end of the chapter, the applicability / fit between the concept and the company is re-evaluated based on a more rounded understanding of the organisation. It is important that the company is an appropriate case for WLC in order to validate that the evidence gained from the case study is appropriate for guiding inductive refinement of the concept and exploring implementation issues for WLC in subsequent chapters.

6.2 COMPANY OVERVIEW

Company X is a precision engineering company located in the North West of England. The company currently employs approximately thirty people and has an annual turnover in excess of one million pounds. Therefore, the company can be considered a small enterprise within the SME spectrum defined in Chapter 2. The company typically produce bespoke subcontracted items, in varying quantities, for larger UK based manufacturers. Thus the majority of the relationships the company has can be considered to be B2B, as commonly found in this type of industry (see, for example, Calosso *et al.* 2003). Typical customers can be found in the aerospace, automotive and defence industries, with a previous diversification into manufacturing parts for Formula One and Le Mans racing teams.

Company X has a base of approximately 25 customers that make a limited number of repeat purchases of previous orders and that make enquiries about new products. The company also produce one-off products for new customers. Hence, the company has to compete for every order that they receive, except on the small number of occasions when the product has been previously produced for the customer. As a result, the company can be considered to be both a RBC and a VMC. The products that Company X produce vary in quantity, total work content, number of operations (the typical job has approximately four operations) and shop floor routing. Jobs can start and finish at any machine; however, there is considered to be a dominant flow to the shop floor, hence configuration can be classified as a General Job Shop.

Company X currently lacks a formalised approach to production planning and control. The low turnover of the company and the limited resources that the company have has enabled planners to use a manual scheduling approach to control the shop floor. For example, the current approach to planning production is to use a list of machines on a whiteboard and to simply write the job reference numbers of urgent jobs over the next few days under each relevant machine. The board is reviewed every three to five days, and jobs are wiped off the board when they are completed, with other urgent jobs being added in their place. However, there does not seem to be a long-term strategy to this approach, and the supervisor has to spend his time continuously rushing urgent jobs through the shop floor. The supervisor has informally commented that:

> "*.... because we're so busy, it can be a case of whoever shouts the loudest will get their jobs out of the door the quickest ....*"

The current procedure also suffers from a lack of communication at the customer enquiry stage between the supervisor and the estimator. In addition, half of the machines are planned by the supervisor and half by the operations manager. Good communication between these two members of staff is also needed for such a system to work effectively.

Despite the obvious weaknesses in the current system, a white board can be a useful visual production signal clearly outlining to shop floor operatives what is to be achieved each day. It may be particularly useful to the night shift that have less contact with the supervisor. However, over the four years that the company have been in operation, turnover, machine facilities and the number of employees have all been steadily increasing. Therefore, it is anticipated that if the size of the company continues to increase, the current informal and ad-hoc planning measures will start to become unmanageable and the need for an effective planning and control system, such as WLC, will increase. If favoured by shop floor operators, a white board can be incorporated into a formalised planning system; however, when used in conjunction with a more structured approach, the supervisor and operations manager will be able to use greater schedule visibility and foresight when planning for the shop floor.

Prior to four years ago, the company was operating under another name, with a greater workforce and turnover, before subsequently going bankrupt. Company X was formed from this previous company. The company is located at the same site as the previous one, has many of the same employees and customers, has the same management personnel and structure and manufactures the same type of products. It is now generally understood by management that problems previously encountered were the result of poor production planning and control. As a result, the company is very receptive to new ideas to improve the company, such as Workload Control, in an attempt to avoid history repeating itself. The company should have learnt some valuable lessons from the experience and there is now cautious optimism surrounding the company.

The characteristics of the case study company are summarised in Table 6.1 below based on the criteria presented in Chapter 2. From this table and the subsequent discussion it will also become clear that Company X comply with the characteristics of MTO companies, given in Table 1.1 of Chapter 1. Further company details, such as the frequency of order arrivals, are given in Table 6.11 where the organisational fit to Workload Control is considered.

Section	Criteria	Company X
2.2.1	**Product Customisation**	Mainly MTO (some ETO)
	Customer Type(s)	RBC and VMC
	Typical Markets	Aerospace, Automotive and Defence Industries
2.2.2	**Shop Configuration**	General Job Shop
2.2.3	**Company Size**	SME
	Employees	30
	Turnover	> £1m

Table 6.1: Overview of Company X

6.3 HUMAN RESOURCES

The workforce of Company X is made up of 'direct' and 'indirect' employees. Direct employees are those that can be attributed to a machine or an activity relating to a specific job on the shop floor. Indirect employees are those that are not specifically involved in performing value-adding activities on the shop floor, such as estimators, planners and administrative staff. Hence, for PPC purposes, the main focus of this discussion is on value adding employees that directly affect the capacity of the shop. Meanwhile, the planning tasks at the customer enquiry and job release stages will be performed by 'indirect' employees and hence indirect employees also play an important role. Company X currently has 20 'direct' employees working on the shop floor.

Typically, each employee on the shop floor is designated to a particular machine, but may be skilled in one or perhaps two other activities. This provides some multi-skilling and capacity flexibility through the reallocation of operators from under-loaded to overloaded resources. Employees may also be able to operate more than one machine at a time. In order to compensate for employees operating multiple machines and to account for the varying work rates, workloads, skills and experience of employees, management evaluate employees and give each of them an efficiency rating. With reference to his time and motion studies, this is an approach that provokes comparisons with Taylor's scientific school of management. The general rule of thumb for this measure is that if an employee operates a single machine then they can do so at an efficiency of 100%, or one machine hour per operator hour, (after allowing for planned downtime) and if they are operating two or more machines they can do so at their individual efficiency rating.

For example, a new and inexperienced employee with an efficiency rating of only 60% may operate two machines simultaneously for 8 hours; hence the capacity of the two machines collectively would equal 9.6 hours. On the other hand, an experienced operator, with an efficiency of 90%, may operate the same two machines simultaneously for 8 hours with a collective capacity of 14.4 hours. If both operators were present at the same time, they would each run a single machine at an individual efficiency of 100%; hence the machines would have a collective capacity of 16 hours. Although this provides the greatest possible capacity, more man-hours would have been spent in providing this. It is acknowledged that this system assumes that experienced and inexperienced operators can both run a single machine at an efficiency of 100%; however, it is considered that in reality an experienced operator could operate the machinery at an efficiency of, for example, 120%.

A further complexity is provided by the varying shift patterns under which employees operate. However, while the efficiency measure used to approximate capacity is rather individual to Company X, the shift patterns used are of a more generic nature. In other words, similar shift patterns are likely to be used in other MTO companies where the DSS could be applied. There are three different shift patterns: 'Days', 'Lates' and 'Nights'. Employees working 'Days' work from 07.45 until 16.30 (Monday to Friday). Employees working 'Lates' work from 14.00 until 22.00 (Monday to Friday), and employees working 'Nights' work from 22.00 until 06.00 the following morning (Monday to Thursday). On a typical day (Monday to Thursday), this can create an almost 24 hour production routine on machines that are allocated an operator from each shift pattern, as shown in Figure 6.1.

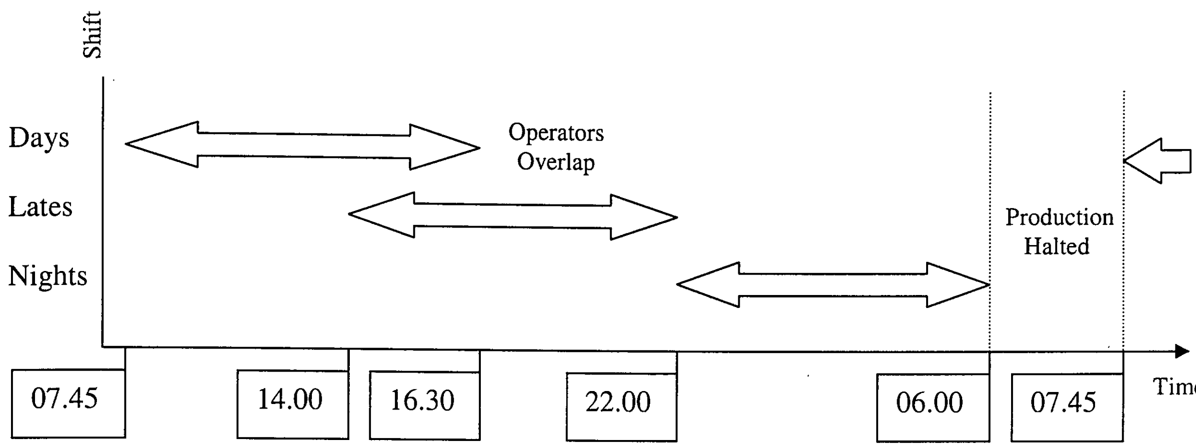


Figure 6.1: Distribution of Working Hours for Each Shift Type at a Shop Floor Resource

Employees also have an informal agreement with management regarding the use of overtime, where operators have overtime hours that they normally work each week, such as an hour before or after the start of a shift. The overtime that different employees choose to work can vary widely, resulting in employees often running a number of machines on their own, and hence at a reduced level of efficiency. However, overtime is largely independent of the load of the shop, although the shop is generally overloaded as it experiences its current period of growth, a factor that may have consequently contributed to this decision. The details of the current mix of employees at Company X, including their working practices, skills and efficiencies, are summarised in Table 6.2.

The use of overtime, coupled with varying shift patterns and the persistent use of efficiency ratings for direct employees, increases the complexities of planning and control within Company X. A typical 24 hours (across all shop floor resources), between Monday and Thursday, is illustrated in Figure 6.2 below, where green bars represent the normal shift hours, and yellow bars indicate the typical overtime of each employee. This provides a useful visual indication of the variation in output rate of shop floor resources over a day.

6.4 MACHINE RESOURCES

The shop floor of Company X consists of twenty three core machines. Having been accumulated over time; they vary in age, and hence vary in specifications, processing speeds and replacement costs, as summarised in Table 6.3. It could also be argued that the older machines are more likely to breakdown / delay production than newer machines. The majority of the machines are considered heavy machinery, and require an operator to be present at all times while they are running. A small number of the 'machines' are lighter hand held tools and are less regularly used. As a result, operators are not directly assigned to these operations on a permanent basis, but designated operators are moved across from other machines to perform these operations when they are required. Hence, operations to which employees are not permanently allocated are paired with specific resources that do have operators permanently assigned and from which operators are reallocated. In addition to the machining operations described in the table, a further key operation is deburring. Within Company X this can be a timely and manual process.

Emp No.	Shift	Regular Overtime	Core Machine(s)	Reallocation Options	Efficiency (%)
1	Days	Not Applicable	Cinc 2 Cinc 3	Matsuura 510 Matsuura 660	70
2	Days	Not Applicable	Cinc 2 Cinc 3	Matsuura 510 Matsuura 660	70
3	Nights	Not Applicable	Cinc 2 Cinc 3	Matsuura 510 Matsuura 660	70
4	Nights	18.00 – 22.00 (Mon – Thurs)	Matsuura 510 Matsuura 660	Cinc 2 Cinc 3	85
5	Nights	21.00 – 22.00 (Mon – Thurs)	Matsuura 510 Matsuura 660	Cinc 2 Cinc 3	75
6	Days	16.15 – 17.15 (Mon – Fri)	Matsuura 510 Matsuura 660	Cinc 2 Cinc 3	90
7	Days	Not Applicable	Matsuura 510 Matsuura 660	Cinc 2 Cinc 3	50
8	Lates	Not Applicable	Citizen L25 Citizen L32	Citizen M20 Citizen M32	70
9	Days	16.15 – 17.15 (Mon – Fri)	Citizen L25 Citizen L32	Citizen M20 Citizen M32	70
10	Days	16.15 – 17.15 (Mon – Fri) 08.00 – 12.00 (Sat)	Citizen M20 Citizen M32	Citizen L25 Citizen L32	80
11	Nights	22.00 – 06.00 (Fri and Sun)	Citizen M20 Citizen M32	Citizen L25 Citizen L32	85
12	Days	Not Applicable	ACT 3, ACT20, Superturn, Dooturn	Not Applicable	90
13	Nights	Not Applicable	ACT 3, ACT20, Superturn, Dooturn	Milling	50
14	Days	16.15 – 17.15 (Mon – Fri)	ACT 3, ACT20, Superturn, Dooturn	Not Applicable	80
15	Days	16.15 – 17.15 (Mon – Fri) 08.00 – 12.00 (Sat)	Hardinge HC3	Not Applicable	90
16	Days	06.45 – 07.45 (Mon – Fri)	Deburr Triumph 2000	Drilling Grinding, Saw	90
17	Days	06.45 – 07.45 (Mon – Fri)	Deburr	Saw	90
18	Days (P/Time)	Not Applicable	Deburr	Saw	90
19	Days	16.15 – 17.15 (Mon – Fri) 08.00 – 12.00 (Sat)	Inspection	Not Applicable	Not Applicable
20	Days	16.15 – 17.15 (Mon – Fri) 08.00 – 12.00 (Sat)	Inspection	Not Applicable	Not Applicable

Table 6.2: Summary of Employee Skills and Working Patterns

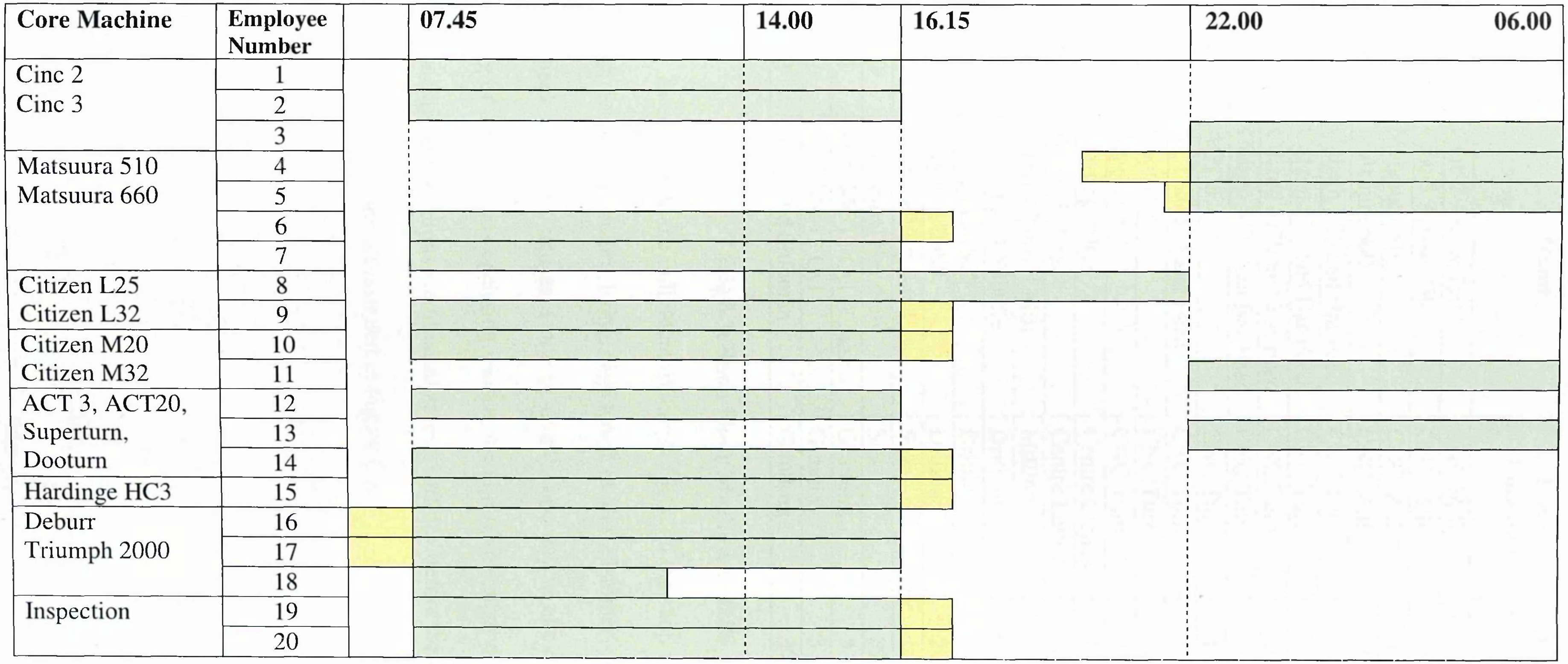


Figure 6.2: Typical Daily Shift Pattern (Between Monday and Thursday)

Machine No.	Name	Type / Function	Age (Years)	Estimated Replacement Cost (£)
1	Cinc 2 Arrow 750	CNC Mill	9	30,000
2	Cinc 3 Arrow 750	CNC Mill	9	30,000
3	Matsuura 510	CNC Mill	8	90,000
4	Matsuura 660	CNC Mill	3	120,000
5	Citizen L25 and Bar Feed	CNC Turn	7	120,000
6	Citizen L32 and Bar Feed	CNC Turn	7	120,000
7	Citizen M20 and Bar Feed	CNC Turn	2	160,000
8	Citizen M32 and Bar Feed	CNC Turn	2	160,000
9	ACT 3	CNC Turn	13	60,000
10	ACT 20 and Bar Feed	CNC Turn	7	50,000
11	Dooturn 4	CNC Turn	9	60,000
12	Superturn 3	CNC Turn	20	60,000
13	Hardinge HC3	Centre Lathes	17	8,000
14	Triumph 2000	Centre Lathes	15	12,000
15	Anayek Turrert Mill	Milling	15	12,000
16	Meddings 4 Spindle	Drilling	15	1,000
17	Arboga EM825	Drilling	24	1,000
18	Arboga U2508	Drilling	29	1,000
19	Startrite Vert.Band	Saw	14	2,000
20	Horizontal Bandsaw	Saw	29	4,000
21	Myf. MG12 Cyl A/Size	Grinding	33	8,000
22	Myf. MG12 Cyl	Grinding	37	8,000
23	Jones and Shipman	Grinding	37	7,000

Table 6.3: Shop Floor Machine Details

In addition to the individual routings of jobs on the shop floor, all jobs must go through inspection before being dispatched to the customer. This is considered a bottleneck operation, and as a rule of thumb, one day is allowed at the end of the routing of a job for this operation. Hence, the aim of the supervisor must be to ensure that machining operations are finished at least one day before the delivery date.

The shop floor is illustrated in Figure 6.3:

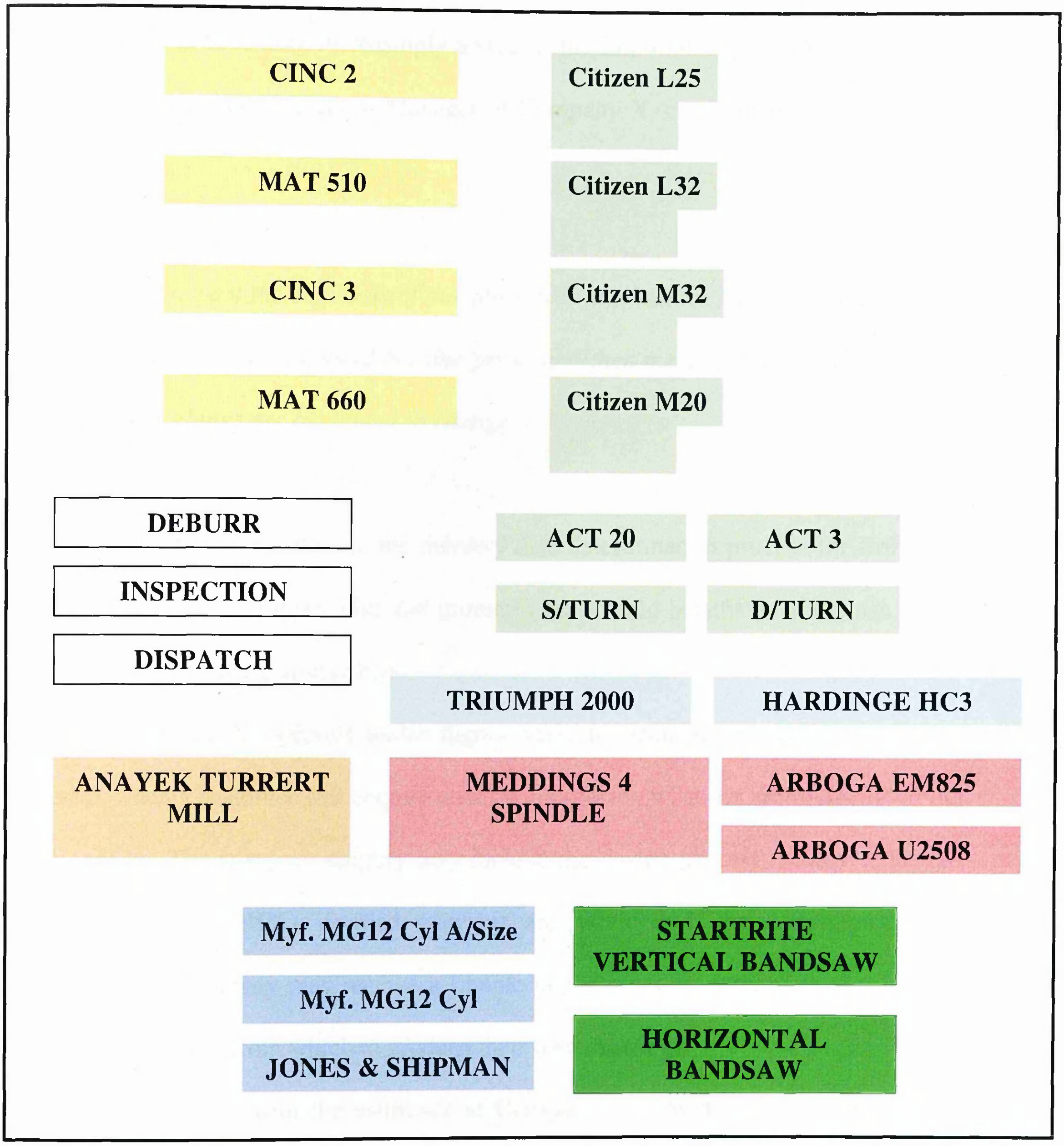


Figure 6.3: Machine-Level View of the Shop Floor

6.5 CUSTOMER ENQUIRIES AND SETTING DELIVERY DATES

Company X is becoming increasingly aware of the importance of delivery dates and their reliability. The Operations Manager of Company X, hereafter referred to as LN, remarked that:

> "…. *in the past the emphasis of our objectives has been to focus on quality, followed by providing an affordable price, and then meeting delivery dates; however, things are beginning to change* …."

Despite this realisation, the delivery date determination process for Company X has a number of complexities and problems that would benefit from the use of the DSS at the customer enquiry stage.

Company X operates under highly variable demand; the company cannot predict when a customer will enquire about a job or even what the requirements of the job will be. The customer enquiry may include the design process; however, for the majority of jobs (95%), detailed drawings are provided. If the design process is required, the company may receive a sample of the product, perhaps produced by a previous supplier, from which to produce their own drawings.

Discussions with the estimator at Company X provided an insight into the current approach to determining delivery dates. It is acknowledged that the introduction of the DSS would have implications for the working practices of the estimator and hence this person was somewhat cautious with his answers. However, by using open-ended questioning techniques it was possible to encourage the estimator to elaborate with his responses. The estimator is also the father of LN and hence already has an understandably open relationship with management. Therefore, the estimator is considered a relatively reliable source of information.

When a prospective customer makes an enquiry, the details of the enquiry are passed to the estimator. This person will then consider the requirements of the job in terms of shop floor routing, machine set up and processing requirements and raw material purchasing needs. The estimator will then assess the pricing requirements of the quotation manually, using a calculator. This is based on the time required per operation (set up and processing times) multiplied by an hourly labour cost in addition to the current price of raw materials. The level of detail determined and time spent at this stage varies with each job. The lead time for the job is estimated from experience and usually varies between two and six weeks. However, the current load and capacity of the machines is not directly considered in this process. The quote is checked by LN before being typed up into a formal tender and being sent to the potential customer. The experience of the estimator is important in the delivery lead time or delivery date determination process. However, at the same time, this process could benefit from considering capacity and workload constraints.

The estimator goes through a systematic process when quoting the price and delivery date. However, it is also acknowledged that the identity of the customer influences the delivery date proposed. If the quotation is for a new customer, the company may make a more competitive lead time quotation than normal, in an attempt to win new business. If the customer is well known to the company, the estimator will be aware of the expectations of the customer. In fact, LN has stated:

> "*.... I know what lead times my regular customers expect, so I know what I have to quote to win their business ....*"

Such a tender may include a specific delivery date, or it may include a delivery lead time (such as 3 weeks) from receipt of confirmation of the order. This can be a useful way of coping with highly variable customer confirmation times and allows the company to avoid having to renegotiate the delivery date at the job entry stage if the customer does not confirm the order for a prolonged period of time. The tender the company submits may include a series of different prices and lead times for a number of different quantities. This may provide an incentive for the customer to place a larger order where raw material economies of scale can be introduced and set up costs spread over a greater volume. Also note that some customers provide a suggested delivery date to the company, placing pressure on the company and influencing their quotation.

The time it takes for the prospective customer to respond is also important and can vary greatly from order to order and from customer to customer. If a tender has been rejected by the customer, the company may never be informed. However, the company will attempt to query this after a number of weeks (approximately 8 weeks) to determine the status of the tender. For example, it is possible that the decision has been delayed, alternatively the job may no longer be required, or the work may have been given to another company. However, this uncertainty adds to complexity when determining medium term capacity requirements, scheduling in advance and when quoting delivery dates for other enquiries.

The company is aware that it has previously accepted work knowing that it cannot meet the delivery date; however, this is not a strategy for good customer relations or long-term success. There is a reluctance to turn work away; however, the acceptance of jobs for delivery dates which the company has very little chance of achieving can severely deteriorate the reputation of the company and the likelihood of repeat business with a new customer. It is possible that the overall performance of the company could benefit from the rejection of a small number of jobs as an input control measure at the customer enquiry and job entry stages.

6.6 MAIS: AN INTERNAL INFORMATION SYSTEM

From previous experience, management of Company X is aware that it needs to improve the way the organisation is run. The company contacted a number of ERP vendors with a view to finding out more about the costs and modules contained within such systems (one such module would be finite / infinite capacity planning). However, deterred by price (the most appropriate package costing an initial £30,000), and dissatisfied with the functionality of the packages, management decided to develop their own 'tailor-made' in-house software solution, hereafter referred to as MAIS.

MAIS has been under development for almost three years and now covers a wide range of functions. However, the system is still not finished and these functions have not been widely implemented within the company during the course of this research project. The features of the system include a database of employee and customer details, payroll information, a database of previous customer enquiries and quotations, a facility for determining the price of quotations and a database of supplier information. This can provide a great deal of useful information and reports for the company; however, it does not contribute directly to PPC.

Despite this, the development of MAIS has inadvertently created the data infrastructure that the WLC DSS would require in order to effectively plan and control the shop. This includes a recording system for workload and capacity information, such as processing times, set up times, and employee shift patterns. Therefore, the WLC DSS can 'plug' into an existing database. Integrating the two systems will avoid the duplication of tasks for the user (that would waste time and may lead to errors). Having to input the data into both systems may have also led, for example, to the WLC DSS being neglected while MAIS is kept up to date.

For the meantime, management within Company X are reluctant to fully integrate the two systems together until they have more confidence in the plans generated by the DSS. In addition, future research may be able to isolate the impact of WLC on the company more definitively if it is kept separate from MAIS. Hence, details can be extracted from the database, but changes will not be relayed. As a result, the DSS must support its own limited data storage requirements. Over the course of time, after the DSS has been implemented, it is anticipated that the company will start to take greater ownership of the system, trusting the delivery dates the DSS suggests and the schedules it creates. Therefore, in time, the two systems can be more formally integrated.

The company hopes to sell MAIS to other similar organisations in the future. As a result, in many ways management is using Company X as a case study for their own software. In order to cater for the needs of a wide range of companies, the development stage of the MAIS system is proving to be a long process. There are concerns about the preoccupation of management with selling MAIS to other companies, as this is not a core competence of the company, and management has no previous experience in such markets. In addition, it may be more beneficial for Company X to resolve outstanding core manufacturing problems before attending to such peripheral objectives.

6.7 END-USER DETAILS

From the beginning of the relationship with Company X it was clear that the Operations Manager, LN, intended to be the primary end-user of the system. Giving this responsibility to a single person will hopefully lead to consistency in decision-making. To improve the acceptability of the DSS, it can be necessary to meet the functional expectations of the user (see, for example, Shim *et al.* 2002); such expectations can be accommodated more easily when there is only one end-user to consider. Initial discussions took place with LN to determine his expectations for the system and experience within production planning and control.

LN has worked in manufacturing for the majority of his working life and has progressed from machining work (7 years shop floor experience) to quality control (8 years experience) to running his own company (13 years experience). As a result of such wide experience in a variety of roles it is anticipated that the user will be well qualified to operate the DSS. LN has expressed a desire for the system to involve a minimum amount of direct input, without being an automatic system. For example, LN has stated:

> "*.... I'm very busy during the week and don't get much time to spend planning. At the moment I try to do that sort of thing on a Saturday morning .... I need to make decisions quickly so I'm keen to see a lot of information at once without having to click through endless screens to find the data that I want ....*"

The interface preferences of the user can be considered when refining the DSS. However, it is considered, for example, that the DSS already consists of a minimal number of screens and displays sufficient information in each screen in a variety of formats. It is acknowledged that the user is already very busy within the organisation, spending a great deal of time 'fire fighting'. However, although LN already has a wide range of responsibilities, taking on a number of further roles is common within the limited hierarchical structure of such a small company.

As LN has already commissioned the development of the MAIS system and been heavily involved in the design of the system, the look and feel of MAIS can be used as a benchmark in order to ease eventual integration. It is also known that the end user is particularly keen to have access to detailed information over the first three weeks of the planning horizon where planning is inevitably less rough cut. The attitude of the user towards WLC must also be noted, at the implementation stage LN needs to understand the importance of delaying the release of jobs in accordance with the RBL limits of shop floor resources, and quoting realistic delivery dates. In the early contact stages of the project, the user was given a basic introduction to the principles of WLC and handed a one-page summary on the subject; lengthy explanations have also been provided throughout the process.

It is likely that LN will install the DSS on a single desktop computer and a laptop. In total, the company have five desktop computers and one laptop computer on a Local Area Network (LAN). Hence, the company have sufficient hardware available; however, it will be useful to assess the capacity and speed of the existing server in use within the company. If this is inadequate (too slow or prone to 'crash'), the DSS could be run independently on a single machine until this has been upgraded.

Given that LN intends to be the sole end-user, this would not cause any significant implementation problems.

6.8 ORGANISATIONAL POLITICS

Implementing change within an organisation is a major challenge in which company culture, the distribution of power and the individual political agendas of social actors play key roles. Pfeffer (1993) describes an organisation as a political coalition and explains that in almost every organisation there are varying interests; when managing change, one of the first things that must be done is to diagnose the political landscape, evaluate what the relevant interests are and what important political subdivisions characterise the organisation. Burnes (2004) supports this view and explains that organisations consist of shifting coalitions attempting to protect or enhance their own interests. Inevitably, a company's goals may not necessarily tie in with the interests and aspirations of individuals within a company; therefore, to facilitate change it is important to attempt to view the change from the (political) perspective of subgroups within an organisation.

Burnes (2004) explains that political behaviour is a part of organisational life (where there are cultures, there are usually subcultures and counter-cultures) and that political behaviour is particularly prevalent when major change initiatives are being considered or implemented. The author adds that changes in an organisation present an ideal opportunity for wielding, achieving or maintaining power. Kumar & Thibodeaux (1990) agree that organisational change is inextricably linked with organisational politics, while Levine & Rossmoore (1995) warn that if the power and political relationships within an organisation are not diagnosed, a key factor in managing the human threat to IT implementation will have been overlooked. Radical change in particular threatens the established power relations of an organisation far more than minor change (Sauer 1993). Implementing WLC is considered a major change for Company X leading to a radical new company wide approach; hence, examining the political agendas and the role of power within Company X is of major importance to the successful management of change.

Mangham (1979) explains that more often than not, all parties claim to be acting in the best interests of an organisation; however, the author elaborates to explain that planned change will be marked by the strong advocacy of some and the strong opposition of others. The self-interest of both groups is at stake and every trick and resource will be called into service to bring about or successfully to oppose the innovation under consideration. Hence, political agendas are rarely exposed, they tend to be covert and therefore it is important to look beneath the surface and 'read between the lines' in order to identify each person's true motives.

Vigoda & Cohen (2002) examine factors influencing the political agenda of an individual within an organisation; influential factors include their level in the hierarchy, their degree of participation in decision making, job satisfaction, organisational commitment, influence tactics, education, status and person-to-organisation fit. The following subsection outlines the perceived political motives and agendas of the key social actors / subdivisions involved in the case study company prior to implementation: the Operations Manager (LN), the estimator, the software developer, the shop floor supervisor and the machine operators. Their view of the company will be affected by factors such as those outlined above by Vigoda & Cohen (2002). The effect that these political agendas had on the research project, and the way in which actors sought to enforce and gain support for their own agendas through developing and wielding power, will be evaluated in Chapter 8.

6.8.1 Political Agendas Within Company X

- The Operations Manager (LN)

LN's 'pet project' over the last four years has been the design and development of MAIS. LN is keen to extend the functionality of the system and is motivated by a belief that by doing so he will be able to sell the software package to other companies and recuperate the considerable money he has invested in the development of the system. LN's brother has begun a similar business next door to Company X and LN hopes to persuade his brother to become the first customer for this software.

LN has explored various avenues of inspiration for MAIS; while he is aware what his needs are, he is keen to find out what the functionality requirements of other potential customers might be. For example, he has gained ideas by consulting local planning software vendors on the pretence that he intends to buy their system for Company X. Meanwhile, LN is also interested in integrating WLC into MAIS if it proves to be successful within Company X. He showed great enthusiasm towards WLC at the start of this research and was motivated by the potential impact of WLC on his company and in time on others. LN was very keen to use WLC to make the shop floor leaner, reduce time spent planning manually and admitted to being poor at calculating realistic delivery dates; an area where WLC could provide considerable guidance. LN has had a rather short term attitude towards managing his relationships with customers in the past, due in part to an inability to gain order visibility. He spends the majority of his time fire fighting, meaning that he does not have time to plan ahead. LN has admitted:

"*I'm a born optimist ... we tend to quote short delivery dates because we don't want to lose an order, even if that means quoting dates that are unrealistic.*"

He tends to tell customers what they want to hear in order to 'buy time' and get them 'off his back' in the short term, managing customer relationships on the basis of social capital. In other words, he trades one customer off against another by ensuring that he meets the delivery dates of customers with whom he currently has a poor relationship, by neglecting the orders of customers with whom he has a good social credit rating (knowing that he can get away with this in the short term until his social credit with the customer reduces). However, LN indicated that he wanted to change this attitude in the future, hence the reason for optimism surrounding the implementation of WLC in this company. LN agreed to make a financial contribution to the cost of the research. Although this only extended to travelling expenditure, it nevertheless provided a form of commitment on the part of the company towards the project. By developing MAIS and implementing WLC, LN was hoping to be able to improve delivery performance and improve customer perceptions of the company.

If WLC were to be integrated into the MAIS system and subsequently sold to other companies (as suggested by LN), then clearly from a research perspective, this would also provide rapid access to multiple further case studies, improving the contribution and generality of the findings. Hence, it should be acknowledged that, if successful, this venture also provides a potential political gain for the researcher.

- The Estimator

The customer enquiry stage module of the WLC system will directly affect the role of the estimator and the way in which he handles tenders; hence, although overtly enthusiastic and helpful, it must be acknowledged that from a personal point of view the estimator may secretly be averse to the idea. This opinion has been briefly acknowledged in Section 6.5 of this chapter. For example, the estimator is approaching retirement, is accustomed to a paper-based system and will not want a major change in working practices at this stage in his career. He is also rather apprehensive of computer based systems due to his previous experiences. Both the secretarial staff and the estimator have access to an old computer system that stores some order details; this has a tendency to 'crash' on a regular basis, has a very dated user interface, and is considered very unreliable by users. Hence, unless convinced otherwise, office staff will have similar expectations for MAIS and WLC.

- The Software Developer

The outside software developer works freelance for a number of different clients and is not a full time or permanent member of staff. He is currently employed by Company X to work on MAIS for twenty hours a week; hence his work with Company X represents approximately half of his income at the present time. His outside status may give him greater objectivity than other interviewees, but also leads to a number of disadvantages as discussed below.

When the system is complete he will be able to receive a percentage of income from sales to other companies and have a role in supporting and updating the application (MAIS Version 2.0, and so on); however, the number of regular hours of work that he will receive from Company X will be dramatically reduced. Hence, until he has another client that wants his services on a regular basis, it is debateable whether he would want to see the system completed. Therefore, he encourages LN to commission further extensions to the system; clearly this would have knock-on effects for the implementation of WLC. His lack of urgency to complete MAIS also reflects his level of confidence in making money from selling the package to other companies.

No contact was made with the developer during the initial visits to Company X as he was not on site during this time, although attempts were made to make visits coincide. Upon finally meeting the developer it became clear that he had preconceived ideas about the effectiveness of production planning and the way in which it should be performed, although he was not familiar with the WLC concept. At this point it became clear that the developer may be an obstacle to the implementation of the system. Despite this, as an 'outsider' he was not expected to hold a great deal of power and LN provided assurances that he would ignore the developer's ideas on scheduling and that the two systems could 'pull in the same direction' without any significant problems.

- Machine Operatives and the Shop Floor Supervisor

The shop floor supervisor and the operators of machines on the shop floor also have their own agendas that they want to pursue. Operators currently have overtime hours that they have built into their weekly routines to supplement their incomes. They are aware that demand is volatile and job specifications variable, hence there is a danger that their overtime may be reduced in the future. Therefore, they protect their overtime by slowing down their production rate at certain times, depending on the load of the factory (and, for example, whether Christmas is approaching, etc) to maintain an overtime buffer of work. For example, by ensuring that towards the end of the week they have enough work to justify working overtime at the weekend. Some operatives also suffer from a lack of commitment to the company, inevitable given the history of the (previous) company and the lack of job security that this promotes. It must be acknowledged that shop floor operators will be initially sceptical of a system that seeks to increase transparency and remove shop floor buffers.

Although openly compliant during discussions, the shop floor supervisor will also be apprehensive of a system, such as WLC, that supports the planning and control of production. Until he is convinced otherwise, due to a fear of the unknown he is likely to see this as undermining his authority and reducing his responsibilities (although WLC would actually give him greater freedom); hence, communication and training are important factors in overcoming obstacles to implementation and improving awareness. The shop floor supervisor already feels that his authority is being undermined as LN oversees production on half of the machines on the shop floor; this can also cause problems with synchronising production if the supervisor and LN are not communicating effectively.

Overall it was concluded that the political landscape within Company X, as diagnosed at the start of the project, was suitable for a WLC implementation study. While a number of issues have been identified (as described above), it was felt that there was considerable management support and commitment towards the project and it was hoped that evaluating the political agendas in advance would help to overcome any problems encountered during the project.

6.9 COMPANY SPECIFIC PPC REQUIREMENTS

With the development of MAIS, it is possible to simplify the input requirements for the DSS. However, such simplification can only be accommodated while this does not affect the methodology of the LUMS approach and the aims of the project. For example, the MAIS system already caters for pricing decisions; hence, the DSS will not be enhanced to incorporate a pricing function for this case study. Such a function would not have provided direct benefits to the core WLC system. On the other hand, Company X would like to continue to quote delivery dates based on the experience of the estimator, and has not built a delivery date determination function into MAIS. However, it is important that reliable and realistic delivery dates have been quoted at the customer enquiry stage. As a result, the DSS will show the delivery date that the estimator provides for MAIS, whilst also indicating the advised earliest delivery date that the DSS recommends. It is hoped that through extended use, the company will gradually accept the delivery dates the system suggests and take full advantage of this module.

In addition to the above considerations, the company have a number of specific requirements to consider when refining the DSS, as listed below. The inclusion of these is important in order for the system to run effectively and not become neglected by the user.

(1) *Assembly Structure*: The products that Company X manufactures are small engineered parts that require processing at a number of machines. As these are typically small components, the operations generally take place on a single structure in a sequential order. As a result, the complexity of production is

reduced, without the need for concurrent or parallel production on sub-assemblies, before the final assembly. On the few occasions that Company X applies a sub assembly structure, the company considers each sub assembly and the final assembly as separate jobs, with separate delivery dates. As a result, the DSS is able to cater for the needs of Company X in its existing form. However, it is likely that other companies will require provisions for parallel production and more sophisticated assembly structures.

(2) *Lot Splitting*: A job could run concurrently on separate machines if the lot is split or released in separate parts. Although this can make it more difficult to track the progress of the whole job and ensure the full order is delivered on time, lots are regularly split within Company X and this can aid in the reduction of throughput times. In order to maintain flexibility and mirror the production environment on the shop floor, the DSS already accommodates lot splitting at the job release stage. If capacity cannot be sufficiently increased to allow the release of the whole job, Company X can use the part release function in an attempt to keep backlog lengths below their maximum levels and balance workloads.

(3) *Subcontracting*: Based on historical data, approximately 9% of the total work content of the jobs Company X produce are subcontracted to other suppliers. This is made up of work that the company does not have the production capabilities to manufacture and work that the company does not have the capacity to process. Subcontracting can relate to a whole job or it can be a single operation within the routing of a job. It is hoped that through better

delivery date determinations and workload balancing, the work subcontracted due to insufficient capacity can be reduced. However, it is important that the DSS can allow for all eventualities in this area. Although the amount of work subcontracted is kept to a minimum, this is accommodated in the DSS. For example, if a single operation in the routing of a job is subcontracted, a number of days, equal to the anticipated subcontracting lead time, are by-passed in the backwards scheduling procedure of shop floor resources.

(4) *Schedule flexibility*: The complexity of production and the unpredictability of demand within a job shop environment mean that detailed discrete scheduling can be impractical. The lead times, total work content and processing requirements of the mix of jobs is constantly changing, consequently, discrete forward planning is likely to result in the ceaseless rescheduling of jobs when new jobs are accepted at the job entry stage. WLC caters for the job shop by planning at a higher and broader level, providing LRD's and OCD's to guide the release decision. However, the company would like to try to schedule jobs more precisely to produce a schedule to strictly adhere to rather than to guide the release decision and promote the supply of up to date feedback information. This has already been accommodated to some extent in order to reflect the scheduling flexibility required in practice. For example, LN is able to interact with the Gantt chart function the DSS provides and change OCD's. Due to the work involved with manual re-scheduling, it is not envisaged that this intervention will be a long-term strategy, given the minimum user input LN has requested.

6.10 CAPACITY MANAGEMENT OPTIONS

A flexible approach to capacity management can be a valuable resource in order to manipulate backlog lengths. This can help to improve the competitiveness of delivery date quotations, stabilise lead times, balance workloads and improve flexibility at the job release stage. With the recent growth of Company X, the input rate of work at the job entry stage has been intensified. However, this is largely out of proportion with growth in resources. In addition, there is a reluctance to reject business. Meanwhile, the three main methods through which to manage the output rate (overtime, reallocation of operators and subcontracting) are restricted, as described below:

(1) *Overtime:* As described in Section 6.2, the company has a rather informal approach to overtime. Shop floor employees are not normally directly asked to work additional overtime; however, they are empowered to decide when overtime is required and to work if they are available. This generally results in an inflexible capacity management approach. Employees develop routines, for example, habitually working on Saturday mornings or an extra hour on Friday afternoons. This overtime then becomes an extension of their normal shift patterns, rather than a reflection of the relationship between workload and capacity. As a result, although the DSS has been developed to incorporate overtime and support decisions regarding the recommended levels of overtime, it is unlikely that this will be used to its full potential by Company X. This illustrates the gap between the theoretical assumptions of WLC and the practice of real MTO companies.

(2) *Reallocation of Operators:* From the skills and experience of operators on the shop floor of Company X it is clear that there is some scope for reallocating operators from under-loaded to overloaded resources as a way to reduce backlog lengths in the short term. Employees can generally be reallocated to a discrete number of machines; however, the current state of the backlogs of the company suggest that, until control is established, resources are rarely under-loaded. If the company do reallocate employees to other machines, they are assumed by management to have the same efficiency at the resource to which they are reallocated as they do at their usual machine. The company also take on some short-term contract workers when possible; however, these tend to be involved in 'indirect' duties, and hence do not affect the capacity of shop floor resources. In general, the reallocation of operators is preferable to overtime and subcontracting, as this can be performed at no additional direct cost.

(3) *Subcontracting:* Although the company use subcontracting on a regular basis, it has also been made clear that management intend to reduce this wherever possible, by attempting to produce all work in-house that the company has the facilities to manufacture. Hence, the company may be reluctant to use subcontracting as an I/OC mechanism. Additional job release measures, such as lot splitting in an attempt to expedite at least part of a job, are favoured over subcontracting.

6.11 PRE-IMPLEMENTATION DATA ANALYSIS

This section analyses historical data collected from the case study company for two reasons: (1) as a gauge for the post-implementation performance of the company and (2) to assist in the initial set up of the system (see Section 6.11.5). This data largely corresponds to the period from the end of August 2003 to the beginning of December 2003. This interval was chosen as it corresponds to one year before it was anticipated that the company would begin to use the WLC DSS and as it represents a similar period of overload. It was considered that this would provide the most directly comparable data set for post-implementation performance and provide useful guidance when setting norms at the customer enquiry stage. Clearly, the original intention of this data was to provide a benchmark for evaluating the impact of WLC. In such a case, statistical techniques could then be used to compare two data sets, for example, examining correlations, using cross-tabulation and significance tests (for example, to investigate differences between the pre- and post-implementation performance of the company). Literature on this is widely available in management research and more general statistics texts (see, for example, Remanyi *et al.* 1998; Morris 2000; Baker 2003; Kvanli *et al.* 2003).

Although the research has evolved in a different direction, this data analysis helps to provide an insight into the type of data researchers should collect during an empirical WLC research project. Collecting data proved to be a very time consuming process and the data available was often incomplete or unavailable. Guidance can be found in the literature regarding how to analyse incomplete information, particularly in the context of questionnaire responses, see, for example, Van der Velde *et al.* (2004). In this case, incomplete data was discarded before data analysis.

It is also acknowledged that there are many other measures for determining the success of an implementation project. Finlay & Forghani (1998) provide a review of such measures, including profitability (Garrity 1963), widespread use (Swanson 1974), better teamwork, better control, time and cost savings (Keen 1981) and time taken in decision-making (Nunamaker *et al.* 1989). Such measures could be used as an alternative or to augment the type of data presented below.

The data described below gives an overall impression of the company. Note that as Company X use night shifts and weekends, the shop floor often has capacity available seven days a week. Therefore, this data analysis has been conducted by treating each calendar day equally, in other words assuming a seven day week.

6.11.1 Delivery Date Adherence

Due to the limited and old-fashioned recording system used in-house it was necessary to extract delivery details by typing individual reference numbers into an existing company database (containing basic administrative information) before transferring the details into a Microsoft Excel package for further analysis. This proved to be a very time consuming process. The exploratory data collection process is outlined below:

- Initial Sample:

449 deliveries between 1st September and 30th November 2003 were recorded from a total of 35 different customers (213 deliveries to 23 different customers were obtained for September 2003; 132 deliveries to 8 different customers for October 2003; 104 deliveries for 26 different customers for November 2003).

- Cleaning the Data:

Part 1: From this sample, partial deliveries were removed so that the remaining deliveries represented whole orders that the company had fulfilled during the period. Delivering part of an order on time was considered insufficient, and the inclusion of several partial deliveries corresponding to one complete order could lead to some duplication. This resulted in a subset of 256 completed deliveries.

Part 2: From the sub category of complete orders, further deliveries were removed if information was incomplete. For example, some orders did not provide specific delivery dates, but for example, merely asked for delivery as soon as possible. In such cases it was considered difficult to reliably interpret delivery date performance.

- Final Sample Size:

This process resulted in a final sample size of 171 deliveries.

The analysis does not discriminate between customers or order size; each order is treated equally as the company are looking to improve performance for all customers and all types of jobs. The results of this analysis are summarised in Table 6.4 and Figure 6.4 below. In the first column, the table splits delivery date adherence into three groups: On Time, Early and Late. The top row indicates the number of days, early or late, that a delivery has been made. Hence, 0 days (column 2) indicates a delivery was made on time. A number of cells in the table are shaded where infeasible column and row matches are made. For example, a delivery cannot be both On Time (column 1: row 2) and more than 28 days early / late (column 5).

Days Early / Late	0		0 < Delivery ≤ 7		7 < Delivery ≤ 28		Delivery > 28		Overall (%)	
	No.	%	No.	%	No.	%	No.	%		
On Time	11	6.433							11	6.433
Early			12	7.018	11	6.433	2	1.170	25	14.620
Late			25	14.620	53	30.994	57	33.333	135	78.947
Total									171	100

Table 6.4: Delivery Date Adherence Summary

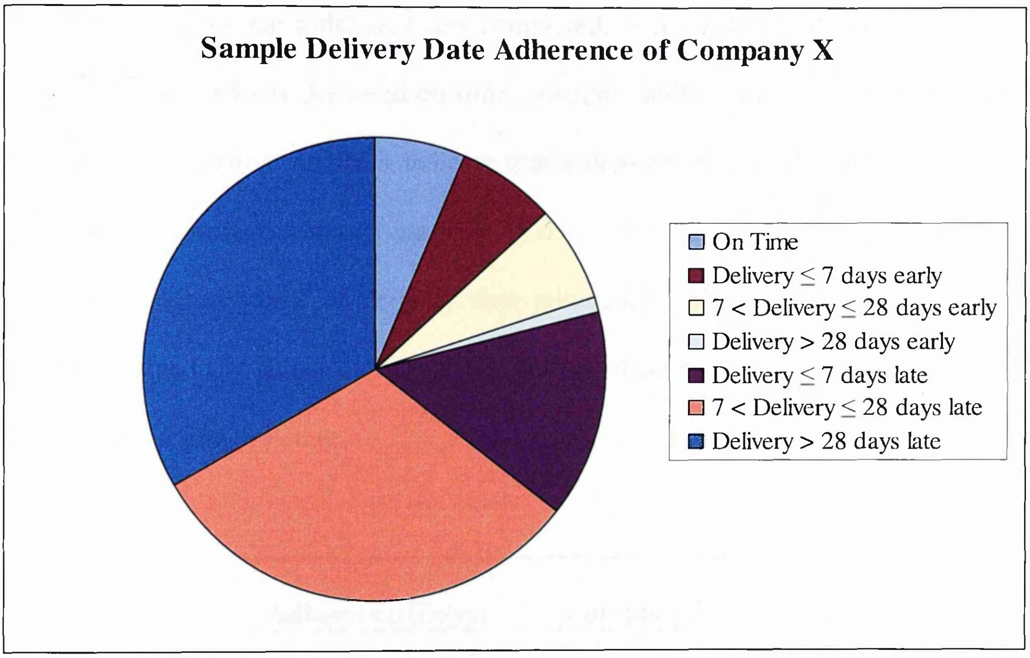


Figure 6.4 Pie Chart Showing Sample Delivery Date Adherence of Company X

The table and figure show that, based on the results of this sample, the company delivers most items after the agreed delivery date. Although part of the delivery may be on time, when the order is finally completed, the delivery date has often passed, with over 64% delivered more than a week late. However, the high number of partial deliveries observed when sampling indicates the problems of a lot splitting policy on the shop floor and the problems the company has in meeting delivery dates. This may also indicate that some customers understand the difficulties of meeting tight delivery dates and instruct Company X to deliver a certain quantity by a given date and the remainder as soon as possible. Only 6.4% of orders were completed on the specified delivery date, in other words, 'on time'. A further 14.6% of orders were completed early. However, companies operating under a stockless manufacturing philosophy may consider an early delivery to be almost as problematic as a late delivery.

Table 6.5 below summarises some of the key features of the distribution of days (early or late) that a delivery was completed. A mean of zero would represent that the average order is delivered on time; positive numbers indicate a delivery was made late and negative numbers indicate that a delivery was made early. The table shows that the average delivery was over 16 days after the agreed delivery date. The high variation and range of delivery date adherence indicates a lack of stability between planned and actual delivery dates, with implications for planning and control at the customer enquiry stage.

Adherence (Days)	Company X
Mean	16.75
Median	16
Mode	34
Standard Deviation	19.76
Range	140
Minimum	-47
Maximum	93
Count	171

Table 6.5: Delivery Date Summary Statistics

6.11.2 Delivery Lead Time and Lead Time Variation

For this analysis, the following procedure was applied:

- Initial Sample:

The analysis began with the refined sample of 171 deliveries used in Section 6.11.1.

- Cleaning the Data:

Thirteen further orders were removed where the required information was incomplete.

- Final Sample Size:

This resulted in a subset of 158 completed deliveries.

Analysis of the planned delivery lead times is summarised in Table 6.6. The table shows that the mean desired (or quoted) time between the receipt of a confirmed order and delivery to the customer is over 18 days (more than two and a half weeks), with a median and mode of 15 days. The standard deviation and range indicate high lead time variation. This is likely to further contribute to the difficulties the company has experienced when quoting delivery dates. From the sample, the largest lead time was over 9 weeks from receipt of enquiry to the quoted delivery date.

Quoted DLT (Days)	Company X
Mean	18.25
Median	15
Mode	15
Standard Deviation	12.51
Range	86
Minimum	0
Maximum	86
Count	158

Table 6.6: Summary of Quoted Delivery Lead Time Statistics

Analysing the achieved (or actual) delivery lead time of the company, for the same set of orders, provides an indication of the reliability of the quoted delivery dates. This provides a further indication of delivery date adherence and an insight into the accuracy of the current ad-hoc approach to determining delivery dates. The achieved delivery lead times are summarised in Table 6.7 below.

Actual DLT (Days)	Company X
Mean	35.01
Median	36
Mode	49
Standard Deviation	20.20
Range	104
Minimum	0
Maximum	104
Count	158

Table 6.7: Summary of Achieved Delivery Lead Time Statistics

Although the range has not increased greatly, the variation has increased and the mean achieved delivery lead time is approximately double the desired / quoted levels, with the median and mode indicating an even greater difference between quoted and actual performance. This further highlights the significant problem that the company has in meeting delivery dates.

6.11.3 Inventory Analysis

At present, only a limited impression of the inventory of the company can be gained from historical records. However, this is the best available information and future research with the company can work towards improving the availability of this data. Inventory information is collated monthly for accounting purposes, as shown in Table 6.8, for the period January 2003 to July 2003. This data groups WIP, FGI, raw material costs and labour costs together. FGI relates to both items produced ahead of schedule and to over production (for the purposes of economies of scale), where the company anticipate a repeat purchase will be made in the future. The company has a large amount of money invested in WIP and FGI, although it has proclaimed ambitions of becoming leaner. Given the fluctuations in WIP, the table illustrates a lack of stability, hence reducing and stabilising the level of WIP will be key criteria for WLC.

The data provided in each row of the table is explained as follows:

(1) *Material*: The cost of raw material used during the month.

(2) *Labour:* The cost of labour used during the month (calculated as the total selling price of products for the month minus the material costs of these products).

(3) *Complete:* The total value (selling price) of FGI.

(4) *Total*: The total inventory value of the shop, based on (1), (2) and (3) above.

(5) *Change in WIP*: The difference between the total inventory values from one month to the next.

(£)	Jan 2003	Feb 2003	Mar 2003	Apr 2003	May 2003	Jun 2003	Jul 2003
Material	13178	10046	7123	7891	5894	6719	3597
Labour	32977	41746	29667	42902	39110	44202	42151
Complete	40922	62869	154715	45331	55480	58280	57646
Total	87077	114661	191505	96124	100484	109201	103394
Change in WIP		27584	76884	(-95381)	4360	8717	(-5807)

Table 6.8: Monthly Financial Assessment of Inventory

6.11.4 Machine Utilisation and Backlogs

Although the shop is currently considered overloaded and configuration can be described as a general job shop, certain machines are notoriously busier than others. From experience, management are aware which machines are usually under-loaded and which are overloaded. This could also be observed by viewing the physical queues (direct workload) at each resource on the shop floor. In general, this is also reflected in the allocation of operators. For example, no operators are permanently allocated to the machines and tools involved in sawing and cutting. Meanwhile, inspection and deburr operations are considered bottlenecks, and are permanently staffed, with all jobs having to visit inspection. Efforts to improve the availability, and hence collection, of this data could be pursued in the future.

6.11.5 Company Strike Rate Percentage and Customer Confirmation Time

An initial analysis of two of the factors particularly important to a MTO Company at the customer enquiry stage of PPC has been conducted: the simple strike rate percentage and the distribution of customer confirmation times. These two factors play an important role in the DSS at the customer enquiry stage, while the strike rate also provides a further insight into the performance of the company and the level of competition to which the company are exposed. The higher the strike rate of the company, the more important it is to consider this in the delivery dates determined at the customer enquiry stage.

Company X has previously estimated the overall strike rate of the company to be 15%, and has also acknowledged that the Customer Confirmation Time (CCT) varies widely from quote to quote. This analysis will help to guide the initial values to be set in the DSS. Although the strike rate of a company can be calculated in the form of a complex probability matrices, it is considered sufficient for the purposes of this initial study to look at the overall strike rate of the company as this is the value currently incorporated in the DSS. In order to accurately analyse the strike rates of, for example, individual customers, a much greater sample size would be required. For many customers, only a small sample of historical data is available due to the length of relationships, while Company X itself is only in its fourth year of production.

The basic approach taken to data collection is described below:

- Initial Sample:

A sample of 414 quotations made between September and December 2003 were extracted from Microsoft Word files.

- Cleaning the Data:

Quotations were removed if the information was incomplete, for example, if the outcome of the enquiry was unknown.

- Final Sample Size:

This resulted in a final sample size of 293 quotations made to 34 prospective customers.

From this sample of 293 quotations, 68 led to confirmed orders. Hence, the overall strike rate of the company is estimated to be 23.2%, over 8% higher than the estimate made by Company X. Therefore, based on these initial results, the overall strike rate of the company has improved beyond the previous perceptions of management.

From the 68 confirmed orders, the distribution of customer confirmation times can also be analysed. This is an important factor in the determination of delivery dates. Using a subset of 59 orders, after those where the exact date when the order was confirmed is unknown, the CCT can be summarised, as shown in Tables 6.9 and 6.10 below.

CCT (Days)	Company X
Mean	21.42
Median	9
Mode	9
Standard Deviation	360.68
Sample Variance	941.49
Range	102
Minimum	0
Maximum	102
Count	59

Table 6.9: Summary of Customer Confirmation Time Analysis

Customer Confirmation Time	Frequency	Percentage (%)	Cumulative Frequency	Cumulative %
Same Day	5	8.47	5	8.47
1 – 7 days	13	22.03	18	30.51
8 – 14 days	20	33.90	38	64.41
15 – 21 days	12	20.34	50	84.75
22 – 28 days	0	0.00	50	84.75
Over 28 days	9	15.25	59	100

Table 6.10: Distribution of Customer Confirmation Times

The tables show that the customer confirmation time suffers from extremely high variation, as previously noted by management. Management also believed that most orders are confirmed within the first two weeks; this is largely supported by the analysis above, meaning a two-week window would give a reasonable estimation of the expected customer confirmation time, although for some orders this would be an over estimate. This can be considered when the company set a default for the customer confirmation time in the customer enquiry module of the DSS. There are also some jobs that are not confirmed until three months after the initial enquiry. At this stage, customers would have to expect that delivery dates would be subject to change and renegotiation. Hence, flexibility is required within the DSS regarding the expected customer confirmation time and in relation to determining delivery dates in general; the experience of the estimator can play an important role in the delivery date process, but it is likely that the estimator can also benefit from decision support to directly consider workloads and capacities when making this decision.

The high variation in customer confirmation times adds a further dimension to the complexities of determining delivery dates at the customer enquiry stage in the MTO industry. It is difficult to put an expected value on the customer confirmation time, as a result, the feasibility of delivery dates previously quoted at the customer enquiry stage will have to be reassessed at the job entry stage, leading to possible renegotiation or a number of rush jobs. Also note that, given the high uncertainty and variation in confirmation times, it was important to collect this data some time after the quotations had been made to minimise the chance of a late response after the data had been collected. As a result, this data was collected more than 150 days after the last customer enquiry was made, hence more than 48 days longer than the greatest observed customer confirmation time (102 days). However, although unlikely, it must be acknowledged that this value could rise marginally if customers confirm orders after the data was collected.

6.11.6 Additional Factors

If the pre- and post-implementation performance of the company were to be evaluated, for research rigour, it would also be important to be aware of any additional factors that may affect the performance of the company, other than WLC. However, it is difficult to isolate such influences and it can be difficult to quantify the impact they have on the performance of the company. A number of these issues are acknowledged below, while some more general issues were previously raised in Chapter 3. It is likely that these will have a collective responsibility contributing towards any change in performance within the company.

(1) *Fear of job losses*: The financial history of the company and the commonly observed fear (promoted through the company 'rumour mill') when a change to working practices is implemented is likely to have an impact on performance. Fear of job losses may have a negative effect on morale, undermining the system. However, this may be counter balanced by the Operations Manager being the user of the system.

(2) *Heightened Awareness*: In preparing to install a new PPC software package there is likely to be a general increase in awareness of the importance of meeting delivery dates. This is likely to make employees extra vigilant; however, this is also likely to be a short-term effect that is soon reduced if the hype surrounding the project is not sustained.

(3) *MAIS*: Although the MAIS system does not directly provide PPC, it illustrates that the company is beginning to take the problems that the company has previously experienced more seriously. This may also have a positive effect on the performance of the company.

(4) *Customer Pressure*: The recent poor delivery record of the company with important customers has highlighted the PPC problems that the company is experiencing. The threat of losing future work with customers that the company has worked with for a long period of time is likely to emphasise the importance of this issue to management, a message that will be relayed to the shop floor.

(5) *Efficiency Rating*: The use of an efficiency rating for employees may encourage some shop floor operators and improve performance. On the other hand, it may have a negative impact on the performance of others, who begrudge having their productivity monitored, in an old-fashioned scientific management style approach. In addition, if this efficiency rating is inaccurate, it will also contribute to poor performance, by providing an inaccurate

representation of capacity. This is a distinct possibility, as it has only been based on minimal historical data, and is somewhat subjective. Further data collection would be beneficial if the company are to persevere with this system.

6.12 ORGANISATIONAL FIT TO WORKLOAD CONTROL

The general applicability of Company X for WLC was determined in Chapter 3 based on the overall characteristics of the company. This can be further assessed now that more in depth knowledge about the company is available. Henrich *et al.* (2005) presented a framework for evaluating the applicability of a company to WLC (see Table 6.11). The framework covers a number of key areas from the customer enquiry stage to priority dispatching, considering factors particular to MTO companies. For example, (a) 'arrivals' could be considered a measure of the customer enquiry and job entry stages, (b) 'due dates' a measure of the customer enquiry stage, (c) 'operations' a measure of customisation and (d) 'routings' a measure of the job release and priority dispatching stages. The framework is based on using a High and Low rating for the desired characteristic. However, what is considered high is perhaps open to interpretation and more easily determined when comparing a company against another (benchmark) company. Therefore, in Table 6.11, Company X has been evaluated using High, Medium and Low, to provide some middle ground. Alternatively, an attribute could be left blank to indicate that the characteristic is neither of notably high or low significance.

Shading has been used to illustrate the fit between the company and the WLC framework. Green suggests a perfect match; amber suggests the attribute is not particularly significant (or a semi-match); red indicates that there is a poor match between the company and the particular attribute in the framework. Overall, the table shows a high suitability between the concept and the company. The framework itself will also be further validated if the eventual outcome of a future project is positive. The only area where there is poor fit between the company and the concept is in the area of delivery date setting. This is inevitable given the current procedures inside the company; hence, overcoming the approach to determining delivery dates is a major factor and will improve the fit between the WLC framework and the company.

	Indicator	Comments	Company X		'Best-fit'
Arrivals	(a_1) arrival intensity	A high arrival rate allows greater flexibility with job release and workload balancing.	The company process a large number of small jobs with a medium arrival intensity: approx 5 new jobs per day.	Medium	High
	(a_2) inter-arrival time variability	High inter-arrival time variability adds to the difficulties of advanced scheduling.	Arrival times are unpredictable. It is difficult to know if a job will be accepted / rejected. This is not considered significant, with no obvious variation during year.	Medium	High
Due dates	(b_1) due date tightness	Small slack (ERD close to LRD) limits available options in pool and requires a small pool delay.	DD's very tight in order to be competitive. Capacity not directly considered in quotations.	High	Low
	(b_2) variability of due date allowances	High variability allows, for e.g., flexibility and use of priorities.	New and high priority customers have tighter DD's. However, in general, delivery dates are quite standardised.	Medium	High
Operations	(c_1) processing time lumpiness	'Lumpy' processing times limit ability to foresee when jobs will arrive downstream. Therefore affecting job release and queue lengths.	Lots of small orders rather than a majority of large orders, hence lumpiness is low.	Low	Low
	(c_2) processing time variability	High variation likely in MTO industry, allows greater flexibility, e.g. for the supervisor.	Job processing times may be very different due to customisation and routing variability.	High	High
	(c_3) set-up/processing time ratio	Low processing times allow greater workload balancing. Sequence dependent set up times cause complications.	Most set up times low; however, some processing times also small.	Medium	Low
Routings	(d_1) routing sequence variability	WLC suited to the job shop, i.e., high routing sequence variability.	Sequence variability is high, but with a dominant flow direction (general job shop).	High	High
	(d_2) routing length	Long routings make it difficult to consider indirect load at the moment of job release.	An average of 4 operations per job.	Low	Low
	(d_3) routing length variability	High variability provides a greater number of options and a greater mix of jobs for job release and workload balancing.	Some routing length variability, but not a significant amount.	Medium	High
	(d_4) routing flexibility	Routing flexibility allows machines to be grouped and allows the allocation of work to resources to be delayed.	A choice of between 1 and 4 machines.	Medium	High
	(d_5) level of convergence	High convergence suggests dominant assembly structure. May also result in bottlenecks.	Jobs do not typically converge on operations until inspection and dispatch.	Low	Low

Table 6.11: Applicability of Company X for WLC (based on Henrich *et al.* 2005)

6.13 CONCLUSION

This chapter has illustrated the complex nature of the manufacturing environment in which MTO companies, such as Company X, operate. By catering for the majority of the company's needs, the chapter indicates that the DSS is highly applicable to Company X. Where refinements to the DSS are required, these reflect the idiosyncratic procedures particular to the company and which would be difficult to have foreseen. For example, bringing the internal delivery date forwards by one day to account for inspection and accounting for the efficiency ratings of operators. It is important to keep the DSS as generic as possible, while satisfying the complex needs of the particular company. However, many ERP packages still require some tailoring to the needs of individual companies. The design process has emphasised flexibility in order to accommodate changes in the production environment of Company X and ease implementation within other companies. Not only may the needs of other companies differ, the needs of Company X may change over time, particularly as it is currently experiencing a period of growth and self-evaluation.

From the data analysis conducted, the most striking statistic is the delivery date adherence of the company. It is clear that Company X has struggled to meet delivery dates, with a large difference between the delivery lead times quoted to customers and those achieved in practice. Using such data analysis, it may be possible to categorise the PPC requirements of companies. Two types identified are described below, where the latter appears to be the case for Company X. This indicates that the company is appropriate for studying the particular strengths of the LUMS approach:

(1) *An issue of job release*: If an analysis of delivery date adherence were to illustrate that a company experienced the random distribution of early and late completion dates, this may indicate a poor approach to sequencing jobs on the shop floor, resulting from an inappropriate mix of jobs chosen at the job release stage. In such a scenario, it could be argued that delivery date adherence could be dramatically improved by redistributing resources from jobs that will be delivered early to a customer to those few jobs that will be delivered late. Hence, such a company could benefit from greater control at the job release stage to choose an appropriate mix of jobs to sequence on the shop floor.

(2) *A more fundamental problem:* If the data analysis of a company were to suggest that the majority of jobs are delivered late, this may indicate a more fundamental problem for the company stemming from the customer enquiry and job entry stages. The shop cannot be dramatically improved by simply reallocating resources to the most urgent jobs, as the majority of jobs are in need of expediting. This indicates a lack of I/OC at the higher planning levels.

In summary, Figure 6.5 presents a number of factors that contribute to the complexities of PPC in Company X. The figure is split into five contributory factors. The DSS described in Chapter 5 has been developed to maintain flexibility; for example, it is able to cope with various sources of uncertainty (such as, variable customer confirmation times and routing requirements) and accommodate a number of internal and external complexities (such as, lot splitting and customers not informing the company when a tender has been rejected). If the DSS is to be effective in practice, the process of implementation must work towards resolving more of the issues identified in the figure, for example, those relating to grouping machines into work centres and determining workloads and capacities. Hence, despite the functionality of the system, in order for the DSS to be successful it is essential that the company is prepared for implementation and works hard to sustain performance after implementation.

It is therefore concluded that Company X is a suitable company for Workload Control from the point of view of the company characteristics, although it is acknowledged that organisational politics have a key role to play in successful implementations. Thus, implementation strategies are explored in the next chapter, in order to investigate how political issues can be overcome.

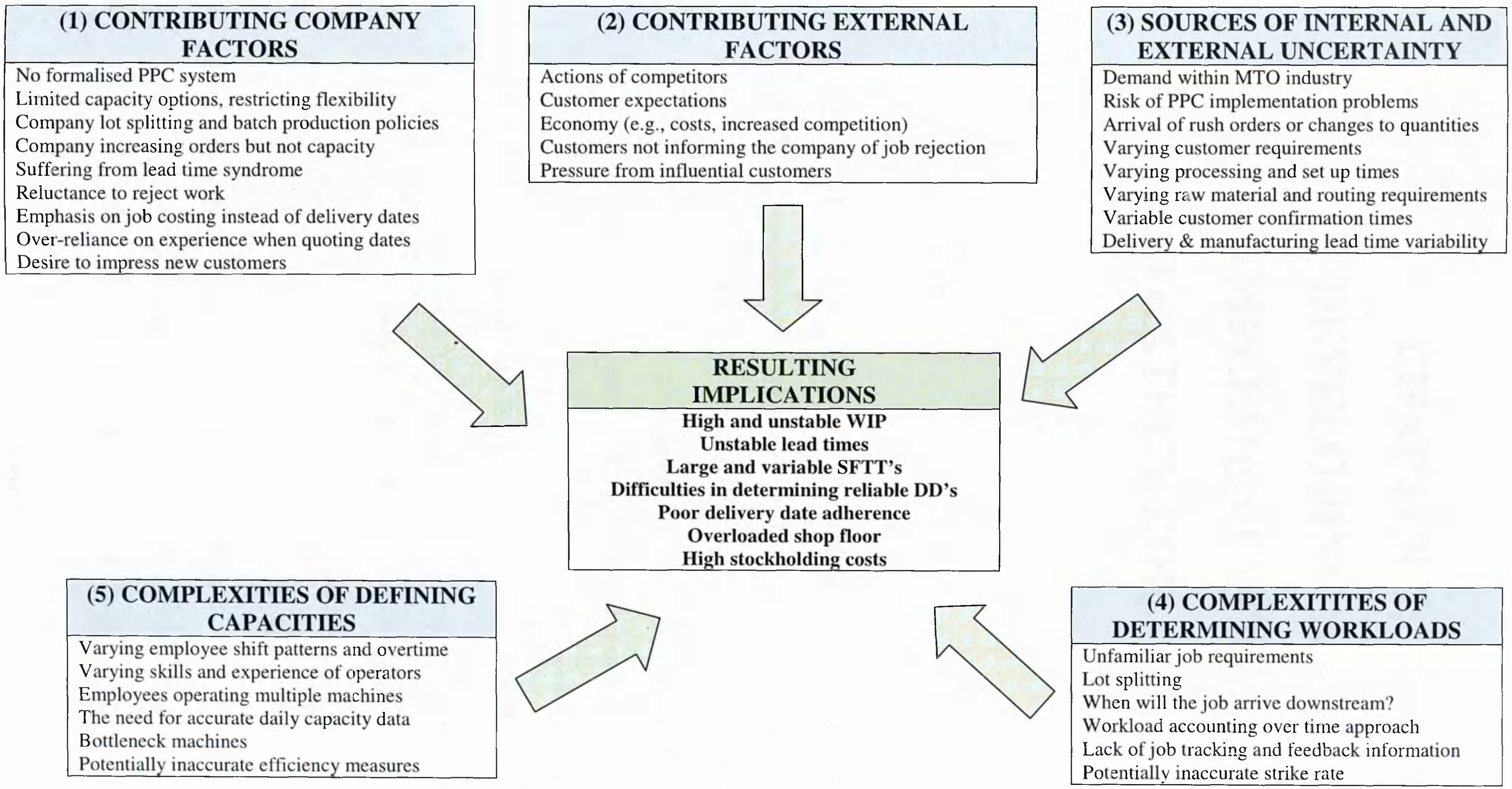


Figure 6.5: Summary of Contributory Factors to the Production Planning and Control Problem in Company X

CHAPTER 7: DEVELOPING AN IMPLEMENTATION STRATEGY FOR WLC

7.1 INTRODUCTION

The implementation of an Information System (IS) impacts upon the way an organisation is run, the roles of individuals and the distribution of power and authority (Laudon & Laudon 2001). Many implementation projects fail to meet the objectives set at the start of the project, as illustrated in the context of MRP and ERP systems in Chapter 2 (see, for example, Hong & Kim 2002). It has also been suggested that manufacturing firms have the lowest levels of satisfaction from the implementation of an IS (see Palvia & Palvia 1999). Hence, the implementation of systems, initiatives and innovations is a major research topic across many branches of literature. Therefore, the process of implementing the DSS developed in this thesis is likely to be a major project in itself, requiring careful change management and a clear implementation strategy. This chapter focuses on developing such a strategy to implement the LUMS approach within MTO companies.

Newell *et al.* (2003), in referring to Galliers & Newell (2001), explain that the information systems / Information Technology (IT) field has shown a tendency to embrace new concepts, leading to the field being inundated by a succession of fads. The authors explain that the problem is that the latest fads often appear to disregard the past, thus failing to learn from the literature. Although WLC cannot be described as the latest fad, and although every company is unique, it is acknowledged that it is important to learn from the experiences of other researchers in the wider literature when developing the implementation strategy. This necessity is further intensified by a lack of guidance towards the process of implementation in the particular context of WLC and the emphasis of much systems research on large companies, with a lack of empirical research involving small companies (see Doukidis *et al.* 1996; McGovern & Hicks 2004).

Therefore, the chapter begins by examining some of the relevant literature in the field of implementing information systems, both in the context of WLC and in the wider literature. This does not aim to be a definitive guide, but to draw attention to some important themes to consider when undertaking this process. The chapter presents a six step strategy towards the implementation and sustained use of WLC in practice before describing how specific steps have been followed in order to prepare the case study for WLC. The chapter therefore contributes to the second research question outlined in Chapter 1, in other words, identifying and addressing WLC implementation issues.

7.2 OVERVIEW OF IMPLEMENTATION LITERATURE

7.2.1 General Implementation Issues and Strategies

In order for an implementation project to be successful, it is first of all important to develop, or select, an IS that is appropriate for the contextual requirements of the company. In a study of success factors for ERP implementation, Hong & Kim (2002) highlight the importance of 'organisational fit' with the company, in other words, ensuring that the DSS is appropriate for the contextual requirements of the company. It is hoped that through the thorough approach taken to conceptual refinement and case study selection described in preceding chapters that the DSS will meet the requirements of Company X.

Although this is important, it is acknowledged that it is not usually the functionality of information systems that lead to implementation failure (see, for example, Petroni 2002), but less tangible aspects such as internal political factors (see Finlay & Forghani 1998; McGovern & Hicks 2004), company culture, the level of management support, degree of functional integration and data accuracy. Companies of different sizes approach implementation differently, such as in the case of ERP (see Mabert *et al.* 2003). Mabert *et al.* (2003) also suggest that the benefits of implementation can vary with company size, implying that company size is an important issue for implementation strategy and success. In addition, McGovern & Hicks (2004) explain that the IT requirements for a company pursuing a MTO strategy are very different to those of a MTS company. Hence, the size of a company and the industry in which the company operates play an important role in implementation. Company X is a small MTO company, and hence represents a sector that has received relatively little attention in the literature in this context.

It is important for any implementation project to have the backing of the powerful 'players' within the company, such as top-level management. Gaining the backing of management can be a particularly important factor when conducting empirical research with a small company. In a SME, such as Company X, it is inevitable that a small number of individuals have a very dominant influence on the strategy and culture of the company. McGovern & Hicks (2004) refer to Thong & Yap (1995) and Fuller (1996) when explaining that the success of implementation in small companies is strongly influenced by assumptions, expectations, knowledge, background and characteristics of the owner-manager. In a small company, where individuals are able to exact greater power and influence, the support of the managing director is particularly important (see McGovern & Hicks 2004). This support can help to enforce change on the company, provide credibility to the project and ensure the necessary financial resources are available.

Finlay & Forghani (1998) review the 'key actors' involved in decision support systems other than management, these include, for example, the end user, the systems builder, clerical staff and a 'DSS champion' for the project. The authors also emphasise the importance of maintaining the support and commitment of these key actors, such as by gaining the support of the direct superior to the user of the system in order to try to ensure that the DSS is used effectively. Emphasis is also put on ensuring that everyone is aware not only of how the DSS can help the company as a whole, but also the way it can help individuals, thus demonstrating the importance of the DSS to key actors within a 'business focus'. In a small company, such as Company X, it is likely that a number of these roles will overlap and be performed by a single individual. Due to his dominance in this project and within Company X, LN is likely to become a user-champion for the DSS.

The level of management involvement in this case study provides both advantages and disadvantages. One benefit is that management support will not be required to motivate the end-user, but to open up communication channels and reiterate the recommendations from the DSS onto the shop floor. This may include chairing regular meetings, creating cross-discipline teams and giving presentations to make it clear what the intentions of the system are and the impact the system will have on individuals and the company as a whole. On the other hand, as it is management that has been primarily involved in driving the project forwards, it could be argued that shop floor employees do not have a sense of ownership of the system. Without the DSS becoming accepted by everyone it will affect (such as the supervisor), a change to the current working practices may be resisted (directly or indirectly).

In an attempt to avoid resistance, before going ahead with implementation, it can be important to consider the following from the perspective of each stakeholder group (see Johnson & Scholes 1993):

(1) *Acceptability*: Are 'key actors' in the organisation in favour of the idea? What are the benefits and disadvantages of the change to the key actors? For example, will the supervisor see the DSS as a threat that will diminish his responsibility and scheduling flexibility?

(2) *Feasibility*: Does the organisation have the appropriate capability to implement the DSS? For example, can sufficient feedback information be supplied?

(3) *Suitability*: Would the course of action sustain or improve the effectiveness and efficiency of the organisation? For example, will this lead to a long term sustained improvement in the strike rate of the company?

Resistance to change is particularly prevalent if a new system is replacing existing and well-established working practices. Resistance may also be associated with the previous experiences of employees in implementation projects and the notorious difficulties involved. For example, previous implementations may have had a negative impact on morale and threatened the financial stability of the company.

Laudon & Laudon (2001) suggest that the satisfaction of the user should be directly considered in the design and implementation of the system. Joshi & Lauer (1998) summarise some of the perceived potential *impacts* on the working environment of employees when facing the implementation on an IS system. Possible positive outcomes of implementation include a useful system, a more pleasant working environment, more opportunity for (career) advancement and better service to customers; negative outcomes could include reduced job satisfaction, threat of job losses and reduced importance / control. The authors explain that implementation may also affect *inputs* from the user in a positive or negative way. For example, a new information system may mean more data input for the employee, require the user to learn new skills and increase anxiety for the user. On the other hand, it may reduce the need to search for an effective solution to a problem, reduce manual effort required and result in less rework previously caused by errors.

If employees anticipate a negative impact on their working environment as a result of a new IS, they may decide to sabotage this in some way. Laudon & Laudon (2001) refer to Keen (1981) in stating that an implementation strategy must address the issue of counter-implementation. The authors explain that counter-implementation relates to a deliberate strategy to thwart the implementation of an information system or innovation in an organisation. Cooper (1994) finds that when information technology conflicts with the culture of an organisation it can be resisted in one of two ways, thus reducing the potential of implementation. Firstly, employees may undermine the analysis and design process: if the system is developed the potential of it will be under-utilised or the implemented system sabotaged. Secondly, users may adapt the system (to suit their needs) once implemented or use it in a way that reduces conflict.

A further issue for consideration is the relative importance of the project to the company compared with other projects that the company are currently involved with. It could be argued that by developing and implementing MAIS at approximately the same time as this DSS, Company X will already be culturally well prepared for implementation. However, the relative importance of the DSS compared with MAIS must be considered. Company X have committed more resources to MAIS over the past three years than to this DSS and hence may see MAIS as a more crucial system to implement, although the direct benefits of MAIS may be less tangible. The two systems will have the same user and same support network; as a result the two projects are closely linked. If the eventual implementation of MAIS fails, this will have inevitable repercussions for the WLC system in the future. The company have also expressed a wish to sell MAIS to other companies if it works well within Company X. As a result, the outcome of the implementation will have a substantial impact on the long-term strategy of the company.

In the context of ERP and Knowledge Management systems, Newell *et al.* (2003) describe how the two systems can be implemented in tandem, complementing each other to good effect. The authors refer to Alavi & Leidner (2001) in explaining that this is currently a common trend across organisations. However, the authors warn that this effect is not automatic, and must be fostered. It is hoped that a similar outcome can be fostered in the context of WLC and MAIS.

It may also be possible to learn from other sources of implementation literature, such as project management and lean manufacturing. Designing, developing and implementing an information system is a major project, and like many other major projects it can suffer from exceeding time and budget constraints. Hence, the implementation of an information system could benefit from the use of project management techniques such as project network analysis, the critical path method and from the Programme Evaluation and Review Technique (PERT). For an introduction, see for example, Slack *et al.* (2004).

Implementing JIT often requires a change of company culture and philosophy (see, for example, Schonberger 1982; Shingo 1989; Schniederjans 1993). Although the lean manufacturing ideas underpinning WLC and JIT are similar, they are designed for different production environments. Schniederjans (1993) discusses the idea of implementing projects in isolated areas followed by an extension to other areas of the business once employees have seen the benefits of a technique and are more receptive; however it is debatable whether this would be a workable solution in the context of WLC. An alternative would be to use a prototype to demonstrate the benefit of a DSS, as described in Chapter 5 and as used by De Souza (1995) in a MTO context.

7.2.2 Workload Control Implementation Problem Issues

The problems encountered when implementing ERP packages have been previously highlighted; similarly, previous attempts to implement WLC have often proven difficult. This is inevitable given the lack of prior empirical research and guidance. In addition to this, there are many cultural obstacles, such as overcoming the lead time syndrome, that need to be overcome before WLC can be successfully applied. Hendry (1989) encountered a number of these cultural issues when attempting to apply WLC in practice. This led to only a partial implementation of WLC, with the user often misusing the system. The user tended to ignore the advice of the system and instead chose to force release jobs onto the shop floor in a similar fashion to before implementation. Hence, the system was utilised more as a storage system for job information than as a DSS for controlling workloads.

Hendry *et al.* (1993) discuss the case of an artist's studio, where ultimately WLC was also not widely used. The authors note long delays between completion of the DSS and implementation, in order to find an end-user, purchase a new computer and to link the system to an existing database. In this case, the end user was a member of the secretarial staff and did not have sufficient production planning experience. Hence, the operator once again misused the system. The authors also noted a lack of historical data meaning norms such as shop floor queuing times and average required rework had to be determined by management, and will be in need of adjustment through time. The case was valuable in illustrating a number of problems implementing WLC and highlighting the need for local knowledge in determining parameters. Many of the problems encountered related to the assignment of an inappropriate user; this is an obstacle that this research has sought to avoid. Difficulties obtaining sufficient historical data have also been noted in the context of Company X. Although Chapter 6 demonstrates that a substantial amount of data was collected manually, management are also likely to have an important say in the setting of parameters, promoting ownership of the DSS.

7.2.3 Existing Workload Control Implementation Strategies

Simulation experiments have begun to assist in the setting of WLC parameters, as previously described (see Perona & Portioli 1998; Land 2004a), while some additional insights into other WLC implementation requirements can be gained from the limited number of previous empirical implementation projects. However, not only is there a lack of previous empirical research, many of the existing papers do not discuss implementation issues in detail beyond those of software requirements, thus failing to give a sufficient insight into the full complexities of implementing WLC in practice.

Bechte (1988) touches on the issue of start up effects, similar to those commonly found in simulation. When implementing a new system, it will take time for appropriate parameters to be determined. In addition, the shop floor is a constantly changing working environment; thus it will take time to capture the current state of the shop floor at the moment of implementation. As is the case with Company X, Bechte (1988) notes that some machines in the company are only used now and again. For such machines the author explains that the machines are given 'full capacity' to avoid difficulties encountered at the job release stage (essentially disregarding the practical limitations of such machines). In the case of Company X, the machines will be given sufficient daily capacity if it is available at the 'partner resource' (the resource from which an operator is allocated). This is elaborated upon later in this chapter (see Section 7.4.2).

Bechte (1994) describes how, for the implementation of Load Oriented Manufacturing Control, a new calendar was installed for lead time calculations and backwards scheduling in addition to a new work centre data file and the design of a new transaction data file. Every company will be in a different stage of readiness for implementation, meaning that the implementation strategy required for each company is very different. Park *et al.* (1999) describe the development of a DSS programmed using C and Oracle languages and discuss the pre- and post-implementation state of the case study company. However, the authors offer little in the way of explaining how in depth issues involved at the implementation stage were addressed.

Fry and Smith (1987) offered six practical steps towards implementing an Input-Output Control system, as listed below:

(1) Change from local efficiency measures to global throughput measures

(2) Identify bottlenecks to determine the maximum system throughput

(3) Set maximum inventory levels between work stations

(4) Reduce production lot sizes

(5) Work on the correct items

(6) Set input equal to output

To a limited extent this can be applied to Company X; however, although the case presented by Fry & Smith (1987) is of a job shop, items appear to be standardised, hence the more continuous nature of production means that this has limited relevance. Step one relates to the targets employees are set, and how these should not be based on individual efficiencies. Although operators in Company X are given efficiency ratings, these are not public knowledge and there is little emphasis on improving these, but simply accounting for these in capacity considerations. Rather than becoming preoccupied with efficiency ratings, operators concentrate on clearing the queue of work in front of their machine and as listed under each machine on the supervisor's white board. In step two bottlenecks should be determined; in the case of Company X however, additional emphasis will not be placed on these resources, although the supervisor can pay extra attention to any bottlenecks if he deems it necessary. The merits of bottleneck oriented production planning methods were explored in Chapters 2 and 4 of this thesis. Step three relates to setting maximum inventory levels and is applicable as backlog limits are set for all work centres; however, this framework fails to provide any real guidance for determining what these inventory levels should be.

Step four proposes a reduction of lot sizes. This must be considered if quantities become too large and repeat purchases are being batched together. However, this was emphasised because of the standardised nature of production in the case study presented by Fry & Smith (1987). Step five relates to job release and the scheduling and sequencing of jobs on the shop floor. If the company consider the slack of jobs (based on the LRD when in the pool and based on OCD's when on the shop floor) then this will ensure that they are working on the most urgent jobs. This can also be supplemented by priority considerations. Step six states that input should be set equal to output. The DSS will ensure that this is met at each stage in the hierarchy of backlogs; however, this is particularly emphasised in the approach taken to backwards scheduling.

Wiendahl (1995) provides some guidance for the implementation of Load Oriented Manufacturing Control, emphasising the need to provide, for example, information regarding machine availability, personnel capacity and feedback information. This includes a discussion of the possibility of automating some shop floor processes and improving the flow of shop floor information; however, there is limited scope to apply such ideas to Company X at present. Like Fry & Smith (1987), the author provides six steps towards implementation, where each stage has been considered during this case study, as detailed below:

(1) Manufacturing Analysis, e.g., analysing the current performance of the company.

(2) Manufacturing Process Improvement, e.g., changing attitudes and procedures.

(3) Feedback Accuracy Improvement, i.e., exploring ways of promoting the feedback of information from the shop floor.

(4) Monitoring System, i.e., setting up a system to measure shop performance.

(5) Checking Present Manufacturing Control, i.e., monitoring the shop and promoting continuous improvement.

(6) Load Oriented Manufacturing Control, i.e., working towards an implementation strategy for the LUMS approach.

Wiendahl (1995) also explains that if implementation is beginning from the start, in other words if the company is considered totally 'unready' for implementation, at least a year must be spent at each step to ensure permanent improvement can be expected, and if some steps have already been taken, the minimum time for implementation is two years. The research described in this thesis has been conducted in close collaboration with Company X for over eighteen months. While the majority of the first year focussed on systems development and applicability, the research has also continuously worked towards implementation. Given the state of the company when the research commenced and given that Wiendahl (1995) considers the minimum time for the implementation of LOMC to be two years, it is unsurprising that a full implementation of the LUMS approach has not been achieved during this research project. Therefore, the aim has been to investigate implementation factors important to the application of WLC in practice in parallel to improving information availability.

Further WLC Considerations of Relevance to Implementation Strategy

WLC literature has also recently begun to advocate the use of grouping machines as a means to improve the feasibility of implementing WLC in practice. The most notable contribution comes from the University of Groningen; see, for example, Henrich

(2005). The reasons why machines should be grouped in practice include the following:

- Having a large number of individual machines on the shop floor makes it difficult to ensure that the necessary level of detailed feedback information required by the aggregate load oriented WLC method can be provided. By grouping machines, individual machine data can be collated within the work centre and reported back to the system at regular intervals.
- Grouping machines can simplify the WLC system and make it more manageable. For example, less PBL limitations have to be considered when planning jobs and less RBL limits have to be considered at the job release stage.
- Grouping machines also reduces the number of parameters that have to be determined as less workload restrictions and less queuing norms are required, thus simplifying implementation requirements.
- Under various shop conditions, including job shops, it has been shown that beyond a certain point, the performance improvement resulting from increasing the number of shop floor feedback points on the shop floor becomes minimal (see Henrich *et al.* 2003).
- Grouping machines that are interchangeable means that the decision of designating jobs to a particular machine can be delayed, thus providing greater short term scheduling flexibility (see Henrich *et al.* 2004). The supervisor has more freedom to allocate a job to a machine at a later date, a rare and valuable commodity in such a highly changeable environment as the job shop.

- When attempting to expedite a job, alternative routings do not have to be considered, as similar machines will already be grouped together using one backlog of work / capacity grouping.

A final implementation issue to consider is the need for training in WLC. From a series of interviews conducted within 39 companies (including planning and control and MRP problems), Finlay & Forghani (1998) conclude that there appears to be no need for either the user or staff intermediary to know the DSS programming language or understand the methodology underpinning the DSS. This should be true to some extent in the case of WLC; however, the use of WLC is based on a number of ideas that may clash with traditionally held views in manufacturing scenarios. This is an issue also touched upon by Wiendahl (1995) who explains that for implementation, companies must give up the 'traditional concepts' of manufacturing. Hence, as has been found in the implementation of other types of information systems, the successful implementation of WLC may hinge on overcoming cultural issues, rather than the functionality of the system. In the context of Company X, the implementation of the LUMS approach requires cultural change towards the following:

(1) The delivery date determination procedure
(2) The moment at which production commences (Job Release)
(3) The scheduling and sequencing alternatives available to the supervisor
(4) The way the shop floor feeds back information
(5) The attitudes of planners with regards to idle (non-constraint) machinery (it may be advantageous to delay the release of some non-urgent jobs even if machines will become idle, i.e., setting some minimum RBL's equal to zero)

(6) Attitudes towards rejecting jobs when resources are overloaded and delivery dates infeasible

7.2.4 Summary of Implementation Factors

From this opening discussion it is clear that there are many factors that affect the success of an implementation process. Hence, the implementation of a new PPC initiative is a major project that should not be underestimated. It is possible to learn from previous insights in the literature; however, a great deal depends on the individual factors most prevalent in each practical scenario, such as those factors specific to the individual company and the concept being implemented. However, the ground work for this implementation process has been completed rigorously as, for example, the concept is MTO specific, has the backing of top level management and will be used by an experienced member of staff. Figure 7.1 below summarises some of the factors that have been touched upon in this opening discussion and that may impact the outcome of an implementation project. The figure helps to make sense of the wide range of issues that have been touched upon in this opening discussion, before a strategy for implementing the LUMS approach is formulated based on the research conducted so far in this thesis.

The figure splits implementation issues into three categories: issues of company culture and company specific characteristics – many of these will vary with the organisation and industry; issues of project readiness, preparation and commitment – such factors can be fostered / promoted; and issues relating to systems development and their contextual applicability – many of which relate to issues of organisational fit.

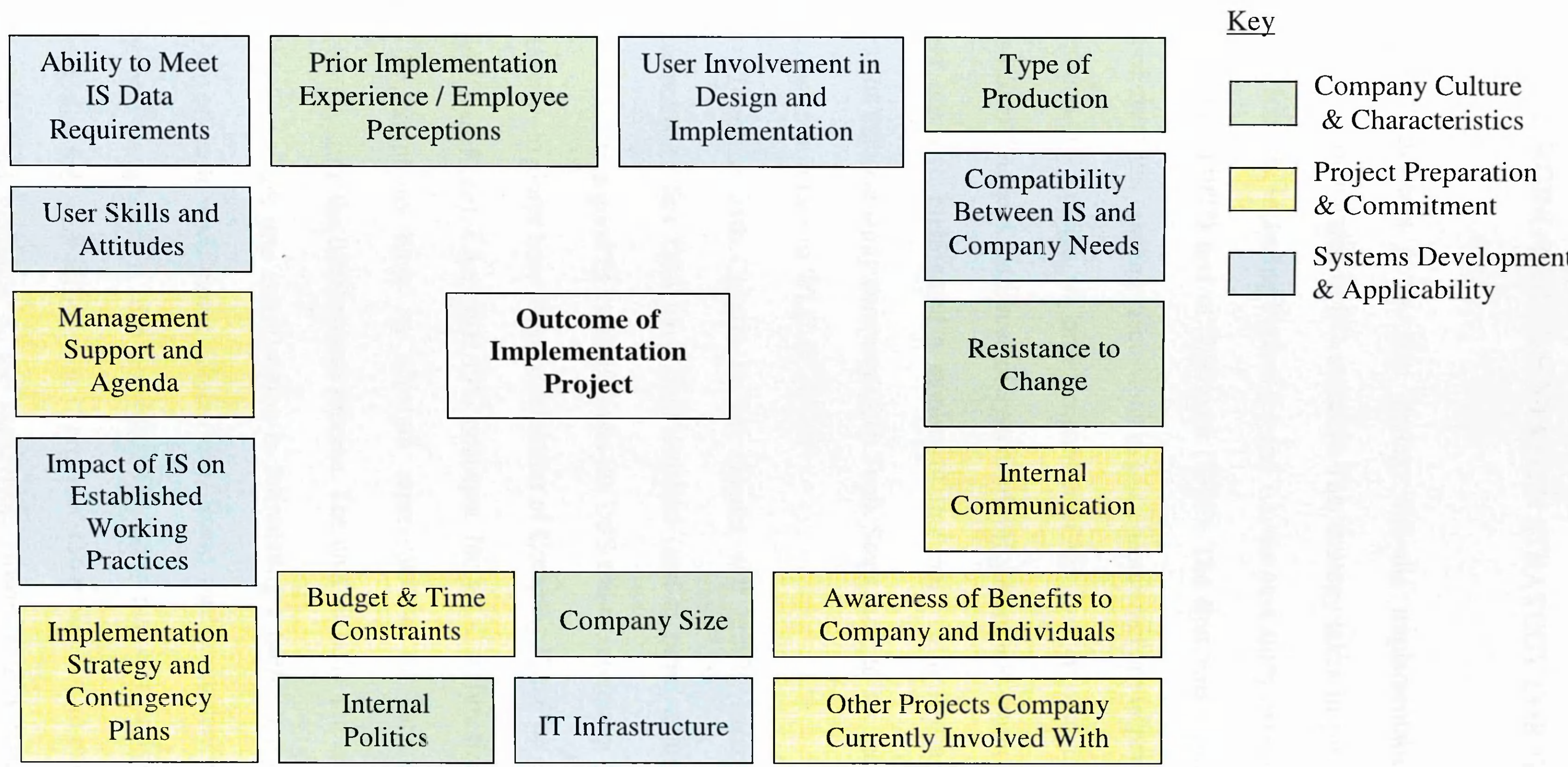


Figure 7.1: Factors Influencing the Outcome of an Implementation Project

7.3 AN EMERGING IMPLEMENTATION STRATEGY FOR WLC

Figure 7.2 presents a six step strategy for the implementation of the WLC methodology developed in this research. This strategy takes inspiration from a wide range of sources, including Figures 6.5 and 7.1, the case study experience, the work of Fry & Smith (1987) and of Wiendahl (1995). The first two steps are also largely deduced from the opening discussions in this chapter and are important issues in any implementation process. A large proportion of the first six chapters have revolved around *Step One* and the issues of systems development and applicability, while this chapter has also highlighted a number of important cultural change issues in the context of the case study company (*Step Two*). Steps three to six focus in on issues of particular importance to WLC.

Together with Chapter 8, this chapter will briefly explore how the data requirements of this DSS have been satisfied (and at times adjusted) for the case study, to ensure a good fit exists between the DSS and the company (*Step Three*). This chapter also explores how the core machines of Company X can be grouped into work centres (*Step Four*). Like other PPC concepts, for WLC to function effectively it is also important to have an accurate representation of capacity without this overcomplicating the development process. The chapter takes the case study's ad-hoc efficiency measure into consideration in formulating a useful approximation for the capacity of each work centre (*Step Five*). Some further guidance for determining norms and parameters is also provided. The other major requirement for WLC is ensuring that feedback information is provided (*Step Six*). To an extent this relies on the support and vigilance of the supervisor. However, this issue has also been extensively catered for in the design of the DSS (see Chapter 5).

Figure 7.2 also emphasises the need to take a continuous review and improvement approach. Rather than seeing WLC as a one-off project, it is important to monitor the status of norms and parameters, to ensure that capacity approximations remain accurate and that a disciplined approach to feeding back information from the shop floor is maintained if the performance improvements expected from WLC are to be sustained. Norms and parameters can also be altered over time to act as targets for direct and indirect employees, to reflect increasing management expectations and to reflect changes within the industry.

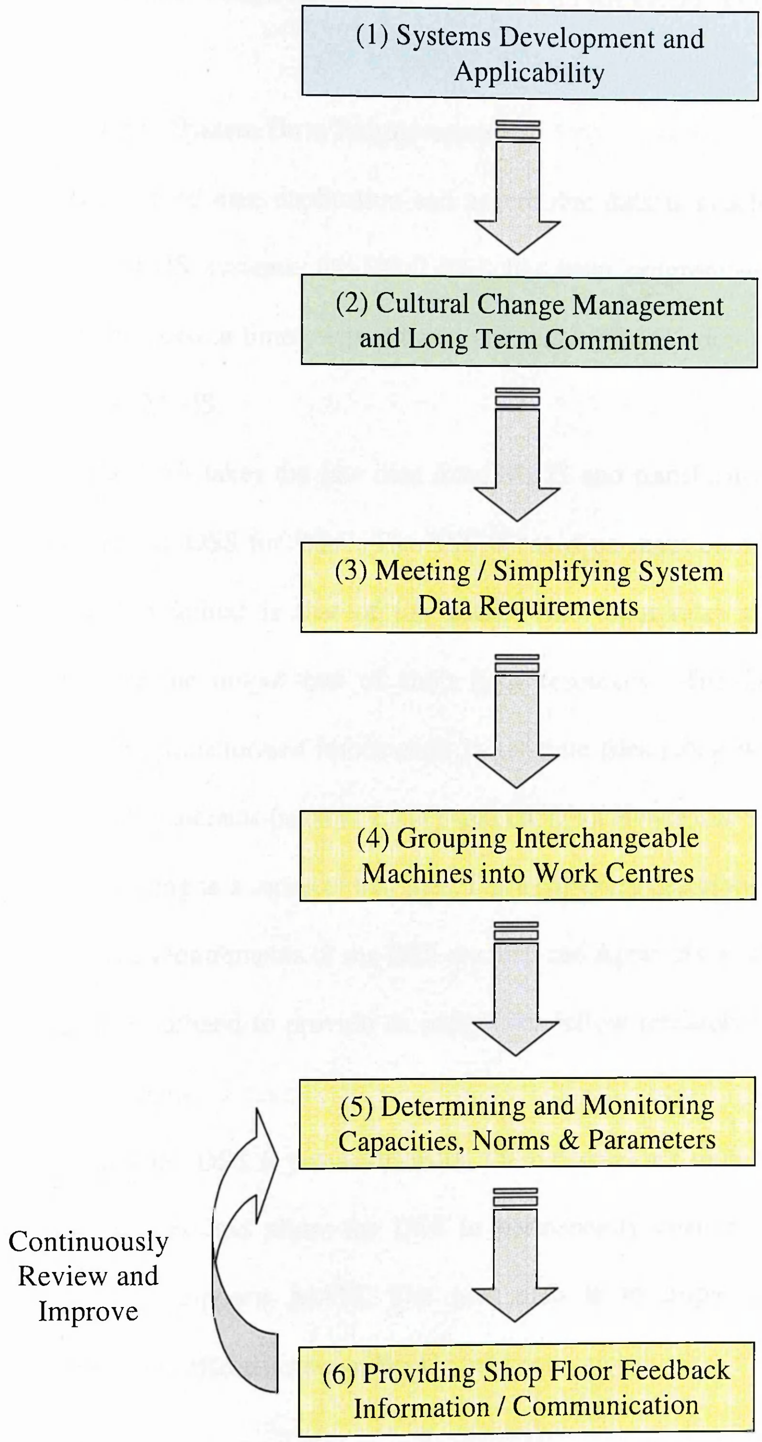


Figure 7.2: Six Step Implementation and Continuous Improvement Strategy

7.4 APPLYING THE IMPLEMENTATION STRATEGY TO COMPANY X

7.4.1 Meeting System Data Requirements

In order to avoid user duplication and ensure that data is synchronised between the DSS and MAIS systems, the WLC DSS has been programmed to import product routings, processing times, set up times and quantities, in addition to basic employee details from MAIS.

The DSS takes the raw data from MAIS and transforms this into the format required by the DSS for WLC. The DSS is based on input-output control; hence, the information required is that of job details (the input rate) and employee details (determining the output rate of shop floor resources). The DSS then stores and maintains the transformed information in separate files along with additional details that the DSS generates (such as LRD's and OCD's). Hence, the DSS relies on reading from and writing to a series of text files. For a complete description of file formats and how the data requirements of the DSS are met, see Appendix 1. The data saved by the DSS is also outlined to provide an insight for fellow researchers developing similar software systems.

Until the DSS is proven to work, the company are reluctant to fully integrate the two systems and allow the DSS to permanently change and add data to the database that supports MAIS. The next step is to implement the system and demonstrate the effectiveness of WLC to the company.

7.4.2 Grouping Machines into Work Centres

As described in Chapter 6, the shop floor of Company X consists of twenty three core machines. For the implementation of the DSS, where possible, shop floor machines have been grouped into work centres. Despite the advantages summarised in Section 7.2.3, the grouping of machines into work centres can be a difficult process. A company often accumulates machines over time; hence they vary in age, specification, processing speed and set up times, making it rare that they are completely interchangeable, therefore distorting the capacity of the work centre. As a result, to maintain control over information feedback, it can be necessary to group semi-interchangeable machines. This was highlighted in Table 6.3, where the age and replacement cost of machines in Company X is provided.

Also as described in Chapter 6, in the case of Company X, employees operating shop floor machines are commonly skilled in one or perhaps two value-adding activities (covering a number of machines), while it is also possible for employees to simultaneously operate two machines at once, at a reduced level of efficiency. Hence, employees tend to be allocated to a single machine or a pair of machines and can be reallocated to a discrete number of alternatives. Past research has suggested that cross training operators in at least two different departments can improve shop performance (see Kher & Malhotra 1994) and improve flexibility by providing more options to reallocate operators; however, more recent results have found that multi-skilling can have an adverse impact in the context of MTO production (Muda & Hendry 2003), see also Stratman *et al.* (2004) for a further exploration of the effects of skill dynamics. Grouping machines can provide greater flexibility not only for allocating work, but also for allocating operators to resources. The limited amount of reallocation available within Company X provides a compromise between the two viewpoints and could arguably improve performance and flexibility by providing a useful means to facilitate short-term capacity adjustments within the DSS.

Machines were subsequently grouped into twelve work centres (see Table 7.2 on page 260) consisting of between one and four machines, based primarily on the functional capabilities (interchange-ability) of the machines and the skills of employees. For example, similar machines that an employee was likely to operate at the same time would logically fit together into a work centre and it would have been difficult to separate the capacities of the machines if they were not to be grouped. It can also be important for grouped machines to be physically located near to each other on the shop floor. The milling, drilling, grinding and sawing operations, where no operators are permanently allocated, can also be accommodated.

Tailoring the DSS to Work Centre Requirements

The provision for the four 'unmanned work centres' is one of the areas in which the DSS has to be directly tailored to the needs of the company. Within Company X, each 'unmanned work centre' is paired with a work centre to which operators are permanently allocated and from which operators are reallocated when required at the 'unmanned work centre' with which they are paired. When one of these peripheral operations is required, the capacity of the work centre from which the employee is reallocated is depreciated to reflect the workload of the job. This can also be incorporated within the backwards scheduling procedure. The DSS must find available capacity at the appropriate 'manned' work centre and reallocate this when it is required elsewhere; alternatively the user can do this through manual adjustments in the capacity management module.

To clarify, supposing it is known in advance that when a job requires milling, a CNC operator moves across to complete the task when they are next available to do so. Therefore, to schedule the job, the DSS must find available capacity on the CNC machine and move this across to milling. Unless a specific job has been scheduled or the user has manually changed capacities, the daily capacity of milling will be zero. An alternative solution would be to omit the operations from the DSS altogether on the basis that they are rarely used, or give the operations unlimited capacity, as described by Bechte (1988). However, although the operations are required infrequently, when they are required, the work content of the operations is relatively high and should be accounted for in the system. The DSS has also been tailored to account for a day required at the end of the routing of each job to inspect products before delivery, by bringing the 'internal delivery date' forwards by a day, to ensure that enough time is allowed for quality control before dispatch.

The Interchange-ability of Machines

A number of the resulting machines within work centres are interchangeable, while some are approximately 80% interchangeable, a percentage considered sufficient by management. For example, two CNC machines were grouped into a work centre (Citizen L25 and L32), where one machine could be used with metal up to a thickness of 25mm and the other up to a thickness of 32mm. Hence, jobs arriving at the work centre with a thickness of up to 25mm can be processed by either machine; hence, for such jobs the two machines are 100% inter-changeable. However, jobs with a thickness greater than 25mm can only be processed by the one machine. The supervisor can be empowered to look ahead at the requirements of imminent jobs about to be released from the pool or from a previous operation and utilise the capacity of the unrestricted machine accordingly. However, this illustrates that grouping machines into a single work centre has to be performed cautiously and is only feasible if the machines can perform similar or identical tasks. In a heavily overloaded situation, if two machines that are not wholly interchangeable are grouped together, this could lead to serious delays in the throughput of a job. In this example, if the company had a particular mix of jobs where all involved steel with a thickness of 32mm, it is likely that one machine would be idle and the other machine would be heavily overloaded. This is a risk that is accepted as a compromise necessary to gain the advantages of grouping machines, and is considered by management to be unlikely to occur in practice.

7.4.3 Determining Capacities

The determination of work centre capacities is affected by a combination of machine and employee specific factors, making the shop more difficult and sophisticated to model. Due to the relationship between the output rate of machines and the number of operators and their efficiency, employee shift patterns and attitudes towards overtime directly affect capacity. In addition, if employees are reallocated to other work centres, the number of existing operators at the corresponding work centre will affect the impact that reallocation has on capacity. Issues relating to the interchange-ability of machines were explored in the previous subsection; therefore this subsection focuses on employee specific factors.

The efficiencies calculated by management are either subjective estimates or based on a small sample of historical data, hence accurately modelling the specific working patterns of employees, and accounting for each individual's efficiency rating, within a single day would not necessarily yield an accurate representation of capacity.

It is also assumed by management that employees who are reallocated to another work centre can operate the machinery at the same efficiency with which they are able to perform their core operations. The overtime that different employees choose to work can vary widely, resulting in employees often running a work centre on their own, and hence at a reduced level of efficiency. Overtime is largely independent of the load of the shop, although the shop is generally overloaded at present, contributing to this relaxed attitude.

Figure 7.3 provides a simplified illustration of the complexities involved in capacity determination for Company X when incorporating the company's existing efficiency measurement method. The six operators shown in Figure 7.3 operate two machines at a work centre at differing times. The shaded part of the bars represent when the two machines are both running at 100%, in other words, two operators are present at once and are operating one machine each. The numbers on the bars indicate how many machines each worker is operating at a certain time. When the complete employee shift pattern illustrated in figure 6.2 is considered, the full extent of the sophistication of this situation can be understood.

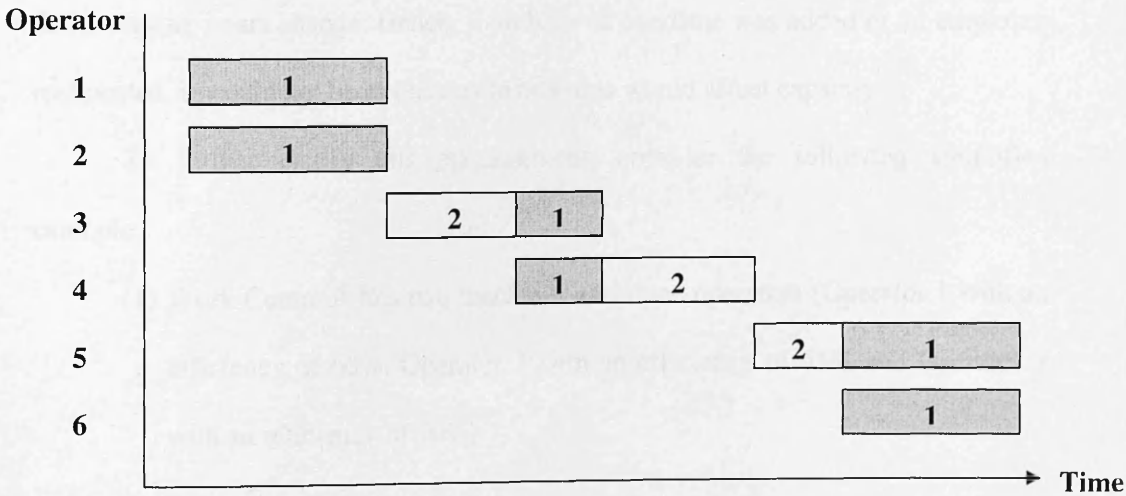


Figure 7.3: Operator Distribution and Machine Allocation at a Work Centre

Considering the concerns regarding the accuracy of data, and the level of information available, it was considered sufficient in the short term to employ a simplified rule of thumb, in keeping with the simplistic nature of the aggregate WLC concept. The intention of using a simplified rule of thumb was to avoid the concept becoming too sophisticated for a potential small increase in accuracy. A number of ad-hoc and simplified methods for determining capacity were explored; however, a simple approach based on the average work centre capacity per operator hour has been applied to the model.

The expected capacity of each work centre, based on the typical shift patterns of each employee and their individual efficiencies (including normal overtime), was determined. From this, an average output rate per employee hour at work can be found and used as an approximate measure. Therefore, should operators be absent, be reallocated or overtime used, the capacity of the work centre can be altered based on the change in hours and capacity per man hour value (work centre efficiency rating). The average capacity per employee hour is more useful than, for example, the average capacity per machine hour, as this cannot be adjusted as the number of employees and their working hours change. Hence, if an hour of overtime was added or an employee reallocated, it would not be as clear as to how this would affect capacity.

To further clarify this measurement, consider the following simplified example:

(1) Work Centre A has two machines and three operators (Operator 1 with an efficiency of 60%, Operator 2 with an efficiency of 65% and Operator 3 with an efficiency of 70%).

(2) Operators 1 and 2 work the day shift each week (8 hours a day in this simplified example, Monday to Friday). Hence, both operate a single machine at an efficiency of 100%.

(3) Operator 3 works alone on the night shift each week (8 hours a day, Monday to Thursday). Hence, Operator 3 runs both machines at an efficiency of 70%.

(4) Operator 1 works regular overtime on Saturday mornings (4 hours), running both machines at an efficiency of 60%.

(5) Therefore, the total number of man-hours in this average week is equal to 116.

Hence, the work centre capacity (machining hours) per man-hour ratio, is as follows:

[(8hrs x 1 machine x 5 days x 100%) + (8hrs x 1 machine x 5 days x 100%) + (8hrs x 2 machines x 4 days x 70%) + (4 hours x 2 machines x 1 day x 60%)] / 116 operator hours.

Therefore,

Work Centre Efficiency, E_w = 1.12, or 1.12 work centre hours to every 1 operator hour.

The equation for calculating the capacity of work centre w on day d (C_{wd}) is therefore given by (1) below, where capacity can be manipulated by changing the operator hours allocated to a work centre on a given day or by altering the efficiency rating of the work centre.

$$C_{wd} = E_w \text{ x } OH_{wd} \quad (1)$$

where,

C_{wd} = Capacity of work centre *w* on day *d*

E_w = Efficiency value for work centre *w*, based on an average week

OH_{wd} = Operator hours allocated to work centre *w* on day *d*

This simple approach means that the identity of operators does not have to be specified when reallocating operators or applying overtime. In reality, identifying operators is also unlikely to be feasible, as it may be difficult to attribute a piece of work to one operator or to specify which operator is being reallocated when decisions have to be made quickly and user input into the system kept to a minimum. In addition, it is unlikely that overtime could be offered to one employee individually, hence two hours of overtime may lead to two operators working an hour each rather than one operator working for two hours.

The proposed method for determining capacities is equal to the measure used by management based on aggregated weekly operator hours and capacity data but varies slightly at a daily level. Hence, on days when the operator hours are 'typical', the approximation is likely to correlate more closely with capacity in practice. This can be illustrated using Work Centre 1 (Cinc 2 & 3) and the data provided in Table 6.2 and 7.1.

(1) Operators 1 and 2 work the day shift. In practice this equates to 7.75 hours a day, Monday to Thursday, and 6 hours on a Friday. Both operators have an efficiency of 70%.

(2) Operator 3 works the night shift. In practice this equates to 7.75 hours a day, Monday to Thursday. Operator 3 also has an efficiency of 70%.

Therefore, on a typical day, between Monday and Thursday, the 'actual' capacity of the work centre using the approach favoured by management is equal to:

[(7.75 hours x 2 machines x 100%) + (7.75 hours x 2 machines x 70%)]

= 26.35 hours capacity

The total 'actual' weekly capacity (Monday to Friday) is equal to:

[(26.35 x 4 days) + (6 hours x 2 machines x 100%)]

= 117.4 hours capacity

Using the approximation measure developed in this chapter, the capacity of the work centre on a typical day, between Monday and Thursday, is equal to:

E_w x OH_{wd}

= [1.12 x (7.75 hours x 3 operators)]

= 26.04 hours capacity

Using the approximation measure over the week, the estimate of capacity is equal to:

(7.75 hours x 3 people x 4 days) + (6 hours x 2 people x 1 day) = 105 hours

1.12 x 105 hours = 117.6 hours capacity

The accuracy of this approximation is summarised in Table 7.1 below:

Shift Pattern	Actual Capacity (Hrs)	Capacity Approximation (Hrs)	Error (Hrs)	% Error
Typical Day	26.35	26.04	0.31	1.18
Typical Week	117.40	117.60	0.20	0.17

Table 7.1: Summarising the Performance of the Capacity Approximation Measure

The discrepancy on a daily level is considered relatively small, and the error is outweighed by the speed and simplicity of the calculation. As many delivery dates are set for the ending of a certain week and as WLC operates at the upper planning level by providing aggregate planning for a work centre on a daily basis, it is not envisaged that this will cause major additional problems. In this sense, the model is able to maintain simplicity without affecting the performance of the WLC concept.

When planning production, the supervisor can be left to consider the current job mix and determine the sequence of jobs, whether a job should be performed on a single machine and who should operate the machine(s) based on their skills and experience. Fixing the average value to employees rather than machines or work centres allows more opportunities to dynamically manage capacities across work centres and more clearly see the impact of changing employee allocation and overtime. By using an average capacity per man-hour, it would be possible to find a reasonable estimate for capacity based on the number of man-hours per work centre. However, it is difficult to separate employee working hours from work centre hours to distinguish individual machine hours. Hence, this further complexity of determining capacities adds to the need to group machines into work centres, as for some machines, capacities are not independent of each other.

The DSS has been tailored to account for this efficiency rating and management can also intervene and change the average hourly output rate within the system. However, it is also acknowledged that by increasing the capacity per man-hour ratio, the company can instantly / artificially reduce the backlog lengths. Furthermore, if a new operator is added to a work centre, the operator hours assigned to the work centre are likely to increase, therefore so will capacity. However, it may be helpful for the user to initially reduce the efficiency rating of the work centre if the operator is unfamiliar with the activity / less experienced than other members of the team.

Table 7.2 summarises the process of grouping machines into work centres, the capacity conversions and the reallocation possibilities available for output control. Hence, the grouping of machines and the capacities of work centres have been influenced by both the 'interchange-ability' of the machines and of the operators.

WC No.	Work Centre Name	Machines	Capacity : Operator Hour Ratio	Reallocation Options
1	Cinc 2 and 3	Cinc 2 Cinc 3	1.12 : 1.0	Matsuura 510 and 660
2	Matsuura 510 and 660	Matsuura 510 Matsuura 660	1.19 : 1.0	Cinc 2 and 3
3	Citizen L25 and L32	Citizen L25 Citizen L32	1.3 : 1.0	Citizen M20 and M32
4	Citizen M20 and M32	Citizen M20 Citizen M32	1.35 : 1.0	Citizen L25 and L32
5	CNC Lathes	ACT 3 ACT 20 Dooturn Superturn	1.3 : 1.0	Milling
6	Triumph 2000	Triumph 2000	0.9 : 1.0	Deburr
7	Hardinge HC3	Hardinge HC3	0.9 : 1.0	None
8	Deburr	Various	0.87 : 1.0	Triumph 2000, Drilling, Saw, Grinding
9	Milling	Anayek Turrert Mill	1.0 : 1.0	Not Applicable
10	Drilling	Meddings 4 Spindle Arboga EM825 Arboga U2508	1.0 : 1.0	Not Applicable
11	Saw	Startrite Vert.Band Horizontal Bansaw	1.0 : 1.0	Not Applicable
12	Grinding	Myf. MG12 Cyl A/Size Myf. MG12 Cyl Jones and Shipman	1.0 : 1.0	Not Applicable

Table 7.2: Summary of Machine Groupings and Reallocation Possibilities

7.4.4 Determining Norms and Parameters

Chapter 4 provided a brief insight into the determination of parameters for WLC while Chapter 5 described how the refinement of the concept reduces the need to set some of the norms for the job entry stage onwards. This process can take advantage of the pre-implementation data analysis performed in Chapter 6. However, although the determination of norms and parameters is important when implementing WLC, research to date suggests that this is an iterative process based on trial and error. Hence, the best insight into this process can be gained with the benefit of hindsight at a post-implementation stage. In other words, looking at how the parameters were initially set, how management changed these over time, what effect this had on performance and what causal relationships can be identified between the parameters. In this sense, it is only after the implementation of a DSS that this can be analysed. As a result, this research does not focus more extensively on this issue. However, some guidance from working with Company X is provided in Table 7.3 below, where the planning stage at which each parameter is utilised is also indicated.

Of these parameters, it is the backlog lengths that can be the most important to consider. However, due to the implementation stage reached in this case study, actual values for the backlog lengths have not yet been set. Also note that backlog lengths can be set for the shop and individually for each work centre. However, it may not be necessary to set the restrictions differently for each work centre, as the backlog lengths have been calculated in such a way as to automatically account for the varying capacities of work centres. For example, a backlog length of three days at Cinc 2 and 3 and a backlog length of three days at milling does not mean that the total work content of the two work centres is the same. Hence, if management of Company X wish to provide a balanced workload across work centres and minimise changes to the capacities of work centres, the best policy may be to set the backlog length restrictions of work centres equal to each other.

Some of the other parameters could be omitted, for example, a priority system is not central to the methodology, but can complement the LUMS approach to reflect the current working practices of the shop floor within a particular organisation. From the table it can be seen that in order for the LUMS approach to cater for MTO production, in other words, provide additional control at the customer enquiry stage, it is necessary to determine up to five extra values. Hence, although parameter setting is an important concern within other PPC concepts, it is a particularly important research topic within the context of PPC concepts designed for the MTO industry.

Parameter	Guidance	Relevant Planning and Control Stage
Total Backlog Length Restrictions	Consider quoted and actual DLT's. The TBL is also related to the size of the planning horizon and the majority of jobs should have DD's within the current planning horizon. Therefore, the largest DLT (plus the customer confirmation time) of jobs that the company commonly compete for must be considered.	Customer Enquiry
Planned Backlog Length Restrictions	Consider the current and desired in-house MLT's. With the addition of a pool delay under WLC, the MLT will be significantly smaller than the DLT quoted to the customer.	Job Entry
Released Backlog Length Restrictions	The smaller the distance between the minimum RBL and the maximum RBL, the more constant the level of WIP. The desired SFTT's and level of WIP must be considered when setting these restrictions.	Job Release
Pool Delays (Normal and Pool Priority Jobs)	Pool delays are to be considered in relation to maximum RBL's, the use of force release and the release frequency. Normal priority jobs are expected to be delayed for longer than those with pool priority. Management may have no previous experience in setting these delays.	Customer Enquiry
Maximum % of Pool Priority Jobs	If the maximum pool priority percentage is too large or is regularly exceeded, then the pool delay norms for normal and pool priority jobs will no longer reflect actual waiting times. However, again it is difficult to set this prior to implementation due to a lack of management experience with the use of a pre-shop pool.	Job Release
Shop Floor Queuing Times (Normal and Shop Floor Priority Jobs)	The reduced level of WIP facilitated by the job release mechanism means that queuing times will be relatively small. However, queuing times at bottleneck resources may be greater than at other work centres. Historical throughput time data may be of use when setting these parameters.	Customer Enquiry
Maximum % of Shop Floor Priority Jobs	If too many jobs are given shop priority, this will undermine the schedules and DD's determined for normal priority jobs. Also consider the number of permitted hot jobs in the determination of these values.	Priority Dispatching / Shop Floor Control
Force Release Restrictions	Previous theoretical development of the LUMS approach has suggested placing a maximum on the proportion of force released jobs. However, the use of force release is not advised. Hence, a warning is displayed in the DSS every time the user releases a job that will break the workload restrictions of shop floor resources.	Job Release
Strike Rate	This has been set by management based on historical data; however, this must be regularly reviewed and updated, particularly in volatile markets.	Customer Enquiry
Customer Confirmation Time	This does not have to be set definitively, and can be changed for each DD consideration. A rule of thumb for Company X is that most responses are expected within two weeks. Similarly, the MAD can be set for each job but a default of three days is also given as most suppliers to Company X deliver within this timescale.	Customer Enquiry
Efficiency	Initial efficiency values have been calculated, as in Table 7.2. These can be changed over time if they prove to be misrepresentative or if the mix of employees and their skills change. An alternative approach would be to set them all initially equal to one and then gradually changed them over time to reflect practice.	Customer Enquiry to Job Release

Table 7.3: Summary of WLC Parameters and Planning Stages

7.5 CONCLUSION

From this discussion it is clear that for the successful implementation of a DSS, there is an array of issues to overcome. Hence, implementation can be a difficult, unique and prolonged procedure requiring careful planning making it prone to failure. The factors that influence the implementation process cover a wide range of areas from the type of information system and the concept underpinning the system to the contextual characteristics of the company, such as the culture of an organisation and user expectations. Hence, the implementation of a system such as this is subject to overcoming issues affecting:

(1) All information systems

(2) The particular concept underpinning the system

(3) Contextual conditions where the system is being implemented

Implementation is a major project in itself, and it is important to have a great deal of support if a project is to be successful. Managers must play an important role in the implementation process, including championing the project, if the concept is to be accepted on the shop floor. Although they may have vast experience to draw from, this may involve making some new decisions. For example, management may be unfamiliar with using an order pool, and thus do not have prior experience determining expected pool delays. Hence, the implementation of the concept can be a learning process for all personnel within an organisation.

This chapter has presented a six step strategy to implement and maintain the LUMS approach within MTO companies. It has then worked towards applying this strategy to the case study company in order to 'operationalise' the theory of a WLC concept in a practical setting.

Hence, the chapter has taken important steps towards exploring the process of implementing the LUMS approach. This contribution is continued in the following chapter where further refinements are made to both the WLC concept and implementation strategy, in the light of a partial implementation of the DSS.

CHAPTER 8: OUTCOMES FROM THE CASE STUDY – REFINING THE WLC APPROACH AND THE IMPLEMENTATION STRATEGY

8.1 INTRODUCTION

Through working with a case study company, a number of areas have emerged in which the LUMS approach can be further refined to promote greater practical use. Hence, the application of WLC to the case study company has provided a third stage in the conceptual development of the LUMS approach. While it has been important to accommodate the needs of the company in this process, it has also been important to protect the core methodological structure of the LUMS approach to WLC. As a result, the concept that emerges seeks to provide effective planning and control while emphasising simplicity, thus aiming to provide a powerful, rapid and user friendly planning tool for modern managers. This chapter describes a number of the issues that have been addressed; while the features of the system are tailored to the needs of Company X, it is anticipated that similar measures will need to be accommodated in research with other companies. Thus they are considered to be relatively generic issues which can be incorporated in the revised LUMS concept.

At the outset of this project it was hoped that this research would provide a successful account of WLC implementation, with sustained company improvements. However, despite the extensive preparation for implementation described in the preceding chapters, this has proven to be beyond the scope of this project, partly due to time constraints and partly as a result of factors outside the control of the research. The chapter concentrates on qualitative aspects that have emerged from observations, interviews / feedback and practical experience within the case study. Therefore the chapter begins with an examination of barriers encountered to the successful implementation of WLC in this case study, before describing further proposed refinements to the model. The approach taken to partially implement the DSS has also led to the refinement of the six implementation steps presented in the previous chapter towards a more gradual strategy and the development of a detailed framework.

8.2 REFLECTIONS ON THE CASE STUDY

One of the key reasons for the postponement of the implementation of WLC in Company X has been the delayed implementation of MAIS. It had been anticipated that the information system would be in place a number of months before the use of WLC was planned to commence. Hence, a disciplined and established approach to data recording would already be inherent within the culture of the organisation. As a result, the data requirements of the system were tailored to the anticipated information availability within Company X at the implementation stage (see, for example, Appendix 1). However, despite assurances from management throughout the project, it became clear that MAIS would not be completed or implemented in the foreseeable future. One of the reasons for this is that management are preoccupied with extending the functionality of MAIS in order for the system to cater for other production environments and have the required level of functionality and flexibility to be sold to other companies. Hence, MAIS was not able to provide the WLC DSS with the necessary job routing and capacity information within the project timescale.

As a counter-measure, the DSS was adapted into a standalone package, whilst maintaining the option to be linked into MAIS at a later date, thus avoiding duplication. The DSS now enables the user to enter job routing, set up and processing time information directly into the WLC system. In addition, the system was supplied with an up to date record of employee shift patterns at the time of implementation, in the same format that would be generated by MAIS. Therefore, despite the problems caused by the failure to complete MAIS, the research project was able to adapt in order to allow the implementation of the DSS to continue. This demonstrated the flexibility of the system to the changing requirements of the company. However, although this problem was successfully overcome, the key problem with the delayed implementation of MAIS was that the company and key personnel were not culturally ready for the implementation of WLC.

Reservations have been expressed throughout the research process about the dominant role of the owner-manager (LN) in this project, and these concerns have resurfaced as a key issue at the implementation stage. LN is the only person that has the expertise to provide the information required by the system, and this information is not written down / recorded. Hence, the project relies on this person inputting the data directly or communicating it to other people. However, the problems with MAIS have meant that LN has been distracted from the WLC project and has spent the majority of his time working towards the completion of MAIS. Although LN had suggested that the priorities of the company were changing from quality and price towards delivery date reliability, it was clear that production planning was still not top of the agenda. Management saw less of an incentive to provide the necessary data at this stage as it would not be input directly into MAIS. Although steps had been taken to allow the DSS to be used immediately, MAIS was still considered a higher priority and thus a prerequisite to the use of WLC. Hence, the perceived relative importance of MAIS compared to the DSS has caused major problems for the implementation of WLC. This is considered to be partly due to the perceptions of WLC by management; unlike other concepts, such as TOC, Kanban and MRP, there is a lack of awareness in practice regarding the benefits of WLC to MTO companies such as Company X. While efforts were made to increase awareness of the benefits of WLC, this proved to be a gradual process.

It is conceded that there are some practical reasons why MAIS is seen as a prerequisite to WLC. The implementation of MAIS is going to have major repercussions on the working practices of employees all across the company, including the internal job reference / day book numbering system, fundamental to the identification of each job. Each customer has their own internal numbering system for orders made with their suppliers, such as Company X. Each order is given a number and may consist of several different jobs / items with different quantities and delivery dates. Company X converts this single order number to a series of internal numbers that distinguish between each job; hence one customer order number may contain several job reference numbers, see Figure 8.1 for an example. However, when MAIS is introduced, the company intend to introduce a new internal numbering system, starting from 'One'. Therefore, this provides a major reason why management are reluctant to provide data at this stage, as this will be a major change that requires company wide synchronised integration.

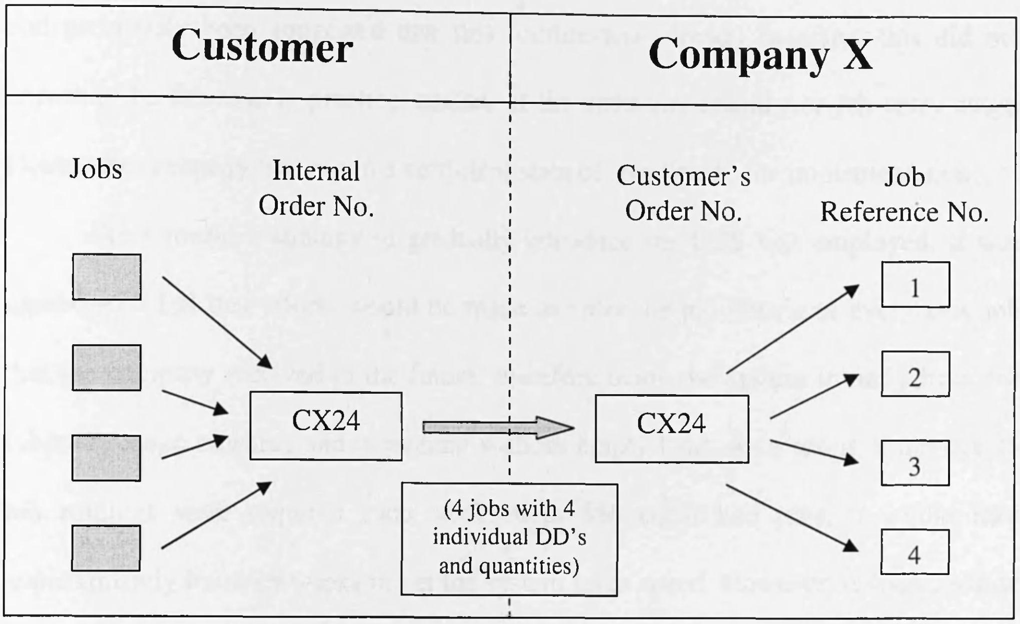


Figure 8.1: Example of Job Reference Numbering System

8.2.1 Towards the Gradual Implementation of Workload Control

It was anticipated that without the presence of the author, the WLC project would progress no further until MAIS had been successfully implemented. Hence, in an attempt to speed up the implementation process and gain positive results, I began to visit the company on a daily basis, directly entering the details of jobs into the DSS whenever I was able to obtain sufficient information from management. This information was supplied verbally or by providing the manager with simple routing sheets to fill in for each job at his convenience. However, it quickly became clear that it would be difficult to get the system up to speed, reflecting the current workload of the shop, and that this would have to be a much more gradual process. At any one time, the company has approximately 350 accepted jobs within the system, and an order arrival rate of five new confirmed jobs per day. Hence, it was important to get management into a rhythm / routine of supplying data on a daily basis. Although it had previously been suggested that this routine was already in place, this did not appear to be the case in practice, neither at the customer enquiry or job entry stage. Hence, the company was not in a sufficient state of 'readiness' for implementation.

As a result, a strategy to gradually introduce the DSS was employed. It was agreed with LN that efforts would be made to enter the job details of every new job that the company received in the future, therefore using the system initially from the job entry stage onwards and beginning with an empty load. As a result, a modest 25 job routings were required each week; with 350 confirmed jobs, it would take approximately fourteen weeks to get the system up to speed. However, it soon became clear that the required level of detail would be difficult to feasibly obtain for one-off jobs, and new jobs were arriving at a rate quicker than the speed at which I was able to obtain information from management. The concept remains feasible, but only when more time can be dedicated to the project. Therefore, LN suggested that the system be initially used to enter data for the confirmed jobs of one repeat customer only, a major aerospace company, considered to be the company's most important customer. This provided an opportunity to input useful data at a more realistic rate.

This customer purchases bespoke items on a repeat basis. Hence, once the routing data has been provided, it can be reused on any future orders for the same item, irrespective of quantities or delivery dates. Once a complete record of job routings is supplied for this customer, the procedure can be easily extended to delivery date negotiations with the customer (the customer enquiry stage). This was considered a compromise and a way of getting the company to supply routing information and observe the usefulness of the system. This would also allow the shop floor to gradually get used to the discipline of supplying up to date feedback information. It is anticipated that as this becomes more routine, the procedure can be extended to other customers and the customer enquiry stage. Hence, through necessity, the project has developed a process of gradual implementation beginning with confirmed jobs with one customer, before extending to the customer enquiry stage and to other customers. When this is extended to other customers, this strategy can begin with other repeat purchasers before moving to one-off items where more time is required to assess the requirements of jobs and prepare a tender. Meanwhile, MAIS may also be implemented by this time, further easing implementation. This strategy is illustrated in Figure 8.2.

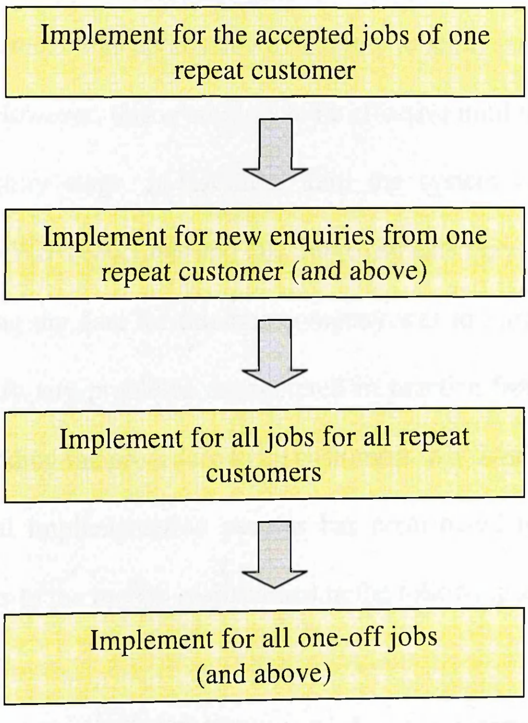


Figure 8.2: The Gradual Implementation of WLC

Using the WLC system for one company would present its own set of problems; it would be difficult to reflect the workload of jobs for other customers in capacity availability and the backlogs of work centres, thus affecting delivery date quotations, backwards scheduling and job release decisions. Hence, it is difficult to apply WLC to one customer when resources are shared with other jobs. One solution would be to isolate a percentage of shop capacity, assuming that only this proportion of capacity was available for the customer, thus allowing the system to account for the load provided by other jobs. This percentage of capacity can be based on historical records of the amount of work supplied by the customer in comparison to that by other customers. This would be similar to the implementation approach taken by Fry & Smith (1987) where Input-Output Control is used on one product line, representing 40% of sales, the difference being that rather than isolating *one* standardised product sold to *many* customers, this approach would apply to *many* customised products sold to *one* customer. However, this is unlikely to be effective until the procedure is used at the customer enquiry stage. In addition, until the system is implemented for all customers, overall WIP reductions and DD improvements may be minimal. Hence, the intention of gaining the data for this one company was to introduce the data capture routine and identify any problems encountered in practice from using the system in 'test', before extending the procedure to all customers in a 'live' environment.

This partial implementation process has contributed to the identification of further refinements to the model, as discussed in the following subsection.

8.2.2 The Effects of Power and Politics on the Implementation of WLC

The role of power and politics can be a particularly important issue within SME's, where a small number of individuals are able to dominate the culture of an organisation, monopolise the distribution of power and enforce their own political agendas on that of the organisation. According to Burnes (2004), the political view of the firm can explain much of what may seem to be irrational behaviour within organisations; for example, employees withholding information, restricting output, attempting to build empires, and so on. Beginning with the primary contact (LN), the impact that the key actors in this project have had on the implementation of WLC is described below.

- The Operations Manager (LN)

MAIS had a much greater impact on the research project than was initially envisaged due to the slower than expected rate at which it has been developed. During the course of the project, it also became clear that Company X was experiencing financial difficulties and the focus on MAIS was to the detriment of the core engineering side of the business. A large repeat customer was threatening to take their business elsewhere unless Company X gave them a retrospective discount on the previous year's orders as a sign of goodwill and a penalty for their unsatisfactory performance. However, as LN's problems with the core engineering side of his business grew, rather than reverting to his core competencies, he gradually began to view MAIS as a means of improving the financial stability of the company (an 'escape route' for the company). The longer the MAIS project goes on, and the more money the company invests in MAIS, the more important it becomes that MAIS is a huge success. Hence, MAIS has gradually increased in significance within Company X during the course of this research.

The difficulties that the company faced were either not envisaged by LN at the start of the project or simply not disclosed. In fact, he indicated the contrary - that Company X was in fact a steadily growing company increasing its turnover and workforce. Similarly, colleagues at University, who have worked with Company X in the past, were also unaware of any problems with the business and vouched for the company as a good source of research. Through time, LN's agenda for MAIS led to serious conflicts with the objectives of this research project in the following areas:

(1) **Access:** In order to protect the functionality of MAIS, the project was clouded in secrecy, both internally and externally. This secrecy surrounding MAIS restricted the access that this research project was able to obtain to suppliers, customers and employees, and at times it also restricted responses obtained in interviews. LN also did not want software vendors to know that he was developing his own system, as this would restrict the access he had to their ideas; while they were under the impression that he intended to purchase one of their systems they were happy to disclose detailed information about the inner workings of their products. Another reason for secrecy was that LN did not want shop floor operatives to be distracted from their core jobs until absolutely necessary. Secrecy and restricted access limited the ability of the researcher to increase awareness regarding WLC and promote change.

(2) **Timescale:** LN wanted to implement MAIS before or at the same time as WLC. As LN intended to sell MAIS to other companies, he also began to extend the functionality and generality of the system in order to provide the types of features he believed that other companies would want, dramatically increasing the timescale involved. Not only did LN not want to sell MAIS until he had extended the functionality of the system further, he did not want to use MAIS internally until he was completely satisfied with the functionality of the system (he certainly did not take a prototype approach to systems development). Therefore, every time

the functionality of MAIS was extended, the implementation of WLC was further delayed. A further delay was caused by the fact that once MAIS is implemented within Company X, it will create further work for the user. Therefore, if LN is to be the end-user he will have to make changes to his roles and responsibilities in order to make time to use MAIS effectively. However, despite spending so much time developing the system he seems reluctant to do this, as this would inevitably involve delegating some responsibilities to other employees; something he seems unprepared to do. Hence, while this research was restricted to a three year timescale, LN was prepared to go beyond this in order to follow his own agenda. By the end of the research, even the software developer could not explain why LN was not using MAIS internally. For example, he commented:

"*I don't know why he isn't using the system yet ... I encourage him to do so and he agrees, but the next time I come in he's got another excuse or another add-on that he wants to include ... the reality is that it's been fit for use in-house for a long time now.*"

(3) **Legal Conflicts:** Selling MAIS to other companies created legal conflicts between the role of the researcher and the objectives of LN (and his company). The potential to incorporate WLC into MAIS provoked negotiations over the share of the profits from MAIS and raised concerns relating to the protection of intellectual property rights; however, while the system remained in development (and LN was gaining knowledge), he was able to avoid making a decision over revenue sharing. LN was naturally keen to make MAIS as effective as possible, but was also unwilling to share the profits that he expects to make. As a researcher, the main

interest was in fulfilling the research objectives; however it was also important to protect the intellectual property rights of the University, while LN argued that the University would have to pay for a share of the development costs of MAIS if it wanted to receive a share of the profits. Ultimately, it proved impossible to come to an agreement over the financial contributions and revenue that LN anticipated the project would generate; however, it was hoped that when LN saw the impact of WLC in-house he would see how important it can be to organisations such as Company X, and contract negotiations could be reinitiated. Thus this issue caused project delays, bringing conflicting objectives to the surface that could not be quickly resolved.

In addition to the issues surrounding the implementation of MAIS, the level of power experienced by LN also affected the progress of the project. Graetz *et al.* (2002) explain that the application of power in one form or another must be used in order to overcome resistance. Similarly, Pfeffer (1992) states that innovation and change in almost any arena requires the skill to develop power and the willingness to employ it to get things accomplished. To be effective WLC needed the support of powerful people within Company X, and most importantly, the operations (and owner-) manager, LN. Due to LN's unwillingness to formally integrate WLC into MAIS (and the University into his contract), he remained interested in learning about WLC while using delaying tactics to avoid making a decision. Hence, his enthusiasm and drive to implement WLC gradually diminished, and as a result he did not champion the project in the latter stages as much as was needed.

As LN founded the company, and has therefore been employed there longer than any other member of staff, he has been able to dictate the culture of the company.

His position is strengthened by the fact that he maintains the majority of power within the organisation, and in pursuing his political agenda, LN was able to wield his considerable power within Company X. Levine and Rossmoore (1995) suggest that the key elements of power in organisations are the authority to hire, fire, promote, reassign, reward, and allocate valued resources; within Company X, all these bases of power are held by LN. Similarly, Senior (2002) refers to Morgan (1997) in reviewing the sources of power within organisations. These include formal authority, the control of scarce resources (such as budgets and promotions) and the control of knowledge and information (expert power); again these are all controlled by LN.

Power can be a very useful and constructive asset when used in the right way, but also very destructive when abused. In terms of this research project, LN had power over access to employees, customers, vital information and was able to further maintain control by positioning himself as the end-user of the system. Burnes (2004) explains that Robbins (1986) also identified sources of power, including Knowledge Power, i.e., the control of information. LN was able to exercise Knowledge Power over the research project and over his members of staff. On occasions he was the single point of contact for the research within Company X as he was the only person that had the information that was required. This resulted in LN drip-feeding information and taking momentum out of the project. Ultimately, his power and influence as the owner-manager of the company restricted the progress of the WLC system.

A further reason why LN was ultimately reluctant to use WLC was because he was unwilling to change his approach to managing customer relationships and to quoting delivery dates despite previous claims of wanting to reform this strategy. He was aware and understood that he was not meeting delivery dates and that by continuing with the same approach of accepting all jobs at shorter-than-achievable delivery dates this was unlikely to change, but insisted on taking a short term approach and was happy to worry about the consequences of late deliveries at a later stage. Towards the end of the research period, LN commented:

"*I don't need a system that is going to tell me what I already know* (i.e., that deliveries are going to be late) …"

This change in attitude towards WLC showed a lack of understanding of its benefits. Whilst every effort had been made to ensure the full benefits of the system were fully understood, it was ultimately difficult to proceed further given LN's lack of desire to change this aspect of his working practice.

- The Estimator

During interviews, the estimator suggested that detailed job specifications were available for every job for which Company X provided a quotation and hence his assurances had a direct impact on the design and information requirements of the WLC system. Indeed, samples of the data were provided; however, it became apparent that this data was not available for all jobs (as discussed further in Section 8.3.1). This is considered unlikely to have been a direct attempt to sabotage the project, and indeed his description of the quotation method was corroborated by LN; however, in retrospect it is felt that the estimator has been following his own agenda. By approximating the price and delivery dates of jobs in an imprecise manner (based on experience) instead of considering detailed job specifications, the estimator was effectively taking short cuts. His lack of acknowledgment of this fact suggested he was conscious that he wasn't operating as effectively as he could, but didn't want to admit this.

Not only did he not want to acknowledge this, more significantly, he knew that his responses were being incorporated within the coding of a computer program. Hence, it appears that he wanted the system to be developed in the way that he felt he was meant to be quoting delivery dates and prices and how he expects future estimators will work after his retirement. From a researcher's perspective it would have been much more beneficial if he had been honest with his answers, as this would have led to a system that mirrored the realistic information availability on a day-to-day basis in practice rather than in a perfect world.

- The Software Developer

As discussed in chapter 6, the software developer has been developing packages for different clients for more than ten years. As the project progressed, it became apparent that this had not only included information systems, but had also covered the development of discrete job shop scheduling packages. His difficulties with developing an effective tool to this end meant he was sceptical about WLC. Despite having the differences between the two (and the merits of WLC) explained to him on numerous occasions, his views proved difficult to change. For example, he made the following comments about his experiences with trying to develop effective discrete scheduling software tools:

"*You finish scheduling the current order book* (for discrete time periods), *and then five minutes later another order comes in and the whole schedule has to change …*"

"I've been writing programs like this for ten years and I haven't found the answer …"

His preconceived ideas in this area were noted early in the project, but his tunnel vision attitude proved more difficult to change than expected, and he was also able to gain more power within the company than was expected for a non-permanent member of staff due to the programming skills that he possessed. He was also somewhat protective of his code and the MAIS system in order to avoid parts of his code being stolen. This meant he kept his guard up during discussions and made it difficult to talk to him openly. Like LN, he also does not want to share the potential revenue from sales of MAIS with a third party.

The longer MAIS remained in development, the more power the software developer acquired within the structure of Company X. As the project has been ongoing for so long, LN is unlikely to terminate it until it has been concluded to his satisfaction. If he brought in a new (faster) developer to replace the current one, a great deal of time would be wasted while they got up to speed with the program, and due to secrecy and personal preference, the current developer is unwilling to work alongside another programmer. In summary, his motives and inability to complete the MAIS system has had direct repercussions on the implementation of WLC.

- Machine Operatives and the Shop Floor Supervisor

The restricted access given to shop floor operators meant that the reaction of these individuals to the WLC system remains an under researched area. However, evidence of their feelings towards the development of MAIS has been collected and may have bearings on development of other systems such as WLC.

As highlighted, the slow rate at which MAIS is developing has been a major reason why WLC has not been widely implemented in Company X. In addition, the longer that MAIS remains in development, the greater the scepticism regarding the system from those not involved in the project. Shop floor employees who do not know a great deal about MAIS, but who know how long has been spent developing the system, are sceptical about the freelance software developer and his intentions towards finishing the project, similarly they are accustomed to LN devoting time to 'fads' which fail to deliver tangible benefits. Shop floor machine operatives have made the following comments, firstly about the software developer and secondly about LN:

"*He's only here from ten till two, and in between he spends most of the time on his mobile phone ...*"

"*He's been dreaming this up for years, but at the rate they're going I can't see it ever being finished.*"

Although MAIS is a separate project, it is likely that WLC will suffer from associations with MAIS which is over budget, error prone and has exceeded a number of deadlines. Of the sources of power reviewed by Senior (2002) the one key area where LN is not the most powerful actor is the control of the 'informal organisation'. Here, the shop floor supervisor is considered to have more power; he is able to develop networks and interpersonal alliances with both the front and back end of the factory. Gaining the political support of this gate keeper will be very important if WLC is to be fully implemented in the future.

8.2.3 Reflections on the Political Landscape

In hindsight, it is clear that this research would have benefited substantially from being given greater freedom within the research arena. One such area is access; Burnes & James (1995) examine the impact of employee involvement (or lack of it) on the success of change projects. The authors explain that in an organisation where a culture of trust exists and change is the norm, the need to consult and involve employees is less necessary as employees are more receptive to change. In the reverse scenario it is necessary to overcome suspicion and resistance and to gain the confidence and commitment of staff by giving them a positive role to play in the process. Unfortunately, the culture of Company X is that of the latter; hence, the implementation project required greater access to shop floor operators on a more formal basis than was granted. This would have provided a wider range of data sources for the research and generated greater awareness and momentum for the project enabling the advantages of WLC to be communicated more effectively to everybody. The project would not only have benefited from greater access to internal stakeholders, but from also extending this access to customers.

Access would also have provided a means to promote conflict. Marris (1993) suggests that any process of reform should encourage conflict, in order to confront important issues and give people a chance to react and make sense of a situation. With the benefit of hindsight, the project may have made greater progress if conflict was encouraged between the key social actors rather than avoided, such as between LN and the software developer.

To summarise the experience; while there was a definite political undercurrent within Company X, as identified in Chapter 6, Company X still remained a suitable company for WLC and it was hoped that the political landscape could be successfully traversed. However, during the course of the project LN used his considerable power to slow down the progress of the project while providing sufficient encouragement to avoid the researcher from looking elsewhere for a suitable case to study; ultimately it became a 'stalemate situation'. By the end, the researcher was the only advocate for change and the only person driving the implementation of WLC forwards and, without LN, lacked the power and authority to be able to do this effectively. To have promoted change in a more active manner would have required a shift in emphasis from observational skills to a greater degree of participation. By the time that it became evident that a full implementation of the system would not be possible, the time remaining to complete the research meant that attempting to find another company would have been impractical. Hence, the direction of the research switched to a focus on implementation issues, rather than the results of implementation on the performance of the company. Although the research reencountered a number of problems, it still provides a much needed contribution to knowledge. For example, the difficulties encountered with the case study company meant that a greater understanding of the barriers to implementation associated with production planning concepts, and WLC in particular, could be obtained (a summary of the contribution of this research is provided in the following chapter).

8.3 REFINING THE LUMS APPROACH USING CASE STUDY EVIDENCE

The case study research has led to four major refinements to the methodology used in the LUMS approach spanning the complete spectrum of planning and control stages applicable to make-to-order companies. A further change is also highlighted that refers to an adaptation of the DSS to solve a particular problem encountered with the case study company (see Section 8.3.5).

8.3.1 Data Input at the Customer Enquiry Stage

As described, the user has shown limited enthusiasm towards inputting data, particularly at the customer enquiry stage. Although previous discussions with both LN and the estimator had suggested that this level of detailed information was readily available, attempts to obtain this in practice have indicated that this is not the case. In attempting to gain access to this data, two striking observations were made. Overcoming these cultural issues and attitudes is crucial to the future of the research with MTO companies such as Company X:

(1) As management of the company perceive the overall strike rate of the company to be approximately 15%, the user feels that 85% of time spent entering job details at the customer enquiry stage is wasted, as the customer will award the contract to another company. If data is not entered at the customer enquiry stage, the data requirements would be passed to the job entry stage for the subset of confirmed jobs. However, by spending more time at the customer enquiry stage it may be possible to gradually improve the strike rate of the company in the future by promoting trust in relationships through improved delivery date reliability. In addition, the customer enquiry stage is considered particularly important to MTO companies and within the LUMS approach, making the implementation of WLC at the customer enquiry stage crucial to the control of the lower planning levels. Furthermore, using the DSS in DD negotiations can help to reduce DD tightness, thus improving the options available at the job entry and release stages.

(2) The attitude of the user to data entry also shows a clear division between repeat and one-off customers. It seems that the company are prepared to enter job routing information into the DSS if it is for a repeat purchase, as this information will be directly reusable in the future, whereas the routing information of one-off jobs is unlikely to be used again. Despite this, it could be argued that it is the supply of routing information for one-off jobs that is most important as the company have not produced these jobs before and may need particular help with the planning and control of such jobs that are unfamiliar to the supervisor and shop floor operatives.

The job information that the DSS requires is a subset of the information that the company intend to record within MAIS. Hence, the DSS does not require any information that the company do not intend to record. In fact, the data required for the DSS is a fraction of that which MAIS will have the capability to store. Therefore, it seems inevitable that the eventual implementation of MAIS is likely to suffer from the same problems. In addition, the level of information the company would like to store seems far greater than that which a typical SME is likely to supply on a daily basis. As a result, efforts have been made to refine the concept and reduce the data input required at the customer enquiry stage, thus making the DSS simpler to implement in practice and faster to use.

Rather than relying on the order quantity, processing and setup times at each operation in order to consider the total work content of each individual job in delivery date negotiations, the concept can be simplified to control norm work centre throughput times. Norm work centre throughput times refer to the expected (or desired) amount of time it will take for a job to queue and be processed at a particular work centre. To cater for job shop production, norms can be set for each individual work centre and applied as an approximation for each job that will visit the work centre, for example, a throughput time of one day. If the user supplies a list of resources a job will require, the total shop floor throughput time of a job can be estimated by summing the norm throughput times of each work centre the job will visit. This means that, given the sequential nature of production, the user need only tick a series of boxes to indicate the work centres that a job is expected to visit.

The delivery date of unconfirmed job i (DD_i) would then be calculated as follows, where w refers to the subset of work centres that job i will visit:

$$DD_i = ED_i + CCT_i + MatLT_i + PD_p + \sum_{w=1}^{W} WCTT_w \qquad (1)$$

where,

ED_i = Enquiry date of job i

CCT_i = Estimated customer confirmation time for job i

$MatLT_i$ = Anticipated material lead time of job i

PD_p = Expected pool delay constant for a job of priority level 'p'

$WCTT_w$ = Norm throughput time at work centre w

This assumes that each job takes the same amount of time to go through each work centre, thus if the processing times of each job are very different, large jobs may be expected to queue for smaller periods of time. This means that the work centre throughput time of each job can be standardised, irrespective of the size of the job, thus providing more predictable delivery dates. Refining the concept in this manner has obvious advantages; however, there are also two major implications to consider, as outlined below:

(1) This approach requires a two-stage data input procedure. Previously, all the information the DSS needed was input at the customer enquiry stage. In contrast, here the user must input quantities, processing and set up times when jobs are confirmed for use at the job entry stage. However, this is now for the subset of confirmed jobs, and hence with a strike rate of 15%, the time and data requirements are still greatly reduced.

(2) This approach means that throughput time norms have to be determined by management for each work centre and optionally for each priority level, thus increasing the parameter setting procedure. This also means that the total work content of a job cannot be incorporated in the total backlog of the shop until the job entry stage when it also becomes part of the planned backlog. Unless the user is asked to provide an overall estimate of the total work content of a job at the customer enquiry stage, this would reduce the hierarchy of backlogs from three levels to two.

If available, it is considered that the customer enquiry data requirements outlined in Chapter 5 would be more representative of the workload of a job. However, this again leads to a trade-off between the marginal accuracy gains of increased sophistication and the speed, user friendliness and practical orientation of simplification. It seems that in practice, the company take short cuts with a large number of jobs and it is argued here that it would be more beneficial to have some information on all jobs rather than very detailed information on some and no information regarding others. As a result, it is proposed that the methodology should incorporate both types of data entry at the customer enquiry stage, to allow for the particular data availability of each company.

8.3.2 Forwards Scheduling at the Job Entry Stage

Due in part to the slow input of data and to the delivery date tightness of jobs, it has been observed that by the time that job details have been entered into the system, there is insufficient time to backwards schedule jobs between the delivery date and the current date. In addition, clustered delivery dates and an overloaded shop floor further contribute to the difficulties of backwards scheduling. On some occasions, the delivery date has even passed by the time that details have been entered into the system. However, although the delivery date has passed, such jobs can often still be found queuing or being manufactured on the shop floor. As a result, delivery dates are often renegotiated with the customer when it becomes clear that a job will not be completed on time.

This problem could be partly solved by providing more realistic delivery dates, such as by using the DSS at the customer enquiry stage, but also by rejecting some jobs and providing faster data input as described above. However, in order to make the system effective, when jobs cannot be scheduled in time, it may be necessary to provide an option to find a new and more realistic delivery date. Hence, if the job cannot be backwards scheduled, and capacity cannot be adjusted to facilitate this, the user can choose to forwards schedule the job from the earliest release date, or current date. This ensures that otherwise unscheduled jobs are reflected in the planned backlog of the shop and provides a useful production schedule for the supervisor. The date to which the DSS forwards schedules can also be considered when renegotiating the delivery date with the customer. If a delivery date does have to be renegotiated, it is particularly important that this revised date is met. Hence, it is important that the new date is determined accurately.

8.3.3 Part Releasing Jobs at the Job Release Stage

From working with this company it became clear that there were only limited opportunities to take advantage of the output control measures advocated in the literature. As a result, in order to maintain flexibility the company are more likely to use lot splitting / the part release of jobs onto the shop floor as a means to improve flexibility than, for example, subcontracting jobs. As a result, the concept has been adapted to allow the user to release part of a job onto the shop floor and release the remainder at a later stage, such as when backlog lengths have reduced. However, it is important to ensure that the whole job is delivered to the customer on time; this is also briefly highlighted in Chapter 5 and is an important practical refinement to the concept. This emerged from both the programming and implementation stages of this project and is therefore referred to in both chapters. This is comparable with previous development of the LUMS approach when a measure to allow the user to 'Force Release' jobs onto the shop floor was accommodated.

8.3.4 The Structure of the Backlog Control Hierarchy

Chapter 5 briefly describes how the LUMS approach has been modified to compensate for the current manufacturing climate. For example, with lead times as short as two weeks it is necessary to monitor daily workloads, rather than weekly intervals as regulated in previous versions of the methodology. However, the experience of this case study suggests that a compromise between the two time intervals can emerge. While the work centre backlogs used at the released backlog level are instantaneous, those used at the planned backlog level are time phased. At this stage, discrete time periods are required in order to sufficiently determine operation completion dates. Hence, it is considered that daily workloads must be determined and monitored for the purposes of input-output control and backwards scheduling. A time phased and instantaneous backlog is provided at the total backlog level; however, at this higher planning level management are looking for a broad summary of the distribution of delivery dates, therefore it is not necessary to provide this discrete level of detail. Hence, it is sufficient to monitor the total backlog on a weekly level as delivery dates are prone to change at this uncertain stage. Previous development of the LUMS approach provided only an instantaneous representation of the TBL. Hence, providing weekly planning for the time-phased TBL provides a significant refinement to the methodology.

8.3.5 Job Reference Numbering System

As illustrated, the job referencing system currently employed by the company differentiates between products within a customer order; however, each order for a (repeat purchase) product may consist of a number of deliveries scheduled over a period of three months. Despite this, the job is grouped under one reference number. For example, an order of 300 of a particular component may state that 100 are to be delivered at the end of each of the next three months. Essentially this is equivalent to three separate repeat orders; hence it may be unwise to produce the whole order as a single batch, as 200 of the items will have to be held as FGI for a considerable amount of time. In addition, it is likely that the capacity of those work centres affected by the job could be more effectively utilised by processing jobs with greater urgency.

However, at present the company would have to enter this job under one reference number, with a quantity of 300 and a delivery date equal to that of the first 100 items.

Therefore, for effective and flexible planning to take place, it is necessary to distinguish between each job within an order and each delivery date within a job. As a result, where a job supplied by MAIS contains several delivery dates, the WLC system will differentiate between them by appending the reference number with a lettering system. For example, job reference number 25, with four separate deliveries of the same item will be entered into the system as 25a, 25b, 25c and 25d in delivery date order. This means that each delivery is uniquely identifiable for WLC purposes, while compatibility between MAIS and the WLC DSS is maintained. This seems a simple change to the functionality of the DSS; however, the compatibility of inter-organisational order referencing procedures can be a significant problem issue for companies. Job reference numbers are also appended if part of a job is released to the shop floor and part remains in the pool. This ensures that the DSS keeps track of the whole job.

8.4 REFINING THE EMERGING IMPLEMENTATION STRATEGY

It is argued here that the gradual implementation of the WLC concept, described in this chapter and summarised in Figure 8.2, is a more realistic strategy in practice if the concept is to be accepted by shop floor workers. This process enables employees to be gradually introduced to WLC and the benefits it has to offer, and may be more likely to lead to sustainable long term improvements. By incorporating these four gradual steps, this chapter contributes to the refinement / continued development of the implementation strategy proposed in the previous chapter (see Figure 7.2). In the light of this experience, an enhanced version of the strategy is provided in Figure 8.3. This gradual strategy to implement WLC has been a necessary process within Company X; however, it is acknowledged that, where feasible, a more direct approach may be preferred.

From this case study research, a greater understanding of the implementation issues involved with WLC, and how they can be addressed, also emerges. This is the focus of the second research question presented in Chapter 1. To summarise the process, Table 8.1 provides a starting point for the development of a framework for empirical WLC research covering pre-implementation, implementation and post-implementation phases. Depending on the sophistication of a company and the level of preparation already undertaken, a number of these steps may not be required, while some of the steps can also be performed in parallel. It is hoped that this will provide a useful insight for practitioners and a guide for further practical research in this field.

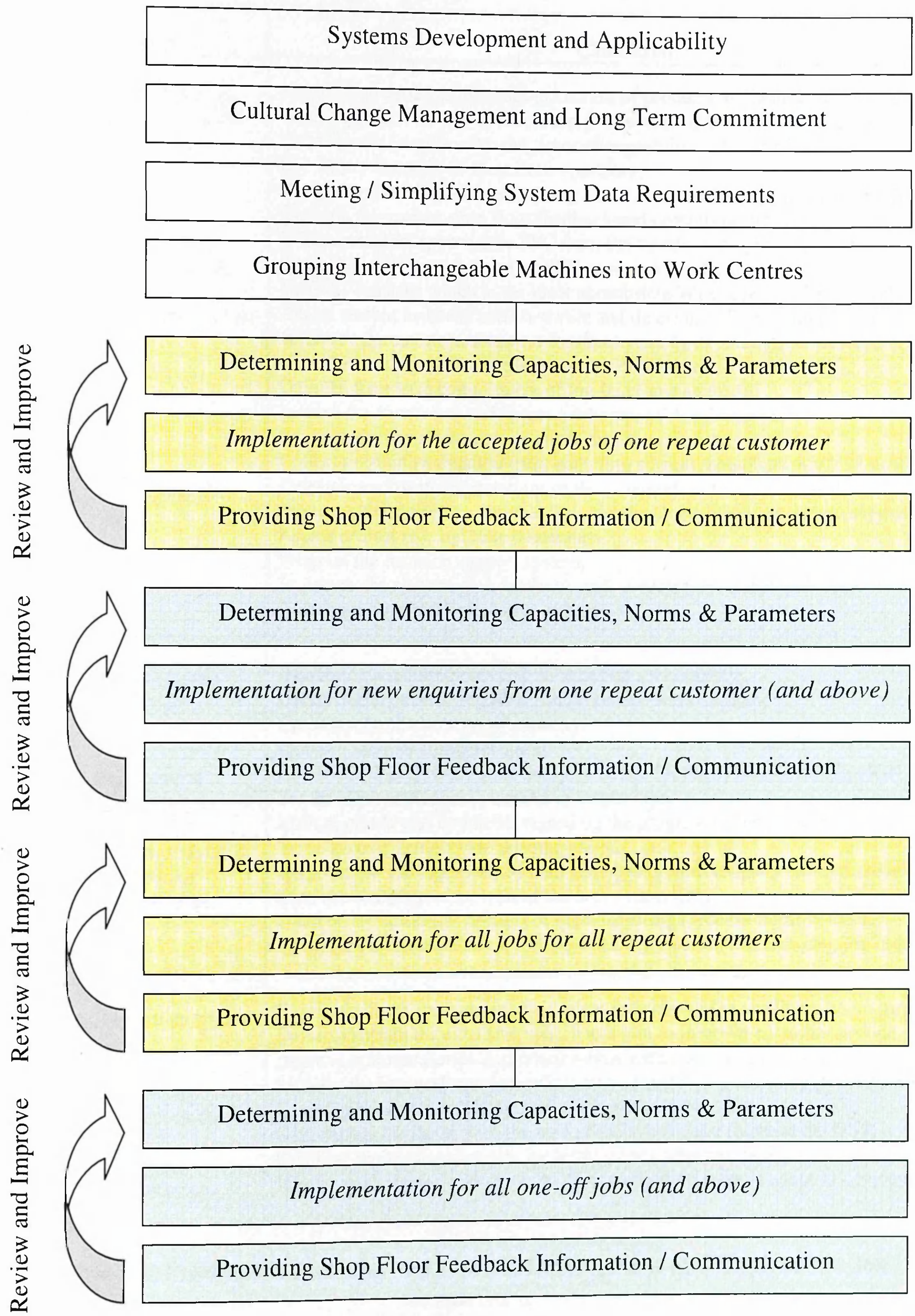


Figure 8.3: Enhanced (Gradual) Implementation Strategy

	Stage	Checklist
Pre-Implementation	*Determining the PPC needs of the company*	Assess shop configuration and the nature of production / degree of customisation; Assess the need for any special shop provisions, such as for bottlenecks; Establish the functionality and 'inter-changeability' of machines; Determine the skills of shop floor operators; Gauge the flexibility of capacity, e.g., overtime constraints (output control); Evaluate the current shop floor feedback and communication system; Evaluate current approach to PPC from the customer enquiry stage (input control);
	Determining the required functionality of the system	Determine the most appropriate PPC approach for the shop; If WLC, consider which is the most appropriate WLC concept for the shop; Assess current in-house soft/hardware and determine if upgrading is required; Allocate appropriate end-user(s) for the system (with enough time to dedicate); Gain the backing of the immediate superior to the end-user(s); Gain the long term commitment of top-level management; Involve the supervisor and secure a 'champion' for the project; Evaluate shop performance measures and shop monitoring system; Collect pre-implementation data, including current manufacturing lead times;
	Developing the DSS	Determine software expectations of the company and in particular the end-user(s); Agree a system specification between the developer, the user and management; Assess project risk and time constraints; Program the decision support system; Prototype the system, gain feedback and, if necessary, adapt and improve; Develop a clear implementation strategy.
Implementation	*Organising the shop floor*	Finalise data requirements and information accessibility; Group (semi-) interchangeable machines into work centres; Create accurate estimates of capacity; Improve internal communication;
	Determining parameters	Determine appropriate norms and parameters for the system, including RBL's; Set the input rate equal to a realistic output rate; Meet regularly and update all regarding the progress of the project;
	Gaining trust and overcoming cultural issues	Train the user and provide documentation; Demonstrate the impact the system can have on the company and individuals; Gain the confidence and trust of the user / supervisor; Overcome traditional concepts of manufacturing (process improvement); Emphasise on time delivery, feeding back information and delaying job release.
Post-Implementation	*Promoting 'repeat use'*	Ensure the hype surrounding the project remains (or the problems will return); Strive to sustain the current approach and aim to improve customer service; Improve communication and relationships with customers (and suppliers);
	Sustaining improvements	Monitor the key performance indicators and improve (sustaining performance); Review parameters regularly, and adjust where necessary;
	Continuous improvement	Gain further feedback from the user of the system and improve the DSS; Continue to develop channels for feeding back information from the shop floor; If conditions change over time, the PPC methodology must adapt to compensate.

Table 8.1: Production Planning and Control Development and Implementation Framework

8.5 CONCLUSION

Although the implementation of the DSS has encountered a number of problems during the various stages of development, it has also highlighted a number of important issues leading to significant refinement of the WLC concept, giving the methodology greater practical orientation. This case study has also validated the previous argument surrounding the aggregate load methodology. In other words, the claim that managers favour simplicity and have a limited amount of time available for planning and control activities. Simplicity is also a useful means of promoting repeat use of the DSS. This vindicates the decision made to employ the aggregate release method at this stage, rather than a more complex approach such as LOMC. The resulting methodology provides an excellent platform from which to implement WLC in practice once a disciplined approach to providing data has been integrated into the culture of the organisation.

A rigorous approach was taken to selecting the case study company (see Chapters 3 and 6); however, it could be argued that if the project had commenced with a different organisation, a more straightforward implementation may have taken place. However, such a project would have been unlikely to contribute to the improvement of the conceptual model or the implementation strategy presented in this chapter.

The case study has helped to provide a practical insight into the implementation requirements of WLC and contributed to the conceptual development of the LUMS approach. One of the key features of any system designed for use in practice is flexibility; this is particularly true when it is designed for the diverse job shop environment and highly customised make-to-order industry. It is also important that the data requirements of the concept do not exceed the data availability within the company. These two factors have been considered throughout the stages of conceptual refinement described in this thesis. It is however hoped that this is not the final result from the case study and that in time the research project can be continued, thus leading to successful and sustained use of the WLC concept. It is also hoped that through collaboration with other researchers actively involved in case study applications of WLC in Europe, that more generalised conclusions regarding both the design of WLC concepts and of implementation strategies can emerge through the triangulation of results.

CHAPTER 9: CONCLUSIONS AND FUTURE RESEARCH POTENTIAL

This thesis is geared towards bridging the gap between the theory of WLC and the practice of MTO production planning. Section 9.1 is organised around the two research questions outlined in Chapter 1 and repeated in the relevant subsection for reference, thereby giving a clear summary of the contribution of this thesis. Section 9.2 then describes avenues of future research.

9.1 CONTRIBUTION: Building the Bridge from Theory to Practice

9.1.1 Refining a WLC Concept

> *(1) How can theoretical aspects of the LUMS approach be refined to facilitate practical implementation of the Workload Control concept, thus bridging the gap between theory and practice?*

This research began with a largely theoretical concept that was highly effective in simulation but which made unrealistic assumptions about the practice of MTO production planning and which had not been successfully implemented. A key contribution of the research is the refinement of the LUMS WLC methodology in line with practice whilst protecting the core methodology which made it so effective in previous simulations. Throughout the refinement process it was important to balance the performance advantages of increasing the sophistication of the concept against the practical advantages of simplicity. The approach now makes more realistic assumptions about the practice of planning and control in MTO companies.

The theoretical development and refinement process encapsulated elements of both deductive and inductive research. Deductive research led to major refinements to key assumptions underpinning the LUMS approach, such as the following (for further details, see Chapter 5):

- The restructuring of the hierarchy of backlogs around the control of daily rather than weekly workloads to reflect the competitiveness of modern day MTO industries, where customers are requiring increasingly short lead times.
- Discrete backwards scheduling to replace an overly complex algebraic method of calculating operation completion dates, reducing the importance of determining queuing norms and providing greater guidance for the order release decision.
- Refinements that reduce the data requirements and parameter setting burden of the LUMS approach, providing a concept of greater relevance to real-life job shops and to managers on a day-to-day basis.
- The adaptation of the concept to accommodate theoretical assumptions, which are otherwise difficult to satisfy in practice, for example, promoting the immediate supply of feedback information within the system.
- A multiple release option, allowing management to assess the cumulative impact of jobs on shop floor resources before making the final release decision.

These refinements were incorporated into a DSS, which was then adapted for a specific case study company.

The inductive phase of the research was conducted through a longitudinal case study, leading to further significant theoretical development of the LUMS approach. The key refinements resulting from this stage are as follows (for further details, see Chapter 8):

- Refinements to incorporate limited data availability at the customer enquiry stage; a stage considered crucial to the control of lower levels of the hierarchy of backlogs within MTO companies. This is considered a particularly significant refinement as many of the theoretical approaches to WLC in the literature assume that full job routing data is available at the customer enquiry stage. However, this proved not to be the case for this company, and it is concluded that the same would be true for other companies which have a low strike rate. As argued by the management of the case study company, it is not considered worthwhile to determine the detailed job routing for a job that you only have a small percentage chance of winning. Therefore, it was necessary to consider an alternative way to approximate the delivery dates as discussed in detail in Section 8.3.1 of Chapter 8.
- The incorporation of a forwards scheduling option at the job entry stage to accommodate the re-negotiation of delivery dates. Such re-negotiation was required given the common delays between making a bid and receiving confirmation of an order. Again, this is considered to be an important consideration, likely to be of relevance to other SME's given their typical position in the supply chain.
- The addition of a part-release option. This makes the methodology less restrictive, reflects the types of lot splitting decisions made by production planners in practice

and hence it is less likely that users will neglect the system because it does not allow them to carry out the type of release to which they are accustomed. This is an element considered important to accommodate if repeat use of the WLC concept is to be achieved and the effectiveness of the system is to be maintained.

Whilst these refinements are the result of research into the LUMS approach, it is suggested that these issues are of relevance to the WLC concept in general.

The case study experience suggests that modern managers within SME's, performing multiple tasks, have limited time available for planning and control, and favour simplicity over more complex concepts. Thus refinements have been made that avoid increasing the complexity of the methodology. Whilst these conclusions relate to one company at present, it is felt that they are likely to be of general relevance and hence important to retain within the refined LUMS methodology. For reasons outlined in Chapter 4, it is sometimes appropriate to use another variant of the WLC concept, for example, due to the shop floor layout or the presence of bottlenecks. As discussed above, it is concluded that many of the refinements identified in this research are also appropriate for other variants of the WLC concept, particularly the three pertinent issues identified during the inductive research phase.

9.1.2 Addressing Issues of Implementation

(2) What Workload Control implementation issues can be identified, and how can they be addressed in practice?

One of the key factors in bridging the gap between the extensive literature on WLC in theory and the very limited case study literature is the process of implementation. The implementation process can be considered to be the point at which theory meets practice; however, the literature has so far failed to provide sufficient empirical evidence to support this process. By providing an in depth case study account in which implementation issues of particular relevance to WLC are both identified and addressed, the research provides an original and much needed contribution to knowledge.

A number of issues have been identified during the case study research which contribute towards the complexity of WLC implementation. The issues identified and addressed include the following (for further details, see Chapter 7):

- Determining accurate estimates of capacity. WLC simulations to date have failed to account for the interaction between the productivity of individuals and the workload level. In this case study, an ad-hoc approach is applied to account for the varying skills and experience of operators within the approximation of capacity when the level of workload increases (see Section 7.4.3 of Chapter 7).
- Encouraging the feedback of information from the shop floor to the WLC system. This research has noted the difficulties of supplying feedback information in practice without existing procedures in place to relay this information from the shop floor. To address this issue, it is concluded that it is important that the operator of the WLC system has some information on the progress of jobs, even if more detailed procedures for collecting such information are not in place.
- The importance of grouping machines on the effectiveness of WLC has been previously identified through simulation studies. Ideally, machine groupings

should consist of machines that are 100% interchangeable; however, this research highlighted the need to group semi-interchangeable machines.

- The partial implementation of the WLC system led to the development of an implementation strategy for WLC and a detailed framework for production planning and control concepts. The experience suggests that a gradual strategy to implement WLC may be applicable; however, the full benefits will only be realised when WLC is used across all planning levels and all jobs.
- The research indicates that users would more welcome the implementation of WLC if the methodology was more autonomous. However, the degree of complexity in MTO environments means that certain tasks, such as capacity management decisions, delivery date negotiations and the criteria for releasing jobs, rely on user involvement.

The extent to which the implementation of WLC is successful has been shown to be strongly influenced by organisational politics, company culture, the distribution of power and the extent to which these can be manipulated within a company. This is a topic that has been neglected in previous WLC literature. By exploring these issues in detail, the thesis provides a further original contribution to knowledge. Ultimately, the political landscape within the case study company at the present time meant that a full implementation of the WLC system was not possible. Nonetheless, the research enabled a number of important implementation issues to be raised and developed a gradual approach to implementing the concept; this is considered to be of particular significance when political and cultural issues are in need of a great deal of change.

Bridging the gap between theory and practice thus involves a compromise that incorporates fostering both theoretical change and change in practice. To conclude, the contribution of this research is summarised in Table 9.1. It is noted that the table summarises both the issues discussed above and the contributions to knowledge that arise from the study of the literature. In terms of the latter, Chapter 2 provides an extensive contemporary review of the production planning and control literature and identifies a number of important research gaps to be addressed in this field. In addition, Chapter 4 extensively reviews the WLC variants showing the advantages of the LUMS approach.

	Feature of the Research	Extending the Boundary of Knowledge	Thesis Navigation
Bridging the Gap Between Theory and Practice	Literature Investigation	Identification of WLC as a continuing key approach for MTO companies, with advantages over alternatives such as ERP, CONWIP and POLCA.	Chapter 2
		The identification of key characteristics of contemporary WLC concepts, thereby verifying that the LUMS approach to WLC contains the required features.	Chapter 4
	Refining the LUMS WLC Approach	Deductive refinements to the LUMS WLC concept, including allowing queuing norms to vary across work centres, discrete backwards scheduling with a daily hierarchy of backlogs and promoting the provision of information feedback.	Chapter 5 (see Table 5.3)
		Inductive refinements to the LUMS WLC concept from a rare case study account, including accommodating limited data availability and forwards scheduling for delivery date re-negotiations.	Chapter 6 and Chapter 8 (see Section 8.3)
	Identifying and Addressing Implementation Issues	Determining machine groupings, capacities and reallocation options	Chapter 7 (see Table 7.2)
		A Six Stage Implementation Strategy for WLC	Chapter 7 (see Figure 7.2)
		A Revised (Gradual) Implementation Strategy for WLC	Chapter 8 (see Figure 8.3)
		A Detailed PPC Implementation Framework	Chapter 8 (see Table 8.1)
		Insights into the effects of power and politics on the implementation of WLC.	Chapter 8 (Section 8.2.2)

Table 9.1: Summarising the Contribution of the Research

9.2 FUTURE RESEARCH SCOPE

A great deal of potential for further research emerges from the contribution of this thesis. Researchers should look to use this thesis as a platform for generating empirical results from the widespread use of the WLC concept in practice. By continuing to forge long term relationships with companies such as this case study, research can examine how to sustain the benefits of WLC on a day to day basis once the initial hype surrounding the project has diminished.

Firstly, therefore, future research should look to implement the WLC concept within a diverse range of companies. This would allow the research community to build up a body of case study results, across varying shop conditions, company sizes and manufacturing capabilities. Applying WLC to larger companies may present an additional set of implementation issues. For example, it may be more difficult to change the culture of a large hierarchical organisation, on the other hand, the company may be able to commit more resources and technology may be more advanced. This could also contribute to enhancing the implementation strategy and framework presented in this thesis. It would also be interesting to investigate the application of the WLC concept in other contexts, such as in the service sector or as a means to manage inter-organisational / supply chain activities.

Secondly, research can also seek to further increase flexibility and the generic nature of system functionality in order to improve the robustness of WLC concepts. For example, the scheduling function could be developed to accommodate more complex product trees, such as sub-assembly structures, while the DSS could also incorporate the strike rate in the form of a more sophisticated probability matrix. Other ideas include linking the DSS to a shop floor bar coding system, providing specific planning and control for rework and design stages, incorporating a pricing module and developing a more detailed help library for the user. Further issues of generic functionality may emerge from visiting a large number of companies, gaining feedback from potential users and assessing how the DSS would have to be adapted in order for WLC to be used within each company.

Thirdly, future research should also seek to investigate practical extensions to the WLC concept. For example, the addition of web functionality to the DSS, as highlighted in Chapter 2 as an area in need of further research. One such use is in providing customers with online job progress reporting, in other words allowing customers to view the progress of their jobs prior to delivery, thus increasing order visibility in the supply chain. For such a project, it will be important to conduct research across a large number of companies to establish the web familiarity of SME's and other features that customers would like to see included. While it is acknowledged that studies of the use of technology in SME's have been conducted, a further exploration is required to tailor the available data to the requirements of such a study.

Finally, future simulation studies should seek to incorporate the characteristics of real life job shops and MTO companies, as have been identified in this project. For example, the capacity approximation applied to Company X can provide the starting point for more realistic simulations of the effect of workloads on productivity. In addition, future simulations could better reflect the political realities of implementation, as identified here.

REFERENCES

Abdul-Nour, G., Lambert, S., and Drolet, J., 1998, Adaptation of JIT philosophy and kanban technique to a small-sized manufacturing firm: A project management approach, *Computers & Industrial Engineering,* 35, 3 - 4, 419 - 422.

Alavi, M., and Joachismthalser, E.A., 1992, Revisiting DSS implementation research: A meta-analysis of the literature and suggestions for research, *MIS Quarterly,* 16, 1, 95 - 116.

Alavi, M., and Leidner, D.E., 2001, Review: Knowledge management and knowledge management systems: Conceptual foundations and research issues, *MIS Quarterly*, 25, 107 – 136.

Alter, S.L., 1980, *Decision support systems: Current practices and continuing challenges*, Reading, MA, Addison-Wesley (ISBN: 0201001934).

Amaro, G.M., Hendry, L.C., and Kingsman, B.G. 1999, Competitive advantage, customisation and a new taxonomy for non make-to-stock companies, *International Journal of Operations and Production Management*, 19, 4, 349 - 371.

Anavi-Isakow, S., and Golany, B., 2003, Managing multi-project environments through constant work-in-process, *International Journal of Production Management*, 21, 9 - 18.

Argyris, C., and Schon, D.A., 1974, *Theories in practice*, Jossey-Bass, San Francisco.

Ash, C.G., and Burn, J.M., 2003, A strategic framework for the management of ERP enabled e-business change, *European Journal of Operational Research*, 146, 374 - 387.

Axsater, S., and Rosling, K., 1999, Ranking of generalised multi-stage kanban policies, *European Journal of Operational Research*, 113, 560 - 567.

Baker, M.J, 2003, *Business and management research: How to complete your research project successfully*, Western Publishers Ltd, Scotland (ISBN: 094643302X).

Baskerville, R., and Wood-Harper, T., 1996, A critical perspective on action research as a method for information systems research, *Journal of Information Technology*, 11, 3, 235 – 246.

Baskerville, R., and Pries-Heje, J., 1999, Grounded action research: A method for understanding IT in practice, *Accounting Management and Information Technologies*, 9, 1 – 23.

Bechhofer, F., 1974, Current approaches to empirical research: Some central ideas, in *Approaches to sociology*, (ed) Rex, J., Routledge, London.

Bechte, W., 1988, Theory and practice of load oriented manufacturing control, *International Journal of Production Research*, 26, 3, 375 - 395.

Bechte, W., 1994, Load oriented manufacturing control just in time production for job shops, *Production Planning and Control*, 5, 292 - 307.

Benbasat, I., Goldstein, D.K., and Mead, M., 1987, The case research strategy in studies of information systems, *MIS Quarterly*, 11, 3, 369 – 386.

Benbasat, I., Goldstein, D.K., and Mead, M., 2002, The case research strategy in studies of information systems, in *Qualitative research in information systems*, (eds) Myers, M.D., and Avison, D., Sage Publications, London (ISBN: 0761966323).

Bergamaschi, D., Cigolini, R., Perona, M., and Portioli, A., 1997, Order review and release strategies in a job shop environment: A review and a classification, *International Journal of Production Research*, 35, 2, 399 - 420.

Bertrand, J.W.M., and Wortmann, J.C., 1981, *Production control and information systems for component-manufacturing shops*, Elsevier Scientific Publishing Company, Amsterdam (ISBN: 0444419640).

Bertrand, J.W.M., and Muntslag, D.R., 1993, Production control in engineer-to-order firms, *International Journal of Production Economics*, 30 - 31, 3 - 22.

Bertrand, J.W.M., and Van Ooijen, H.P.G., 2002, Workload based order release and productivity: A missing link, *Production Planning and Control*, 13, 7, 665 - 678.

Bhattacherjee, A., 2000, Beginning SAP/R3 implementation at Geneva pharmaceuticals, *Communications of the Association for Information Systems*, 4, 2, 1 - 38.

Bidgoli, H., 1989, *Decision support systems: Principles and practice*, West Publishing Company, St. Paul (ISBN: 031446560X).

Blaikie, N., 2000, *Designing social research: The logic of anticipation*, Cambridge, Polity Press (ISBN: 0745617670).

Blazewicz, J., Domschke, W., and Pesch, E., 1996, The job shop scheduling problem: Conventional and new solution techniques, *European Journal of Operational Research*, 93, 1, 1 - 33.

Bobrowski, P.M., 1989, Implementing a loading heuristic in a discrete release job shop, *International Journal of Production Research*, 27, 1935 - 1948.

Braiden, P.M., Alderman, N., and Thwaites, A.T., 1993, Engineering design and product development and its relationship to manufacturing: A programme of case study research in British companies, *International Journal of Production Economics*, 30 - 31, 265 - 272.

Breithaupt, J.W., Land, M. J., and Nyhuis, P., 2002, The workload control concept: Theory and practical extensions of load oriented order release, *Production Planning and Control*, 13, 7, 625 - 638.

Brown, D.H., and Qi, H., 2000, Strategic development in China, in *Global change: The impact of Asia in the 21st Century*, 273 - 290, (eds) Thorpe, R., and Little, S., Palgrave, Hants (ISBN: 0333920066).

Brown, S., and Bessant, J., 2003, The manufacturing strategy-capabilities links in mass customisation and agile manufacturing - an exploratory study, *International Journal of Operations and Production Management*, 23, 7 - 8, 707 - 730.

Bruun, P., and Mefford, R.N., 2004, Lean production and the internet, *International Journal of Production Economics*, 89, 247 - 260.

Burnes, B., 2004, *Managing change*, 4th Edition, Prentice-Hall (ISBN: 0273683365).

Burnes, B., and James, H., 1995, Culture, cognitive dissonance and the management of change, *International Journal of Operations and Production Management*, 15, 8, 14 - 33.

Cagliano, R., Caniato, F., and Spina, G., 2003, E-Business strategy: How companies are shaping their supply chain through the internet, *International Journal of Operations and Production Management*, 23, 10, 1142 - 1162.

Calosso, T., Cantamessa, M., Vu, D., and Villa, A., 2003, Production planning and order acceptance in business to business electronic commerce, *International Journal of Production Economics,* 85, 233 - 249.

CBI, 2000, The future of manufacturing?, *Confederation of British Industry Manufacturing Brief*, December Edition.

Chang, S-H., Pai, P-F., Yuan, K-J., Wang, B-C., and Li, R-K., 2003, Heuristic PAC model for hybrid MTO and MTS production environment, *International Journal of Production Economics*, 85, 347 - 358.

Cigolini, R., Perona, M., and Portioli, A., 1998, Comparison of order review and release techniques in a dynamic and uncertain job shop environment, *International Journal of Production Research*, 36, 11, 2931 - 2951.

Cigolini, R., and Portioli-Staudacher, A., 2002, An experimental investigation on workload limiting methods with ORR policies in a job shop environment, *Production Planning and Control*, 13, 7, 602 - 613.

Cook, D.P., 1994, A simulation comparison of traditional, JIT and TOC manufacturing systems in a flow shop with bottlenecks, *Production and Inventory Management*, First Quarter, 73 - 78.

Cooper, D.R., and Schindler, P.S., 2003, *Business research methods*, Eight Edition, McGraw-Hill Irwin (ISBN: 0072498706).

Cooper, R.B., 1994, The inertial impact of culture on IT implementation, *Information and Management*, 27, 1, 17 – 31.

Costello, P.J.M., 2003, *Action Research*, Continuum, London (ISBN: 0826464793).

Coughlan, P., and Coghlan, D., 2002, Action research for operations management, *International Journal of Operations and Production Management*, 22, 2, 220 – 240.

Cox, J.F., and Spencer, M.S., 1998, *The constraints management handbook*, St. Lucie Press, Florida (ISBN: 1574440608).

Croom, S., 2002, Methodology editorial: Introduction to the special issue on research methodology in operations management, *International Journal of Operations and Production Management*, 22, 2, 148 – 151.

Dallery, Y., and Liberopoulos, G., 2000, Extended kanban control system: Combining kanban and base stock, *IIE Transactions*, 32, 4, 369 - 386.

Davis, S., 1987, *Future perfect*, Addison-Wesley, Reading, MA (ISBN: 0201517930).

De Souza, A.A., 1995, Developing a knowledge based decision support system to aid make-to-order companies in cost estimation and pricing decisions, *PhD Thesis, Lancaster University, Lancaster, UK.*

Ding, F.Y., and Yuen, M.N., 1991, A modified MRP for a production system with the coexistence of MRP and kanbans, *Journal of Operations Management*, 10, 2, 267 - 277.

Doukidis, G.I., Lybereas, P, and Galliers, R.D., 1996, Information systems planning in small business: A stage of growth analysis, *Journal of Systems Software*, 33, 2, 189 – 201.

DTI, 1999, *Small and medium enterprise (SME) statistics for the United Kingdom: 1998*, Department of Trade and Industry SME Statistics Unit, August Edition (URN 99/92).

Duclos, L.K., and Spencer, M.S., 1995, The impact of a constraint buffer in a flow shop, *International Journal of Production Economics*, 42, 175 - 185.

Easterby-Smith, M., Thorpe, R., and Lowe, A., 1991, *Management research: An introduction*, London, Sage (ISBN: 080398393X).

Easton, F.F., and Moodie, D.R., 1999, Pricing and lead time decisions for make-to-order firms with contingent orders, *European Journal of Operational Research*, 116, 2, 305 - 318.

Easton, G., 1992, *Learning from case studies*, Prentice-Hall (ISBN: 0135286883).

Eden, C., 1994, On the evaluation of 'wide-band' GDSS's, *European Journal of Operational Research*, 81, 302 – 311.

Eden, C., and Huxham, C., 1996, Action research for management research, *British Journal of Management*, 7, 1, 78 – 86.

EEF, 2004, Engineering outlook: First release, *eef, The Manufacturers organisation*, September Edition.

EITO, European Information Technology Observatory, 2000, Frankfurt.

Emory, C., and Cooper, D., 1991, *Business research methods*, 4th Edition, Homewood, Illinois, Richard D. Irwin (ISBN: 0256092656).

Enns, S.T., 1995, An economic approach to job shop performance analysis, *International Journal of Production Economics*, 38, 117 - 131.

Enns, S.T., and Prongue Costa, M., 2002, The effectiveness of input control based on aggregate versus bottleneck workloads, *Production Planning and Control*, 13, 7, 614 - 624.

Er, M.C., 1988, Decision support systems: A summary, problems, and future trends, *Decision Support Systems*, 4, 3, 355 - 363.

EUROPA, 2003, http://europa.eu.int/comm/enterprise/enterprise_policy/sme_definition/index_en.htm.

Finlay, P.N., and Forghani, M., 1998, A classification of success factors for decision support systems, *Strategic Information Systems*, 7, 53 – 70.

Flynn, B.B., Sakakibara, S., Schroeder, R.G., Bates, K.A., and Flynn, E.J., 1990, Empirical research methods in operations management, *Journal of Operations Management*, 9, 2, 250 – 284.

Ford, D., 1990, *Understanding business markets: Interaction, relationships, networks*, Academic Press, London (ISBN: 0122621417).

Forrester, J.W., 1961, *Industrial dynamics*, MIT Press, Cambridge, MA (ISBN: 0915299887).

Fowler, J.W., Hogg, G.L., and Mason, S.J., 2002, Workload control in the semiconductor industry, *Production Planning and Control,* 13, 7, 568 - 578.

Freyenfeld, W.A., 1984, *Decision support systems: An executive overview of interactive computer-assisted decision making in the UK*, NCC Publications, Manchester (ISBN: 0850124875).

Fry, T.D., and Smith, A.E., 1987, A procedure for implementing input / output control: A case study, *Production and Inventory Management Journal*, Fourth Quarter, 28, 4, 50 - 52.

Fry, T.D., Karwan, K.R., and Steele, D.C., 1991, Implementing drum-buffer-rope to control manufacturing lead time, *International Journal of Logistics Management*, 2, 1, 12 – 18.

Fuller, T., 1996, Fulfilling IT needs in small business: A recursive learning model, *International Small Business Journal*, 14, 4, 25 – 44.

Galliers, R., and Newell, S., 2001, Back to the future: From knowledge management to data management, *9th European Conference on Information Systems,* *ECIS, Bled, Slovenia, Moderna Obganizacija, Conference Proceedings,* 609 – 615.

Garrity, J.T., 1963, Top management and computer profits, *Harvard Business Review*, 41, 6 - 12, 172 - 174

Gaury, E.G.A., Pierreval, H., and Kleijnen, J.P.C., 2000, An evolutionary approach to select a pull system among kanban, CONWIP and hybrid, *Journal of Intelligent Manufacturing*, 11, 157 - 167.

Gelders, L.F., and Van Wassenhove, L.N., 1981, Production planning: A review, *European Journal of Operational Research*, 7, 2, 101 - 110.

Gill, J., and Johnson, P., 1991, *Research methods for managers*, Paul Chapman Publishing, London.

Glassey, C.R., and Resende, M.G., 1988, Closed-loop job release control for VLSI circuit manufacturing, *IEEE Transactions on Semiconductor Manufacturing*, 1, 36 - 46.

Goldratt, E.M., 1990a, *What is this thing called theory of constraints and how should it be implemented?,* North River Press, New York, NY (ISBN: 0884271668).

Goldratt, E.M., 1990b, *The haystack syndrome: Sifting information out of the data ocean,* North River Press, New York, NY (ISBN: 0884270890).

Goldratt, E.M., and Cox, J., 1984, *The goal: Excellence in manufacturing*, North River Press, New York (ISBN: 0884270610).

Gorry, G.A., and Scott Morton, M.S., 1971, A framework for management information systems, *Sloan Management Review*, 13, 1, 50 – 70.

Graetz, F., Rimmer, M., Lawrence, A. and Smith, A. 2002, *Managing organisational change*, John Wiley and Sons.

Grunwald, H., Striekwold, P.E.T., and Weeda, P.J., 1989, A framework for quantitative comparison of production control concepts, *International Journal of Production Research*, 27, 281 - 292.

Gummesson, E., 2000, Qualitative methods in management research, Sage Publications Ltd (ISBN: 0761920145).

Haskose, A., Kingsman, B.G., and Worthington, D., 2002, Modelling flow and jobbing shops as a queuing network for workload control, *International Journal of Production Economics,* 78, 3, 271 - 285.

Hendry, L.C., 1989, A decision support system to manage delivery and manufacturing lead times in make to order companies, *PhD Thesis, Lancaster University, Lancaster, UK.*

Hendry, L.C., 2005, Product customisation: An empirical study of competitive advantage and repeat business, *Lancaster University Management School Working Paper Series.*

Hendry, L.C., and Kingsman, B.G., 1989, Production planning systems and their applicability to make to order companies, *European Journal of Operational Research*, 40, 1 - 15.

Hendry, L.C., and Kingsman, B.G., 1991, A decision support system for job release in make to order companies, *International Journal of Operations and Production Management*, 11, 6 - 16.

Hendry, L.C., Elings, P., and Pegg, D., 1993, Production planning for an artist's studio – a case study, *European Journal of Operational Research*, 64, 12 - 20.

Hendry, L.C., and Kingsman, B.G., 1993, Customer enquiry management: Part of a hierarchical system to control lead times in MTO companies, *Journal of the Operational Research Society*, 44, 1, 61 - 70.

Hendry, L.C., and Wong S.K., 1994, Alternative order release mechanisms: A comparison by simulation, *International Journal of Production Research*, 32, 12, 2827 - 2842.

Hendry, L.C., Kingsman, B.G., and Cheung, P., 1998, The effect of workload control (WLC) on performance in make-to-order companies, *International Journal of Operations Management*, 16, 63 - 75.

Hendry, L.C., Kingsman, B.G., and Amaro, G.M., 2003, Product customisation and competitive advantage: An empirical study, *One World? One View of OM? EUROMA Conference Proceedings, Lake Como, Italy,* 1, 119 - 128.

Henrich, P., 2005, Applicability aspects of workload control in job shop production, *PhD Thesis, University of Groningen, The Netherlands*, Labyrint Publications, Ridderkerk, The Netherlands (ISBN: 9053350470).

Henrich, P., Land, M.J. and Gaalman, G., 2002, Introducing the concept of workload control into MTO companies: Determining applicability, *12th International Working Seminar on Production Economics, Igls, Innsbruck, Conference Proceedings*, 1, 111 - 124.

Henrich, P., Land, M.J., Gaalman, G., and Van Der Zee, D.J., 2003, The effect of information on workload control, *One World? One View of OM? EUROMA Conference Proceedings, Lake Como, Italy,* 2, 611 - 620.

Henrich, P., Land, M.J., and Gaalman, G., 2004, Grouping machines for effective workload control, *13th International Working Seminar on Production Economics, Igls, Innsbruck, Conference Proceedings*, 4, 141 - 160.

Henrich, P., Land, M.J. and Gaalman, G., 2005, Introducing the concept of workload control into MTO companies: Determining applicability, *International Journal of Production Economics* (Article in Press).

Hill, T., 1993, *Manufacturing strategy: The strategic management of the manufacturing function*, MacMillan Press Limited (ISBN: 0333576489).

Hill, T., 1995, *Manufacturing strategy: Texts and cases*, MacMillan, Basingstoke (ISBN: 0333636708).

Hill, T., 2000, *Operations management: Strategic context and managerial analysis*, MacMillan Press Limited (ISBN: 0333775929).

Hill, J, and Wright, L.T., 2001, A qualitative research agenda for small to medium sized enterprises (SME's), *Marketing Intelligence and Planning*, 19, 6, 432 – 443.

Hong, K.K., and Kim, Y.G., 2002, The critical success factors for ERP implementation: An organisational fit perspective, *Information and Management*, 40, 25 – 40.

Hopp, W.J., and Spearman, M.L., 1996, *Factory Physics: Foundation of manufacturing management*, Irwin, USA (ISBN: 0071143548).

Hopp, W.J., and Roof, M.L., 1998, Setting WIP levels with Statistical Throughput Control (STC) in CONWIP production lines, *International Journal of Production Research,* 36, 4, 867 - 882.

Hsu, M., and Chen, B-L., 2000, Labor productivity of small and large manufacturing firms: The case of Taiwan, *Contemporary Economic Policy*, 18, 2, 270 - 283.

Hunter, L.M., Kasouf, C.J., Celuch, K.G., and Curry, K.A., 2004, A classification of business-to-business buying decisions: Risk importance and probability as a framework for e-business benefits, *Industrial Marketing Management,* 33, 145 - 154.

Hussey, J., and Hussey, R., 1997, *Business research, A practical guide for undergraduate and postgraduate students*, McMillan Press Ltd, London (ISBN: 033360704X).

Jain, A. S., and Meeran, S., 1999, Deterministic job shop scheduling: Past, present and future, *European Journal of Operational Research*, 113, 2, 390 - 434.

Jain, V., Swarnkar, R., and Tiwari, M.K., 2003, Modelling and analysis of wafer fabrication scheduling via generalised stochastic Petri net and simulated annealing, *International Journal of Production Research*, 41, 15, 3501 - 3527.

Jankowicz, A.D., 2000, *Business research projects*, 3rd Edition, Business Press: Thomson Learning (ISBN: 1861525494).

Johnson, G., and Scholes, K., 1993, *Exploring corporate strategy: Text and cases*, Third Edition, Prentice Hall, New York (ISBN: 013297441X).

Joshi, K., and Lauer, T.W., 1998, Impact of information technology on users' work environment: A case of Computer Aided Design (CAD) system implementation, *Information and Management*, 34, 349 – 360.

Kanet, J.J., 1988a, MRP 96: Time to rethink manufacturing logistics, *Production and Inventory Management Journal*, 29, 57 - 61.

Kanet, J.J., 1988b, Load-limited order release in job shop scheduling systems, *Journal of Operations Management,* 7, 3 - 4, 44 - 58.

Karaesmen, F., and Dallery, Y., 2000, A performance comparison of pull type control mechanisms for multi stage manufacturing, *International Journal of Production Economics*, 68, 59 - 71.

Karmarkar, U., 1989, Getting control of just-in-time, *Harvard Business Review*, 67, 5, 122 - 131.

Keen, P.G.W., 1981, Information systems and organisational change, *Communications of the ACM*, 24, 1.

Keen, P., Scott Morton, M., 1978, *Decision Support Systems: An Organisational Perspective*, Addison Wesley Publishing, Reading, MA (ISBN: 0201036673).

Kehoe, D.F., and Boughton, N.J., 2001a, Internet based supply chain management: A classification of approaches to manufacturing planning and control, *International Journal of Operations and Production Management*, 21, 4, 516 - 524.

Kehoe, D.F., and Boughton, N.J., 2001b, New paradigms in planning and control across manufacturing supply chains: The utilisation of internet technologies, *International Journal of Operations and Production Management*, 21, 5 - 6, 582 - 593.

Keynote, 2002, *Small businesses and banks: 2002 market assessment*, (ed) Taylor, S. Keynote Limited (ISBN: 186113868).

Kher, H.V., and Malhotra, M.K., 1994, Acquiring and operationalizing worker flexibility in dual resource constrained job shops with worker transfer delays and learning losses, *Omega*, 22, 5, 521 - 533.

Kingsman, B.G., 2000, Modelling input-output workload control for dynamic capacity planning in production planning systems, *International Journal of Production Economics*, 68, 1, 73 - 93.

Kingsman, B.G., Worden, L., Hendry, L.C., Mercer, A., and Wilson, E., 1993, Integrating marketing and production planning in make-to-order companies, *International Journal of Production Economics*, 30 - 31, 53 - 66.

Kingsman, B.G., Hendry, L.C., Mercer, A., and De Souza, A., 1996, Responding to customer enquiries in make-to-order companies: Problems and solutions, *International Journal of Production Economics*, 46 - 47, 219 - 231.

Kingsman, B.G., and Mercer, A., 1997, Strike rate matrices for integrating marketing and production during the tendering process in make-to-order subcontractors, *International Journal of Operational Research*, 4, 1, 251 - 257.

Kingsman, B.G., and Hendry, L.C., 2002, The relative contributions of input and output controls on the performance of a workload control system in make to order companies, *Production Planning and Control*, 13, 7, 579 - 590.

Klein, M., and Methlie, L.B., 1990, *Expert systems, a decision support approach with applications in management and finance*, Addison Wesley, Reading MA (ISBN: 0201175622).

Knight, G., 2000, Entrepreneurship and marketing strategy: The SME under globalisation, *Journal of International Marketing*, 8, 2, 12 – 32.

Krajewski, L.J., and Ritzman, L.P., 1998, *Operations management: Strategy and analysis*, Fifth Edition, Addison-Wesley Publishing Company Inc (ISBN: 0201331187).

Kumar, K., and Thibodeaux, M., 1990, Organisational politics and planned organisation change, *Group and Organization Studies,* 15, 4, 357 – 365.

Kuroda, M., and Takeda, K., 1998, General structure and characteristics of quick response production system, *Computers & Industrial Engineering,* 35, 3 - 4, 395 - 398.

Kvanli, A.H., Guynes, C.S., Pavur, R.J., and Keeling, K.B., 2003, *Introduction to business statistics: A microsoft excel integrated approach*, 6th Edition, Thomson / Southern Western, Mason, Ohio (ISBN: 0324156987).

Land, M.J., 2004a, Parameters and sensitivity in workload control, *13th International Working Seminar on Production Economics, Igls, Innsbruck, Conference Proceedings*, 1, 279 - 298.

Land, M.J., 2004b, Workload control in job shops: Grasping the tap, *PhD Thesis, University of Groningen, The Netherlands*, Labyrint Publications, Ridderkerk, The Netherlands (ISBN: 9053350276).

Land, M.J., and Gaalman, G., 1996, Workload control concepts in job shops - a critical assessment, *International Journal of Production Economics*, 46 - 47, 535 - 548.

Land, M.J., and Gaalman, G., 1998, The performance of workload control concepts in job shops: Improving the release method, *International Journal of Production Economics*, 56 - 57, 347 - 364.

Laudon, K.C., and Laudon, J.P., 2001, *Essentials of management information systems: Organisation and technology in the networked enterprise*, International Edition, Fourth Edition, Prentice Hall International UK Ltd, London (ISBN: 0130495425).

Laudon, K.C., and Laudon, J.P., 2002, *Management information systems,* Prentice Hall Inc, New Jersey (ISBN: 0130994219).

Lee, H.L., Padmanabhan, V., and Whang, S., 1997, The bullwhip effect in supply chains, *Sloan Management Review*, Spring, 93 - 102.

Levine, H. G., and Rossmoore, D., 1995, Politics and the function of power in a case study of IT implementation, Journal of Management Information Systems, 11, 3, 115 – 133.

Lewin, K., 1946, Action research and minority problems, *Journal of Social Issues*, 2, 34 - 46.

Lewin, K., 1947, Frontiers in group dynamics: Channel of group life: Social planning and action research, *Human Relations*, 1, 143 - 153.

Lewin, K., 1951, *Field theory in social science*, Harper and Bros, New York.

Mabert, V.A., Soni, A., and Venkataramanan, M.A., 2003, The impact of organisation size on enterprise resource planning (ERP) implementations in the U.S. manufacturing sector, *The International Journal of Management Science*, 31, 235 – 246.

Mabey, C., and Mayon-White, B., 1993, *Managing change*, 2nd Edition, The Open University (ISBN: 1853962260).

Mabin, V.J., and Balderstone, S.J., 2003, The performance of the theory of constraints methodology: Analysis and discussion of successful TOC applications, *International Journal of Operations and Production Management*, 23, 6, 568 - 595.

Machuca, J.A.D., and Barajas, R.P., 2004, The impact of electronic data interchange on reducing bullwhip effect and supply chain inventory costs, *Transportation Research Part E*, 40, 209 - 228.

Maffin, D., and Braiden, P.M., 2001, Manufacturing and supplier roles in product development, *International Journal of Production Economics*, 69, 2, 205 - 213.

Mandal, P., and Gunasekaran, A., 2003, Issues in implementing ERP: A case study, *European Journal of Operational Research*, 146, 274 - 283.

Mangham, I.L., 1979, *Politics of organisation change*, Greenwood Press.

Marris, P., 1993, The management of change, in *Managing change*, Second Edition, (eds) Mabey, C., and Mayon-White, B., The Open University.

Mather, H., and Plossl, G., 1978, Priority fixation versus throughput planning, *Production and Inventory Management*, 19, 27 - 51.

Matsuura, H., Kurosu, S., and Lehtimaki, A., 1995, Concepts, practices and expectations of MRP, JIT and OPT in Finland and Japan, *International Journal of Production Economics,* 41, 1 - 3, 267 - 272.

Maylor, H., and Blackmon, K., 2005, *Researching business and management*, Palgrave MacMillan, Hampshire, UK (ISBN: 9780333964070).

McCutcheon, D.M., and Meredith, J., 1993, Conducting case study research in operations management, Journal *of Operations Management*, 11, 239 – 256.

McGovern, T., and Hicks, C., 2004, How political processes shaped the IT adopted by a small make-to-order company: A case study in the insulated wire and cable industry, *Information and Management*, 42, 243 – 257.

McNiff, J., 2000, *Action research in organisations*, Routledge, London (ISBN: 0415220122).

Meador, C.L., Guyote, M.J., and Keen, P.G.W., 1984, Setting priorities for DSS development, *MIS Quarterly*, 8, 2, 117 - 129.

Melnyk, S.A., and Ragatz, G.L., 1989, Order review / release: Research issues and perspectives, *International Journal of Production Research*, 27, 7, 1081 - 1096.

Melnyk, S.A., and Handfield, R.B., 1998, May you live in interesting times…the emergence of theory-driven empirical research, *Journal of Operations Management,* 16, 4, 8, 311-319.

Meredith, J., 1998, Building operations management theory through case and field research, *Journal of Operations Management*, 16, 441 – 454.

Mintzberg, H., 1988, Generic strategies: Toward a comprehensive framework, in *Advances in Strategic Management*, Fifth Edition, 1 - 67, (eds) Lamb, R., and Shrivastava, P., Jai Press Inc, Greenwich, CT (ISBN: 0892327669).

Missbauer, H., 1997, Order release and sequence-dependent set-up times, *International Journal of Production Economics*, 49, 131 - 143.

Missbauer, H., 2002, Lot sizing in workload control systems, *Production Planning and Control*, 13, 7, 649 - 664.

Morgan, G., 1997, *Images of organisation*, Second Edition, Sage, London.

Morris, C., 2000, *Quantitative approaches in business studies*, 5th Edition, Pearson Education Ltd (ISBN: 0273638289).

Motwani, J., Mirchendani, D., Madan, M., and Gunasekaran, A., 2002, Successful implementation of ERP projects: Evidence from two case studies, *International Journal of Production Economics*, 75, 83 – 96.

Muda, M.S., 2001, A new world class manufacturing model for small and medium sized make to order companies, *PhD Thesis, Lancaster University, Lancaster, UK.*

Muda, M.S. and Hendry, L.C., 2003, The SHEN model for MTO SME's: A performance improvement tool, *International Journal of Operations and Production Management*, 23, 5, 470 - 486.

Muscatello, J.R., Small, M.H., and Chen, I.J., 2003, Implementing Enterprise Resource Planning (ERP) systems in small and midsize manufacturing firms, *International Journal of Operations and Production Management*, 23, 8, 850 - 871.

Nahuis, R., 2004, One size fits all? Accession to the internal market; An industry-level assessment of EU enlargement, *Journal of Policy Modelling*, 26, 571 - 586.

Neely, A.D., and Byrne, M.D., 1992, A simulation study of bottleneck scheduling, *International Journal of Production Economics*, 26, 187 - 192.

Newell, S., Huang, J.C., Galliers, R.D., and Pan, S.L., 2003, Implementing enterprise resource planning and knowledge management systems in tandem: Fostering efficiency and innovation complementarity, *Information and Organisation*, 13, 25 – 52.

Nunamaker, J., Vogel, D., Heminger, A., Martz, B., Grotowski, R., and McCoff, C., 1989, Experiences at IBM with group support systems, *Decision Support Systems*, 5, 183 - 196.

O'Brien, J.A., 1994, *Introduction to information systems*, Irwin Inc (ISBN: 02561188413).

Olhager, J., 2003, Strategic positioning of the order penetration point, *International Journal of Production Economics,* 85, 319 - 329.

Oosterman, B., Land, M.L., and Gaalman, G., 2000, The influence of shop characteristics on workload control, *International Journal of Production Economics*, 68, 1, 107 - 119.

Ottosson, S., 2003, Participation action research – A key to improved knowledge of management, *Technovation*, 23, 87 – 94.

Palvia, P.C., and Palvia, S.C., 1999, An examination of the IT satisfaction of small business users, *Information and Management*, 35, 3, 127 – 137.

Park, C., Song, J., Kim, J-G., and Kim, I., 1999, Delivery date decision support system for the large scale make-to-order manufacturing companies: A Korean electric motor company case, *Production Planning and Control*, 10, 6, 585 - 597.

Pearson, M.J., and Shim, .J.P., 1995, An empirical investigation into DSS structures and environments, *Decision Support Systems*, 3, 141 – 158.

Perez, J.L., 1997, TOC for world class global supply chain management, *Computers and Industrial Engineering*, 33, 1 - 2, 289 - 293.

Perona, M., and Portioli, A., 1998, The impact of parameters setting in load oriented manufacturing control, *International Journal of Production Economics*, 55, 133 - 142.

Perona, M., and Miragliotta, G., 2000, Workload control: A comparison of theoretical and practical issues through a survey in field, *11th International Working Seminar on Production Economics, Igls, Innsbruck, Conference Proceedings*, 1 - 14.

Petroni, A., 2002, Critical factors of MRP implementation in small and medium sized firms, *International Journal of Operations and Production Management*, 22, 3, 329 - 348.

Pfeffer, J., 1992, *Managing with power: Politics and influence in organisations*, Harvard Business School Press, Boston, Massachusetts.

Pfeffer, J., 1993, Understanding power in organizations, in *Managing change*, Second Edition, (eds) Mabey, C., and Mayon-White, B., The Open University.

Philipoom, P.R., Malhotra, M.K., and Jensen, J.B., 1993, An evaluation of capacity sensitive order review and release procedures in job shops, *Decision Sciences*, 24, 6, 1109 - 1133.

Plenert, G., 1999, Focusing material requirements planning (MRP) towards performance, *European Journal of Operational Research*, 119, 91 - 99.

Plenert, G., and Best, T.D., 1986, MRP, JIT and OPT: What's "best"?, *Production and Inventory Management*, Second Quarter, 22 - 29.

Popper, K., 1959, *The logic of scientific discovery*, Hutchinson, London (ISBN: B0000CK67X).

Portioli, A., 2002, General bucket: A new release procedure for workload control, *12th International Working Seminar on Production Economics, Igls, Innsbruck, Conference Proceedings*, 2, 305 - 406.

Ptak, C.A., 1991, MRP, MRP II, OPT, JIT, and CIM - succession, evolution, or necessary combination, *Production and Inventory Management*, Second Quarter, 7 - 11.

Quayle, M., 2002, E-Commerce: The challenge for the UK SME's in the twenty-first century, *International Journal of Operations and Production Management*, 22, 10, 1148 - 1161.

Radovilsky, Z.D., 1998, A quantitative approach to estimate the size of the time buffer in the theory of constraints, *International Journal of Production Economics*, 55, 113 - 119.

Rahman, S., 1998, Theory of constraints: A review of the philosophy and its applications, *International Journal of Operations and Production Management*, 18, 4, 336 - 355.

Ramsay, M.L., 1990, Push, pull and squeeze shop floor control with computer simulation, *Industrial Engineering*, 22, 2, 39 - 45.

Remenyi, D., Williams, B., Money, A., and Swartz, E., 1998, *Doing research in business and management: An introduction to process and method*, Sage Publications Ltd, London (ISBN: 0761959491).

Riezebos, J., Korte, G.J., and Land, M.L., 2002, Enhancing a Theory of Constraints (TOC) application using workload control principles, *12th International*

Working Seminar on Production Economics, Igls, Innsbruck, Conference Proceedings, 1, 241 - 262.

Robbins, S.P, 1986, *Organisational behaviour: Concepts, controversies, and applications*, Prentice Hall, Eagle Wood Cliffs, New Jersey.

Robson, C., 1993, *Real world research: A resource for social scientists and practitioner researchers*, Oxford, Blackwell (ISBN: 0631176896).

Rose, O., 1999, CONLOAD - A new lot release rule for semiconductor wafer fabs, *Winter Simulation Conference,* 850 - 855.

Rupp, T.M., and Ristic, M., 2000, Fine planning for supply chains in semiconductor manufacture, *Journal of Materials Processing Technology*, 107, 390 - 397.

Russell, R.S., and Taylor III, B.W., 2003, *Operations management*, Fourth Edition, Pearson Education, Inc, New Jersey (ISBN: 0130493635).

Sabuncuoglu, I., and Karapinar, H.Y., 1999, Analysis of order review/release problems in production systems, *International Journal of Production Economics*, 62, 259 - 279.

Sarker, S., and Lee, A.S., 2003, Using a case study to test the role of three key social enablers in ERP implementation, *Information and Management*, 40, 813 - 829.

Sauer, C., 1993, *Why information systems fail: A case study approach*, Alfred Waller: Henley-on-Thames.

Saunders, M., Lewis, P., and Thornhill, A., 1997, *Research methods for business students*, Pitman Publishing: Pearson Professional Limited (ISBN: 0273620177).

Schniederjans, M.J., 1993, *Topics in just-in-time management*, Simon and Schuster, Inc, Massachusetts (ISBN: 0205136001).

Schniederjans, M.J., and Kim, G.C., 2003, Implementing enterprise resource planning systems with total quality control and business process reengineering, *International Journal of Operations and Production Management*, 23, 4, 418 - 429.

Schonberger, R.J., 1982, *Japanese manufacturing techniques: Nine hidden lessons in simplicity*, The Free Press, Macmillan Publishing Co, Inc, New York (ISBN: 0029291003).

Schonberger, R.J., 1983, Applications of single-card and dual-card kanban, *Interfaces*, 13, 4, 56 - 67.

Scudder, G.D., and Hill, C.A., 1998, A review and classification of empirical research in operations management, *Journal of Operations Management*, 16, 91 – 101.

Shim, J.P., Warkentin, M., Courtney, J.F., Power, D.J., Sharda, R., and Carlsson, C., 2002, Past, present and future of decision support technology, *Decision Support Systems*, 33, 111 – 126.

Shingo, S., 1989, *A study of the Toyota production system from an industrial engineering viewpoint*, English re-translation copyright by Productivity, Inc, Norwalk (ISBN: 0915299178).

Silva, C., and Magalhaes, J.M., 2003, Production planning in a make to order environment: The case of a mould manufacturer, *One World? One View of OM? EUROMA Conference Proceedings, Lake Como, Italy,* 2, 729 – 738.

Simons, J.V. and Simpson III, W.P., 1997, An exposition of multiple constraint scheduling as implemented in the goal system (formerly disaster), *Production and Operations Management*, 6, 1, 3 - 22.

Singh, N., and Brar, J.K., 1992, Modelling and analysis of just-in-time manufacturing systems: A review, *International Journal of Operations and Production Management*, 12, 2, 3 - 19.

Senior, B., 2002, *Organisational change*, 2nd Edition, Prentice-Hall (ISBN: 0273651536).

Slack, N., Chambers, S., and Johnston, R., 2004, *Operations Management*, 4th Edition, Pearson Education Ltd (ISBN: 0273679066).

Smet, R.D., and Gelders, L., 1998, Using simulation to evaluate the introduction of a kanban subsystem within an MRP-controlled manufacturing environment, *International Journal of Production Economics*, 56 - 57, 111 - 122.

Soman, C.A., Van Donk, D.P., and Gaalman, G., 2004, Combined make-to-order and make-to-stock in a food production system, *International Journal of Production Economics*, (Article in Press).

Sotskov, Y., Sotskova, S.K., and Werner, F., 1997, Stability of an optimal schedule in a job shop, *Omega*, 25, 4, 397 - 414.

Sower, V.E., and Abshire, R.D., 2003, Successful implementation of advanced manufacturing technology: A cross sectional survey, *International Journal of Computer Applications in Technology,* 16, 1, 12 - 20.

Spearman, M.L., Hopp, W.J., and Woodruff, D.L., 1989, A hierarchical control architecture for CONWIP production systems. *Journal of Manufacturing and Operations Management,* 2, 147 - 171.

Spearman, M.L., Woodruff, D.L., and Hopp, W.J., 1990, CONWIP: A pull alternative to kanban, *International Journal of Production Research,* 28, 5, 879 - 894.

Spearman, M.L., and Zazanis, M.A., 1992, Push and pull production systems: Issues and comparisons, *Operations Research,* 40, 3, 521 - 532.

Sprague, R.H.Jr., and Carlson, E.D., 1982, *Building effective decision support systems*, Prentice Hall, Englewood Cliffs, NJ (ISBN: 0130862150).

Spring, M., and Dalrymple, J., 2000, Product customisation and manufacturing strategy, *International Journal of Operations and Production Management*, 20, 4, 441 - 467.

Stake, R.E., 1995, *The art of case study research*, Sage Publications, London (ISBN: 0803957661).

Stratman, J.K., Roth, A.V., and Gilland, W.G., 2004, The deployment of temporary workers in assembly operations: A case study of the hidden costs of learning and forgetting, *Journal of Operations Management*, 21, 6, 689 - 707.

Stringer, E.T., 1999, *Action research*, 2nd Edition, Sage Publications, London (ISBN: 0761917128).

Stuart, I., McCutcheon, D., Handfield, R., McLachlin, R., and Samson, D., 2002, Effective case research in operations management: A process perspective, *Journal of Operations Management*, 20, 419 – 433.

Suri, R., 1999, How quick response manufacturing takes the wait out, *The Journal for Quality and Participation,* 22, 3, 46.

Susman, G., 1983, Action research: A sociotechnical systems perspective, in *Beyond method: Strategies for social research*, (ed) Morgan, G., Sage, Newbury Park.

Swanson, E.B., 1974, Management information systems: Appreciation and involvement, *Management Science*, 21, 2, 178 - 188.

Symon, G., 1998, Qualitative research diaries, in *Qualitative methods and analysis in organisational research*, (eds) Symon, G., and Cassell, C., Sage Publications, London (ISBN: 0761953507).

Tardif, V., and Maaseidvaag, L., 2001, An adaptive approach to controlling kanban systems, *European Journal of Operational Research,* 132, 2, 411 - 424.

Tatsiopoulos, I.P., 1983, A microcomputer-based interactive system for managing production and marketing in small component manufacturing firms using a hierarchical backlog control and lead time management technology, *PhD Thesis, Lancaster University, Lancaster, UK.*

Tatsiopoulos, I.P., 1997, An order release reference model as a link between production management and shop floor control software, *Computers in Industry*, 33, 335 - 344.

Thong, J.Y.L., and Yap, C.S., 1995, CEO characteristics, organisational characteristics and information technology adoption in small businesses, *International Journal of Management Science*, 23, 4, 429 – 442.

Tobin, N.R., Mercer, A., Kingsman, B., 1988. A study of small subcontract and make to order firms in relation to quotation for orders. *International Journal of Operations and Production Management,* 8, 6, 46 - 59.

Tubino, F., and Suri, R., 2000, What kind of 'numbers' can a company expect after implementing quick response manufacturing?, *Quick Response Manufacturing 2000 Conference Proceedings*, Society of Manufacturing Engineers Press, 943 - 972.

Turban, E., 1995, *Decision support and expert systems: Management support systems*, New Jersey, Englewood Cliffs (ISBN: 0133203832).

Turban, E., and Aronson, J., 2001, *Decision support systems and intelligent systems,* Prentice Hall (ISBN: 0130894656).

Ukplc, 2002, *A financial analysis of corporate Britain: 2003 Edition*, (eds) Robertson, A., Carr, E., and Haddock, P., The Prospect Shop Limited (ISSN: 14789051).

Uzsoy, R., Lee, C.Y., and Martin-Vega, L.A., 1992, A review of production planning and scheduling models in the semiconductor industry Part I: System characteristics, performance evaluation and production planning, *IIE Transactions on Scheduling and Logistics*, 24, 47 - 61.

Uzsoy, R., Lee, C.Y., and Martin-Vega, L.A., 1994, A review of production planning and scheduling models in the semiconductor industry Part II: Shop floor control, *IIE Transactions on Scheduling and Logistics*, 26, 44 - 55.

Van der Velde, M., Jansen, P., and Anderson, N., 2004, *Guide to management research methods*, Blackwell Publishing Ltd, Oxford (ISBN: 1405115122).

Van Ooijen, H.P.G., 1996, Load-based work order release and its effectiveness on delivery performance improvement, *PhD Thesis, Eindhoven University of Technology, Eindhoven, The Netherlands* (ISBN: 9038602553).

Van Ooijen, H.P.G. and Bertrand, J.W.M., 2003, The effects of a simple arrival rate control policy on throughput and work-in-process in production systems with workload dependent processing rates, *International Journal of Production Economics*, 85, 61 - 68.

Vigoda, E., and Cohen, A., 2002, Influence tactics and perceptions of organisational politics: A longitudinal study, *Journal of Business Research*, 55, 4, 311 - 324.

Vollmann, T.E., Berry, W.L., and Whybark, D.C., 1997, *Manufacturing Planning and Control Systems*, 4th Edition, Irwin, Boston (ISBN: 0786312092).

Voss, C., Tsikriktsis, N., and Frohlich, M, 2002, Case research in operations management, *International Journal of Operations and Production Management*, 22, 2, 195 – 219.

Wagner, B.J., and Ragatz, G.L., 1994, The impact of lot splitting on due date performance, *Journal of Operations Management*, 12, 1, 13 - 25.

Wahlers, J.L., and Cox, J.F., 1994, Competitive factors and performance measurement: Applying the theory of constraints to meet customer needs, *International Journal of Production Economics*, 37, 2 - 3, 229 - 240.

Wein, L.M., 1988, Scheduling semiconductor wafer fabrication, *IEEE Transactions on Semiconductor Manufacturing,* 1, 3, 115 - 130.

Westbrook, R., 1995, Action Research: A new paradigm for research in production and operations management, *International Journal of Operations and Production Management*, 15, 2, 6 – 21.

Wiendahl, H.P., 1995, *Load oriented manufacturing control*, Springer-Verlag, Berlin Heidelberg New York (ISBN: 3540197648).

Wight, O., 1970, Input / output control: A real life handle on lead-time, *Production and Inventory Management*, Third Quarter, 9 - 30.

Wilson, E., and Howcroft, D., 2005, Power, politics and persuasion in IS evaluation: A focus on 'relevant social groups', *Journal of Strategic Information Systems*, 14, 17 – 43.

Yin, R.K., 2003, *Case study research: Design and methods*, 3rd Edition, Sage Publications, London (ISBN: 076192552X).

Yusuf, Y., Gunasekaran, A., and Abthorpe, M.S., 2004, Enterprise information systems project implementation: A case study of ERP in Rolls-Royce, *International Journal of Production Economics*, 87, 251 - 266.

Zäpfel, G., and Missbauer, H., 1993, New concepts for production planning and control, *European Journal Of Operational Research*, 67, 297 - 320.

APPENDIX 1: MEETING THE DATA REQUIREMENTS OF THE DSS

1. MEETING THE DATA REQUIREMENTS OF THE DSS

The DSS relies on reading data from and writing data to a series of text files, as summarised in Table I below.

File Name	Description	Loaded From / Saved To
WLC_JOB	Unconfirmed Job Details	Loaded
WLC_EMP	New Shift Patterns	Loaded
WLC_WIP_JOB	Confirmed Job Details	Saved
WLC_SAVED_EMP	Existing Shift Details	Saved
WLC_ASSIGNED_WORKLOAD	Work Centre Assigned Workloads	Saved
WLC_PARAMETERS	Saved Parameter Details	Saved

Table I: Text Files Required by the Decision Support System

1.1 Importing Data from MAIS: Job Details

The job details file (WLC_JOB.txt) contains details of unconfirmed jobs and jobs that have recently been accepted. This data is read from the company's internal database (MAIS) where it has been directly input at the customer enquiry stage. MAIS contains all the necessary job routing information and delivery date information required by the DSS. However, it is important that the company keep this information up to date and that the estimator fully considers the requirements of each job. Hence, the new information system may increase the time that must be spent on quotations; this may be a problem at busy periods.

The WLC DSS can read this data in and display unconfirmed jobs in the customer enquiry management form. Newly accepted jobs are displayed in the job entry form. When the program is saved and updated, the file is rewritten, with the newly accepted jobs omitted from the file, i.e., the file is cleared before the unconfirmed jobs are copied back into the file. The newly accepted jobs are now placed in a WIP file saved by the DSS. The file is written to when the status of a job changes from 'unconfirmed' to 'accepted' or appended when tenders are submitted for new jobs. Bids that the company consider to have been rejected are removed from the file. Hence, the only file handling requirements are the initial supply of job details, the removal of rejected jobs and the status updating of accepted jobs ('0' to '1'). Note that should part of a job be subcontracted, i.e. visit machine 20 (see Table III), then the set up time should be replaced with the subcontract lead time (days) and the processing time left blank. This procedure can be easily coded into MAIS and triggered when data is input or changed by the user.

Each job consists of a series of lines in the text file (one line for each operation) as detailed in Table II below:

Field	Format	Length	Start Pos	End Pos	Notes
Customer Name	String	30	1	30	Names longer than 30 characters are appended
Job Reference ID	String	15	31	45	Unique job reference
Routing Sequence	Integer	2	46	47	Denotes order of machine within job routing sequence
Machine ID	Integer	2	48	49	*See Table III*
Set up time	Integer	3	50	52	Machine set up time (minutes)
Processing Time	Integer	4	53	56	Processing time per unit (minutes)
Quantity	Integer	6	57	62	Number of units
Planned Delivery Date	YYYYMMDD	8	63	70	Planned delivery date
Job Status	Integer	1	71	71	*See Table IV*

Table II: Job Details Flat File Format

The machine and job status information referred to in Table II above is provided in Tables III and IV below. An example then follows to illustrate this format.

Machine I.D. Number	Machine / Operation Details
1	Cinc 2
2	Cinc 3
3	Matsuura 510 (Red Mat)
4	Matsuura 660 (Blue Mat)
5	Citizen L25
6	Citizen L32
7	Citizen M20
8	Citizen M32
9	Act 3
10	Act 20
11	Dooturn
12	S/Turn 3
13	Triumph 2000
14	Hardinge HC3
15	Deburr
16	Milling, e.g. Anayak mill
17	Drilling, e.g. Meddings or Arboga drill
18	Grinding, e.g. Jones and Shipman grind
19	Saw, e.g. Horizontal Bandsaw
20	Subcontracted Operation
21	Other (non-core) Machine

Table III: Machine ID Reference Table

Number	Job Status	Key
0	Unconfirmed	Job subject to confirmation
1	Confirmed	Job accepted by customer

Table IV: Job Status Reference Table

Job Details File Format Example

Consider the following unconfirmed job:

Job Reference:	LANC0001
Customer:	Lancaster Engineering Company
Delivery Date:	23rd December 2004
Quantity:	20
Status:	Unconfirmed

LANC0001 has the following Operation Details, see Table V below:

Routing Sequence	Machine	Set up Time (mins)	Approx Processing Time per Item (mins)
1	Cinc 2	60	10
2	S/Turn 3	10	5
3	Subcontracted Op	(3 days lead time)	(Not applicable)
4	Triumph 2000	30	5
5	Deburr	30	15

Table V: Example Operation Details

Hence the flat file will contain the following five lines (one line per operation):

(*Line 1*) Lancaster Engineering Company LANC0001 1 1 60 10 20 200412230

(*Line 2*) Lancaster Engineering Company LANC0001 2 1210 5 20 200412230

(*Line 3*) Lancaster Engineering Company LANC0001 3 203 20 200412230

(*Line 4*) Lancaster Engineering Company LANC0001 4 1330 5 20 200412230

(*Line 5*) Lancaster Engineering Company LANC0001 5 1530 15 20 200412230

If it is not possible to give a delivery date for certain jobs, such as if a quotation contains a delivery lead time instead of a specific date, the delivery date can be replaced with an integer representing the delivery lead time (weeks). The Workload Control software system will then approximate the delivery date, with the delivery lead time and the expected customer confirmation time added to the current date. However, this should only be applied to unconfirmed jobs, all accepted jobs should have a specific delivery date.

With a production lead-time of 6 weeks, the input for the above example becomes:

(*Line 1*) Lancaster Engineering Company LANC0001	1 1 60 10	20	6		0
(*Line 2*) Lancaster Engineering Company LANC0001	2 1210 5	20	6		0
(*Line 3*) Lancaster Engineering Company LANC0001	3 203	20	6		0
(*Line 4*) Lancaster Engineering Company LANC0001	4 1330 5	20	6		0
(*Line 5*) Lancaster Engineering Company LANC0001	5 1530 15	20	6		0

1.2 Importing Data from MAIS: Employee Details

The employee details file (WLC_EMP.txt) represents the expected working week for each 'direct' employee, including expected / regular overtime, such as Saturday mornings. This information will be contained within MAIS for payroll requirements. The workload control system reads this data into the package and transforms it into information used for the determination of backlog lengths and scheduling at the planned backlog level. The usual working week is used to extrapolate forwards over the planning horizon. Small changes to the working patterns of employees can be incorporated within the 'Capacity Management' form of the DSS, such as those caused by changes to overtime or as a result of absenteeism.

However, the file should be re-sent from MAIS if, for example:

(a) Permanent changes are made to the shift patterns of employees
(b) New operators are employed or existing employees leave the company
(c) Long term changes occur to the allocation of employees to machinery

When the WLC system is updated / saved, the system clears the text file and copies the transformed data into another file. Next time the system is opened, if this file is empty (in other words, MAIS has not sent a new file and therefore no changes to the number of employees or their shifts have occurred), the system uses the saved capacity data. However, if MAIS has sent a new data set to the file, the system uses the new capacity information.

The first line of the file represents the date on which the file is sent, in the following format: YYYYMMDD.

The remainder of the file follows the format in Table VI below:

Field	Format	Length	Start Position	End Position	Notes
Employee Key	Number	4	1	4	Unique employee ID
Machine ID	Number	2	5	6	*See Table III*
Operator Hours	Number	5	7	11	Total working hours (including decimal point)
Day of the Week	String	3	12	14	Mon – Sun

Table VI: Employee Details Flat File Format

Employee Details File Format Example

Consider the following example of an employee's normal working week:

Shift Details Commencing:	1st December 2004
Employee ID:	1
Machine:	Cinc 2
Shift:	Days (Mon – Fri)
Planned Overtime:	Saturday Mornings (8.00 a.m. – 12.00 noon)

Hence, the flat file will contain the following seven lines (the first line is the date followed by one line per working day, with the employee not working on a Sunday):

(*Line 1*) 20041201

(*Line 2*) 00010107.75Mon

(*Line 3*) 00010107.75Tue

(*Line 4*) 00010107.75Wed

(*Line 5*) 00010107.75Thu

(*Line 6*) 00010106.00Fri

(*Line 7*) 00010104.00Sat

(The file then continues with the details of the next employee).

1.3 Saving Data from the DSS: Job Details

The file (WLC_WIP_JOB.txt) contains details of confirmed jobs and the current location of each job, whether this be, for example, in the pool or at a particular resource on the shop floor. Each time the details of jobs are saved, the file is updated. When a job has been completed, it is removed from the file. The file format is summarised in Table VII below. This summary also highlights the majority of factors relating to individual jobs that are required for the LUMS approach to operate effectively.

Job Details	Job Details Record Description	Record Details	File Position
Customer Name	Name of Customer	Jobs[i].customer	1 – 30
Job Reference	Unique Job Reference	Jobs[i].job_reference	31 – 45
Routing Sequence	1..n for number of operations	Jobs[i].routing_sequence[j]	46 - 47
Work Centre	Work centre routing	Jobs[i].work_centre[j]	48 – 49
Set Up Time	Set up time for job at current WC	Jobs[i].setup_time[j]	50 – 52
Processing Time	Processing time per item at the work centre	Jobs[i].processing_time[j]	53 – 56
Quantity	Quantity ordered	Jobs[i].quantity	57 – 62
Delivery Date	Delivery Date for job	Jobs[i].delivery_date	63 – 70
Status	Pool / Shop Floor	Jobs[i].status	71
Priority	Normal / Pool / Shop / Hot	Jobs[i].priority	72
Earliest Release Date	ERD from pool	Jobs[i].erd	73 – 80
Latest Release Date	LRD from pool	Jobs[i].lrd	81 – 88
Operation Completion Date	OCD at current WC	Jobs[i].ocd[j]	89 – 96
Scheduled	Scheduled / Unscheduled	Jobs[i].scheduled	97
Position	Position on shop floor if released	Jobs[i].position	98
Sequence	Part release information	Jobs[i].sequence	99

Table VII: Confirmed Job Details File Format

1.4 Saving Data from the DSS: Work Centre Daily Details

The file (WLC_SAVED_EMP.txt) contains the transformed version of the employee shift patterns. From the raw data a cumulative total of daily work centre hours is calculated by extrapolating daily trends forwards over the planning horizon. If the trend changes, a new file is sent and used in future scheduling and backlog considerations.

This is the data used if no changes to the shift patterns or number of employees utilised in the shop are made. If operators are reallocated from one work centre to another or additional overtime is assigned, this is also recorded in the file. The file takes the format summarised in Table VIII below.

Field	Format	Length	Start Position	End Position	Notes
Date	YYYYMMDD	8	1	8	Date on which hours apply
Work Centre	Integer	2	9	10	Corresponding work centre
Hours	Extended	5	11	15	Total operator hours for the day at that work centre

Table VIII: Daily Work Centre Hours

1.5 Saving Data from the DSS: Work Centre Assigned Workloads

When the DSS uses the backwards scheduling approach at the job entry level, it compares capacity with the workload already assigned to the work centre on that day (the assigned workload) in order to determine the available capacity. Hence, the system has to save details of the assigned workload of each work centre on each day. This must be saved in a separate file (WLC_ASSIGNED_WORKLOAD.txt) to employee information, as this is not affected by changes in shift patterns or the reallocation of operators. It is only affected by the rescheduling of jobs. If the user chooses to reschedule the whole workload of the shop, then all the assigned workloads are reset to zero and all jobs, starting with the most urgent, are rescheduled. The file takes the format outlined in Table IX below.

Field	Format	Length	Start Position	End Position	Notes
Date	YYYYMMDD	8	1	8	Date on which hours apply
Work Centre	Integer	2	9	10	Corresponding work centre
Hours	Extended	5	11	15	Total operator hours assigned to the workload of the work centre

Table IX: Assigned Workload File Format

1.6 Saving Data from the DSS: Workload Control Parameters

The parameters that are set in the parameters module of the DSS are saved in a text file (WLC_PARAMETERS.txt), and changed if the user decides that they require alteration. The parameters module will be heavily used in the initial phase after implementation. Changes will also be made as the environment in which the company operates begins to change. When changes are made in the parameter setting module, the user can choose to save the changes as the future default settings, and changes throughout the system can be initiated. The text file is then rewritten so that the new defaults will still apply next time the DSS is used. The parameters contained within the file are summarised in Chapter 7.