Suppliers versus lead users: examining collaboration in mass customisation

Al-Zu'b, Zu'bi Mohammad

SUPPLIERS VERSUS LEAD USERS: EXAMINING COLLABORATION IN MASS CUSTOMISATION

Zu'bi Mohammad Al-Zu'bi

Thesis submitted in fulfilment of the requirements
for the degree of Doctor of Philosophy

Durham Business School

Durham University

September 2008

To my parents
Who instilled in me a love of learning
And sacrificed so much to make it possible

ABSTRACT

Mass customisation has been hailed as the manufacturing paradigm of the future, and has accordingly received much academic interest. Nevertheless, it is important to gain a better understanding of the ways in which mass customisation performance may be enhanced, in the light of the number of reported failures of mass customisation ventures. This thesis explores the use of collaboration in product development processes as a means of increasing mass customisation operational performance. The two collaborative partners of interest are suppliers and lead users – a specialised subset of users. The effects of lead users in the product development processes of mass customisation have not previously been evaluated, nor has their value been compared to that of suppliers. Accordingly, the aim of this study is to investigate the relative effects of collaborating with suppliers and lead users in the product development processes on mass customisation. This is achieved by measuring mass customisation operational performance in terms of four attributes derived from the literature: development cost, development time, customer influence and product scope.

Hierarchical regression analysis of survey data collected from two hundred and fifty-one UK consumer products manufacturers revealed a significant positive relationship between lead user collaboration and all four mass customisation operational performance attributes, while supplier collaboration was found to positively affect three of the four attributes, with the exception of customer influence. In addition, analysis revealed that lead user collaboration had a greater effect on the operational performance than supplier collaboration. These results give a valuable indication to scholars as well as manufacturers of the importance of lead users in the product development processes of mass customisation.

DECLARATION OF RIGHTS

ACKNOWLEDGMENTS

First and foremost, I want to direct my thanks to God, for blessing me with the opportunity to learn. I hope that, through this, I will be better able to help others to learn.

I must thank my supervisors, Professor Timothy Clark and Dr Christos Tsinopoulos, who have provided much-needed support and advice throughout my four years in Durham. I also want to acknowledge the input of others within the Business School and the wider Durham University, who have provided assistance from the administrative to the academic.

Working towards a PhD can, at times, be a lonely experience. I am grateful for the support of so many friends here in Durham. My fellow PhD students at Durham Business School have shared the journey with me, through all its ups and downs. A significant part of my experience was my association with Ustinov College, through which I was challenged and nurtured, and in which I made many valuable friendships which will, I hope, last a lifetime.

This PhD would not have been possible without much support from Jordan. I must thank the University of Jordan for its sponsorship of my degree, and in particular, Dr Rifa't Shannak who, from the beginning, has continued to provide unconditional support and guidance.

Finally, I could not have completed this PhD if it were not for the support of my family.

TABLE OF CONTENTS

ABSTRACT i

DECLARATION OF RIGHTS ii

ACKNOWLEDGMENTS iii

LIST OF FIGURES x

LIST OF TABLES xi

LIST OF APPENDICES xiii

CHAPTER ONE: INTRODUCTION 1
1.1 Overview 1
1.2 Problem Statement 2
1.2.1 Background 2
1.2.2 Research Problem and Hypotheses 4
1.2.3 Justification for the Research 7
1.3 Research Approach 8
1.3.1 Methodology 8
1.3.2 Definitions 9
1.3.3 Scope of the Study 11
1.4 Thesis Outline 12
1.4.1 Conclusion 15

THEORETICAL FRAMEWORK

CHAPTER TWO: MASS CUSTOMISATION 16
2.1 Introduction 16
2.1.1 The Birth of Mass Customisation 17
2.1.2 Early Mass Customisation 18
2.2 The Theory of Mass Customisation 20
2.2.1 Definitions of Mass Customisation 20
2.2.2 The Role of Mass Customisation in Industry 22
2.2.2.1 Mass Customisation as the Way of the Future? 22
2.2.2.2 Mass Customisation vs Mass Production 25
2.3 The Mechanisms of Mass Customisation 32
2.3.1 Mass Customisation in Practice 32

2.3.1.1 Functions of Mass Customisation 32
2.3.1.2 The Costs and Benefits of Mass Customisation in Practice 34
2.3.2 Achieving Mass Customisation 36
2.3.2.1 The Progression from Mass Producer to Mass Customiser 36
2.3.2.2 A Strategy for Mass Customisation 40
2.3.2.3 Defining Common Levels of Mass Customisation 44
2.3.3 Features of Mass Customisation 46
2.3.3.1 Modular-Based Manufacturing 47
2.3.3.2 Postponement 52
2.3.3.3 Product Development 54
2.3.3.4 Technology 57
2.4 Improving Mass Customisation Performance 59
2.4.1 Enablers of Mass Customisation 61
2.4.1.1 Agile Manufacturing 63
2.4.1.2 Lean Manufacturing 65
2.4.1.3 Technology 66
2.4.1.4 Supply Chain Management 67
2.4.1.5 Communication and Networks 71
2.4.1.6 Customer-Driven Design and Manufacturing 72
2.4.2 A Mixed Approach to Improving Mass Customisation 75
2.4.2.1 Collaboration in Product Development 76
2.5 Concluding Remarks 79

CHAPTER THREE: COLLABORATION IN PRODUCT DEVELOPMENT 82
3.1 Introduction 82
3.2 Utilising Collaboration 83
3.2.1 Product Development 83
3.2.2 Collaborative Product Development 85
3.2.2.1 Motivations for Collaboration 89
3.2.3 Enablers of Collaboration 93
3.2.4 Technology Brokering 94
3.2.5 Knowledge Management for Collaborative Product Design 97
3.2.5.1 Communities of Practice 97
3.2.5.2 Process Networks 99
3.2.6 Mechanisms of Collaboration 100
3.2.7 Collaborative Partners for Product Development 102
3.3 Collaboration with Suppliers 104
3.3.1 Early Supplier Involvement 106
3.3.1.1 Advantages of Early Supplier Involvement 108
3.4 Collaboration with Users 111
3.4.1 The Customer-Active Paradigm 113

3.4.2 Lead Users ... 116
3.5 Comparing Collaborative Contributions ... 122
3.6 Concluding Remarks ... 125

CHAPTER FOUR: CONCEPTUAL MODEL ... 126
4.1 Introduction ... 126
4.2 Collaboration in Mass Customisation ... 127
4.2.1 Supplier Collaboration in Mass Customisation ... 127
4.2.2 Lead User Collaboration in Mass Customisation ... 129
4.2.3 Research Question ... 131
4.3 Measuring Mass Customisation Performance ... 132
4.3.1 Attributes of Mass Customisation ... 132
4.3.1.1 Low Product Development Cost ... 136
4.3.1.2 Short Product Development Time ... 137
4.3.1.3 Customer Influence ... 138
4.3.1.4 Product Scope ... 140
4.3.1.5 Characterising Mass Customisation and its Antecedents ... 143
4.4 Hypothesis Generation ... 144
4.4.1 Hypotheses Concerning Lead User Collaboration ... 146
4.4.1.1 Development Cost ... 147
4.4.1.2 Development Time ... 149
4.4.1.3 Customer Influence ... 150
4.4.1.4 Product Scope ... 151
4.4.2 Hypotheses Concerning Supplier Collaboration ... 152
4.4.2.1 Development Cost ... 153
4.4.2.2 Development Time ... 154
4.4.2.3 Customer Influence ... 155
4.4.2.4 Product Scope ... 156
4.5 Conclusions ... 157

EMPIRICAL TESTING

CHAPTER FIVE: RESEARCH DESIGN AND METHOLOGY ... 159
5.1 Introduction ... 159
5.2 Research Method ... 160
5.2 Survey Design and Administration ... 163
5.3.1 Introduction ... 163
5.3.2 Scale Design and Development ... 164
5.3.3 Item Selection ... 167
5.3.4 Focus Groups ... 169
5.3.5 Lead User Identification Tool ... 173

5.3.6 Pilot Study ... 174
5.3.7 Total Design Method ... 177
5.3.8 Sample Determination ... 180
5.3.8.1 Sampling Frame ... 182
5.3.8.2 Sample Size ... 183
5.3.9 Potential Sources of Bias ... 186
5.4 Ethical Issues ... 190
5.5 Conclusions ... 191

CHAPTER SIX: DATA ANALYSIS ... 193
6.1 Introduction ... 193
6.1.1 Sample Size and Response Rate ... 194
6.1.2 Sample Description ... 195
6.3 Screening the Data ... 202
6.3.1 Missing Data and Outliers ... 202
6.3.2 Testing Assumptions of Factor Analysis and Multivariate Analysis ... 204
6.3.2.1 Normality ... 205
6.3.2.2 Homogeneity of Variance: ... 209
6.3.3 Conclusions ... 210
6.4 Exploratory Factor Analysis ... 211
6.4.1 Factor Analysis for Mass Customisation Attributes ... 212
6.4.2 Factor Analysis for Independent Variables ... 218
6.5 Descriptive Statistics and Analysis ... 225
6.5.1 The Dependent Variables ... 225
6.5.2 The Independent Variables ... 236
6.6 Regression Analysis ... 246
6.6.1 Hierarchical Multivariate Regression ... 246
6.6.2 Model 1: Development Cost ... 248
6.6.2.1 Model specification ... 248
6.6.2.2 Model Results ... 249
6.6.3 Model 2: Development Time ... 256
6.6.3.1 Model specification ... 256
6.6.3.2 Model Results ... 257
6.6.4 Model 3: Customer Influence ... 261
6.6.4.1 Model Specification ... 262
6.6.4.2 Model Results ... 263
6.6.5 Model 4: Product Scope ... 267
6.6.5.1 Model Specification ... 268
6.6.5.2 Model Results ... 269
6.6.6 Validation of Results ... 273
6.6.7 Conclusions ... 275

6.7 Analysis for Variance 276
6.7.1 Industry Effect 277
6.7.2 Effect of Supplier Relationship 279
6.8 Validity, Reliability and Bias Testing 282
6.8.1 Validity and Reliability 282
6.8.2 Common Methods Bias 285
6.8.3 Non-Response Bias 285
6.9 Conclusions 287

CHAPTER SEVEN: DISCUSSION OF RESULTS 288
7.1 Introduction 288
7.2 Evaluation of Methodology 288
7.3 Overview of Findings 291
7.4 Hypothesis Testing 294
7.4.1 Lead User Effect 294
7.4.1.1 Relationship with Development Cost 296
7.4.1.2 Relationship with Development Time 298
7.4.1.3 Relationship with Customer Influence 300
7.4.1.4 Relationship with Product Scope 302
7.4.2 Supplier Effect 304
7.4.2.1 Relationship with Development Cost 305
7.4.2.2 Relationship with Development Time 308
7.4.2.3 Relationship with Customer Influence 311
7.4.2.4 Relationship with Product Scope 313
7.4.3 Summary of Hypothesis Testing 314
7.5 Suppliers or Lead Users: Comparing the Effects 315
7.5.1 Model 1: Development Cost 316
7.5.2 Model 2: Development Time 317
7.5.3 Model 3: Customer Influence 318
7.5.4 Model 4: Product Scope 319
7.5.5 Summary and Overall Comparison 320
7.6 Conclusions 322

CHAPTER EIGHT: CONCLUSIONS 323
8.1 Introduction 323
8.2 Overview 326
8.3 Implications of this Study 330
8.3.1 Implications for Theory 331
8.3.1.1 Measuring Mass Customisation Operational Performance 334
8.3.1.2 Lead User Identification Method 334
8.3.2 Implications for Practice 335
8.4 Limitations of the Research 339
8.5 Directions for Future Research 340
8.6 Concluding Remarks 344

REFERENCES 345

APPENDICES 371

LIST OF FIGURES

Figure 1.1: Outline of thesis 14
Figure 2.1: The continuum of strategies from standardisation to customisation 26
Figure 2.2: Categorisation of the levels of customisation according to the parameters of cost, lead time and degree of customisation 29
Figure 2.3: Mass customisation as a dynamic system feedback loop 33
Figure 2.4: The manufacturing eras and their impact on the transformation process. 39
Figure 2.5: The four approaches to customisation 41
Figure 2.6: Generic levels of mass customisation and the levels of customisation to which they correspond 45
Figure 2.7: Modularity in the production cycle 52
Figure 2.8: Traditional and postponement approaches to supply chains 53
Figure 2.9: Four business models 55
Figure 2.10: Enablers of mass customisation 61
Figure 2.11: Information flow in the supply chain for mass customisation processes 68
Figure 2.12: Mass customisation archetypes 73
Figure 3.1: Internal and external collaboration in the context of a company 87
Figure 3.2: Framework for classifying motivations for collaboration. 90
Figure 3.3: Spheres of relevance of customer-active paradigm (CAP) and manufacturer-active paradigm (MAP). 115
Figure 3.4: Integration of suppliers and customers in the supply chain 123
Figure 4.1: Three-dimensional view of mass customisation success 135
Figure 4.2: Conceptual model for the research 144
Figure 5.1: The stages of survey development and implementation 164
Figure 5.2: Product development processes 172
Figure 6.1: Normal probability plot for company size 197
Figure 6.2: Normal probability plot for company age 198
Figure 6.3: Normal probability plot for sales level between company and suppliers201
Figure 6.4: Scree plot for dependent variables 218
Figure 6.5: Scree plot for independent variables 221
Figure 8.1: Findings of hypothesis testing 327

LIST OF TABLES

Table 3.1: Top five manufacturer collaboration motives 92
Table 4.1: Comparison of characteristic attributes of mass customisation and its antecedents 143
Table 6.1: Questionnaire response rate 194
Table 6.2: Frequencies analysis of number of product lines 198
Table 6.3: Frequencies analysis of industry type 200
Table 6.4: Frequencies analysis of length of company-supplier relationship 201
Table 6.5: Normality of control variables 207
Table 6.6: Normality of dependent variables 208
Table 6.7: Normality of independent variables 209
Table 6.8: Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) and Bartlett's test of sphericity for mass customisation attributes 213
Table 6.9: Variable-specific MSA analysis for the mass customisation attributes. 214
Table 6.10: Dependent variables factor extraction 216
Table 6.11: Kaiser-Meyer-Olkin Measure of sampling adequacy (KMO) and Bartlett's test of sphericity for the independent variables 219
Table 6.12: Variable-specific MSA analysis for the collaboration variables. 220
Table 6.13: Independent variables factor extraction 221
Table 6.14: Total variables factor extraction 224
Table 6.15: Frequencies analysis of dependent variable cost. 226
Table 6.16: Frequencies analysis of dependent variable development time. 229
Table 6.17: Frequencies analysis of dependent variable customer influence 232
Table 6.18: Frequencies analysis of dependent variable product scope 234
Table 6.19: Frequencies analysis of the independent variable supplier collaboration 237
Table 6.20: Frequencies analysis of the independent variable lead user collaboration 242
Table 6.21: Correlations matrix for development cost 251
Table 6.22: Multicollinearity and independence of errors tests for development cost 252
Table 6.23: Hierarchical regression model- dependent variable: cost 254
Table 6.24: Correlations matrix for development time 258
Table 6.25: Multicollinearity and independence of errors tests for development time 259
Table 6.26: Hierarchical regression model- dependent variable: development time 260
Table 6.27: Correlations matrix for customer influence (CI) 264

Table 6.28: Multicollinearity and independence of errors tests for customer influence 265
Table 6.29: Hierarchical regression model- dependent variable: customer influence 266
Table 6.30: Correlations matrix for product scope (PS) 270
Table 6.31: Multicollinearity and independence of errors tests for product scope 271
Table 6.32: Hierarchical regression model- dependent variable: product scope ... 272
Table 6.33: Cross-validation statistics for each model 274
Table 6.34: Cross-validation statistics for relationships between independent and dependent variables 275
Table 6.35: Test of homogeneity of variances 278
Table 6.36: Analysis of variance across industry type 279
Table 6.37: Test of homogeneity of variances 280
Table 6.38: Analysis of variance across length of supplier relationship 281
Table 6.39: Statistical measures of reliability of the constructs 283
Table 6.40: Test statistics for Kolmogorov-Smirnov and Mann-Whitney *U* test for non-response bias 286

LIST OF APPENDICES

Appendix 1.1: Focus group procedure 371
Appendix 1.2: Email of initial contact 373
Appendix 1.3: Survey cover letter 374
Appendix 2.1: Frequencies analyses for control variables 380
Appendix 2.2: Correlation matrices 381
Appendix 2.3a: Normal probability plots for dependent variables 383
Appendix 2.3b: Normal probability plots for independent variables 385
Appendix 2.4: Normal probability plot of the regression standardised residual for each model 386
Appendix 2.5: Residuals scatter plots for each model 388
Appendix 2.5b: Frequencies analysis of each construct relating to development time 391

CHAPTER ONE

INTRODUCTION

CHAPTER ONE: INTRODUCTION

1.1 Overview

The current market is one of constant growth and evolution, which leads to a continual need for companies and academics alike to better understand industrial paradigms, and to determine ways in which competitiveness can be increased without compromising the quality of products and services offered. Of particular interest in the context of current manufacturing practice is the paradigm of mass customisation. Numerous studies have attempted to derive improvements in the product development processes of mass customisation, of which many expound the importance of collaboration. However, the relative merits of different collaborative partners, and the specific effects of these partnerships on the product development process, are little understood.

This thesis presents an analysis of the impact of collaboration on mass customisation performance through the analysis of survey data collected from two hundred and fifty-one UK manufacturers. Collaboration with external partners significantly enhances the proposed four attributes of mass customisation operational performance: low development cost, short development time, broad product scope and high allowance for customer influence. Importantly, this work has determined that collaboration with lead users – consumers who experienced heightened need for and benefit from product solutions – has significantly greater impact on mass customisation operational performance than collaboration with suppliers. These results give a valuable indicator to scholars as well as manufacturers of the importance of lead users in product development, particularly in mass customisation.

1.2 Problem Statement

1.2.1 Background

Mass customisation is a modern production approach that is driven by the contemporary market demand for high variety and customers' desire for personalisation. It attempts to combine the merits of the two traditional manufacturing paradigms of craft production and mass production, by providing highly customised products at a cost which is comparable to the standard product, without compromising quality (Pine, 1993a). Since the early 1990s, there has been disagreement amongst academics concerning the importance and viability of mass customisation as the production strategy of the future. While some researchers view the paradigm as a panacea, and the inevitable successor of mass production (Davis, 1987, Pine, 1993a), others view mass customisation as a fashionable concept limited only to specific cases (Spring and Dalrymple, 2000). Still others hold the opinion that mass customisation is only one of many production strategies for the future, suggesting that optimum organisational objectives can only be achieved through the marriage of mass customisation with mass production (Kotha, 1995, Sahin, 2000). Despite this contention, there is little dispute that mass customisation has the ability to enable effective and competitive manufacture for the 21st century market.

Since its identification by academics in the late 1980s, the practices and technologies involved in mass customisation have evolved, and the process has expanded into many industries. As a result, much work has been performed to gain both theoretical and practical understanding of the paradigm, in order to enhance the benefits which it can offer to industries and consumers alike. Chapter Two explores the theoretical basis of mass customisation, highlighting the development of understanding which has been gained over the past two decades. Since mass customisation requires the continual evolution of products to suit customer demand, the product development process is crucial to its success. This process has therefore formed the basis of many studies of mass customisation, as is the case for this work.

Because of its great significance, much current research focuses on how companies and consumers can best benefit from mass customisation, either by maximising and broadening the applications of mass customisation, or by investigating the mechanisms to better enable mass customisation (Efstathiou and Zhang, 2004). One primary current area of research lies in collaborations in the product development process, and how various partners can be involved in the development of new mass customised products (Mikkola and Skjott-Larsen, 2004), as discussed in Chapter Three. Of particular importance is the integration of the two external partners: suppliers and users. While the literature is full of indications of the merits of integrating partners in product development processes (Kauffman *et al.*, 1997, von Hippel and Katz, 2002, Fagerstrom, 2003, Hargadon, 2003, Kahn, 2005), little research has examined the effects of such integration or collaboration on the manufacturer's mass customisation capability. Of particular interest to this study is the investigation into the early collaboration of partners into the product development process of mass customisation.

One study identified the importance of suppliers and customers in product development, although not specifically in the case of mass customisation, suggesting that each had different merits (Morash, 2000). Other work (Frohlich and Westbrook, 2001) holds that collaboration with both customers and suppliers is important, with survey findings showing that companies which exhibited high integration of both customers and suppliers have highest manufacturing performance. However, it is neither always cost-effective nor feasible to concentrate energy into collaboration with both suppliers and users, and it is therefore necessary to gain some understanding of the relative merits of each collaboration, particularly if the investigation focuses on a new player which has not previously been studied in this way, that is lead users.

1.2.2 Research Problem and Hypotheses

An understanding of ways in which mass customisation capability may be improved is of particular importance in the light of the significant failure rates which have been reported for many mass customisation initiatives (Pine *et al.*, 1993c, Anderson, 1997, Comstock *et al.*, 2004). While most attempts to understand the causes of these failures have focused on the role of technology, industry types and market needs, the roles of external partners have not been thoroughly and empirically studied in this context. In addition, it is still not understood with which partner – suppliers or the new players, lead users - it is more important to collaborate with in order to achieve better mass customisation attributes, particularly with respect to the operational performance of the mass customising firm.

On the basis of this dearth in the literature, this research attempts to provide a greater understanding of collaborative product development and its role in the improvement of mass customisation ventures. In particular, the problem addressed in this research is:

What are the relative effects of collaborating with suppliers and lead users in the product development processes on mass customisation?

This thesis addresses this question by a mail survey of UK manufacturing firms. In order to compare and measure mass customisation success and draw conclusions about the effects of collaboration, a clear means of assessing mass customisation capability was required. This has been achieved by adopting four mass customisation attributes: low development cost, short development time, high allowance for customer influence and broad product scope. Through this approach, this work has led to the conclusion that while the collaboration with both suppliers and lead users positively influence the success of mass customisation, the collaboration with lead users is more valuable.

On the basis of an extensive literature review concerning collaboration in product development processes, eight hypotheses have been generated to address the research problem:

H1: that there is a significant positive relationship between lead users' collaboration in product development processes of mass customisation and low development cost.

H2: that there is a significant positive relationship between lead users' collaboration in product development processes of mass customisation and short development time.

H3: that there is a significant positive relationship between lead users' collaboration in product development processes of mass customisation and high allowance for customer influence.

H4: There is a significant positive relationship between lead users' collaboration in product development processes of mass customisation and broad product scope.

H5: that there is a significant positive relationship between suppliers' collaboration in product development processes of mass customisation and low development cost.

H6: that there is a significant positive relationship between suppliers' collaboration in product development processes of mass customisation and short development time.

H7: that there is a significant positive relationship between suppliers' collaboration in product development processes of mass customisation and high allowance for customer influence.

H8: There is a significant positive relationship between suppliers' collaboration in product development processes of mass customisation and broad product scope.

1.2.3 Justification for the Research

This research, which attempts to gain answers to the research problems outlined in the previous section, has great importance both on theoretical and practical grounds. Key in its importance is the fact that this work addresses an area which is only poorly understood and about which there are many unanswered questions. The importance of mass customisation as a production paradigm for the future, as discussed in Chapter Two, necessitates greater understanding of the ways in which production can be improved and strategies implemented to maximise benefit to company and consumer alike. Chapter Three discusses the importance of collaborations in new product development processes, highlighting the still poorly-understood yet crucial concepts of supplier and lead user collaboration. Chapter Four provides an extensive literature review which leads to the development of eight hypotheses which represent relationships which are not well understood or developed. This research is lent further importance by the scarcity of empirical, survey-based studies to understand means of improving mass customisation capability, as discussed in Chapter Five.

This lack of a theoretical and conceptual framework for the integration of manufacturers' partners in product development is a main driver for this research, which aims to link partners to the operational performance of these firms. An understanding of the relative importance of collaborative partnerships is valuable knowledge for academics, and will form the basis of much further research into how collaborations can be utilised to improve mass customisation. This comparison will also help to clarify the discrepancies in the literature concerning the enabling factors of mass customisation. For industries, the framework will provide better guidance for mass customisation initiatives, and will help existing mass customisers increase their efficiency and widen their scope of operation, by guiding their decisions in selecting collaboration partners and methods of collaborating and maintaining relationships with them.

1.3 Research Approach

1.3.1 Methodology

This study will address the research problems by employing rigorous, systematic, and appropriate framework and methodology. The hypotheses of this study have been tested through a broad-based survey of UK consumer product manufacturers. A mail survey is selected as the research instrument in order to generate a high number of responses, reduce bias and facilitate the use of scales for ease of quantification and comparison of data.

Scales have been developed to determine the relative importance of supplier and lead user collaboration on various aspects of the attributes of mass customisation. The validity and reliability of these scales has been pretested using focus groups, and a pilot study, thus resulting in the change, adaptation and removal of some items. Exploratory factor analysis, followed by hierarchical regression analysis, has been used to test the hypotheses and determine any statistically significant differences between supplier and lead user collaborations.

1.3.2 Definitions

Definitions adopted by researchers often lack uniformity, so it is important that key terms which may be interpreted in a number of ways are clearly defined to establish the position which will be adopted in this work. The chosen definitions for terms about which there is contention in the literature will be justified throughout the thesis.

Product development: the complete process of bringing a product to market and it consists of: concept development, design, and production.

Collaborative product development: the process in which firms work with external partners (other firms, or groups of individuals) to develop a given product, as distinct from outsourcing from one company to another.

Mass customisation: the ability to deliver a broad scope of customer-influenced products on a large scale, without significantly compromising development cost or time.

Mass customisation attributes: the main constructs or objectives that are used in this study to define the operational performance of a mass customisation venture: low development cost, short development time, high customer influence and broad product scope. Each attribute may be defined as follows:

> *Development Cost:* the total costs of the product development processes, encompassing all costs incurred by the manufacturer, such as concept development, design, and manufacturing costs.

Development time: the period of time between product concept development and final production, comprised of concept development time, product design time, and manufacture time.

Customer influence: the extent to which a manufacturer allows customers involvement in the customisation. This includes enabling customers to select product features, to self-configure the product features, and to design their own product features.

Product scope: the variety of products which are offered by a company. This attribute is a measure of the range of products existing at the end of the development or customisation process, and specifies the boundaries for a firm's product options. This includes the scope of product lines (width), product range (depth), and features (length).

Lead users: the group of users (companies or individuals) who experience heightened needs as yet unknown to the company and to other customers, and develop bespoke solutions to satisfy their needs.

Supply chain: the system concerned with the overall movement of products or services from supplier to consumer. This includes technologies and resources as well as companies and individuals.

1.3.3 Scope of the Study

The research expects to determine relationships between companies and collaborative partners, and to compare the effects of these relationships on product development. The knowledge gained from this research will contribute to the understanding of collaborative product development in mass customisation. In particular, the work should give an insight into the relative value of collaboration with suppliers and lead users. To achieve these effects, deductions must be drawn from data collected from an appropriate sample which is broad enough to allow derivation of general conclusions but narrow enough to ensure that specific and helpful applications and suggestions can be made.

The scope of this research is readily determined from the research problem. It is concerned with mass customisation processes, and therefore excludes any companies or product lines which only involve standardisation (such as mining and extractive industries). Furthermore, of the various tasks involved in mass customisation, this research focuses on the product development processes, which encompasses concept development, design and production. The study is, however, restricted to mass customisation alone, and does not address the integration of mass customisation with other production practices or compare mass customisation to other manufacturing paradigms. This research is targeted to manufacturers which involve their collaborative partners early in the mass customisation processes, from the concept development phase.

Mass customisation encompasses a very broad range of industries, and can describe the production of all manner of goods and services. The focus of this research is on the product development process, and for the purposes of this study, only physical products are considered, not other goods such as software and services. This study has been performed on manufacturers in the UK only. Many of the companies studied are international or multinational but operating in the UK, and the respondents are members of the UK management and were surveyed about their UK manufacturing plant specifically. Selection of companies was screened by the European Standard Industrial Classification codes (1992) to encompass all manufacturing companies with the possibility to mass customise, that is, the manufacturers of consumer products. Companies encompass a range of industries, and varied in size from small to large and in age from young to well-established. This study is performed from an operations management perspective, with the unit of analysis being the manufacturing companies and the respondents are the senior operations manager of the companies, or the product development manager if the operations manager is unavailable.

1.4 Thesis Outline

This thesis will systematically detail the ways in which the research problem was derived and the research was subsequently performed. The outline of the thesis, and the development of concepts are shown in Figure 1.1 overleaf. The literature review which was performed in order to derive the research problem and hypothesis will first be described, followed by an outline of the methodology. The final chapters of this thesis will concentrate on the results and conclusions of the study.

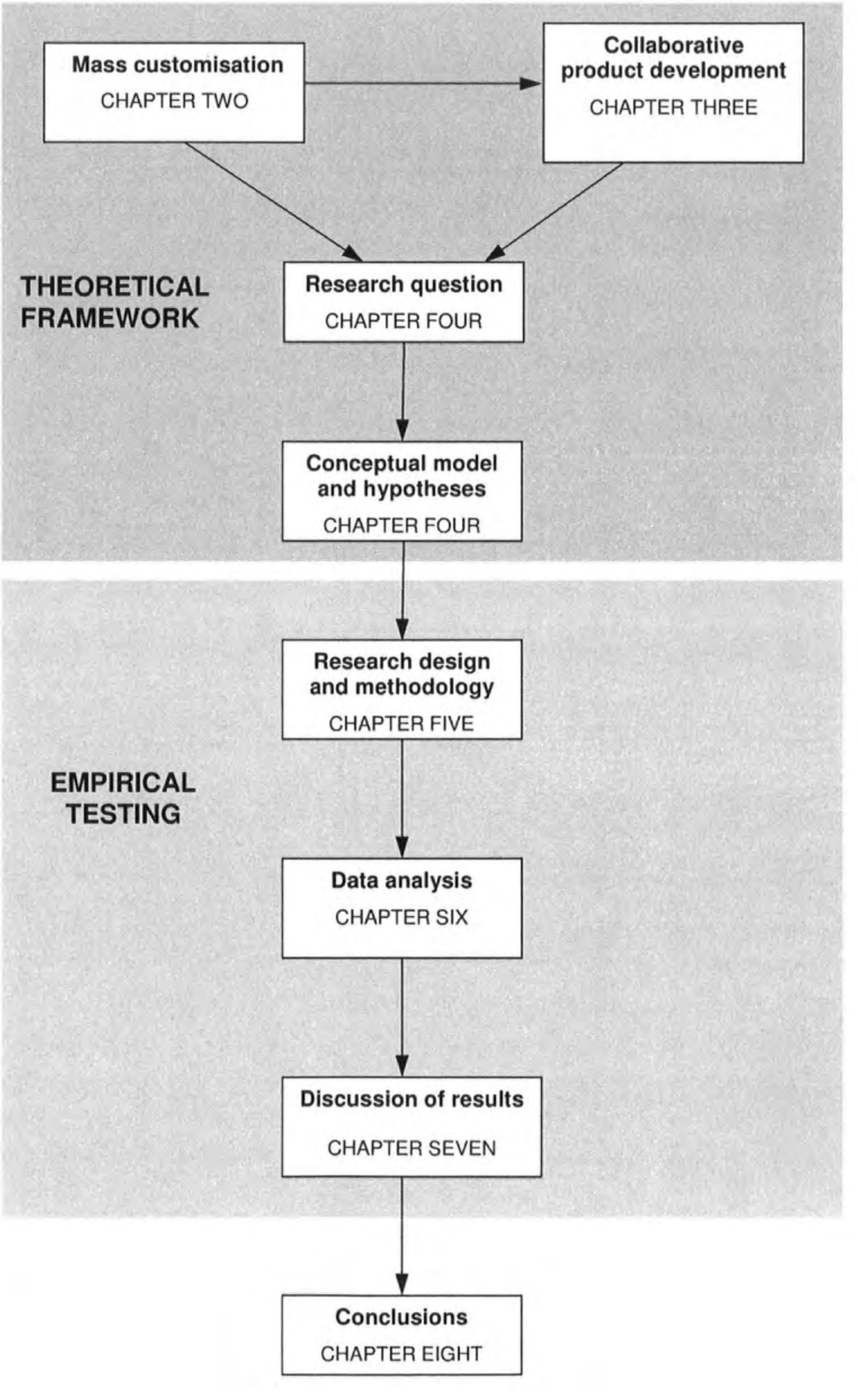

Mass customisation
CHAPTER TWO
Collaborative product development
CHAPTER THREE
THEORETICAL FRAMEWORK
Research question
CHAPTER FOUR
Conceptual model and hypotheses
CHAPTER FOUR
EMPIRICAL TESTING
Research design and methodology
CHAPTER FIVE
Data analysis
CHAPTER SIX
Discussion of results
CHAPTER SEVEN
Conclusions
CHAPTER EIGHT

Figure 1.1: Outline of thesis

Chapter Two explores the concept of mass customisation, beginning with a recounting of the historical basis of the paradigm. The chapter then focuses on the academic understanding of the characteristics and importance of mass customisation. The mechanisms of implementing mass customisation are also discussed in detail. The final section of Chapter Two reviews current literature concerned with the improvement of mass customisation capability through utilisation of various enablers. It ends with the proposition that collaboration is an effective means of improving mass customisation performance.

Chapter Three discusses collaboration in product development. The chapter begins by discussing product development, and explains the basis for adopting a collaborative approach. Various enablers for successful collaborative product development are then presented. The chapter then explores the two collaborative partners of interest to this study: suppliers and lead users.

Chapter Four describes the development of three key ideas, as shown in Figure 1.1. On the basis of the discussion in Chapters Two and Three, the research question is defined. In order to answer this research question, the conceptual model is designed, in the form of four mass customisation attributes. Eight hypotheses for this work are finally presented in this chapter.

Chapter Five explains the research methodology which has been adopted for this study on the basis of the theoretical framework, the research question, and the hypotheses described in Chapter Four. The selection of a survey as the research method is justified. The methods of survey design and administration are described in detail, including the scale design and development, the use of focus groups and a pilot study, and the sample determination. The chapter ends with a discussion of ethical considerations.

Chapter Six details the findings of this research. Following presentation of the descriptive statistics for the sample, the results of the principal statistical methods of factor analysis and multiple regression analysis are described. The results of various reliability and validity tests are also reported.

Chapter Seven contains a discussion of the methodology, and of the research findings, with particular focus on the findings which have been obtained for each hypothesis. The chapter also contains discussion of the relative effects of the two collaborative partners.

Chapter Eight provides a conclusion to the thesis, drawing together the results presented throughout. The contributions which this work has been able to make to the field of study are discussed, and potential areas of future work are identified.

1.4.1 Conclusion

This chapter has provided an overview of the work which is reported in this thesis. It first introduced the research area of new product development in mass customisation, and presented the research problem and the underlying hypotheses. A brief discussion and justification of the methodology was provided, followed by an outline for this thesis. The subsequent sections of this thesis provide a more detailed account of the research.

THEORETICAL FRAMEWORK

CHAPTER TWO

MASS CUSTOMISATION

CHAPTER TWO: MASS CUSTOMISATION

[Mass customisation] at its core is a tremendous increase in variety and customisation without a corresponding increase in costs. At its limits, it is the mass production of individually customised goods and services. At its best, it provides strategic advantage and economic value.' (Pine, 1993a)

2.1 Introduction

The business strategy of mass customisation has gained great momentum over the past ten years, and is being adopted by manufacturers across the globe. As a result, there is an ever-growing demand to refine mass customisation processes to provide further benefit to producers and consumers alike. Such improvements require greater understanding of the factors involved in the success of mass customisation ventures.

This chapter presents the historical development of the study of mass customisation: from the genesis of the term to the current understanding of the nature and mechanisms of the paradigm. This leads to a discussion of the documented attempts to improve mass customisation, through utilisation of one or more enablers of mass customisation. While this chapter discusses the various approaches to achieve greater mass customisation performance, it ends with one particular approach – collaborative product development. This strategy will be discussed in further detail in Chapters Three and Four.

2.1.1 The Birth of Mass Customisation

The industrial revolution of the late 18th and early 19th centuries moved manufacturing from a cottage industry into large-scale factories (Rostow, 1978). Population growth over the ensuing century and the resulting increased economic demands precipitated the evolution of mass production, which was characterised by even greater efficiency of production and lower costs to consumers (Hounsell, 1984). The manufacture of the Model T Ford is the common example of this early mass production.

The impetus for mass customisation arose from the market situation of the 1970s and 1980s. Consumer markets began to change rapidly, and consumers were more demanding than ever (Cox and Alm, 1998). From the viewpoint of the corporations themselves, with globalisation came ever-increasing national and international competition, and the need to maintain status as valuable providers of products and services (Chandra and Grabis, 2004b). This required that companies satisfy the demands of the consumers by providing the choice available in tailor-made manufacturing with the low cost offered by mass production.

The idea of mass customisation is not a new one: Martin Starr (1965) suggested the value of modular production to provide variety to consumers. Alvin Toffler was the first to foresee mass customisation as a process in his 1970 book '*Future Shock*', but it was not until 1987 that Stan Davis named the strategy. He first used the term in his book '*Future Perfect*' (1987), where he anticipated the technological resources and capabilities essential for the mass manufacturing of products that are more varied. He was therefore the first to address the importance of technological change for mass customisation, highlighting the significant role of innovation in this new manufacturing strategy. Davis believed that variety is a requirement to allow companies to meet customers' desires, and that this variety will in turn yield high demand that has to be satisfied by mass production of these individualistic products supported by technological capabilities. This is the momentum for the development of mass customisation. In a subsequent review of this work, Davis (1989) reiterated that the aim of mass customisation is to treat customers in the modern economy of mass production as if they were individuals in the pre-industrial world.

Kotler (1989) expanded Davis' ideas and applied them to marketing management. The task of bringing mass customisation research into the mainstream was left to Pine (1993a), who provided the platform for study into this area in his pioneering book *Mass Customisation: the New Frontier in Business Competition.*

2.1.2 Early Mass Customisation

In his book, Pine outlines the early development of mass customisation processes in industry. He suggests that the sufficiency of mass production was first called into question during the 1960s, the need for a new strategy developed over the 1970s, and was openly recognised in management in the 1980s. The new paradigm of mass customisation developed in the 1990s in response to the increased competition which businesses faced as a result of this breakdown.

The 1980s and 1990s saw the introduction of customisation procedures into various industries. In the automobile industry, there was a three-fold increase in the number of models available, in addition to a dramatic increase in the optional extras offered. In the fast food industry, chains began to allow for individual variation in orders while maintaining the same speed of preparation, while menus were customised to be specific to geographical location. In the information technology industry, the number of varieties of computer increased over the 1980s and 1990s and with this increase, the features available for customisation for each individual user. Pine cites further examples of mass customisation in the telecommunications, personal care, beverage, breakfast cereal, insurance and banking industries.

Since these early days of mass customisation, the practices and technologies involved in mass customisation have evolved, and the process is being adopted by increasing numbers of companies across increasing numbers of industries. This greater importance necessitates a better understanding of the process, to enable companies and consumers to best benefit from mass customisation, either by maximising and broadening the applications of mass customisation, or by identifying mechanisms to better enable mass customisation (Efstathiou and Zhang, 2004). These aims are the focus of the great abundance of current research into mass customisation. Such research can be divided into the theoretical basis of the concept, analysis of the mechanisms and investigation into the means by which mass customisation processes can be improved. A discussion of these areas will form the basis of this chapter.

2.2 The Theory of Mass Customisation

Although mass customisation followed a natural evolution in industrial practice rather than being led by theories, many academics have wrestled with the theoretical aspects of mass customisation. This involves the generation of accurate definitions which encompass the processes, and determination of the place of mass customisation in the broad array of industrial processes.

2.2.1 Definitions of Mass Customisation

Building on Pine's work and based on their explorations of different aspects of mass customisation, many researchers have suggested different definitions. Hart (1995) defined mass customisation in two ways: one visionary, and the other practical. The visionary definition identifies mass customisation as the ability to provide customers with their wants profitably, given the time, place, and the way they want solutions. On the other hand, his practical definition presents the concept as the utilisation of flexible operations and organisational structures to produce customised goods and services which benefit from the economies of scale associated with mass production.

Duray (2002) gave a more operational definition to mass customisation, as the building of products to customer specifications using modular-based manufacturing to benefit from economies of scale. Fernandez (2002) also focused on the technical aspect of mass customisation; by highlighting the manufacturing capabilities required to achieve mass customisation, he defined it as the use of agile production and flexible organisational structures capable of responding to the specific demands of each customer.

These definitions attempted to tailor the use of mass customisation to the specific cases or contexts with which they were concerned (industrial, practical, or theoretical), and all attempts tackled the role of product development, albeit indirectly. Tu *et al.* (2004) stressed the role of product development and technical innovation, when they defined mass customisation as "the ability to produce varieties of customised products quickly, on a large scale and at a cost comparable to mass-production through technical and managerial innovations" (p. 152). Likewise, Yassine *et al.* (2004) argue that the move in recent decades towards mass customisation should be consistent with the concurrent shift towards product development rather than merely basing new products on existing ones.

Numerous suggestions have been made of aspects to include in a definition of mass customisation. Important in the definition of the concept of mass customisation is an identification of the breadth of the market for which it is applicable. McCarthy (2004) notes that, by its very name, mass customisation has relevance for high volume producers. Piller (2002) suggested that mass customisation is defined by its high intensity of information, as every transaction requires communication between the customer and the supplier.

What is clear from these various definitions is that the important features of mass customisation are the breadth of products offered and the tailoring to customer demand, while maintaining competitive aspects of mass production. This research builds on the previous definitions and provides the following description of mass customisation as the working definition for this research: *the ability to deliver a broad scope of customer-influenced products on a large scale, without significantly compromising development cost or time.* The following section describes the application of these definitions to the academic discussion about the place of mass customisation in the market.

2.2.2 The Role of Mass Customisation in Industry

Following the establishment of the concept and definitions of mass customisation, a number of questions arise concerning how mass customisation should be viewed with respect to industry. For example, should mass customisation be the only approach utilised, or only one of many? Should the same approach be adopted by every company across every industry? And what are the relationships between mass customisation and its predecessor, mass production?

2.2.2.1 Mass Customisation as the Way of the Future?

Since it was first brought to the attention of academics, there has been disagreement amongst academics concerning the importance and viability of mass customisation as the production strategy of the future. Early contributors to the theory viewed the paradigm as a panacea, and the inevitable successor of mass customisation (Davis, 1987, Pine, 1993a). This view was challenged in the intervening decade by a number of arguments.

Kotha (1995) cautioned that to view mass customisation as the only feasible option for the future is dangerous because "the message, taken to an extreme, can position the firm as trying to be all things to all people, which is a recipe for competitive mediocrity, rather than competitive advantage" (p. 40). He countered that mass production will not cease to be a viable strategy, even with the rise of mass customisation. Indeed, from his studies of the bicycle industry, he concluded that companies employing both mass customisation and mass production enjoyed the benefits of enhanced knowledge building and strategic flexibility. This view, that mass customisation is only one of many production strategies for the future, and that optimum organisational objectives can only be achieved through the marriage of mass customisation with mass production has been a common theme in the literature; see also (Sahin, 2000). The claim that mass customisation is a new paradigm to supersede the old has been called into question by many subsequent papers. Burgess (1994) answers that the "new" property of agility raised by this paradigm appears to be "a hybrid construct formed from existing competitive priorities" (p. 28)

While these authors considered mass customisation to be important, but not exclusively so, Spring and Dalrymple (2000) view mass customisation even more critically. They performed a broad review of mass customisation literature and synthesised information from various case studies. They argued that examples of mass customisation given by Pine and other early authors on the topic do not represent pure customisation, but merely a variation of simple dimensions such as clothing sizes. This variation in the level of mass customisation will be discussed further in section 2.2.2.2. Spring and Dalrymple's conclusion from their literature review is that "closer examination of 'mass customisation' shows it to have limited novelty and restricted applicability" (p. 448).

Agrawal *et al.* (2001) argue that the application of mass customisation is not appropriate for the manufacture of all goods. Furthermore, they cite a long list of hurdles faced by would-be mass customisers, in the form of the enormous changes required to the existing management paradigms, operations, supply chain and information technology. They suggest instead a strategy shift from building-to-order to locating-to-order, that is, enabling customers to find their desired product amongst those which have already been manufactured.

Despite this controversy which surrounds the status of mass customisation in the future, the literature is in agreement concerning its ability to provide solutions to the industrial challenges of the 21st century – greater competition and rapidly changing consumer demands. Academics also seem to agree that mass customisation is closely interlinked with its predecessor, mass production. The following section will more closely examine the relationships between the two paradigms. This is important in the light of the relative youth of mass customisation, and the resulting sparsity in the literature concerning its improvement. In contrast, mass production has been well-documented and studied over the past century, and the establishment of relationships between the two paradigms will allow some of the conclusions concerning mass production to be applied to mass customisation.

2.2.2.2 Mass Customisation vs Mass Production

Pine (1993a) compared and contrasted the mass production paradigm with that of mass customisation through five main parameters: focus, goals, key features, product and structure. The conclusion of these comparisons were that not only is mass customisation the successor mass production, but also that mass production and mass customisation are in fact incompatible because of the huge differences in these parameters. Pine concluded that mass production is "outmoded and no longer effective" (Pine *et al.*, 1993c, p 264).

The comparisons of mass customisation and mass production in these and other studies (Pine, 1993a, Pine *et al.*, 1993c, Kotha, 1995) resulted in the following descriptions. *Mass production* has a focus on maintaining efficiency through stability, with the goal of producing low cost articles available to almost everyone. Mass production processes are therefore characterised by stable demand, homogeneous markets and long product life cycles. *Mass customisation* has a focus on achieving variety through flexibility, with the goal of developing affordable but varied goods that suit almost anyone, as discussed in section 2.2.1. Mass customisation processes are therefore characterised by fragmented demand, heterogeneous markets and short product life cycles.

In contrast, Mintzberg and Lampel (1996) viewed mass customisation as a combination of two logics: the logic of aggregation and the logic of individualisation. The basis of their argument was that mass production (aggregation) and customisation (individualisation) are not alternatives but rather poles of a continuum of real-world strategies. The logic behind mass production is economical (benefit from economies of scale), and operational (ease of developing, manufacturing, and distribution), while the logic of individualism is social (catering for desires as well as needs) as well as economical (increasing competitiveness).

According to their model, in between these two extremes lies a continuum of mass customisation strategies, namely *segmented standardisation*, *customised standardisation* and *tailored customisation*. Each of these strategies expresses different level of standardisation (aggregation), or customisation (individualisation). This continuum is shown in Figure 2.1, which illustrates the level of customer involvement in each strategy.

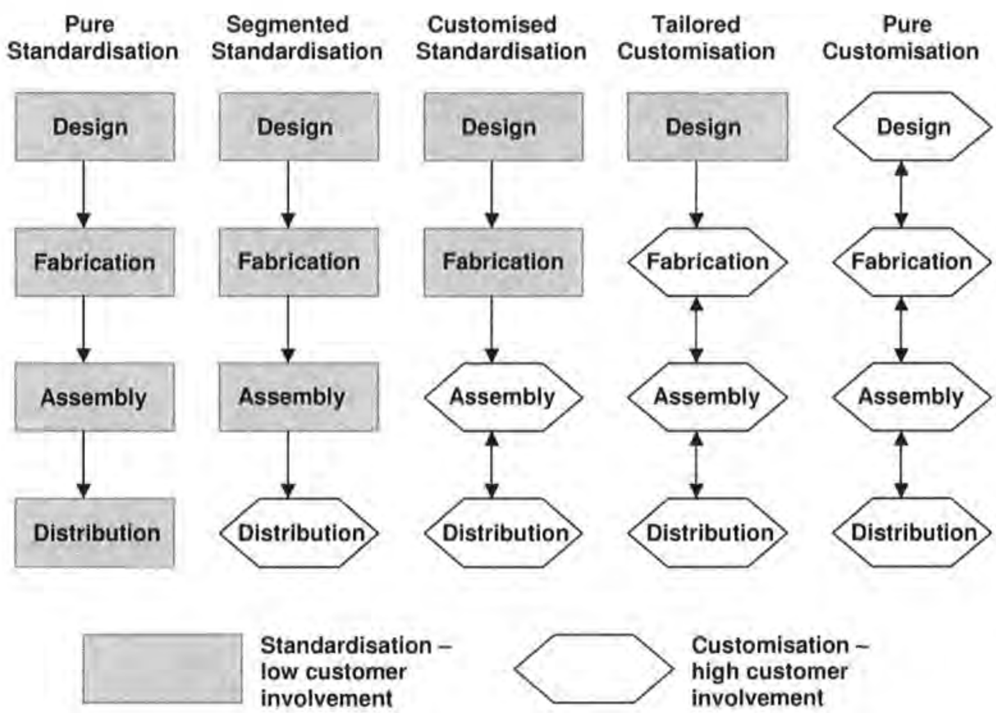


Figure 2.1: The continuum of strategies from standardisation to customisation. Adapted from Lampel and Mintzberg (1996).

Pure standardisation is another term for traditional mass production, in which customers are not involved at any stage of product development. Instead, the process is dependent entirely on the manufacturers and delivers a unified (undifferentiated) product aimed to satisfy the majority of customers. An example is the mass production of standard goods like televisions.

In *segmented standardisation*, or point of sale customisation, customers can directly influence the means of distribution and delivery of the products. As a result, the same, undifferentiated, products may be distributed by different channels to various consumer groups. This is often manifested in a segmentation of the market, in which each segment represents a group of consumers, whether according to geographical area, or age category. As a result, the product is delivered to each segment in a different manner.

Customised standardisation, or standardised customisation, describes the situation in which customers are given the freedom to choose from a predetermined set of options. The design and components are standard, but the configuration of components may be varied. In this way, standardised modules are assembled according to specific requirements. In addition to distribution, the customer can be involved in determining the exact way in which modules are assembled to give the final product, but with no influence over the modules used. This approach is also commonly called "cut to fit". An example of a company using this methodology is Nike, with its internet-based NIKEiD system, by which customers can choose which components to combine to generate a customised shoe. Personal computers which can be built from a catalogue of possible hardware and software also offer customised standardisation.

In *tailored customisation*, the modules themselves may also be customised. Customers have influence in all areas of product development from the fabrication stage, and the producer will change the standardised design according to the client's request. The only standardisation in the process is in the definition of the basic design. A car company, for example, will manufacture cars of a generic type, but customers are able to influence all other aspects of the car's production. Another example of tailored customisation is the manufacture of eyeglasses, in which customers not only select from an inventory of possible frames, shapes and sizes, but the lens is also individually tailored to each customer.

The final category, *pure customisation*, describes craft production, in which the customer influences every aspect of the product delivery process. The result is a product which has been designed and manufactured from scratch to suit the individual customer, and is an exact match of the customer's request. For example, a tailored suit meets the requirements of the customer in all dimensions, including size, colour, material and cut. Construction projects are also examples of pure customisation, in which the customer is involved in the manufacture from the very first stage of architectural design.

From their analysis, Mintzberg and Lampel concluded that the most pursued strategy has been towards customised standardisation. While the initial suggestion of these levels had a theoretical basis, Amaro *et al.* (1999) provided empirical evidence for these levels in a variety of industries.

Skjelstad *et al.* (2005) analysed Lampel and Mintzberg's strategies according to the cost, lead time and degree of customisation, as shown in Figure 2.2. In moving through the continuum from pure standardisation to pure customisation, the degree of customisation increases, but so too do cost and lead time. It is important to find a competitive balance between these three factors.

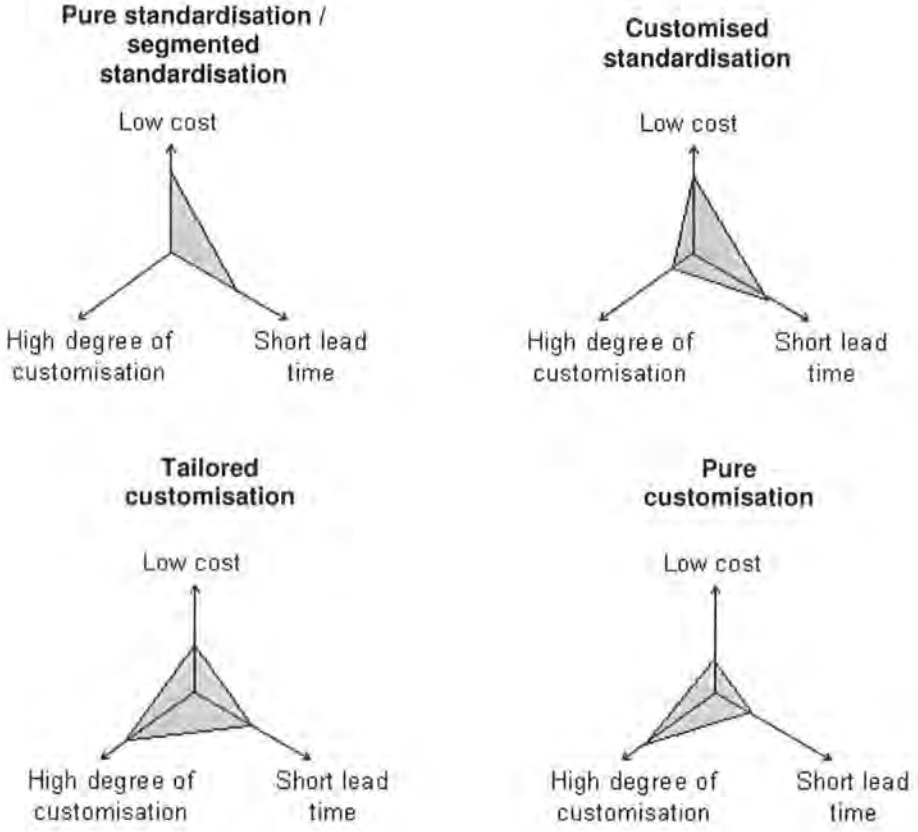


Figure 2.2: Categorisation of the levels of customisation according to the parameters of cost, lead time and degree of customisation. Adapted from Skjelstad *et al.* (2005)

With the recent emphasis on product development as an important stage of the manufacturing process, this model of the continuum of strategies has been altered by some researchers. Yassine *et al.* (2004) suggest that product development should lie above design, thus introducing an additional strategy to the continuum: one in which all stages, including product development, involve customisation. Product development encompasses various activities: idea generation, concept development, product design and specification, prototype manufacture, validation and testing in preparation for full production. These product development processes contribute to a large portion of the overall production costs and production time, and contribute heavily to the allowance for product variety and customer input. It is this form of mass customisation that is of interest of this study as it is represents the greatest potential for improvement due to the high allowance for customisation early in the processes. As a result, product development will be subsequently considered in this study to be an important part of the value chain, as is widely accepted in the literature (Skjelstad *et al.*, 2005, Yassine, 2004). In fact, the focus of this study will be the product development processes of mass customisation.

While the majority of researchers studied the replacement of mass production by mass customisation as a natural progression and an inevitable situation, Kotha (1995), suggested the application of both, as discussed earlier. He studied the different mechanisms, and the simultaneous application of the two, and analysed the operational and managerial implications of such processes. Finally, he scrutinised the effect of each approach on the company's ability to sustain its competitive advantage. Through this study, he was able to provide a detailed description of the linkages which can be made between mass customisation and mass production. Kotha (1995) concluded that companies applying mass customisation and mass production simultaneously would outperform the companies that adopt only one of them, summarising the costs and gains of pursuing the two paradigms concurrently (Table 2.1 overleaf).

Table 2.1: Benefits and costs associated with implementing mass customisation and pursuing mass production and mass customisation simultaneously. Adapted from Kotha (1995).

Potential benefits		Potential costs
Cost savings from:	**Enhancement in firm's ability to:**	**Increased costs from:**
• not requiring finished goods inventories or significant work-in-process inventories • elimination of product obsolescence • elimination of market research required to predict market • elimination of certain activities from the firm's value chain • handling and directing of 'sticky' data to the points of value creation	• effectively utilised highly skilled and motivated employees • refine existing engineering and manufacturing capabilities to allow greater strategic flexibility • rapid and responsive introduction of new products • promotion of a conducive climate for continued learning and improvement • charge price premiums by satisfying unique requirements and needs of customers	• expenditures in advanced manufacturing technologies • investments in database systems • refinements in engineering resources • relatively high amount of managerial time required to implement approach • equipping and training retailers to accurately communicate with customers and manufacturers • increased labour expenditures due to requirement for highly trained and skilled workforce

The previous discussion has highlighted that there appears to be a link and, according to some academics, a very close relationship, between mass customisation and mass production. Mass customisation is a new and distinct paradigm which only entered mainstream research fifteen years ago. Over this intervening period, there has been much study to understand the practical nature of the process. This research will be discussed below, followed by a literature review of the investigation of the ways in which mass customisation processes can be improved.

2.3 The Mechanisms of Mass Customisation

2.3.1 Mass Customisation in Practice

2.3.1.1 Functions of Mass Customisation

Pine (1993a) viewed mass customisation as primarily a management issue where the main concern is to perform the four basic functions of developing, producing, marketing and delivering of products at affordable prices with sufficient variety to satisfy each individual. As depicted in Figure 2.3, the logic of a mass customiser is to cater for the individual wants of customers which will in turn increase sales, thus leading to higher profits. If this is coupled with more research into customer requirements, there will be an increase in the firm's ability to introduce new varied, customised, and tailored products, resulting in further fragmentation of the markets. This fragmentation will allow the company to attract more customers and better fulfil the desires of the existing customers, since the company is already out-competing rivals in variety and differentiation of products, and so on. The interesting aspect of this paradigm is that it tackles the importance of product and process technology in achieving mass customisation, but does not address the role of collaboration in product development, which lies at the heart of mass customisation.

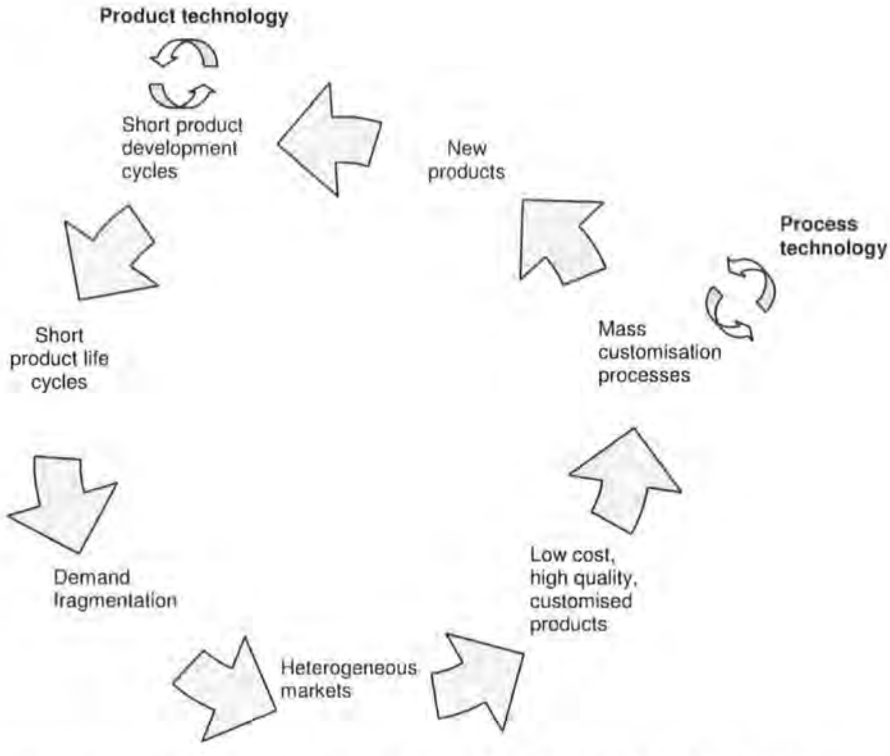


Figure 2.3: Mass customisation as a dynamic system feedback loop. Adapted from Pine (1993a)

Manufacturers pursue mass customisation for many different marketing, operational, financial, and strategic reasons. The increase in customer satisfaction and in the company's market share represent strong motivations for marketing departments to practice pressure on senior management to adopt mass customisation, in addition to the competitive requirements of keeping up with rivals. Operationally, mass customisation reduces the order response time and manufacturing costs and embraces much technological and manufacturing advancement which further increases the flexibility of the process. It is due to these general benefits of higher profit margins, customer satisfaction, and increased business opportunities that mass customisation continues to be an attractive manufacturing paradigm (Tseng and

Jiao 1996; Par *et al*, 1999). The following section evaluates more specific outcomes of mass customisation.

2.3.1.2 The Costs and Benefits of Mass Customisation in Practice

Much of the early literature about mass customisation hypothesised about its potential benefits – there was less discussion on the costs of the approach (Pine, 1993a). It was necessary, however, to determine the true experiences within industry. Åhlström and Westbrook (1999) performed an exploratory survey, from which they were able to identify six direct benefits enjoyed by companies pursuing mass customisation. These benefits read like a company wish-list: increased customer satisfaction, greater market share, increased customer knowledge, reduced order response time, reduced manufacturing cost and increased profit. The majority of companies indicated that the most important benefit was the increase in customer satisfaction, followed by an increase in the market share. These two benefits represent the impetus behind the pursuit of mass customisation.

Many researchers have concluded that mass customisation is the solution to customers' increased demand for variety (Pine, 1993a, Hart, 1995, Zipkin, 2001, Kakati, 2002, Berman, 2002, Agarwal *et al.*, 2003). These authors hold the view that the shortcomings of mass customisation arise from operational factors rather than conceptual failings. This emphasises the need for studies into the ways by which companies currently achieve mass customisation, in order to understand operational problems and find ways of solving them.

The extensive study of Åhlström and Westbrook (1999) also investigated the downfalls of mass customisation, and they, too, concluded that the limitations of the procedure resulted from operational factors rather than theoretical deficiencies. They identified many shortcomings such as increased material and manufacturing costs, fewer on-time deliveries, difficulties to ensure supplier delivery performance, increased order response time and reduction in product quality. They concluded that a poor understanding of customers' desires could result in unsuccessful production. Supply chain management was also identified as a main cause of difficulties, where each member or stage of the supply chain might hinder the implementation process or harm its quality, as mass customisation is a whole system that will be affected significantly by any part's limitations. In addition, Åhlström and Westbrook distinguished the organizational culture as a main difficulty; if not supportive, culture can pose a great threat to the entire implementation process, as there will be no enthusiasm or understanding of its significance.

Åhlström and Westbrook concluded that most deficiencies of mass customisation arise from the operation function, with the following operational barriers being shown to hinder mass customisation. *Inflexible factories* describes the scenario where rigid manufacturing systems do not allow for quick changes in methods of productions, thus impairing the company's responsiveness to market changes. *Costs of products* can hinder mass customisation if operations are inflexible, the products resulting will have higher price due to the increased cost of product development. *Change management*, management skills and abilities, supply management, and the management of distributors/ retailers could create plethora of problems. Finally, deficiencies in *information technology*, resulting from poor management of IT or lack of IT facilities will negatively affect the system, as discussed earlier.

These deficiencies, in the light of the many benefits of mass customisation, emphasise the great need to better understand the ways in which mass customisation capability can be improved. They also indicate that product development processes are important in the success or failure of mass customisation ventures. The following section describes the current understanding in the literature of mass customisation capability can be achieved.

2.3.2 Achieving Mass Customisation

2.3.2.1 The Progression from Mass Producer to Mass Customiser

Most literature which deals with methods of achieving mass customisation explores the issue from the aspect of mass producers who want to become customisers – that is, implementing the procedures and equipment to allow customisation of products where only standardisation was previously provided. It is generally agreed both from theoretical and practical bases that there is no single way to achieve mass customisation (Pine, 1993a, Gilmore and Pine, 1997, Ahlstrom and Westbrook, 1999). Studies have therefore focussed on the range of possible approaches.

Since Pine believed that mass customisation is the inevitable successor of mass production, he based his early work on elucidating the progression from mass production to mass customisation (Pine, 1993b). Accordingly, he suggested five techniques for achieving mass customisation: customised services, embedded customisation, point-of-delivery customisation, rapid response and modular production. The strategies are listed in order from the easiest to apply to the most sophisticated and demanding. All these techniques, however, are achievable for implementation by mass production companies with minimal changes. Pine suggested that companies apply a combination of approaches.

The first technique, of the *customisation of services around standardised products and services*, suggests that companies should start by adding extra features or additional variations at the last two stages of the organization's value chain, which are the marketing and the delivery of products. The second technique, *embedded customisation*, refers to the creation of customisable products and services, by introducing customisation to the development and marketing stages while producing these customised products in a standardised (mass-produced) manner and delivering them in a standardised mode (to a specific segment).

The third strategy is sophisticated and requires high stock levels of raw materials, and technological capabilities. The *point-of-delivery customisation* approach provides exactly what customers want by producing the product or rendering the service at the point of sale or delivery. *Rapid response* is the fourth technique for mass customisation, where time is eminently a vital element. Here the process is reversed; the customisation starts at the point-of-sale or delivery and is pushed back the value chain, forcing each function to mass customise its processes, making better use of its resources due to the time factor.

The final technique, which Pine considers to be "the best method for achieving mass customisation" (p. 196), is *modular production*, which uses interchangeable parts (modules) to introduce a vast array of configurations, resulting in great variety. This strategy simultaneously achieves economies of scale (on these parts), and economies of scope (experience curve resulting from the repetitive use of these modules).

All these approaches devised by Pine stress the importance of developing capability for higher product variety. This requires higher allowance for customer influence, not only in selecting the specific form of the final product, but also in the early stages of the product development process.

Pine's analysis relies on the assumption that the transition from mass production to mass customisation is practically attainable. Duray (2002) argues that even though literature (Pine 1993; Kubiak 1993; Kotha 1995) gives examples of producers achieving mass customisation, little empirical data is available to show this progression from standard or custom product manufacturer to mass customiser. While the important role of the mass customiser is unquestionable, Duray states that it is not straightforward for firms, whether mass producers or craftsmen, to change their practices in order to achieve mass customisation. The difficulty in bridging the gap between standardisation and customisation is illustrated in Figure 2.4, which details the changes required from either pole of the continuum.

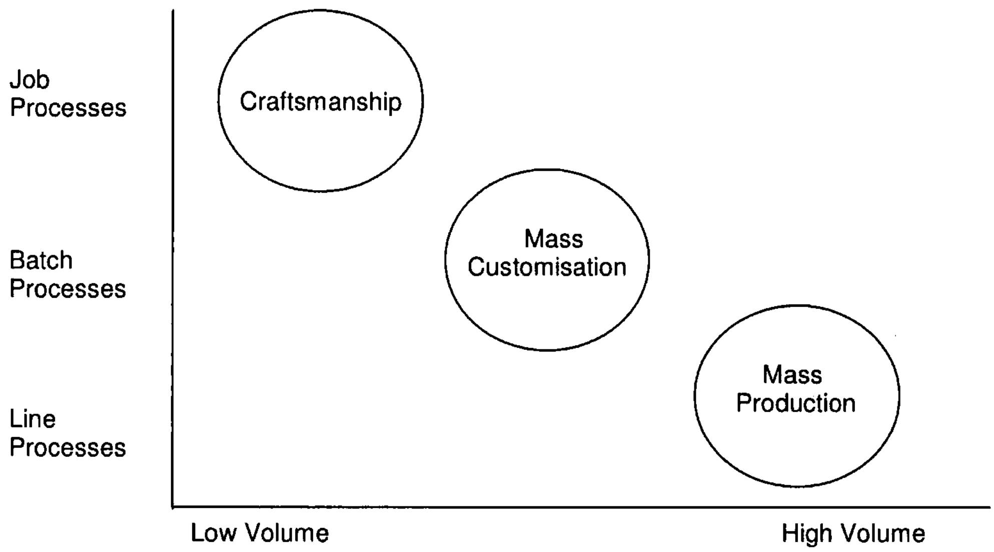


Figure 2.4: The manufacturing eras and their impact on the transformation process. Adapted from Brown and Bessant (2003).

In order for mass producers to become mass customisers, they must change their manufacturing processes from one in which product development follows a linear sequence to a more integrated system, where processes are branched. This inevitably will involve some initial loss of productivity. On the other hand, in order for companies involved in craftsmanship to become mass customisers, they must increase their output volume. This also requires a change in their manufacturing processes; from job processes, in which each product is individually manufactured, to batch processes, involving the simultaneous manufacture of multiple products, or modules. While this section has discussed the mechanisms by which companies may progress from mass production to mass customisation, the following section presents a more general approach for the achievement of mass customisation.

2.3.2.2 A Strategy for Mass Customisation

Early research focussed on the only problem at hand, which was to provide existing, mass producing companies with the capabilities to customise. Since the widespread adoption of mass customising practice, a plethora of company types has emerged, and research must therefore be more varied. More recent studies, therefore, have been conducted to establish, both theoretically and practically, the broad approaches to mass customisation. These may apply to mass producing companies which are attempting to change their strategy or to abandon their existing procedures in favour of completely new production strategies, or for new companies starting primarily as mass customisation ventures.

Ross (1998) identified four types of companies: *active mass customisers*, which possess the capacity to provide customised products by utilising flexible manufacturing techniques; *high-cost customisers*, who employ craft-manufacturing to provide customised products, and therefore have high costs and long lead times; *dormant mass customisers* have the flexible manufacturing system required to mass customised, but have not exploited the capability. The final class of company comprises the *classic mass producers*. Ross's categorisation is based on cost and time of production as signifiers of the level of customisation. In addition he stressed the importance of flexibility to produce wider product scope while still minimising development cost and time.

Gilmore and Pine (1997) provided a framework for the pursuit of mass customisation. They recognised that there are two axes for change: the product itself, and how the product is portrayed and presented to the customer (which they labelled the "representation"). Based on these two variables, there are four distinct approaches to mass customisation: collaborative, adaptive, cosmetic and transparent (Figure 2.5). The principal focus of this research is collaborative mass customisation. Gilmore and Pine provided industry examples of each approach.

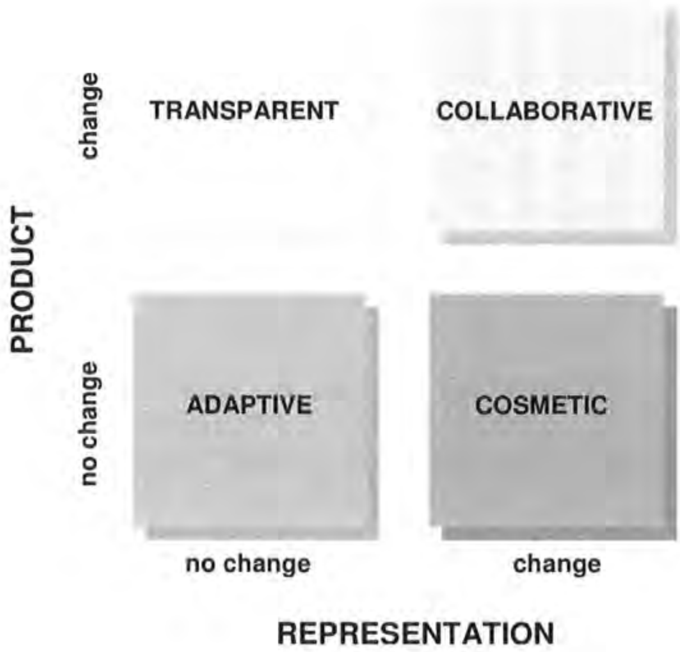


Figure 2.5: The four approaches to customisation. Redrawn from Gilmore and Pine (1997)

Collaborative customisation involves flexibility in both product and representation. In this approach, customers are consulted at the early stages of design, and are encouraged to articulate their needs and identify exactly what form their desired product will take. Such an approach is most applicable to businesses in which customers do not want to be forced to select from set options. Gilmore and Pine's industrial example of this form of customisation is Paris Miki, a Japanese eyewear retailer which has established a system of dialogue to provide consumers with their ideal glasses. The process involves the provision of a number of options for the nose bridge, hinges and arms; the consultation between customer and optician concerning the shape and size of the lens and the use of advanced technology to provide a virtual image of the customer wearing the glasses before the product is assembled in store. As will be discussed later, it is this customisation approach which will form the principal focus of this study.

Adaptive customisation, on the other hand, refers to the strategy in which there is flexibility in neither product nor representation during manufacture, but instead the standard product is designed in such a way that customers are given the possibility of altering the product themselves. This approach is appropriate for companies developing products which are designed to perform in different manners on different occasions. An example of this strategy is the Lutron Electronics Company (Pennsylvania), which produces the "Grafik Eye System". This system involves a number of connected lights within a room which can be programmed to achieve different "moods".

Cosmetic customisation refers to processes which produce a standard product which has varied representations. Customers are presented with different "looks" such as packaging, personalisation, promotion and point of sale. This approach can be used in any situation when different consumers desire a standard product to be delivered in various ways. The production of T-shirts bearing logos is one example of such an approach. Food producers also adopt cosmetic customisation as the packaging and quantities of their products varies according to customer – for example, a frozen food companies may sell small, well packaged quantities to supermarkets but larger quantities with plainer packaging to caterers.

Transparent customisation describes changes to the product with no change in the representation. Companies anticipate and study customers' desires and modify their products accordingly, with no input from the customer. In this way, consumers are being provided with customised products without being told explicitly of the customisation process. Such an approach can be used when the specific needs of customers can be easily deduced. Gilmore and Pine's example of transparent customisation is ChemStation (Ohio), a producer of industrial soap. This company studies the needs of its consumers for various purposes such as car washes and industrial floor-cleaning. It develops and supplies products accordingly without further input from the consumers. Another example of transparent customisation is the suggestions provided by online companies like Amazon, which provides suggestions for possible products based on the consumer's other purchases by determining popular purchases for others who bought the same products.

Gilmore and Pine (1997) suggest that companies carefully consider each approach to determine which (or a combination of which) will best serve their customers. They concluded that "businesses must design and build a peerless set of customisation capabilities that meet the singular needs of individual customers" (p. 101). This framework of customisation approaches paved the way for a number of studies which explored the methods of mass customisation.

While they were proposed to fulfil different purposes, the five strategies of mass customisation presented by Lampel and Mitzberg (1996), Pine's four approaches to the development of mass customising ability (Pine, 1993b) and Gilmore and Pine's four strategies to mass customisation (Gilmore and Pine, 1997) represent just three classifications of the plethora of ways in which companies – mass producers, craftsmen and new firms alike – can achieve mass customisation. It is important to determine a common framework based on these methods in order to assist in further discussion and analysis. This framework will be developed in the following section.

2.3.2.3 Defining Common Levels of Mass Customisation

The categorisation of mass customisation ventures appears to be almost as varied as the number of papers discussing it. Each academic presents an alternative method for determining the level to which a company is mass customising. For example, Spira (1993), through study of the electronics industry, presented the levels of customised packaging, customised services, additional custom work, and modular assembly. In addition to his four types of mass customisers, Ross (1996) suggested five levels of mass customisation: core mass customisation, post-product customisation, mass retail customisation, self-customisation and high variety of products. Alford *et al.* (2000) studied the automotive industry, and described three types of mass customisation: core customisation, optimal customisation and form customisation. In core customisation, the customer is intimately involved in the design process, while in optimal customisation, the customer is given the choice of many products, but not directly involved in their design. Form customisation refers to the practice of changing the form of the standard product at the point of distribution.

While all categorisations involve alternative nomenclature and different numbers of levels, they bear similarities. Most significantly, the differences between the levels represent the different stages of production at which mass customisation takes place. Da Silveira *et al.* (2001) performed an extensive review of mass customisation theory. Based on the frameworks proposed by Pine and Spira, as well as the strategies suggested by Lampel and Mintzberg (1996), they proposed eight generic levels of mass customisation. These levels are design, fabrication, assembly, additional custom work, additional services, packaging and distribution, usage and standardisation (Figure 2.6).

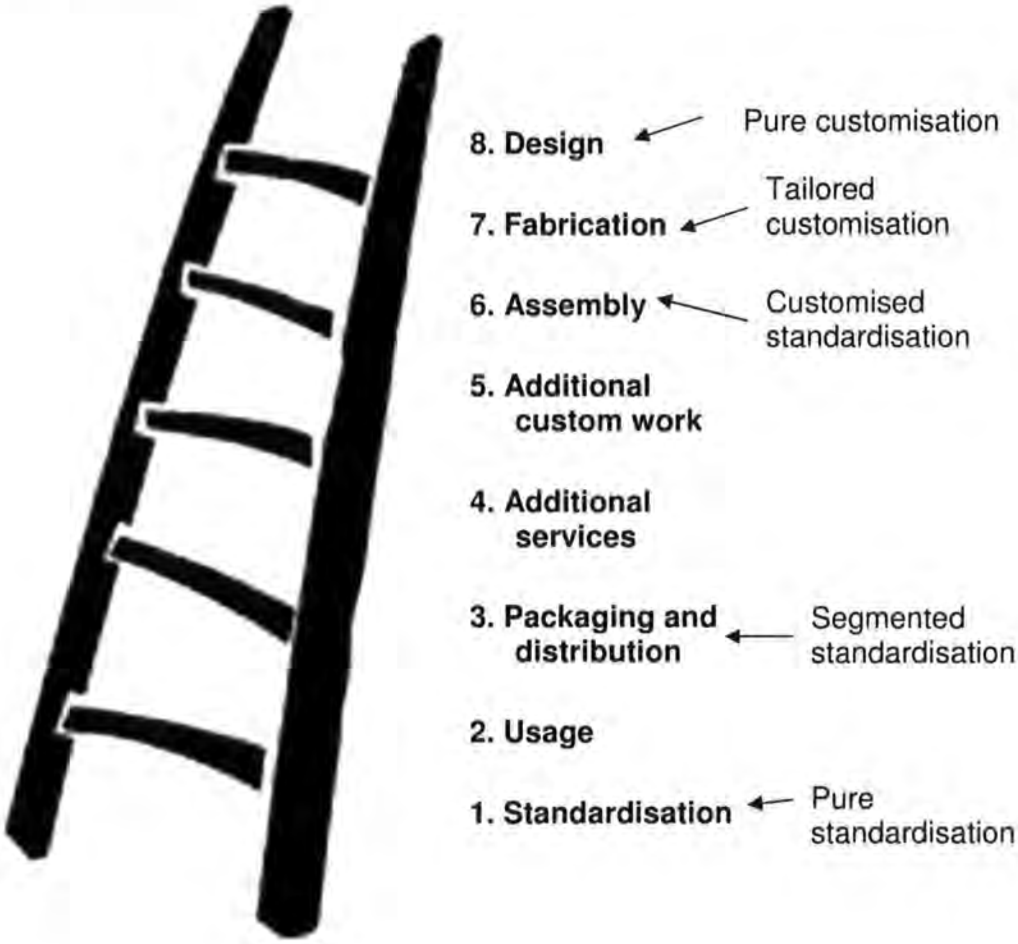


Figure 2.6: Generic levels of mass customisation and the levels of customisation to which they correspond.

The levels of customisation proposed by Lampel and Mintzberg can be placed into these generic levels, as indicated in Figure 2.6 Likewise, the characterisations suggested in other works can also be matched to their corresponding levels. For example, core mass customisation (Ross, 1996), core customisation (Alford *et al.*, 2000) and collaborative and transparent customisation (Pine, 1993b) correspond to the design level, while post-product customisation (Ross, 1996), optional customisation (Alford *et al.*, 2000) and cosmetic customisation (Pine, 1993b) refer to events which occur at the packaging and distribution stage.

Despite disagreements amongst academics concerning the feasibility of mass customisation ventures and the methods of defining the various levels of customisation, the literature does agree on the importance of various techniques such as modular production, postponement, product design, supply chain and customer involvement. These will be the focus of subsequent discussion.

2.3.3 Features of Mass Customisation

While mass customisation ventures may take all manner of forms, and occur at any level of production, they are characterised by a number of common attributes. These features include the modularity of production, postponement, product design, and technology. An understanding of these features is important for any study which attempts to investigate the ways in which mass customisation may be improved.

2.3.3.1 Modular-Based Manufacturing

Modularity is a manufacturing strategy which arose independently from, but concurrently with, mass customisation. Like early mass customisers, proponents of modular-base manufacturing sought to address the needs of the contemporary market situation, and to provide cost-effective solutions to the increasing demands of consumers. The two concepts of modularity and mass customisation have since become very closely interlinked, and modularisation is now considered to be an essential aspect of mass customisation strategy.

At an abstract level, modularity "refers simply to the degree to which a system's components can be separated and recombined. Systems are said to have a high degree of modularity when their components can be disaggregated and recombined into new configurations – possibly substituting various new components into the configuration – with little loss of functionality." (Schilling, 2000) For the purposes of this discussion, modularity can be defined as a means for organising complex processes efficiently by breaking down complex tasks into simpler ones that can be performed separately, and yet still act together as part of the whole (Baldwin and Clark, 1997). In the manufacturing context, this corresponds to the division of the manufacturing process into steps which can be mixed and matched to create a wide range of varied products.

The concept of modularity finds its basis in the theories of the economies of scale and scope. Long before theories of mass customisation reached mainstream academia, Stigler (1958) introduced the concept of economies of scale when assessing optimum firm size. This theory describes the advantages a firm enjoys as a result of its expansion, and involves decreasing the average cost per unit by increasing the level of production. In the light of the changed economic climate over the intervening two decades, Goldhar and Jelinek (1983) suggested that industry should pursue economies of scope rather than economies of scale. They believed that economies of scope existed "where the same equipment can produce multiple products more cheaply in combination than separately" (p. 143). This would occur simultaneously with the development of capabilities such as extreme flexibility, rapid response, greater control of processes, enhanced predictability, faster throughput and distributed processing capability.

Hamed Noori (1990) first indicated the feasibility of the use of modular-based manufacturing when he introduced the term "economies of integration" to describe the economic success that could be achieved through the implementation of contemporary manufacturing strategies such as flexible manufacturing. Such strategies allow both low cost production and high variety of products by concurrently pursuing both economies of scale and economies of scope.

Pine (1993) added that advances in management allow achievement of both economies, and he argued that a company is better able to achieve mass customisation by pursuing a number of goals. The just-in-time approach will reduce inventory costs, increase accuracy, and hasten the process. In addition, reducing setup and changeover times will eventually lead to reduced run size and decreased cost of variety. Moreover, the advantage of generating more rapid production by shortening cycle times will result in elimination of some waste. Finally, producing to order is the acme of technological capability as the time factor is crucial and results in very high customer satisfaction. Indeed, Pine identified modularity as the most important strategy for achieving customisation.

There are numerous advocates of modularity. Ulrich (1992) cited the advantages of modularity as lying not only in increased product variety, but also shortened delivery lead times and the achievement of economies of scope. Baldwin and Clark (1994) suggested that modularity in production could allow companies to achieve the coveted position of both economy of scale and economy of scope. For McCutcheon *et al.* (1994), the use of modular product design was the best means of delivering both variety and speed, which are the main demands of consumers. Pine *et al.* (1995) held that incorporation of modularity of both components and processes is essential for the success of mass customisation ventures.

While the aim of modularity is variation in products, this can be achieved by a number of means, in a multi-dimensional manner. Fine (1998) suggested that modular products are built by modular processes using modular supply chains. As a result, there are three perspectives on modularity: process modularity, supply chain modularity and product modularity. Fine argues that companies are typically characterised by similar product, process and supply chain modularities. For example, a firm which produces standardised products will tend to have standardised processes and supply chains, just as modularity of products suggests modular processes and modular supply chains.

Process modularity is defined by the dimensions of time and space. Processes in which the time is increased (such as production which occurs in multiple short bursts over an extended period) or the geographical considerations are increased (such as production of different components in dispersed locations) are considered to have increased process modularity (Voordijk *et al.*, 2006).

Supply chain modularity is measured by the proximity of the elements of the supply chain. Proximity refers to the combination of geographic distance, organisational differences, cultural barriers such as language, ethical standards and laws, and the capabilities for rapid communication by means such as email and video conferencing. A supply chain in which the manufacturer and the suppliers are located into one geographical region may exhibit high integrality, but is characterised by low modularity.

Product modularity refers to the selection of standard and varied components to introduce diversity. This will be the focus of subsequent discussion. Ulrich and Tung (1991) described the different types of product modularity. These forms of modularity may be employed separately or may be combined in the production of customised goods and services. The differences between the types lie in the nature of the components which are varied, and which remain standardised (Kamrani and Salhieh, 2002). The classes are component swapping modularity, component-sharing modularity, cut-to-fit modularity, mix modularity, bus modularity and sectional modularity.

Component-swapping modularity involves the use of a standard basic component or product to which is added alternative components to create different product variants from the same product family. For example, in the manufacturing of personal computers, customised computers are built from a standard motherboard with the addition of different types of monitors, keyboards and CD-ROMs.

Component-sharing modularity describes the system in which a wide variety of products are made based on common components. For example, the same power cord may be used in a wide range of products. Component-swapping and component-sharing modularities differ only in the definitions of the basic product and components: swapping describes the use of different components with the same basic product, while sharing refers to the use of the same component with different basic products.

Cut-to-fit, or fabricate-to-fit, modularity utilises the variation of the physical dimensions of a module before combination with other modules. This form of modularity is important in any industry where customers require unique dimensions such as height or length. For example, the optical strength of the lenses in eyeglasses can be altered before fitting into the frames.

Bus modularity occurs when any number of basic components can be added to a standard structure. In this way, both the number and configuration of modules can vary. For example, in track lighting, any number of a variety of lights can be added to the standard track.

Mix modularity and sectional modularity are very similar to component swapping. In mix modularity, however, components become indistinguishable and inseparable when they are mixed. For example, house paint is prepared by mixing standard colours to produce a customised colour, but once mixed, the components cannot be separated. In sectional modularity, standard modules can be arranged in all manner of patterns. This is true of the construction industry, in which standard modules can be used to build unique structures.

Duray *et al.* (2000) considered modularity from an operational perspective by relating Ulrich and Tung's system to the production cycle (Figure 2.7). For example, cut-to-fit modularity involves changes in the dimensions of the module prior to assembly, so it must take place during design and fabrication stages. While components themselves cannot be altered during the stages of assembly and use, they can be combined in various ways, and therefore component swapping forms of modularity take place during this part of the production cycle.

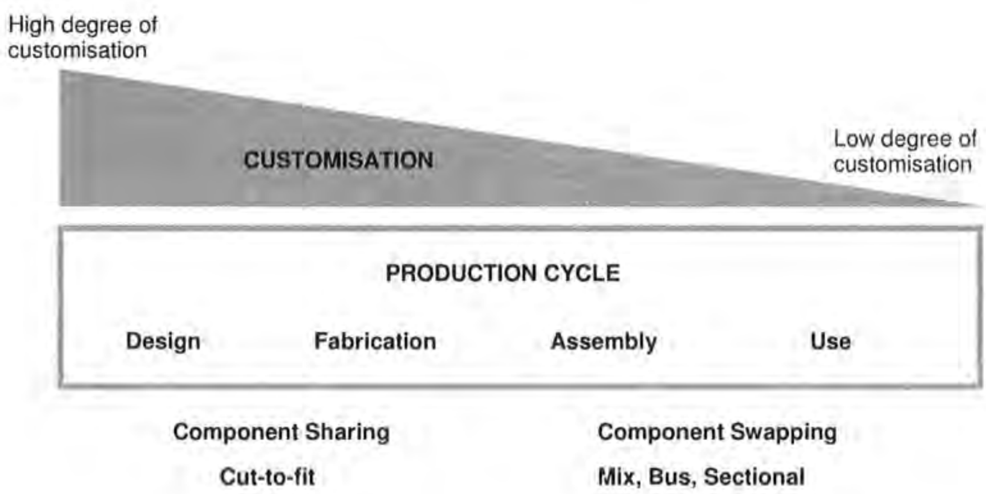


Figure 2.7: Modularity in the production cycle. Adapted from Duray et al. (2000)

2.3.3.2 Postponement

Postponement is the "organizational concept whereby some of the activities in the supply chain are not performed until customer orders are received" (Van Hoek, 2001, p. 161). Postponement can be categorised into three classes: form, time and place postponement (Bowersox and Closs, 1996). In form postponement, also known as postponed manufacturing, companies delay product manufacture (and in some case design) until receipt of customer orders. Time and place postponement, which together are called logistics postponement, involves the delaying of distribution of goods from central points in the supply chain. In practice, however, postponement can occur at any point along the supply chain, from sourcing to distribution to customers (Van Hoek, 2001).

Figure 2.8 shows the transformation from traditional supply chains to those involving postponement. The postponement approach is characterised by delay of the final assembly of products until all supplies have reached the point of manufacture, and direct shipping of the final products to the end users. In this way, materials remain undifferentiated for longer times, and companies can therefore be more flexible in their response to customer demand.

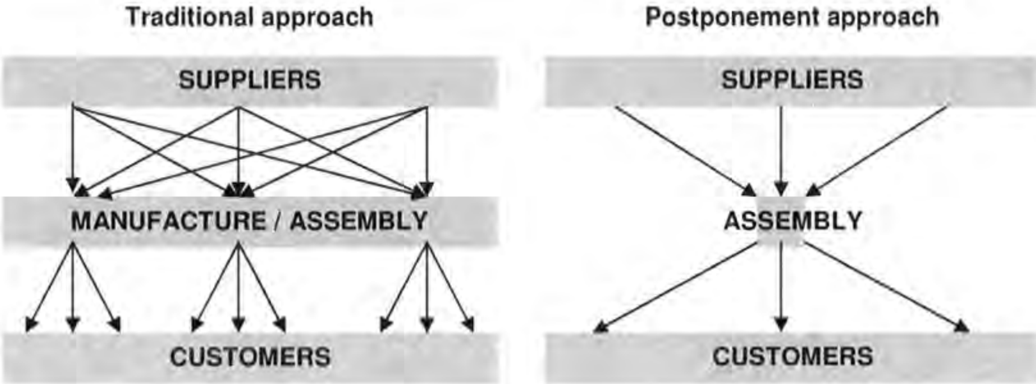


Figure 2.8: Traditional and postponement approaches to supply chains. Adapted from van Hoek *et al.* (1999)

The concept of postponement was first introduced by Bucklin, in 1965. The role of postponement in mass customisation has been recognised since the onset (Pine, 1993a) and subsequently much work has confirmed the importance of adopting postponement on the achievement of mass customisation. It is known that employment of postponement increases the competitiveness of a company by improving customer service at the same time as reducing costs (Van Hoek, 1996, Lee and Billington, 1995). Oleson (1998) holds that agile responsiveness to customers' desires requires the shift from an inventory to a "make to order" approach. Womack and Jones (1997) believe that postponement is a logical operations strategy for companies, which should not manufacturer products without being certain that they are desired by customers. Through their study of Hewlett Packard, Feitzinger and Lee (1997) noted that postponed manufacturing was of paramount importance to the success of mass customisation.

In order for postponement strategies to be effectively implemented, there must be clear communication of customers' needs (Mikkola and Skjott-Larsen, 2004). Close contact with suppliers must also be maintained, in order to ensure that starting materials are at the right place at the right time. As a result, collaboration with both suppliers and users is very important for successful postponement, and therefore mass customisation. These external collaborations are the focus of this study, and will be discussed in more detail in subsequent chapters.

2.3.3.3 Product Development

The requirement for product development in mass customisation was first clearly stated by Boynton, Victor and Pine in their definition of a framework for ways of achieving success in business (Boynton and Victor, 1991, Pine *et al.*, 1993c). They suggested four distinct, but interlinked, business models which different according to the kinetics of product change and process change (Figure 2.9). Invention represents the attitudes of pre-industrial revolution craftsmen who supplied all their customers' needs by problem-solving and innovation. With the industrial revolution came mass production, with its static products and processes. The emergence of mass customisation saw the achievement of customised products in high volumes by employing dynamic product change with minimal change to the manufacturing processes.

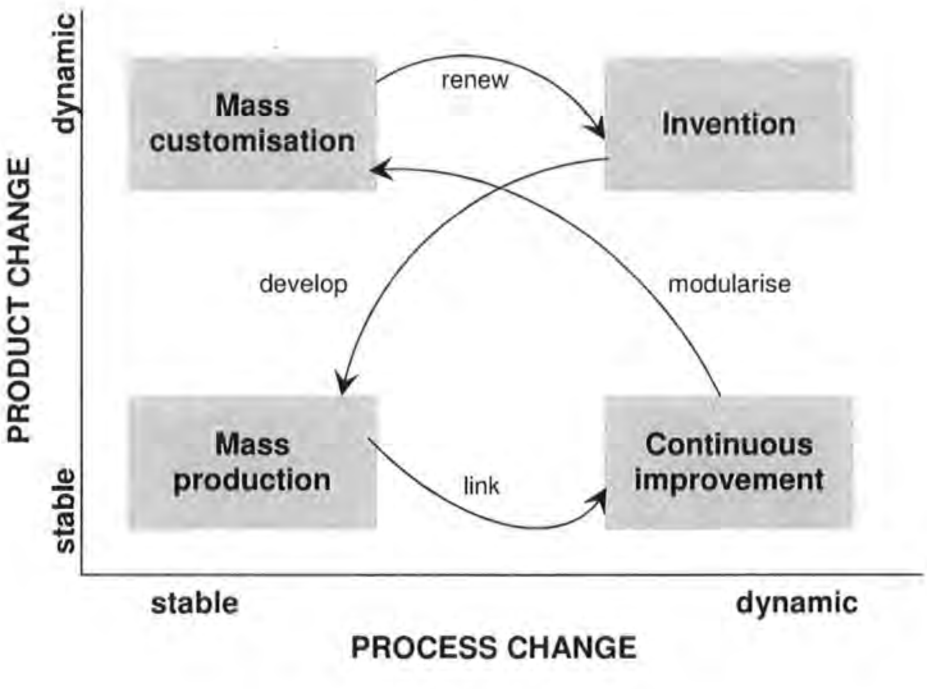


Figure 2.9: Four business models (redrawn from Pine (1998))

Much research has been performed to investigate agile product development. This process involves the rapid introduction of small changes to products which results in new products which are related to the old. In this way, customised products can be manufactured in response to market trends with essential no time lag (Anderson, 1998).

Concurrent engineering has been identified as an essential aspect to agile product development. This involves the employment of multifunctional design teams, which contains all relevant specialties such as marketing managers, industrial designers, finance representative and regulation compliance personnel (Womack *et al.*, 1990). Important in successful multifunctional design teams is a strong team leader who ensures that all key issues are identified and addressed (Dertouzos *et al.*, 1989).

A number of key phases have been identified in the product development process (Anderson, 1998). *Product definition* involves generating a clear description of the product which will satisfy the requirements of the customer. *Product architecture* is the stage in which the simplified concept is outlined and the architecture, including the modularity which will be employed, is identified. *Product and process design* is a very rigorous process which attempts to minimise the requirements for prototypes and pilots. *Ramp-up* describes the introduction of the process into the factory, with a rapid increase in product volume. *Follow-up* is the post-production stage of evaluation and identification of improvements which can be made to future product development.

Important in the product architecture and product design stages is the design for manufacturability. This is the practice of designing products to allow for the greatest ease of manufacture (Anderson, 1990). This can be achieved by a number of methods. Modular production can be optimised by careful design of components.

This may involve increasing part commonality, eliminating right- and left-handed parts, using symmetrical parts, and minimising the number of parts by combining them. Mistake-proof design is essential to ensure that products are not assembled incorrectly (Shimbun, 1987). It is also important to design products so that they can be manufactured on existing equipment, or with machinery that has undergone simple changes. Finally, design for manufacturability requires the considerations of the reliability of the production process.

In order for companies to achieve full mass customising ability, they must implement sophisticated product development processes. Indeed, product development is the aspect of mass customisation with the greatest potential to improve mass customising capabilities, and will therefore be the main focus of this study.

2.3.3.4 Technology

In their extensive study of the methods employed by companies to achieve customisation of their products, Åhlström and Westbrook (1999) identified that most companies focus on the operational aspect of mass customisation, that is, building up technology into their manufacturing systems. This emphasis on technological capabilities is also prevalent in studies by Tu *et al* (2004); they developed a three-dimension approach to mass customisation by which a company can scale its capability for mass customisation. The scale contains three elements (cost, volume, and responsiveness) which were intended to measure, respectively, the *customisation cost effectiveness* which indicates the feasibility of the operation, the *customisation* *volume effectiveness* which indicates the ability to produce large quantities, and *customisation responsiveness* which indicates the ability to reconfigure the production processes quickly to meet customers' changing demands. Each of these dimensions is proportional to the technological capability of the company, and as a result, improvement in this technology might be expected to have a very strong effect of mass customising capability.

Numerous academics have highlighted the importance of technology on the evolution and improvement of mass customisation. Hart (1995) identified technology as an essential enabler for mass customisation processes, as will be discussed in section 2.4.1.3. Lau (1995) noted that mass customisation relies on a advanced technology in the form of flexible manufacturing systems and computer-integrated manufacturing. Early mass customisation ventures attributed at least part of their success to the availability of computer-based technology (Rifkin, 1994). Kotha (1996) identified that in the National Industrial Bicycle Company of Japan, advanced technology was required for successful mass customisation by improving both external (industry-level) and internal (firm-level) factors.

Despite the importance of technological advancements on mass customisation, a number of studies stress that total reliance on technology will not improve mass customising capabilities. For example, the flexibility and responsiveness which are essential for mass customisation cannot be achieved solely by use of advanced information technology and computer-based manufacturing (Garud and Kotha, 1994). Kakati (2002) warns that "simply learning or adopting technology to produce variety will not lead to a successful mass customisation" (p. 93). Technological advances are largely beyond the control of industry, and certainly from the viewpoint of management. As a result, attempts to improve mass customisation attributes must extend beyond a reliance on technology, and must study ways to maximise other aspects of mass customisation.

2.4 Improving Mass Customisation Performance

This chapter has demonstrated the importance of mass customisation as a manufacturing paradigm. As a result, there is a great need for ongoing research to better understand ways in which mass customisation can be improved and the mass customising abilities of companies enhanced. An understanding of these factors is of particular importance in the light of the significant failure rates which have been reported for many mass customisation initiatives (Pine *et al.*, 1993c, Anderson, 1997, Comstock *et al.*, 2004). Because product development is a key feature of mass customisation, as it allows the design and manufacture of products in response to consumer demand, it is important to maximise a firm's capability in this area. Numerous studies have suggested methods of improving mass customisation, and in particular the product development processes.

Since the advent of research into mass customisation, there has been much discussion about and examination of the ways to improve mass customisation ability. Pine *et al.* (1993c) argue that successful implementation of mass customisation requires a complete restructuring of manufacturing practices, rather than a progression from existing structures. In the area of product development, this is manifested in the disbanding of existing, long-lasting relationships in favour of dynamic teams and networks. These teams will be characterised by their rapid adoption and use of technology, creation of a clear vision and ability to learn from failures.

Da Silveira *et al.* (2001) studied mass customisation from an operational perspective, and provided structural and technological requirements for its achievement. They emphasised the role of customer demand for variety as a starting point for adoption of mass customisation capability, which should be coupled to appropriate market conditions and good timing for transition, as first movers will gain competitive advantage over competitors. The value chain should be supportive, with all retailers, distributors, and suppliers ready to act and respond quickly. In order to achieve this outcome, the system must have, or must acquire, adequate technology to enable mass customisation development. In addition, products should be customisable through the introduction of modularity, and knowledge must be disseminated across the company, the value chain, and the supply chain, in order to enhance innovation and quick response to customers' needs. The authors concluded that there is no one best strategy or approach for pursuing mass customisation as each company has different types of customers and firms lie in a variety of industries. Instead, they conclude that the implementation of mass customisation is very complex as it involves many factors and parties. Da Silveira *et al.* (2001) identified enablers of mass customisation as a means of categorising the various contributions to the achievement of mass customisation.

2.4.1 Enablers of Mass Customisation

While there is no single means to achieving mass customisation capability: instead, the ability of a company to implement and achieve high performance mass customisation can be gained through one or more of a number of enablers.

Da Silviera *et al.* (2001), on the basis of a broad literature review, identified six enablers of mass customisation: agile manufacturing, lean manufacturing, supply chain management, customer-driven design and manufacturing, advanced technologies and communication and networking. These six enablers can be categorised into two groups: processes and methodologies, and enabling technologies, as illustrated in Figure 2.10.

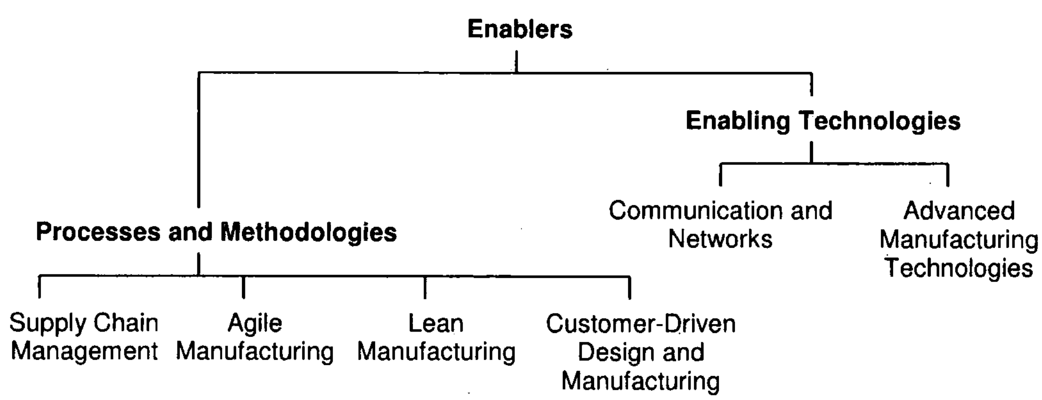


Figure 2.10: Enablers of mass customisation

Da Silviera *et al.* identified the benefits of each enabler: whereas agile manufacturing and communications increase knowledge, supply chain management and lean manufacturing enhance the value of manufacturing processes. Technological gains can be achieved from advanced manufacturing technologies as well as the establishment of communications and networks, while customer-driven design and manufacturing achieves the main aim of mass customisation: customisable products. The overriding theme of this is the focus on modularity and flexibility as ways to introduce wider product variety, or scope, and allow for higher customer influence. The concept of modularity was discussed in Section 2.3.3.1. Flexibility has long been recognised as an important means of achieving economies of scope (Goldhar and Jelinek, 1983). In the context of mass customisation, manufacturing flexibility has been shown to facilitate production of highly customised products at low cost (Dewan *et al.*, 2001).

Numerous studies highlight the importance of one or more of these enablers of mass customisation. Two specific studies which together neatly encapsulate all six enablers of interest are those by Elliman and Orange, and Griffiths and Margetts. Elliman and Orange (2000, 2003) discussed the case of the construction industry, and the changes required to implement efficient mass customisation processes. They noted the importance of early involvement of the customer in the design process, which could be facilitated by electronic exchange of information. They argued that the way forward for mass customisers was to implement e-procurement systems, by which user, manufacturer and supplier can interact. Such processes would require restructuring of the supply chain, and establishment of strong and efficient networks.

Griffiths and Margetts (2000) performed a case study of the automotive industry in order to analyse how different strategies affect mass customisation processes, and their impacts on the suppliers. They identified that overproduction of parts or products led to decreased efficiency, suggesting the need for lean manufacturing and flexibility. Furthermore, companies which employed agile manufacturing procedures enjoyed greatest market success, as did their suppliers. The study also revealed that more rapid and controlled communication allowed for more efficient identification of customer needs.

Subsequently, other authors have confirmed Da Silviera's classification of enablers of mass customisation. Chandra and Kamrani (2004b) performed a review of literature concerning the improvement of mass customisation capability, and categorised all studies into Da Silviera's categories. Since these enablers enhance mass customisation capability, these are the mechanisms upon which it is valuable for researchers and companies alike to concentrate. There is a continual need to develop better understanding of the enablers and their effects, and of how to best utilise these strategies in industries. The following section contains a discussion of the enablers of mass customisation, and the current literature concerning each.

2.4.1.1 Agile Manufacturing

Agile manufacturing, in which incremental changes are made to products which, over time, result in the generation of distinct and novel products, has long been considered an important strategy for mass customisation processes due to its obvious element of flexibility (Anderson, 1998). A number of academics have discussed the imperative to adopt agile manufacturing for successful transition from mass production to mass customisation (Berman, 2002, Duguay *et al.*, 1997). Fulkerson (1997) explored concepts of process flow management and the implementation of resource planning systems, and identified agile manufacturing as a key factor of these processes. Kim (1998) also noted the applicability of agile manufacturing in the establishment of virtual organisations, by setting up intranets.

In addition to these theoretical arguments in favour of agile manufacturing, the importance of the concept has been identified in a number of industrial studies. Worren *et al.* (2003) conducted a survey of firms based on the assumption that the use of modular products is a key enabler of flexibility. They concluded that variety is positively related to firm performance, and that product modularity is positively related to product variety. Yao and Carlson (2003) carried out a case study in the furniture industry, studying in particular decision support systems implemented to manage agile manufacturing processes. Yang and Li (2002) evaluated the agility of mass customisation processes in the casting industry, concluding the importance of this approach.

Karsak and Kuzgunkaya (2002) suggested a model for choosing between multiple agile manufacturing strategies in order to achieve optimised labour, setup and maintenance costs, market response, quality, capital and floor space usage. Penya *et al.* (2003) explained the PABADIS project, which seeks to utilise a product-oriented approach to achieve intelligent manufacturing. They specifically discussed how this strategy can be applied to mass customisation. Pursuit of agile manufacturing capability is therefore a key strategy for the achievement of successful mass customisation.

2.4.1.2 Lean Manufacturing

Lean manufacturing describes the process in which goods are produced by flow systems as an alternative to batch and queue, in order to optimise production and minimise waste (Womack and Jones, 1997). This concept has been discussed in a number of studies. Partanen and Haapasalo (2004) emphasised the use of lean manufacturing as important for fast production in the electronics industry. Hirschhorn *et al.* (2001) examined the chemical industry, and concluded that chemical companies must be redesigned to allow for mass customisation through lean manufacture.

Industrial studies also explore lean manufacturing as an enabler of mass customisation. Fisher and Ittner (1999) analysed the process of automotive assembly, and identified the importance of utilising improved technology to achieve lean manufacturing in order to deliver shorter setup times and flexibility in manufacture. Similarly, Alford *et al.* (2000) studied different types of customisation in the automotive industry, and identified lean manufacturing as an important capability. Alfnes and Strandhagne (2000) devised methodology for furniture manufacture which involves implementation of lean manufacturing by differentiating the manufacturing processes, simplifying the material flow, strategically positioning stocks, decentralising decision-making from management to clearly defined control areas, and ensuring that information is flow-oriented. The achievement of lean manufacturing capabilities requires implementation of sophisticated technology, as will be discussed below.

2.4.1.3 Technology

Technology has proved to be an important aspect of mass customising ability. Maintenance of communication, design of customised products and implementation of low-cost, highly efficient mass customisation requires sophisticated equipment. Many studies have confirmed the importance of technology as an enabler of mass customisation. Partanen and Haapasalo (2004), Alford *et al.* (2000), Hirschorn *et al.* (2001) and Fisher and Ittner (1999) all emphasised advanced technology as a means of achieving lean manufacturing, and other hallmarks of mass customisation.

Bonney *et al.* (2003) presented a conceptual discussion of changes which can be made to the product development process, and the effects of these alterations on mass customisation, in which they noted that it is crucial to have mechanisms in place to respond to these changes. They also identified that new technology is an important factor in such mechanisms. Edwards (2002) discussed the concept of concurrent engineering, in which various manufacturing tasks are performed in parallel as a means for new product development. He concluded that technological advances are required in order to satisfactorily implement such a procedure.

The importance of advanced technology has also been identified in a number of case studies. Eastwood (1996) investigated Motorola's use of mass customisation in the manufacture of various products such as pagers and cell phones, and highlighted technological change as an important enabler in the process. Istook (2002) explored case studies of practices in the textile industry in which computer-aided design was employed to automatically alter garments for individual fit. She noted that the use of such technology enhanced mass customisation capability.

In contrast to the many articles which advocate the adoption of new technology as a sufficient means in itself to achieve mass customisation, and the many business managers who acted accordingly, Kakati (2002) warned of the danger of such a practice. He countered that an understanding of customers is the principal enabling factor of mass customisation, not the theoretical ability of technology to create large quantities of infinite variety. He suggested instead the careful management of the supply chain, vigilant monitoring of customer demand, and a continuous endeavour to improve quality, lead time, flexibility and cost at each step of product development. The following section describes the importance of supply chain management as an enabler of mass customisation.

2.4.1.4 Supply Chain Management

Chandra and Grabis (2004) view supply chain management, along with the agile manufacturing practices, as the essential methodology for enabling mass customisation. Supply chain management has been likened to a glue which holds together the various activities which must be performed in order to achieve mass customisation (Gooley, 1998). Conversely, it can be considered that mass customisation drives supply chain management strategies, forcing suppliers to implement early coordination (Salvador *et al.*, 2002a).

Figure 2.11 shows the flow of information between entities in the supply chain in the case of mass customisation. Production is directly influenced by customer demand, and manufacturers must be able to source materials from suppliers very rapidly.

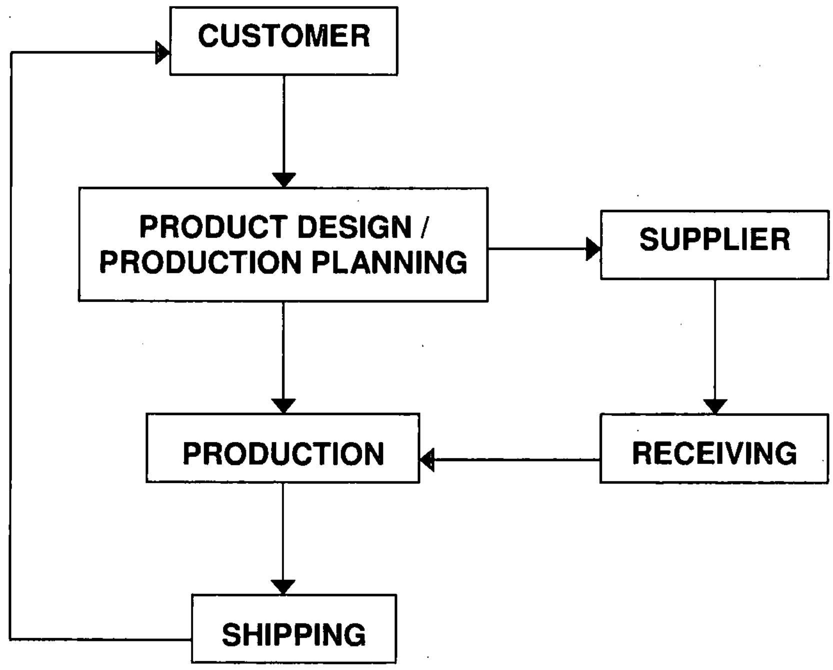


Figure 2.11: Information flow in the supply chain for mass customisation processes. Adapted from Chandra and Grabis (2004b)

Early mass customisation literature established the importance of adapting the supply chain of a company in order to enable delivery of customised products (Boynton and Victor, 1991, Pine, 1993a, Westbrook and Williamson, 1993). Subsequently, advocates of supply chain management abound in the literature (Furst and Schmidt, 2001, Berman, 2002, Salvador *et al.*, 2002a, Partanen and Haapasalo, 2004). Surveys of various industries, from bicycle manufacture (Randall and Ulrich, 2001) to electronics production (Eastwood, 1996) have also identified the importance of supply chain management. Daugherty *et al.* (1992) performed a widespread survey to assess the ability of companies to offer custom distribution, and identified supply chain management as a key factor in this process. Similarly, Salvador *et al.* (2002b) examined case studies from various industries, and demonstrated that mass customisation practice is affected by characteristics of the manufacturing process and the supply chain.

While the importance of the supply chain is widely acknowledged, the exact form the supply chain should take is less well-defined. Hoogeweegen *et al.* (1999) suggested that the supply chain should be modular, consisting of distinct units which operated in relative autonomy. Such a supply chain would be likely to contain geographically and managerially separate entities (Fine, 1998). On the other hand, other academics argue that members of the supply chain should be as tightly linked as possible. In his study of the National Industrial Bicycle Company of Japan, Kotha (1995) noted that the success of mass customisation could be attributed in part to the geographical proximity of suppliers. Such a strategy is common, with suppliers located near the point of assembly, and bound to the manufacturer by long-term contracts (Marx *et al.*, 1997).

A number of factors have been highlighted as bearing great importance on supply chain management. These include the use of an inventory of components (Cheng *et al.*, 2002, He and Jewkes, 2000), third party logistics providers (Gooley, 1998) and the employment of enterprise resource planning (ERP) (Akkermans *et al.*, 2003). Contractor and Lorange (2002) discussed the importance of alliance and knowledge in supply chain management, and Smirnov *et al.* (2003) similarly emphasised the importance of a knowledge source network structure in the supply chain. A successful supply chain strategy is one which employs short-term strategic management (Saisse and Wilding, 1997), implements assembly-initiated production of customised products (Karlsson, 2002) and has carefully monitored organisational capabilities (Feitzinger and Lee, 1997).

Much research has suggested that mass customisation can be achieved without drastic changes to the supply chain by employing postponement strategies (Feitzinger and Lee, 1997, Mather, 1987, Aviv and Fredergruen, 2001, Twede *et al.*, 2000). Postponement is the delaying of production activities until the receipt of customer orders (Van Hoek, 2001). Chiou *et al.* (2002) performed a survey of the Taiwanese electronics industry and identified postponement as an important strategy for the achievement of mass customisation. This was also suggested by Verwoerd (1999), who identified that in the electronics industry, the decoupling point for postponement depends on a number of factors such as the speed of production, distribution and information processing. Ma *et al.* (2002) also suggested that the interaction between processing and procurement times is essential in determining where to decouple multi-stage processes. Van Hoek (2000) noted the importance of third party logistics services in the implementation of postponement strategies.

Salvador *et al.* (2004) performed an extensive review of literature concerning the supply chain, and concluded that academics held three main views. Firstly, loose connections between entities of the supply chain may be advantageous for the flexibility that they afford the firm. Secondly, and in contradiction to the first, tight connection between partners in the supply chain may enable rapid production. Finally, by restricting mass customisation events to the final stages of the supply chain, little need be changed in supply chain management to achieve mass customisation.

Supply chain management is, without doubt, an important aspect of successful mass customisation. It involves the organisation of many relationships and processes involved in product development. Effective supply chain management requires effective means of communication, and well-established relationship networks, as will be discussed in the following section.

2.4.1.5 Communication and Networks

Da Silviera (2001) cited the motivation behind the employment of communications and networks as its provision of direct links between the various players in the product development process, and its enhancement of response time. This perception is supported in the literature. Contractor and Lorange (2002) discussed the importance of creating alliances and managing knowledge in facilitating mass customisation. In addition to agile manufacturing, Fulkerson (1997) identified networks as crucial to successful mass customisation. Gardiner *et al.* (2002) and Akkermans *et al.* (2003) promoted enterprise resource planning (ERP) systems as efficient enablers of mass customisation, through enhanced communication and cooperation between partners.

The literature provides a plethora of examples of the benefits of communication and networks to mass customisation in a variety of industries. Furst and Schmidt (2001) described mass customisation in the automotive industry as driving force for the optimisation of new product development and reorganisation of structures to ensure generation of virtual networks and efficient communication. Ghiassi and Spera (2003) and Kotha (1996) identified the importance of software which facilitates networking and communication in the bicycle industry. Andel (2002) discussed the importance of communications and networks in the manufacture of office products, while Erens and Hegge (1994) suggested that application of product specification concepts and networking allows both manufacturers and customers to be involved in product specification in the manufacture of medical equipment. Sokolov (2001) explored mass customisation in education, and in this field he also identified the importance of networks and communication.

Many academics have highlighted the value of computer-based communication and networking in mass customisation processes. Roy and Kodkani (1999) developed a prototype system to aid product development of industrial equipment through the use of computer networks. The internet aids efficient communication and networking, which can result in the re-engineering of companies towards customisation (Helander and Jiao, 2002) and in conveyance of customer needs to the manufacturer (Turowski, 2002). Walsh and Godfrey (2000) explored electronic commerce as a means of enhancing customisation, while Lee *et al.* (2000) established that mass customisation and electronic commerce are complementary in some situations, through the mutual benefit of networks and communication. The establishment of sophisticated communication and networks is therefore an important enabler of mass customisation.

2.4.1.6 Customer-Driven Design and Manufacturing

Duray *et al* (2000) highlighted the importance of customer involvement in mass customisation in their definition of mass customisation archetypes. These definitions provided a typology that describes for differing approaches to the implementation of mass customisation depending on two main dimensions. *Customer involvement* determines the stage at which customers are integrated in the process; the earlier the customer involvement in the production process, the more customised the products. The second dimension is *modularity*, as discussed in section 2.3.3.1 above.

The combination of the two dimensions gives rise to four different archetypes of mass customisation as illustrated in Figure 2.12.

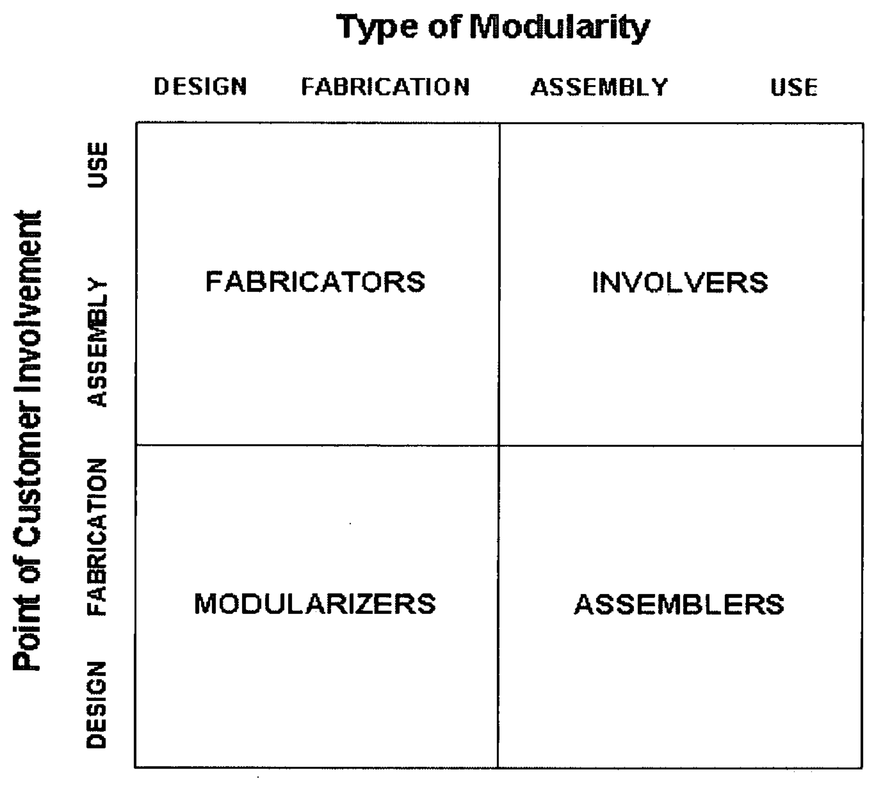


Figure 2.12: Mass customisation archetypes (adapted from Duray *et al.* 2000)

The four archetypes describe different mass customisation approaches. *Fabricators* are mass customisers that involve the customers early in the product design process, at the design and fabrication stage. In addition, modularity occurs at those two stages, resulting in a high degree of customisation. Overall, the outcomes resemble artisan practices. The term *involvers* describes mass customisers that integrate customers early in the design and fabrication processes, but delays modularity applications to the assembly and delivery processes. This gives the customer a sense of customisation, even though no variety is introduced at the design and fabrication level. *Assemblers* are mass customisers that integrate both modularity and customers at the late stages of production, the assembly and use stages. They show greatest resemblance to standard mass producers, but they differ from this approach in that customers can choose between given options, and are able to specify their choice of final product. Finally, *modularizers* are the mass customising firms which integrate modularity earlier in the product development process. As a result, products are less standardised than those produced by assembles. In this case, customer involvement has less impact on the customisation process as modularisation has already taken place.

Based on their model, Duray *et al* (2000) concluded that if manufacturers involved customers in the production process but did not introduce modularity, they should not be considered mass customisers, and the same if the manufacturer introduced modularity but did not involve customers.

A number of other academics have also highlighted the importance of customer involvement in the design process in mass customisation, in a variety of industries. Andel (2002) discussed the importance of customer-driven design in the manufacture of office products. Erens and Hegge (1994) developed the concept of involvement of customers in product specification the in the manufacture of medical equipment. Tseng and Jiao (1997) presented case-based reasoning for the involvement of customers in mass customisation design, citing the provision of power to the customers as a key advantage. Subsequently, Tseng *et al.* (1998) identified that it is important to balance requirements and capabilities of customer involvement by employing virtual prototyping and design by stimulation.

Various studies have emphasised the role of the internet in customer involvement. Helander and Jiao (2002) championed the internet as a key tool to enable customer input. Istook (2002) described the use of computer systems to enable customers to select dimensions as well as product type in the textile industry, while Roy and Kodkaki (1999) identified that internet-based computer-aided design allows collaboration with customers.

This discussion has demonstrated that there is much support in the literature that the six enablers identified by Da Silviera *et al.* (2001) are indeed important for the achievement of improved mass customisation performance, particularly in the product development processes. The following section considers one particular broad approach which involves the achievement of a number of these enablers.

2.4.2 A Mixed Approach to Improving Mass Customisation

The broad base of literature concerned with the improvement of mass customisation highlights the importance of focussing on the six key enablers which have been discussed above. These enablers are, without a doubt, valuable strategies in the achievement of mass customisation. In the light of this importance, it is helpful to utilise techniques which simultaneously incorporate more than one enabler. In this way, the advantages of each enabler discussed above can be enjoyed without any trade-offs, and with concerted efforts being employed in only one direction. The particular approach which will be considered in this study is that of collaborative product development. The following section explains how this strategy encompasses a number of different enablers.

2.4.2.1 Collaboration in Product Development

Collaboration describes the co-operation of multiple actors in the product development processes (Fagerstrom, 2003). This section explores the relationships between collaboration and the enablers of mass customisation identified in the previous section, and justifies the selection of collaboration in product development as a broad approach which can be expected to improve mass customisation performance.

Collaboration encompasses the involvement of a number of different partners, particularly supply chain partners, and customers. These relationships are closely linked to a number of different enablers; indeed, four of the six enablers directly describe mechanisms by which collaboration is facilitated or valued in mass customisation, as will be discussed below.

One of the six enablers of mass customisation identified by Da Silviera *et al.* (2001) is supply chain management. This selection presupposes an essential role of supply chain partners in the outcomes of a mass customisation venture. While many players in the product development processes are internal to the manufacturing company, external partners also play an important role, particularly those involved in the supply chain. The collaboration between these partners and the company itself is therefore crucial to the success of mass customisation.

Another enabler described previously is customer-driven design and manufacture, which describes the aim of mass customisation, to mass produce tailored goods in response to consumer demand. The term "customer-driven" refers to direct input from the customer through partnership, which can be most effectively achieved by user collaboration.

These two enablers of mass customisation – supply chain management and customer-driven design and manufacture – directly describe ways in which collaboration can be utilised to improve mass customisation. In addition, two further enablers – communication and networks, and advanced technologies – are crucial to the achievement of collaboration. In this way, a company which focuses on collaboration is likely to improve both aspects as a means of best reaping the benefits of such partnerships. Each enabler is discussed below.

Communications and networks form the basis on which collaborative relationships can be built, providing links between collaborative partners (Da Silveira *et al.*, 2001). This enabler of mass customisation also assists in creating alliances between collaborators and allows effective knowledge management (Contractor and Lorange, 2002).

Advanced technologies have been shown to be paramount in facilitating various aspects of collaboration. While computer-based systems allow for effective collection of customer input (Helander and Jiao, 2002), technology is also essential for the management of the supply chain, and to ensure interaction between various partners (Alford *et al.*, 2000, Eastwood, 1996, Smirnov *et al.*, 2003). In general, technology provides the means for effective communication and networks within a mass customising process, and therefore facilitates collaboration.

It can be seen, therefore, that collaboration is consistent with the enablers of mass customisation suggested by Da Silviera *et al.* (2001), providing an indication that collaboration is key to the achievement of mass customisation. Since each enabler alone has been shown to lend great benefit to mass customisation, as discussed in section 2.4.1, companies which actively pursue collaboration, which are directly linked to four enablers as discussed above, might be expected to enjoy greater benefits. Such a link has not previously been conclusively drawn, however, and forms the focus of this study.

This section has introduced the concept of collaboration in general terms, and has provided a cursory explanation of the importance of collaboration in improving mass customisation performance. Before developing the research question and hypotheses, however, it is crucial to more deeply investigate the mechanisms of collaboration in product development, the motivations for collaboration, and the nature of the various collaborative partners. This detailed discussion of collaboration, which will form the theoretical basis of the conceptual model, is provided in Chapter Three.

2.5 Concluding Remarks

While academics disagree on the exclusivity of mass customisation as the manufacturing paradigm of the future, there can be no doubt that it has proved to be an effective solution for the current market climate in which customers demand individual satisfaction. This chapter has detailed the work which has been performed to reach a conceptual understanding of mass customisation.

The concept of mass customisation gained momentum in the mid-1980s as a combination of mass production and tailor-made manufacturing. It aimed to increase product scope in order to provide customers with broad choice while offering the low cost and time characteristic of mass manufacturing. It was Pine (1993) who generated the impetus for global academic research into the field of mass customisation. Numerous suggestions have been made concerning an appropriate definition for mass customisation. In the context of this research, the definition which will be adopted is: *the ability to deliver a broad range of customer-influenced products on a large scale, without significantly compromising development cost or time.* As varied as the definitions of mass customisations are the views of its relationship with its predecessor, mass production. While some claim that mass customisation and mass production are mutually exclusive, and indeed incompatible, paradigms, others hold the view that true manufacturing practice lies on a continuum which extends from mass production to mass customisation.

While it is possible for academics to endlessly debate the concept of mass customisation, the mechanisms of the concept are of much greater industrial interest. Much of this chapter has focussed on the current understanding of mass customisation as a manufacturing paradigm. This includes the ways in which mass producers can develop mass customisation ability, the plethora of strategies possible for achieving mass customisation, and an understanding of the different levels of the product development process at which customisation can take place. The discussion continues with an analysis of a number of features of mass customisation: modular production, postponement, product design and advanced technology. The final section of this chapter has explored the methods expounded in the literature for the achievement of improved mass customisation output, in the form of six enablers of agile manufacturing, lean manufacturing, technology, supply chain management, communication and networks and customer-driven design and manufacturing.

This literature review has demonstrated that much work has already been performed to gain an understanding of mass customisation. There continues to be much unfinished work, however, to completely understand the paradigm and the ways in which it can be best implemented in industry. The great importance of mass customisation for manufacturers across so many industries only strengthens this quest.

There are a number of different techniques which have been shown to improve mass customisation performance. In order to enjoy the greatest benefits, however, it is prudent to adopt a mixed approach, in which various enablers are simultaneously dealt with. The particular approach which has been identified for study in this research is collaboration, in particular in the context of product development. Chapter Three provides a detailed discussion of the current understanding of collaborative product development, with a particular focus on external partnerships. Chapter Four then describes how the understanding gained from this chapter and from Chapter Three are combined in the generation of the research question, and in the establishment of the conceptual framework designed to investigate this question.

CHAPTER THREE

COLLABORATION IN PRODUCT DEVELOPMENT

CHAPTER THREE:
COLLABORATION IN PRODUCT DEVELOPMENT

3.1 Introduction

Chapter Two explored the paradigm of mass customisation, and ended with a discussion of the enablers of mass customisation performance. Collaboration was identified as one broad approach by which a number of enablers could be concurrently enhanced. This chapter explores collaborative processes in greater detail, and in particular collaboration in product development, which is the interest of this study. The discussion in this chapter will enable the clear development of the research question and hypotheses, as will be presented in Chapter Four.

This chapter focuses on product development in industry as a whole, and is not restricted to mass customisation alone. As discussed in Chapter Two, an understanding of product development processes is essential for the improvement of mass customisation capability. The discussion provided herein will therefore serve as valuable background for the study, which focuses on product development in mass customisation. This chapter will explore general mechanisms for product development, in particular the importance of collaborations. The role of the external partners, suppliers and users, will be discussed in detail.

3.2 Utilising Collaboration

This section will explain the term collaborative product development, discuss the motivations for collaboration and detail the mechanisms by which it can be achieved. Finally, the two different collaborative partners for product development will be considered, leading to the final sections of this chapter which provide more detailed exploration into these two partnerships. Prior to this discussion, the following section outlines the more general topic of product development to provide a background for collaborative product development.

3.2.1 Product Development

The term product development describes the set of ongoing activities that an organisation must perform to bring a product to the market – consisting of the stages of concept development, design, and production. As discussed in Chapter Two, these activities are essential for mass customisation ventures, and are the result of multidisciplinary efforts that include marketing, research, design, quality assurance, manufacturing, and the chain of suppliers. In addition, product development comprises all strategic planning, capital investments, management decisions and tasks necessary to create the product (Salhieh and Kamrani, 1999).

Product development is an important process which allows companies to achieve their desired market position and attain a competitive edge over their rivals in the market. Traditionally, product development processes were focused around the central business unit, plant, or geographical area. In addition, processes were not well structured and the design functions were co-located, which led to only extremely informal collaboration (Fujimoto *et al.*, 1991).

There is a constant need for companies to improve product development processes to ensure that they retain their competitive edge. Eliashberg *et al.* (1997) surveyed 154 senior marketing officers and found that 79% viewed their companies' product development processes as in great need of improvement. In particular, they recognised the need to move away from systems which only rarely resulted in new or breakthrough ideas.

Wheelwright and Sasser (1989) identified a number of common problems faced in product development. The *moving target* refers to the difficulty to successfully target the rapidly changing market. *Lack of product distinctiveness* results in high competition with firms that have very similar products. *Unexpected technical problems* can cause delays and increases in costs. *Mismatches between functions* result from a lack of communication between members of the product development team, such as engineers and suppliers. Wheelwright and Sasser suggest that these pitfalls can be avoided by thorough mapping of existing products and desired new products. It is also important to note that successful communication between supply chain partners may assist in more effective product development. For example, better understanding of customer desires could minimise problems encountered with the moving target, while effective information transfer within the company, and with supply chain partners, could minimise and alleviate the effects of unexpected technical problems, and could diminish the likelihood of mismatches between functions.

In a later article, Wheelwright and Clark (1992) noted that product development ventures were being embarked upon at a high rate but without bearing the fruit of increased products entering the market. They also highlighted the importance of product mapping, this time in mapping product development projects and identifying areas of overlap or redundancy. Catering to customers' needs remains the chief aim of product development, and communication with customers is therefore of high importance.

One focus of product development research is the acceleration of the process. Product life cycles are becoming increasingly shorter in response to changes in customer demand (Foster, 1986, Kotler, 1988). Gomory and Schmitt (1988) suggested that an efficient competitive strategy is to adopt rapid product development strategies, as these will accumulate to significant product changes. Based on an extensive literature review, Millson *et al.* (1992) identified five main approaches to acceleration of product development. These are to simplify, eliminate delays, eliminate steps, speed up operations and employ parallel processes. In particular, they stress the importance of involving small customer groups in the research and development stages. The particular focus of this study is collaborative product development in mass customisation, which will be discussed in the following section.

3.2.2 Collaborative Product Development

Over the past decade, due to pressures from stakeholders to reduce costs, increase productivity, increase product scope, encourage greater innovation, and meet global requirements, companies consciously began to move towards a more collaborative product development approach, where functions became shared with partners, collaboration more structured, processes streamlined and reusable, and decisions traceable. Collaborative product development stresses the need for efficient communication platforms that support co-operation between multiple actors (Fagerstrom, 2003).

Collaboration in product development is not a new concept, but the availability of information technology and the accessibility to the internet has facilitated its adoption and spread. In addition, increased outsourcing has resulted in greater emphasis on co-ordination between the different parties, thus allowing for more efficient collaboration and free flow of information between the different units and players, which is the key enabler of collaborative product development (Acha, 2005).

Collaborative product development refers to any venture in which two or more parties work together to develop a given product. This can be manifested in a number of ways (Bruce *et al.*, 1995). *Supplier collaboration* involves the participation of one or more suppliers of technology, components or services. In *customer collaboration*, the company forms a partnership with key customers in the product development process. *Collaborative contract manufacturing* describes the involvement of a manufacturer that has been contracted to develop a product. Finally, *collaborative development* refers to partnership between two firms which extends from product design through to delivery. This study is interested in the performance of a manufacturer in its own product development processes from idea generation to the final validation of the product, and will therefore not consider collaborative contract manufacturing or collaborative development, both of which describe situations in which these processes are outsourced to other companies. The former two forms of collaboration will therefore be the focus of this discussion.

Another classification system for the partners in collaborative product development is to divide them into two groups: internal and external partners. Hillebrand and Biemans (2004) define internal cooperation as existing between business functions within the firm, while external cooperation refers to partnerships with other organisations (Figure 3.1). External cooperation, on which this thesis will concentrate, has been shown to be a crucial factor of new product development processes of competitive companies (Hakansson, 1987).

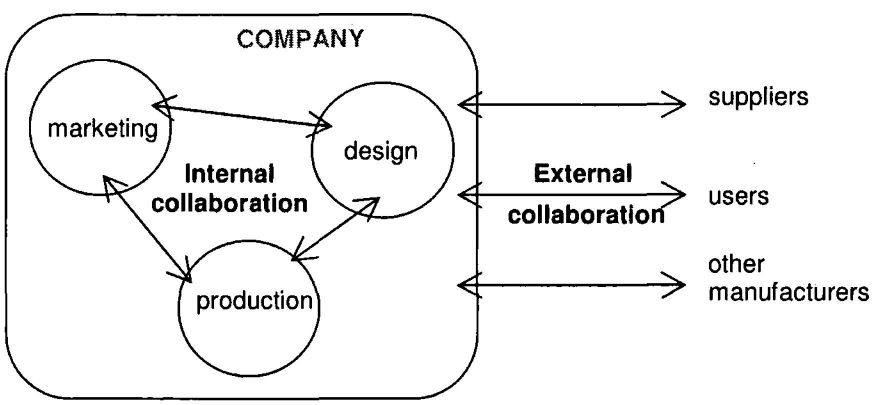


Figure 3.1: Internal and external collaboration in the context of a company.

One specific form of collaborative product development is distributed product development. The term describes the product development which takes place when partners are very far separated in space and time (Fagerstrom, 2003). This is very commonly a feature of external collaboration, as it is unlikely that a company's suppliers, and certainly not its users, are closely located. In such situations, care needs to be taken in the implementation of communication systems to enable efficient cooperation. This can be aided by the use of online workspaces which allow rapid and extensive transfer of information between partners (Court *et al.*, 1997, Court *et al.*, 1998). Hagel and Brown (2005) argue that distributed collaboration is essential for competitive product development as it enables benefit from the best possible partners, wherever they might be situated.

Many have tried to define the concepts involved in collaborative product development. Auerswald and Kauffman (2000) suggest that exaptation, that is shifts in function, is a major source of new ideas, although it is not predictable. Through a distributed, well-spread network, the different and novel uses of existing ideas, devices, parts, new ideas, or systems will increase and support more new ideas. Hargadon (2003) suggested the role of recombinant innovation, arguing that the best structure for nurturing new ideas is through networking and collaborating, and not necessarily depending on an individual genius. Hargadon asserts that most new concepts are extracted from other contexts, and have been in circulation for many years. Such new ideas have simply been recombined in new ways for a new uses. This claim is supported by earlier work of Nelson and Winter (1988), who explored new ideas as a recombination of previous concepts and inventions. Collaborative product development is, without a doubt, important for gaining competitive advantage, as will be expounded in greater detail in the following sections.

3.2.2.1 Motivations for Collaboration

The formation of collaborations and alliances has been heralded as an important strategy for the future of manufacturing. Day (1994) forecast an annual increase in collaborations of 25 percent, while Rackham *et al.* (1996) predicted that the value of partnerships in the USA gave benefits worth billions of dollars, manifested in greater productivity and reduced cost. They went on to suggest that the formation of collaborations was more valuable to companies than the implementation of strategies like downsizing and reengineering which attempt to reduce internal costs. In addition to these financial benefits, collaboration results in the creation of new market opportunities (Varadarajan and Cunningham, 1995) and maintenance of long-term competitiveness (Day, 1994).

Based on the studies of Ellram and co-workers (Ellram, 1990, Ellram and Cooper, 1990, Ellram, 1991), the benefits of collaboration have been divided into four areas: financial, technological, management and strategic benefits. A combination of the four areas encompasses the broad and varied motivations for companies to adopt partnerships. These categories are summarised in Figure 3.2 overleaf. Each will be discussed in turn.

Figure 3.2: Framework for classifying motivations for collaboration. Redrawn from Whipple and Gentry (2000).

Financial motives describe benefits to economic performance as well as the financial stability of the company, and focus on strategies to reduce costs and increase profit (Elliman and Orange, 2000). The principal financial motive is the reduction of cost (Anderson, 1995), which may be achieved by eliminating duplication and waste in the manufacturing process (Rackham *et al.*, 1996) or through reduction of the price of products and services in the supply chain (Hendrick and Ellram, 1993). Further financial motives are found in the sharing of business risk (Ellram and Cooper, 1990) and the implementation of joint product development (Varadarajan and Cunningham, 1995), which is the focus of this study.

Technological motives are those which facilitate the supply process, for example through shared technology and joint product development. A lack of internal technologies and resources can drive firms to collaborate (Brouthers *et al.*, 1995), particularly with partners who possess new technological capabilities (Vyas *et al.*, 1995). Further motivation lies in the current climate of rapid technological change, which makes it difficult for single companies to remain at the forefront of the market in which they must continually assume new technology. By collaboration, these technological advances can be more easily shared and adopted (McFarlan and Nolan, 1995). Another technological motive for collaboration is the desire to gain access to the research and development expertise of partners, which enhances product development processes, and can also decrease development times (Ellram, 1990). In addition, partners can bring ideas for new products or processes (von Hippel, 1977).

Management motives are those which simplify the supply process by reduction in the supply base and the formation of important cooperations. Spekman (1988) argued that successful collaboration requires partnership with fewer suppliers. By way of example, he cited Xerox, which reduced its supply base by over 50 percent and as a result enjoyed better buyer-supplier relationships. A reduction in the supply base can result in easier management (Ellram, 1991) and encourages manufacturers to select the most advantageous collaborations to maintain (Rackham *et al.*, 1996). Managerial benefit can also be found in increased loyalty of supply chain partners through their greater involvement in product development processes (Maltz, 1994).

Strategic benefits are motives which position the supply process competitively, for example by facilitating the achievement of core competency and managing future direction. An important strategic benefit of collaboration is access to new markets

(Ellram and Cooper, 1990), particularly through the formation of global partnerships. Collaboration can also provide competitive advantage by improving the core competency of a firm by incorporating the competencies of partners (Lei, 1993). Other strategic benefits of collaboration are many and varied, from improved quality to increased customer loyalty.

Whipple and Gentry (2000) performed a survey of 180 manufacturing firms to ascertain what benefits primarily motivated them to form collaborations with three different partners: suppliers of materials, customers and suppliers of services. Their findings are summarised in Table 3.1.

Table 3.1: Top five manufacturer collaboration motives (Whipple and Gentry, 2000)

With material supplier	With customer	With service supplier
Reduced cycle time / lead time	Increased customer service	Increased customer service
Reduced inventory	Reduced cycle time / lead time	Reduced cycle time / lead time
Stabilised supply/demand	Improved quality	Improved quality
Improved quality	Increased customer loyalty	Internal cost savings
Increased customer service	Increased customer involvement	Achieved core competency

There are therefore many motivations for the adoption of collaborative product development. As a result, it is valuable to study this strategy as a means of improving the outcomes of product development. The following sections discuss particular mechanisms by which collaborative product development can be best implemented.

3.2.3 Enablers of Collaboration

Fagerström (2003) proposes five main principles behind successful distributed product development. These are *organisational networks*, in which the company is dependent on resources controlled by other firms (Burca and Loughlin, 1995). There are many benefits of such networks, including stable movement of materials, information, and people, shared knowledge, and bigger pool of resources. *Supplier integration* in product development has been reported to lead to lower and shared costs, higher quality, quicker delivery, and input in design. *Design co-ordination,* in which the complications of the design process are controlled by the company. In such a case, the manufacturer is actively involved in the planning, decision-making, organisation and control of the inputting partners, and in maintaining interaction between employees. *Communication* is crucial, and requires the provision a common language for the transfer of information (Danilovic, 1999). *Information and knowledge exchange* is required between all collaboration partners. Knowledge is the result of data and information (Zach, 1999) and it is difficult to transfer these if both parties are not willing to exchange (Van Aken and Weggemann, 2000).

Fagerström's framework could be used as a support when setting up new projects, but it has been viewed by other scholars as only a practical guidance for new start-ups and thus limited in theory and practice. For example, Monplaisir and Salhieh (2000) investigated the integration of Computer Supported Cooperative Work (CSCW) and Quality Function Deployment (QFD) in collaborative product development, and stressed the importance of four general elements: people, product design and development methodologies, product design and development tools and integration technology. *People* are important due to the core role of personal function and interaction in product development. *Product design and development methodologies* describes the selection of suitable methodologies such as Concurrent Engineering, Design for Assembly and Manufacturing (DFA/DFM), Quality Function Deployment (QFD), and Design for X, which is critical to the success of the product development process. *Product design and development technical support tools* include the software packages (CAD/CAM), databases, communication aides, which are a main element to accelerating the development process. The importance of *integration technology* reflects the significance of the Groupware applications in connecting organisations.

The enablers of collaborative product development proposed by Fagerström (2003) and Monplaisir and Salhieh (2000) are all elements which are required to facilitate the collaboration between the firm and its external partners. Two particular enablers which have been widely discussed are technology brokering and knowledge management, both of which aim to assist in the transfer of knowledge, in order to enhance product development processes by enabling sharing of technologies and experience. The following sections discusses the specific mechanisms of these two aspects.

3.2.4 Technology Brokering

Hargadon (2003) wrote extensively about the role of communication and technology transfer in product development. He claims that, throughout history, invention and innovation has resulted not from the work of a single person, but the synthesis of existing ideas and understanding in a new way. By way of example, he cites the invention of the light bulb by Thomas Edison, which was based on the study and innovation of numerous contemporaries. "The web around Edison was thick with ties to other people, ideas and objects that together made up this particular 'invention'" (p. 7). Hargadon names this gathering of existing knowledge, "technology brokering". This refers not only to synthesis of information in a single industry, but also to the application of existing products for entirely different purposes in new ways.

Hargadon then likens the example of Edison to a modern-day example of technology brokering, the company Design Continuum, which provides a vast range of design solutions for various industries. For example, the design of a supportive basketball shoe was based on inflatable splints used for the treatment of ankle injuries. The technology brokering which took place involved the recognition that a technology used in the medical industry could be applied for a different purpose in clothing manufacture. There are numerous other examples of modern technology brokers, from those whose sole interest is innovation, like Design Continuum, to the majority of companies, which seek product development as a means to maintain competitiveness.

Important in the achievement of technology brokering is the establishment of a means for bridging the gap between various possessors of information. This distance may be due to geography, language or due to the absence of any established relationship. As a result, the building and maintenance of networks is essential for the successful transfer of knowledge which is the basis of technology brokering.

Hargadon claims that there are three main ways in which companies pursue technology brokering. Companies whose primary concern is the generation of innovation have their very organisational structure – their work practices and culture – based on achieving technology brokering. Second is the practice adopted by companies comprised of separate divisions which focus primarily on product development to cater to their respective markets. Technology brokering in such cases requires the establishment of communication between these divisions to ensure that knowledge held by any one will be beneficial to all. Finally, for companies which focus on a single market, technology brokering can be achieved by continually scanning for information from other markets which may enable the importing of ideas, or exporting of their products to other applications.

Technology brokering is an example of one way in which product development can be achieved by gathering input from a number of sources, and provides a clear picture of the importance of knowledge transfer has been over a long period of time. Technology brokering may involve gathering secondary information from the literature or from other sources, or from the intentional formation of relationships – that is, collaborations. The latter forms the basis of subsequent discussion. The concept of technology brokering is helpful as it highlights a number of features, such as the need for channels of communication and establishment of networks, which are important to collaborative development on the whole and which will be discussed in subsequent sections. The following section discusses knowledge management which, along with technology brokering, is important for the achievement of collaborative product development.

3.2.5 Knowledge Management for Collaborative Product Design

The term knowledge management refers to the various practices which may be adopted by organisations to enable them to collect and distribute knowledge. The subject has been the focus of much research since the mid-1990s (Stankosky, 2004) as practitioners and theoreticians alike attempt to improve the means by which knowledge can be freely shared and transferred. Efficient knowledge management may be achieved by focussing on technologies chosen to aid knowledge storage and transfer, or through organisational changes. This refers to the creation of relationships and networks which will best facilitate sharing of knowledge. It is this organisational aspect which is of particular interest for this study. A number of different mechanisms have been suggested for the achievement of knowledge management. Two such mechanisms – communities of practice, and process networks – will be discussed. Both processes describe methods of utilising collaboration to accomplish knowledge management.

3.2.5.1 Communities of Practice

A recognised mechanism for organisational knowledge management is the creation of communities of practice, a concept which was suggested by Lave and Wenger (1991) from their studies of modes of learning in apprenticeships. Wenger (1998) defined communities of practice as groups of members who are united by a common interest and improve their understanding and practice of that interest by regular interaction. He suggested that three characteristics were essential for the formation of a community of practice: the domain, which is characterised by a shared interest; the community, in which members work together and the practice, in which members of the community act in response to their enhanced knowledge (Wenger, 2004).

This concept, although finding its origins in education, has found great application in industry, as it provides a model for networks in which knowledge can be shared to enhance product development processes. Such networks are an essential characteristic of collaborative product development. Wenger and Snyder (2000) note that communities of practice may encompass many businesses and even industries. For the management of such communities, Wenger *et al.* (2002) suggest seven principles. *Design for evolution* is the principle in which communities are allowed to change in response to a variety of factors such as improved technology, new partners and paradigm shifts. A second strategy is to *open a dialogue between inside and outside perspectives* which enables deep understanding of community issues, and allows those inside the community to see fresh perspectives and possibilities. *Inviting different levels of participation* from a heavily-involved coordinator to peripheral members can also assist in the management of communities of practice. The fourth strategy involves *development of both public and private community spaces* to maintain and strengthen relationships within the group. It is also important to *focus on value* and the benefits which are likely to come to the community. *Combining familiarity and excitement* can enable effective learning and innovating. Finally, the community of practice can be assisted by attempts to *create a rhythm for the community* which reflects the aims of the community.

These principles refer to various manifestations of collaboration. Dialogue between inside and outside perspectives reflects the importance of internal and external collaboration, as will be discussed later. Different levels of participation correspond to the heavy involvement of the company itself, with less input from external collaborators whose primary interest is not the benefit of the company. Importantly, the use of communities of practice enables manufacturers to increase the inputs they receive from external partners. These principles have paved the way for the use of process networks, as will be discussed in the following section.

3.2.5.2 Process Networks

Another strategy for knowledge management is process networks, which attempts to increase the input from external partners and ensures their continued interest in the product development process. The concept of process networks was suggested in response to the need for companies to develop strategic advantage in rapidly changing markets (Hagel and Brown, 2005). In this model, companies adopt modular management techniques which can be fit with the techniques of other companies to enhance the overall output. In this system, companies become more specialised in their output as they rely on partners to perform many functions. Such a strategy is contrary to the natural tendency of companies to tightly control all aspects of their operation (Brown *et al.*, 2002), but has the benefit of allowing them to ensure that they remain competitive, as they are can chose partners who are similarly at the leading edge of the market.

In forming process networks, a company benefits from the knowledge possessed by other companies, but it also loses the tight control of the entire manufacture. While companies can specify the nature of the product or service which they are obtaining from another company, they cannot specify the procedures which are used to achieve the end result (Brown *et al.*, 2002). A distinct advantage of the process, however, is that by comparing its networking to that of its competitors, a company can assess its competitiveness. For example, if a supplying company at the leading edge of the market is also working with a competitor, it is likely that the competitor is also in a strong position (Hagel and Brown, 2005).

Similarly to communities of practice, process networks describe collaboration between partners in the manufacturing chain. The collaborative partners possess techniques which can be fit together in the overall manufacturing process. The principal collaborative partner involved in process networks is the supplier, which is a company with the capability for producing raw materials or partially-completed products for the manufacturer.

The previous sections have presented the theoretical background for collaborative product development, the advantages of adopting such an approach, and the enablers of collaborations. The following section will build on this understanding, and discuss the specific mechanisms by which collaborative product development can be achieved.

3.2.6 Mechanisms of Collaboration

The merits of collaborative product development are encouraging more firms to adopt this approach to develop their products and to invent new products, or novel uses for existing products. Companies are pursuing collaborative product development in various ways, whether they are driven by the reduced product development costs, the increase in productivity, the compression of the development cycle thus the reduction in development time, or the gain in responsiveness (Sanchez and Mahoney, 1996). The ways in which they approach collaborative product development differs between situations and industries.

Some companies approach collaboration by the outsourcing of technical tasks, which reduces the overhead costs, focuses the company's efforts on core competencies, provides qualified expertise, and introduces new perspectives to the production process. Another approach is to make use of virtually all the industrial and social networks the company can access to attract more ideas and expertise. This provides a huge pool of talents, ideas and skills for the company in a short time and at lower costs (Howe *et al*, 2000). Fagerström (2003) argues that organisations must first assure the availability of some organisational infrastructure, or introduce some changes to their current structure in order to facilitate the efficient adoption and implementation of collaborative product development. He stresses the need to first set up efficient collaboration teams between partners, which are connected by information systems and communication networks to assure rapid and resourceful sharing of knowledge. In addition, structures for coordinating the different partners in the network or the team are needed to avoid any duplication of efforts or conflict of roles, as well as mechanisms for co-ordinating the design, common processes, models, standards, and platforms.

Many researchers (Hameri and Nihtila, 1997; Anderson, 1997; Burgelman *et al*, 2004; Kahn, 2005; Tidd *et al*, 2005) have stressed the organisational context in which collaborative product development can prosper. They highlighted the importance of an interested and supportive management team as a keystone in the establishment of successful product development, to generate interest and provide guidance. This support should be translated into the creation of an organisational structure which has an inherent focus on the generation of new ideas. Anderson (1997) argues that successful product development can only be attained through the development of a nurturing environment, characterised by open communications between all levels of the organisation, and by both internal and external networking. Hagel and Brown (2005) suggest enabling collaborative product development through establishment of a framework for exchanging information, which is particularly important for globally diverse relationships, especially when the company and its partners are globally diverse. This can be achieved by establishing a clear set of unified standards for the exchange of information, before establishing the technology and infrastructures required for such exchanges. The framework described above helps to facilitate collaboration with external partners, but is incomplete without due consideration of the different types of partners. The following section details the various partners with whom businesses can collaborate.

3.2.7 Collaborative Partners for Product Development

Myers and Marquis (1969) studied firms across five manufacturing industries and identified the importance of organisational communication for successful product development. Rubenstein *et al.* (1976) studied 103 projects across industrial firms, and suggested that organisations improve projects by focussing on communication between the various partners involved. This has been confirmed by many other researchers, who similarly found that successful product development relies on strong communication links and cooperation between different players (Souder and Chakrabarti, 1978, Souder and Chakrabarti, 1979, Gupta *et al.*, 1985). Without concerted efforts to bridge the physical and social gaps between collaboration partners, product development will lose effectiveness, and important information could be lost. In order to improve communication, a clear understanding of collaboration partners must be gained.

Brown and Eisenhardt (1995) performed an extensive study of the literature, and identified a number of key factors which are critical for the achievement of successful product development. These include both internal factors, such as the composition and organisation of the product development team (Katz and Allen, 1985) and the effectiveness of team leaders and senior management, and external factors, namely integration of suppliers and customers in the product development process (Clark and Fujimoto, 1991). They highlight that communication with both internal and external partners is essential.

There is no doubt that researchers and practitioners alike hold cooperation as an essential enabler of product development (Easton, 1992, Ford, 1997, Thorelli, 1986). Research into this cooperation has focussed primarily on collaboration with suppliers (Bidault *et al.*, 1998, Bozgodan *et al.*, 1998, Kamath and Liker, 1994) and customers (Ciccantelli and Magidson, 1993, Thomke and von Hippel, 2002, von Hippel, 1988). It is these two groups which will form the focus of subsequent discussion.

3.3 Collaboration with Suppliers

Suppliers have long been viewed as an important collaborating partner in product development. Many studies (Dowlatshahi, 1999; Bidault et al., 1998) indicated the importance of integrating suppliers in the product development processes. Indeed, a reliance on suppliers has long been a feature of the manufacturing industry, dating back to the early days following the industrial revolution (Pine, 1993a). This dependence on suppliers has, however, escalated considerably over the past two decades in response to the tendency of businesses to focus on core activities while outsourcing other tasks to external companies, that is, suppliers (McIvor *et al.*, 1997). As a result, business relationships have evolved from vertical systems to networks of buyers and suppliers have developed (Roy and Potter, 1996). These complex systems require more sophisticated understanding, and careful management of relationships (McIvor *et al.*, 2000).

This collaboration was a primary interest to operations and supply chain researchers in the 1990s. Clark and Fujimoto (1990) investigated the differences between Japanese and American manufacturers in their involvement of suppliers in the product development processes. They studied the Japanese experience as a whole and provided the first in-depth book on such collaboration. However, the research did not examine a wide range of best practices and did not identify the different roles that suppliers play in the various product development processes. Nevertheless, the findings did draw the attention of both academics and manufacturers to the merits of such an approach, and the confirmation that suppliers' integration in product development ensures, for the buying firm, the utility of the suppliers' skills, ideas, sources, and technological expertise (Dowlatshahi, 1997, Bidault *et al.*, 1998). Other studies have determined that supplier involvement leads to innovation (Afuah, 2000), much of which is radical (Afuah and Bahram, 1995) and which can lead to increased financial benefits for the manufacturer (Carr and Pearson, 1999).

Much research has been performed to ascertain the benefits of collaboration with suppliers in the product development process, with positive results obtained in studies of both the Japanese automotive industry (Clark and Fujimoto, 1991) as well as of Western firms (Ragatz *et al.*, 2002, Primo and Amundson, 2002). These studies highlighted many advantages of increased supplier integration, such as greater access to knowledge, better flow of information and improved working relationships. Supplier integration has been heralded as a means of achieving lean manufacturing (Lamming, 1996), which is the method of optimally producing goods using flow systems, rather than batch and queue, leading to minimal waste (Womack and Jones, 1997).

While most studies focussed on the importance of supplier involvement in large-scale manufacturers, Song and Di Benedetto (2008) studied the impact of suppliers in new ventures. They collected data from companies and their suppliers involved in 173 new ventures, and demonstrated that increased supplier involvement at all stages of the product development process resulted in greater product performance. They also noted that supplier involvement was proportional to the magnitude of the specific investments made by that supplier in the company. Despite these many positive indications for supplier collaboration, the integrative process appears to be a fine balance between suppliers and buyers, and any disturbance of the relationship can lead to unproductiveness.

Petersen *et al.* (2005) studied supplier involvement, and particularly the level of supplier responsibility. They found that the effectiveness of supplier involvement was inversely proportional to supplier responsibility: very high responsibility led to decreased success of product development projects. This could reflect the manufacturer's decreased control over suppliers, or decreased accountability on the part of the supplier. Das (2006) similarly concluded that the effectiveness supplier involvement reaches an optimum level, and integration beyond this point can negatively affect product development. Ragatz *et al.* (1997) surveyed the factors required for successful supplier integration, and identified participation in product development teams as the most effective collaborations. They identified trust, communication, confidence and a clear focus as essential for the success of such collaborations. Takeichi (2001) suggested the factor of detailed product knowledge is important to enable successful supplier collaboration.

These studies highlight various ways in which suppliers may be involved in the product development process. One common form of supplier collaboration, and the method which will be the focus of this study, is early supplier involvement.

3.3.1 Early Supplier Involvement

Companies' restless quest for shorter production times driven by the global intense competition, rapid and continuous technological introductions, shorter product life cycles, and increased trends for outsourcing have set the ground for the emergence of a new concept of involving suppliers in the product development process. The principal means of collaborating with suppliers is early supplier involvement (ESI), which is a method of involving suppliers' skills, ideas, sources, and technological expertise in the product development of the buying organization (Dowlatshahi, 1997, Bidault *et al.*, 1998). This mechanism helps the buying company reduce the cost of production, reduce production time, improve quality, and have a bigger market share due to the suppliers' innovative technologies and market expertise, which thus provide the company with strategic flexibility (Handfield *et al.*, 1999). A wide-scale study of American manufacturing companies illustrated the importance of early supplier involvement in product development, with the finding that 92% of top-performing plants had a conscious emphasis on ESI (Industry Week, 1995).

ESI can be utilised in the three general stages of product development. At the planning phase, suppliers are involved in the functional specifications (Clark and Fujimoto, 1991) where their expertise can be valuable in deciding the product features. The suppliers contribute to the purpose of the product and its future use as technical engineers from both firms discuss the possible, and feasible, interface specifications, the lead time requirements for the design and the production processes, product architecture design specifications, and the availability of outsourcing alternatives if some aspects or parts cannot be developed in-house (Mikkola and Skjoett-Larsen, 2003). At the detailed engineering stage (Lammings, 1993), during which both design and production take place, ESI plays a role in the selection of materials, the generation of the blueprints, attempts to minimise parts and components, the building and testing of prototypes, selection of manufacturing processes and equipment, and setting up processes for manufacture (De Toni and Nassimbeni, 1999, Mikkola and Skjoett-Larsen, 2003).

Various studies have investigated the different aspects by which suppliers can collaborate in the buyer's product development processes, and the consequences of such partnerships. O'Neal (1993) found that the establishment of joint engineering teams between the two firms' designers (buyer and supplier) is an ideal mechanism for sharing technical knowledge while simultaneously developing an understanding of the requirements and constraints of each firm. Ragatz *et al* (2002) demonstrated that suppliers can be involved in sharing knowledge and information with the buyer through integrated information technologies which will enable the supplier to share design responsibility by accessing design and specification related data.

3.3.1.1 Advantages of Early Supplier Involvement

Many researchers have identified benefits of involving suppliers early in the product development process. Smith and Reinertsen (1991) note that by incorporating suppliers into product development teams, they can add to the information and expertise which are essential for the generation of new ideas, thus leading to decreased product development time. Ragatz *et al* (2002) similarly argue that by involving suppliers in the knowledge-sharing process, a company should enjoy reduced product development time and concept-to-customer cycle time, notably decreased capital and operational costs, and an improvement in the overall product design quality performance.

Early supplier involvement also allows for identification of potential problems in all steps of the product development process before manufacture begins, resulting in improved quality, decreased costs and the need for repair or redesign (Handfield, 1994, Dowlatshahi, 1997, Meyer, 1993). The involvement of suppliers in product design results in the shift from linear manufacturing to branched networks, with components combining to give the final product. This has the advantages of reducing the internal complexity of each manufacturing task (Brown and Eisenhardt, 1995) and decreasing the critical path length for overall manufacture (Clark and Fujimoto, 1991).

Other advantages of early supplier involvement lie in the resultant improvement in relationships and communication between suppliers and companies. Enhanced information exchange results in decreased delays and product lead times. In addition, smooth supplier-buyer interactions lead to smoother working relationships (Meyer, 1993). Takeichi (2001) identified that integration of suppliers early in the design process in the automobile industry resulted in better product quality.

3.3.1.2 Disadvantages of Early Supplier Involvement

The adoption of ESI practices in product development has not been without its setbacks. Monczka and Trent (1997) performed a widespread study of US manufacturers, and identified that while 70% of firms studied planned to take steps in the future towards formal early supplier involvement, almost 50% identified significant barriers that limited their current ability to collaborate with suppliers. These barriers included resistance (both of supplier and buyer) to the free sharing of information and reluctance on the part of the buying company to give over any responsibility in product development to a second party.

A number of studies have called into question the applicability of ESI in industries which are rapidly evolving or which require high skill in manufacturing. Eisenhardt and Tabrizi (1995) studied product development projects in the computer industry, and identified that ESI was only effective in reducing product cycle time in the case of mature industry. Primo and Amundson (2002) performed similar analysis of the electronics industry, and found that ESI had little effect in projects with high technology uncertainty.

Problems in partnership can also arise if suppliers' technical capabilities are of a lower grade than the buyer firm or simply not available. This can result in a burden on the buyer company and forces it to support and, in some cases, develop the suppliers' in-house technical capability (Wasti and Liker, 1997). On the other hand, the buying firm may pose some challenges for the supplier. For example, resistance from functional departments of the buying firm could result in the absence of a finished product for the suppliers to decide upon, which may lead to ineffective coordination, and might threaten the collaboration in product design (Wynstra *et al.*, 2001). In addition, irregular levels of cooperation resulting from any number of internal or external sources such as differing capabilities and conflicting objectives, could lead to longer development times, and intensely unproductive relationships (Littler *et al.*, 1995; Sako and Helper, 1998).

Other drawbacks of supplier collaboration have been noted in the literature. Velosso and Fixon (2001) warned that an increased dependence on the strategic suppliers might affect the performance of the buyer company and have negative impact on the long run. In addition, they suggested that the buying company faced risks concerning knowledge management, particularly with regards to the ownership of the internal implicit and explicit knowledge which might become vulnerable for rivals to imitate. Also, the process faces the possibility of causing increased standardisation of components through the specified interfaces, and the risk of hollowing out internal competencies is another possible shortcoming (Mikkola, 2003).

Despite these drawbacks, companies experience significant benefits from supplier collaboration, and are therefore motivated to actively seek such relationships. The desired increase in product development efficiency, the access to the suppliers' technological capabilities, and the positive effects of increase suppliers' responsibility due to their role in the development of the product, all generate greater momentum for collaborating with suppliers.

Supplier collaboration, particularly through the employment of early supplier involvement, is therefore a valuable tool for the enhancement of the product development processes. As a result, there is a need to specifically study the effect of supplier collaboration in the product development processes of mass customisation, which is the interest of this study. The following section explores the role of customer collaboration.

3.4 Collaboration with Users

Earlier studies of product development indicated the importance of considering users' needs in product development (Rothwell *et al.*, 1974; Cooper, 1979). This strategy remains of interest (Salter & Gann, 2002; Callahan & Lasry, 2004; Enkel *et al*, 2005) and is generally manifested in the form of user collaboration. It has been shown that the element most crucial to successful product development is the use of a systematic, consumer-based approach (Kane, 1983). In addition, active integration of end users into the product development process is thought to be necessary as a means of ensuring that products comply with their needs (Griffin and Hauser, 1996).

Myers and Marquis (1969) performed a landmark study of 567 product and process innovations across 121 firms. Their primary finding was that identification and understanding of the user's needs is of paramount importance. Economic success was higher for products which had been designed in response to consumer demand, rather than those which utilised new technology. This finding has been confirmed in subsequent studies. It was identified that gaining a deep understanding of customer's needs results in development of products with significant value (Utterback *et al.*, 1976, Cooper and Kleinschmidt, 1987), whether in cost savings, performance advantages or quality (Buzzell and Gale, 1987).

In the 1970s, a thorough study was performed to try to ascertain what differentiated a successful innovation from an unsuccessful one. This study was named project SAPPHO (Scientific Activity Predictor from Patterns with Heuristic Origins) and was performed in two separate phases. The study identified five main differences between successful and unsuccessful ventures, one of which is that "successful innovators...have a much better understanding of user needs" (Rothwell *et al.*, 1974, p. 259). This was also the conclusion of other scholars who, based on evaluation of several studies, claimed that companies which took into account user's views in the product development process were more likely to manufacture more successful products (von Hippel, 1988, Biemans, 1992).

This strategy of involving customer collaboration is not without its critics. Campbell and Cooper (1999) questioned the belief that customer integration is always beneficial, arguing that companies which practiced collaboration with customers were no more successful than those which did not. Seungwha and Gyeong studied the effects of customer collaboration on suppliers, and found that while firms which integrated users performed better financially, they exhibited no differences in innovation or quality (Seungwha and Gyeong, 2003). Gruner and Homburg (2000) found that customer integration at medium stages of the product development process had no effect on the success of the project. In addition to these works which question the utility of customer integration, Enkel *et al.* (2005a) highlighted some risks associated with the practice, such as leaks in knowledge and manufacturers' increased dependence on external factors.

Despite these studies which question the importance of customer integration, the many reported benefits of such collaboration has led to the study of mechanisms by which customers may be integrated into the product development processes. Early studies focussed on the customer-active paradigm, which will be discussed in the following section.

3.4.1 The Customer-Active Paradigm

The customer-active paradigm was derived in response to the long-held understanding that the design of commercially-successful products relies on precise analysis of consumer desires (Rothwell *et al.* 1974, Achilladelis 1971). Achievement of this requires efficient communication of these desires from consumers to those involved in product design. The customer-active paradigm goes one step further, suggesting that ideas for design should not only be based on the views of consumers, but should be generated by consumers themselves.

Von Hippel (1977) first suggested the consumer-active paradigm as a way to generate ideas in a rapidly-changing economic climate. He believed that the dominant strategy of the time was the manufacturer-active paradigm, which was characterised by manufacturers surveying customer needs and analysing the resulting data from which they generate and screen ideas for products. These products are then presented to the customers in the marketplace. The role of the customer is "essentially that of a respondent, 'speaking only when spoken to'." (von Hippel, 1978 p. 40). The manufacturer has the active role, from seeking customers' opinions to developing ideas to testing these ideas. The customers, von Hippel warns, may have been previously unaware of their needs, and are therefore susceptible to being influenced by the manufacturer.

In contrast to this manufacturer-active paradigm, Von Hippel proposed the alternative, customer-active paradigm, which involved presentation of a product idea from a customer to the manufacturer, who then screens the idea and presents the resulting product to the market. In this paradigm, the user has responsibility for innovation, through the development of new ideas. The manufacturer, on the other hand, has a smaller contribution – that of receiving the request, evaluating the idea and deciding on its potential for market (von Hippel, 1979).

Von Hippel investigated available and suitable studies, from which he deduced that there appeared to be evidence that innovations requested by customers were more likely to succeed. Figure 3.3 shows the situations in which the two paradigms are applied as defined by two variables: the customers' awareness of need, and the opportunity for manufacture-managed action.

Figure 3.3: Spheres of relevance of customer-active paradigm (CAP) and manufacturer-active paradigm (MAP). Redrawn from Von Hippel, (1978) p. 44

There has been little dispute of the importance and applicability of von Hippel's novel paradigm, but subsequent literature has advocated further extension of the concept. Foxall and Tierney (Foxall *et al.*, 1985, Foxall and Tierney, 1984) performed empirical studies, and suggested an extension of von Hippel's customer-active paradigm (CAP) to CAP2, in which the users are aware of the possibility of benefiting from their innovation, and therefore attempt to maximise the benefits which they will receive. In this paradigm, there is a move from manufacturerdominated product innovation to customer-dominated product innovation (Foxall and Johnston, 1987).

Such a strategy might manifest itself in user behaviour such as forecasting market needs, ensuring intellectual property protection (through patent or copyright) and negotiation with the company. The manufacturer has not lost any role, but the user has gained importance along with an entrepreneurial role, and stands to derive commercial benefit along with the manufacturer. The user has engaged in more active collaboration with the manufacturer in order to benefit from the potential gains of such a partnership (Kirzner, 1973).

The discussion of the customer-active paradigm to this point has presupposed that all customers play a relatively equal role in the product development process, that is, that all users have the same interest and needs to participate in collaborations, and the same ability to invent. In reality, consumers are not a homogeneous group, and some users are better poised to contribute to product development than others. The concept of lead users seeks to reflect this heterogeneity, as will be discussed in the following section.

3.4.2 Lead Users

The concept of lead users was first suggested by von Hippel (1986) to overcome the concept of the familiarity of products, which is a potential drawback of the customer-active paradigm. This concept states that subjects' familiarity with existing products interferes with their ability to imagine different uses or improvements which could be made. This idea has been supported by much research. Familiarity with a complex problem-solving strategy has been shown to make subjects less likely to try to formulate a simpler strategy (Luchins, 1942), while subjects who are familiar with the use of an object in a certain way find it difficult to use it any other way (Duncker, 1945, Birch and Rabinowitz, 1951, Adamson, 1952). The effect has been shown to be time-dependent; the difficulty with novel use increases as the time since use decreases (Adamson and Taylor, 1954). Finally, if a research group can employ a previously-used problem-solving technique for a new problem, there is a greater chance of success (Allen and Marquis, 1964). As a result, von Hippel concludes, the majority of users are not well-placed to perform the problem-solving required to assess product needs.

In response to this strategy, von Hippel (1986) suggests the use of a small group of users which he called "lead users" for marketing research. These users would be those who do possess experience with concepts of novel products and novel processes, and have an understanding of future needs, and can therefore make accurate predictions with respect to the future. Von Hippel defined two attributes which are characteristic of lead users. Firstly, lead users encounter the same needs as the common marketplace, but face these needs earlier than others. Secondly, lead users stand to benefit significantly from the provision of a solution to their needs.

Lead users may be found within or outside a given target market, and their input is valuable because their quests for solutions for their needs – which are much more severe than the regular user – usually generate new processes or products that can be regarded as a breakthrough (Morrison et al, 2000; Luthje, 2000).

The concepts on which lead user theory is based are not new: is has long been known that the level of benefit from new products and processes differs between users (Mansfield, 1968) and that the level of innovation activity is proportional to the expectation of benefit from the innovation (Schmookler, 1966). What the lead user concept does introduce, however, is the idea that there is a set of users with whom collaboration is most valuable.

Von Hippel suggests that the employment of the lead user approach in market research should be fourfold. Firstly, as always, the market or technical trend must be identified. Secondly, lead users must be identified who both have experience with the trend, and have intense need for a solution. Based on this, the data from these lead users must be collected and analysed. Finally, lead user data is projected onto the general market.

Lilien *et al.* (2002) noted two primary differences between the lead user approach and traditional market research. Firstly, the traditional methods sought representative users who were indicative of the market as a whole, rather than identifying the small group of lead users who have different experience and expectations from traditional users. Secondly, traditional market research seeks information about needs only, and not about new ideas. As a result, the task of identifying possible solutions falls to the manufacturers alone, while the lead user method also aims to utilise ideas of the users.

The lead user theory as an academic construct has been extensively explored and critiqued. Morrison *et al.* (2004) developed a similar construct which they named leading-edge status, composed of three variables: being ahead of the trend, exhibiting high levels of need and actively innovating. They concluded that their method, as well as the lead user method, comprises reflective indicators rather than formative ones. Franke *et al.* (2006) countered this assessment by a study of kite surfing manufacturers, through which they demonstrated that the two variables of lead user theory (ahead of the trend, and high expected benefits) are independent, and therefore are both important aspects.

Lilien *et al* (2002) proposed a practical lead users method to allow companies to benefit from their lead users and use their input in the development of their new products, or improvement of their existing ones. The approach assists in the introduction of lead users' ideas into the company. The first step involves setting a goal for the team or direction of their ideas and forming the team from cross-functional backgrounds. The team then cooperates with the company's main stakeholders to identify their desired level and type of innovation while scanning the industry's to select the target market. Secondly, the lead user team researches the targeted industry to identify embedded technological and market trends, and interviews experts in this market to help narrow their focus to the most important trends. In the third stage, the selected trend or trends are investigated to identify lead users both within and outside the target market. The lead user team begins to interact with these lead users to help identify other potential lead users (the snowballing effect) and to ascertain their needs and the possible solutions they have recognised. Finally, the lead users work with the company engineers, experts, and designers to improve and refine the concepts discussed and generated. Special workshops are conducted to finalise the concepts in a format compatible with the company's goals, capabilities, and needs from a managerial, financial, marketing, and operational perspectives (Eliashberg *et al*, 1997; Von Hippel, 1988).

Since von Hippel's initial proposal (von Hippel, 1986), the lead user method has subsequently been put to the test in numerous studies, both those which attempted to test the theory, and which aimed to generate useful data from the process. The first study was performed by Urban and von Hippel (1988), who studied lead users in the computer industry who desired printed circuit boards. They were able to successfully identify lead users through the development of case-specific indicators, and demonstrated that this group provided suggestions for product needs and possible solutions which were both unique and useful. Herstatt and von Hippel (1992) performed another such study at Hilti AG a manufacturer of construction materials. They studied the "low tech" product line of pipe hangers, identifying lead users and collecting their ideas concerning product needs and potential solutions. They then surveyed traditional users, and found that over 80% preferred the product described by the lead user over the existing model.

As a result of these studies, the lead user approach has been increasingly adopted by companies as a means of product development. It is worth noting that there are various methods for involving lead users in product development, which will be examined by this research. Recent studies have assessed the success of these ventures. Shah (2000) investigated product design among sporting equipment manufacturers, and concluded that user-lead product design had the greatest importance. Although he did not use the term, the users who were involved in product design satisfied the two criteria for lead users – they suggested novel ideas, and had an active interest in developing products. Lilien *et al.* (2002) conducted research within the 3M company regarding the use of the lead user approach. They found use of this approach resulted in much higher annual sales, and the confidence that lead user project ideas are more likely to result in successful product ventures.

The lead user concept has been further enabled by the introduction of the open sourcing approach in product development, in which a community of developers and users are given access to a common technical framework (usually software) by which they are able to modify and adapt the product to their needs. Open sourcing has many advantages over closed sourcing, including lower development costs, increased interoperability, decreased reliance on proprietary vendors, faster implementation, rapid detection of bug, and an increased pool of resources. Perhaps the most well-known example, and amongst the earliest open source software is Linux, which introduced by Linus Torvalds in 1992 with general public licence and no proprietary code. This software depended on a community of volunteers (a type of community of practice) and demonstrated a significant internet presence (DiBona *et al.*, 1999). The concept of open sourcing is particularly applicable in the contemporary environment of distributed product development.

Lead users have been applauded both in industry and academia (Haman, 1996; Lonsdale *et al*, 1990) for generating breakthrough innovations in manufacturing firms, but very little is known about the drawbacks of this approach and the possible side effects on the processes of product development. The relationship between the use of lead users and the performance of manufacturers is ambiguous, and in the case of mass customisation ability – the focus of this study – remains largely under-investigated.

Much has been written about lead users, as detailed in this section. For the purposes of this study, lead users are defined as a group of users (companies or individuals) who experience heightened needs as yet unknown to the company and to other customers, and develop bespoke solutions to satisfy their needs.

3.5 Comparing Collaborative Contributions

Given the plethora of studies expounding the virtues of collaboration with either suppliers or lead users, it is important to consider which partner has greater effect to product development, and whether the two collaborations are mutually exclusive, or can be employed simultaneously. While much literature details the advantages of external integration, or of collaboration with either suppliers or users, little work has compared the two partnerships. Morash (2000) proposed that collaboration with suppliers is more effective than with users if the aim is for cost leadership, while for companies seeking differentiation, customer integration is the key.

Frohlich and Westbrook (2001) explored external collaboration, and suggested a framework for study comprised of two types of integration, as shown in Figure 3.4 overleaf. Delivery integration involves the forwards flow of goods from suppliers to manufacturer to customers. Information integration, on the other hand, is the backwards flow of information from customers through manufacturer to suppliers. This model suggests that customer and supplier integration can be concurrently practised, but also demonstrates that management of both collaborative relationships therefore requires management of these two integration processes.

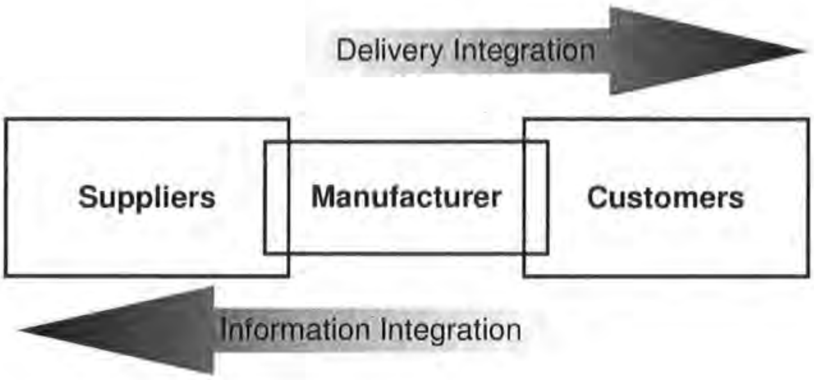


Figure 3.4: Integration of suppliers and customers in the supply chain. Adapted from Frohlich and Westbrook (2001).

While many authors have attempted to determine with which partner to collaborate, Frohlich and Westbrook (2001) present the view that integration of both partners is crucial, and what is significant is the extent of this integration. To illustrate this, they introduced the concept of the arc of integration (Figure 3.5 oveleaf) by which companies can be classified according to the extent to which they integrate (narrow or broad arc of integration) and the direction of integration (customers and / or suppliers).

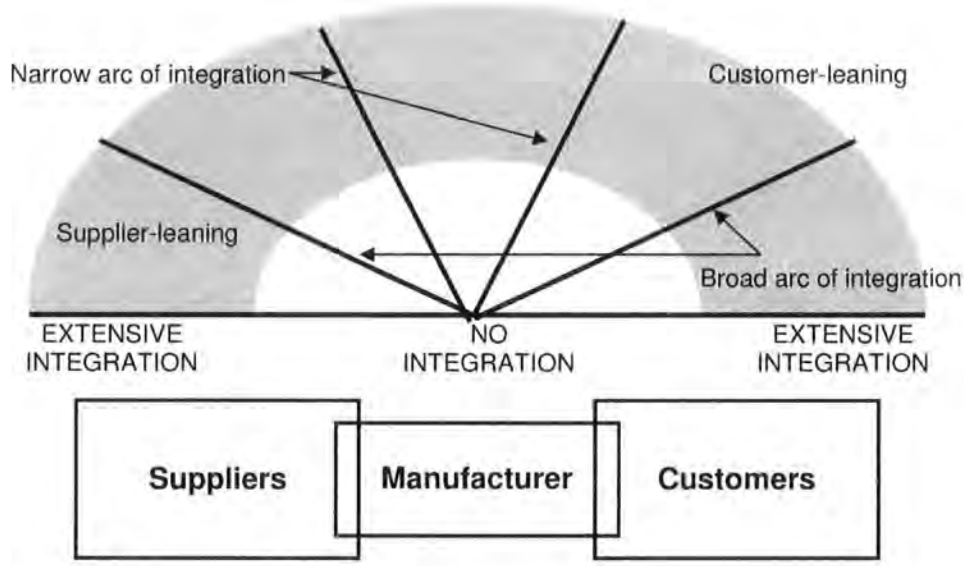


Figure 3.5: Arcs of integration. Adapted from Frohlich and Westbrook (2001).

Frohlich and Westbrook used their model of arcs of integration to study the relationship between the integration of partners and the operations performance. They conducted a global survey of 322 manufacturers, and found that companies with the greatest degree of integration with both suppliers and customers also demonstrated the most improvement in performance.

Through this study, Frohlich and Westbrook identified five distinctive categories into which companies could be divided according to the exact nature of their partner integration. *Inward-facing* companies are those who have only a low degree of integration of both customers and suppliers. *Periphery-facing* companies practise moderate integration of customers and suppliers, while *outward-facing* companies exhibit a high degree of integration. Companies that strongly integrate suppliers but only moderately or weakly involve customers are named *supplier-facing*, while *customer-facing* describes those companies whose customer integration outweighs their partnerships with suppliers. In line with their overall finding that integration is directly proportional to performance, therefore, they suggest that companies should strive to be outward-facing.

3.6 Concluding Remarks

While the discussion in this chapter has demonstrated that it is valuable to collaborate with both suppliers and lead users in the product development process, both partnerships come at some price. Collaboration with lead users, for example, requires the employment of researchers to interact with customers, while installation and maintenance of technology to facilitate communication with suppliers can be costly. It is important, therefore, for companies to determine the most valuable collaborations in which to invest.

Chapter Two highlighted the importance of improving mass customisation performance, and identified collaboration as one means of achieving this outcome. This chapter has explored the processes of collaborative product development in greater detail. The importance of suppliers and lead users specifically in mass customisation will be discussed in Chapter Four, which will lay the foundation for the development of the research question and hypotheses.

CHAPTER FOUR

CONCEPTUAL MODEL

CHAPTER FOUR: CONCEPTUAL MODEL

4.1 Introduction

Chapter Two has discussed the paradigm of mass customisation, examining its establishment as a major manufacturing method and its characteristics and manifestations. The discussion demonstrated that mass customisation is an essential manufacturing paradigm for the future, but that much work has to be done to improve the performance of the method, and allow it to achieve its full potential. In particular, successful product development processes of mass customisation were identified as key to the success of any mass customisation ventures.

Due to the importance of product development, Chapter Three has dealt with this process, and in particular has explored the area of collaborative product development. The essential role of suppliers and lead users as collaborative partners was explored in detail. It is the role of supplier and lead user collaboration in product development in mass customisation which is the specific interest of this thesis, and a synthesis of the understanding in Chapters Two and Three will therefore be provided in this chapter. Following this exploration of collaboration in mass customisation, the research question for this study will be presented. Four mass customisation attributes will be introduced as a method of measuring the success of mass customisation ventures, and finally the conceptual model and the hypotheses of this study will be presented.

4.2 Collaboration in Mass Customisation

Chapter Two discussed the concept of mass customisation, presenting six enablers which have been demonstrated to enhance mass customisation performance. Collaborative product development was suggested as a means for simultaneously improving the output of many of these enabling factors. Chapter Three explored the general concepts of collaborative product development, with particular focus on suppliers and lead users as collaborative partners. Since this study is interested in collaborative product development in mass customisation, it is important to review the current understanding of the effects of supplier and lead user collaboration in mass customisation. This discussion is presented in the following sections.

4.2.1 Supplier Collaboration in Mass Customisation

Supplier collaboration as an important feature of mass customisation was not driven by academia, but its development was a natural progression of mass customisation management. Pine (1993a), in his initial work on mass customisation, identified that the new paradigm is characterised by long-term supplier interdependence, rather than bitter rivalry between manufacturer and supplier. Similarly, Fulkerson and Shank (1999) noted that supplier collaboration in mass customisation is driven by the need to provide low-cost products to the competitive market, so neither partner can exercise full independence. This collaboration is facilitated by technology, such as Electronic Data Interchange, which allows rapid business-business transfer of information.

Cravens and Piercy (1994) hold the view that mass customising companies are those that practise more sophisticated networking and collaboration than other companies. Furthermore, they suggest that all firms interested in enhancing their relationship marketing abilities should study and adopt mass customisation strategies.

As demonstrated in Chapter Three, supplier collaboration in product development processes brings many benefits to the manufacturer, such as reduced lead time, decreased product cost and increased quality (Monczka and Morgan, 1997). While many studies deal generally with manufacturing processes, Meixell and Wu (2004) discuss supplier collaboration in the context of mass customisation, suggesting that supplier collaboration is even more important for this manufacturing paradigm, because in order to derive maximum benefit to customer and company alike, production processes must be selected which support the performance of all members of the supply chain. Yassine *et al.* (2004), in their discussion of mass customisation in the automotive industry, identify that one main mechanism in the movement from mass production to mass customisation lies in the utility of supplier collaboration to move from internally-focused companies to those which are characterized by knowledge networks. Furthermore, they claim that the capacity of an automotive company to communicate and collaborate with suppliers has direct impact on its ability to mass customise. There is indication, therefore, that supplier collaboration is important in mass customisation. A similar review of lead user collaboration is presented in the following section.

4.2.2 Lead User Collaboration in Mass Customisation

Much literature (see Pine, 1993a, Berger *et al.*, 2005, Kamali and Loker, 2002 for example) discusses customer involvement in mass customisation, and the ways it can be mediated and enhanced. These studies concentrate, however, on individual customer input into the exact form which their requested product will take. The customer order decoupling point, for example, categorises mass customisation ventures according to the level of product development at which the customer can exert choice (Rudberg and Wikner, 2008). Customer co-design describes the strategy of enabling individual customers to define the exact specifications of the products they desire (Berger *et al.*, 2005). Customer collaboration, on the other hand, involves input of customers into the general product development of the company. While customer collaboration is undoubtedly valuable for mass customisation, and therefore important to study, the primary focus of this study is lead users, the select group of customers identified in section 3.3.2 as being essential to product development processes. Lead user collaboration describes the partnership of a small group of customers in the overall product design process: the lead users are not making the final choice for each customer, but they are influencing the range of products from which the final consumers can choose, the variety with which they will be presented, and the mechanisms by which these consumers can customise their products as they choose.

Few studies have addressed the effect of lead users as collaborators in mass customisation, although the role of key customers has long been emphasised. In his review of Pine's seminal work on mass customisation, Womack (1993) notes that a customer's choices are collected by the manufacturer and used for future product design: in this way, the customer plays an integral yet implicit role in product development. Franke and Piller (2003) performed a literature review of work concerning user toolkits in mass customisation, and identified that very few empirical studies had been performed, concluding that the partnership between manufacturers and users (primarily the interaction which is achieved by use of toolkits) was only poorly understood. In response to this lack of a literature undertanding, Franke and Piller (2004) surveyed seven hundred and seventeen subjects as to their willingness to pay for various watch designs. Of these subjects, two hundred and sixty-seven used established "toolkits" to design their own products. Franke and Piller found that participants who designed their own watches showed much greater willingness to pay – almost double that of standard watches. Perhaps more significantly, the other survey respondents also showed a greater willingness to pay for user-designed watches than the standard market offerings, suggesting the value of collaboration with select groups of users. This illustrates the importance of user-generated design, which is a role attributed to lead users (von Hippel, 1986). Kotha (1995) studied the development of mass customisation capability in the National Bicycle Industrial Company of Japan. He identified that product development was based on ideas chosen by "innovative" users, which he noted was consistent with the inventions of von Hippel's lead users. Lead users have therefore been implicitly linked to mass customisation, which provides impetus for further study into the direct effects of such collaboration. The following section explains the specific research question which has been identified for study.

4.2.3 Research Question

While there can be little doubt that collaboration with both suppliers and lead users is a valuable strategy for enhancing product development, the specific effects of collaboration in mass customisation are not well understood. In particular, there is a lack of empirical studies exploring these collaborative partnerships. The need for a detailed understanding of the effects of each collaborative partner in mass customisation, and for a clear assessment of the ways in which collaboration can be utilised to best improve mass customisation performance has been highlighted by a number of academics (Ahlstrom and Westbrook, 1999, Da Silveira *et al.*, 2001, Mikkola and Skjott-Larsen, 2004, Enkel *et al.*, 2005a) .

Manufacturing companies have long recognised and acted upon the importance of suppliers' collaboration in the product development process. Lead users have also been recently emerging as important partners for mass customisation. The literature does not, however, provide an understanding of the effect of such integration or collaboration on the manufacturers' mass customisation performance, nor does it indicate the comparative importance of suppliers to the improvement of the mass customisation outputs compared to the effect of lead users. This leads to the questions which will be addressed in this research:

What are the relative effects of collaborating with suppliers and lead users in the product development processes on mass customisation?

This study aims to investigate and compare the impacts of supplier and lead user collaboration on mass customisation performance. In order to achieve this, a measure for the performance of a mass customisation venture must be adopted. The following section details the rationale behind the selection of four mass customisation attributes for this study.

4.3 Measuring Mass Customisation Performance

There are significant advantages for manufacturers that adopt mass customisation strategies, not least in the areas of increasing market competitiveness and maintaining operational efficiency. There is an ongoing quest, therefore, within academia and industry alike, to determine the means by which a company can best maximise its performance, and reap the benefits of mass customising. In order to make such assessments, there must be some form of quantitative measure of mass customisation performance. Mass customisation capability is the ability of a firm to manufacture products that satisfy customer demand at a cost and speed similar to mass production. In order to study the effects of collaboration on mass customisation capability, representative measures must be selected to adequately gauge the operational performance of product development processes. The selection of these measures, which will be referred to as attributes, are discussed in the following section.

4.3.1 Attributes of Mass Customisation

The attributes of mass customisation are the main characteristics that describe the outcomes of the mass customisation processes. They hold positive values that the manufacturer attempts to achieve and which should increase the value delivered to the customer, therefore increasing the appeal of the products to the consumers. Although mass customisation attempts to satisfy the desires of all consumers while maintaining operational efficiency, in reality companies must select limited attributes which reflect customer desire, and measure the importance of each attribute in each manufacturing situation against operational performance (Cavusoglu *et al.*, 2007).

Zipkin (2001) cites customer preferences (influence) in various product attributes as the key driving force for mass customisation. He also argues that companies are limited in their ability to fully mass customise, but that they must instead select ways in which to offer variety. For the most successful mass customisation processes, therefore, manufacturers must select the operational attributes which lead to the desired outputs for the customer.

Because of the great variety between industries and customers, there is no definitive list of mass customisation attributes. While ultimately an appropriate set of attributes is specific to a company and therefore must be derived *in situ*, there are points of similarity across firms and industries, and various studies have attempted to summarise the principle attributes for consideration.

MacCarthy *et al.* (2003a) performed five case studies across different industries to explore the factors which influence the implementation of mass customisation. From these studies, they identified ten attributes which describe aspects of mass customisation from the perspective of the customer. *Dimensional fit/size* refers to adjustments and scaling of the product to suit the customer's requirements. *Hardware function* describes alteration, addition or removal of pieces of hardware.

Software function similarly describes alteration of the programming. *Property of the whole product* involves changing an overall feature such as corrosion resistance. *Grade* changes are usually made to alter cost by up- or downgrading the product without altering the function. The next attribute of mass customisation is *quality level,* which describes the selection of components for their performance, such as reliability. *Aesthetics and style* refers to changes to the physical appearance of the product. *Personalisation* tailors the product to the individual by, for example, adding a name or logo. The attribute of *literature* refers to the addition or alteration of manuals or other documentation. *Packaging* is the final attribute, which describes the process of altering the physical appearance of the packaging, or adding or removing components from the final package. However, these attributes of customers can be met by a much more compact list of operational attributes or outcomes, as will be discussed below.

Skjelstad *et al.* (2005) suggested that mass customisation capability should be assessed in terms of only three attributes: cost, time and customisation, which can be considered along axes in three dimensions (Figure 4.1). In defence of this selection of objectives, they argue that the categorisation of mass customisation according to the customising ability alone is insufficient to measure manufacturing capability, and that a company which achieves high customer integration without also offering low cost and short lead time cannot be considered a true mass customiser. Instead, the integration of the customer must be considered on balance with the cost and lead times which can be offered by the manufacturer.

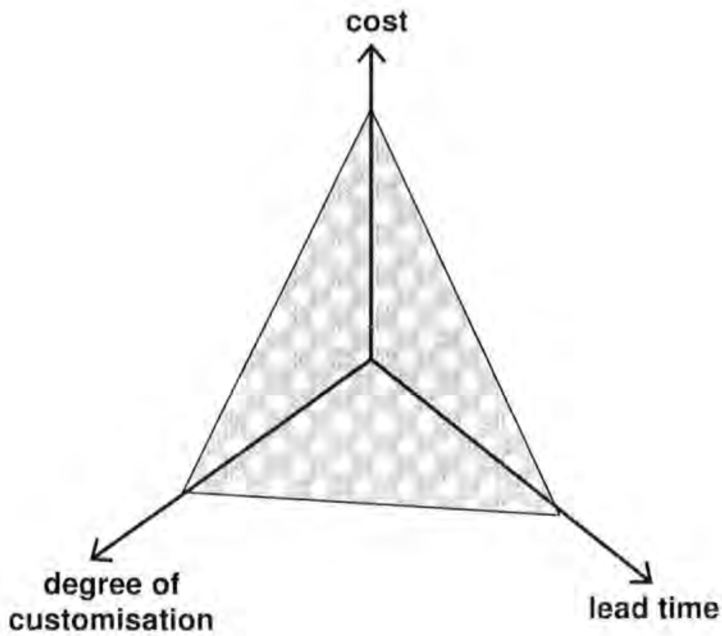


Figure 4.1: Three-dimensional view of mass customisation success. Redrawn from Skjelstad *et al.* (2005)

Wellborn (2005) described an index for mass customisation performance which included a set of four attributes: low cost, short lead time, customer influence and product scope. Wellborn claims that while the attributes do not encompass all aspects of financially successful operations, they include the operational aspects of mass customisation and describe the mass customisation capability of an organisation. Indeed, his selection of elements is similar to that of Skjelstad *et al.* (2005) but with the added objective of product scope.

On the basis of these various studies and their suggested measures of mass customisation operational performance, four attributes have been selected for this research. These attributes are similar to those proposed by Wellborn, but are particularly concerned with the product development processes, which are the focus of this study. The four attributes are low development cost, short product development time, wide product scope, and high customer influence. These four describe very distinct elements of mass customisation, and therefore allow for study of the broad effects of collaboration on mass customisation operational performance. Because of this breadth, these attributes will be suitable for probing a wide range of facets of the process, while avoiding an overwhelmingly large number of aspects. Each attribute will be discussed in turn.

4.3.1.1 Low Product Development Cost

By its very definition, mass customisation attempts to achieve the low costs offered by mass production (Hart, 1995). Low cost is a marker of competitiveness, and is not measured on an absolute scale, but relative to the rest of the market. This attribute of low cost is heavily influenced by the costs incurred by the manufacturer, namely those arising from the development, design and manufacturing processes of product development, and these will constitute the low cost dimensions of this study. This research operationalises the low cost as a function of the summated costs for the entire product development process.

Anderson (2003), in an attempt to dispel some myths regarding the achievement of low cost, cautioned that volume is not a requirement of low cost, as was the experience of mass producers. He argued instead that mass customisation involves the establishment of strategies to achieve low cost regardless of the volume. Furthermore, Anderson warns that the use of cheap parts and cost cutting efforts do not lead to low cost. For an example, an extended study of 800 companies by Mercer Management Consulting identified 120 companies as "cost cutters", but noted that only one third of these companies enjoyed profits over a five year period (Atkins and Slywotzky, 2001).

Anderson suggests instead that strategies to lower cost must focus on the product development process. He notes that eighty percent of the total product cost is tied up in the product design, and therefore cannot be reduced by other cost reduction strategies. It is the product development process of mass customisation with which this study is concerned, and it is therefore appropriate that low development cost is considered as an attribute. The concept of product development cost in this study will be used to describe the costs incurred at all stages of product development, from idea generation, through product design and ending with final product configuration.

4.3.1.2 Short Product Development Time

The second attribute of mass customisation operational performance which has been chosen for this study is short development time. Blackburn (1991) documented the shift in the 1980s from manufacturing strategies focussed on low cost and high quality to one of speed, citing the reason for this shift as a need to retain competitiveness. He identified three aspects to overall time, each of which the manufacturers sought to minimise. *Product development cycle time* describes the period required to convert an idea to a product, while *manufacturing lead time* is to the total time elapsed from conversion of raw materials to finished goods and subsequent delivery to the final destination. *Response time* corresponds to the period from customer order to receipt of the product. For the purposes of this study, the term development time will encompass the time from generating the ideas until the final development of the product, and will be composed of idea generation and concept development time, product design time, and product configuration time.

Product development time is therefore distinct from the time periods proposed by Blackburn (1991). Since there are overlaps between these definitions of time, however, factors which are understood to decrease lead time, for example, are likely also to lead to decreased product development time. In the case of mass customisation, it is difficult to determine when the development time ends due to the involvement of customers in determining the final product configuration. As a result, the product development time will describe the time which passes until the product reaches its final configuration.

Anderson (2003) and Chandra and Grabis (2004) both emphasise the importance of shorter development time in mass customisation. They focus on the essential implementation of procedures to minimise the development time, in various ways such as through modularity, and through minimisation of the time consumed by suppliers. This study therefore aims to understand the impact of collaboration with suppliers and lead users on the attribute of short product development time.

4.3.1.3 Customer Influence

The level of customer influence reflects the extent to which a manufacturer allows customer involvement in the customisation process. Low customer influence is typified by a company which gives customers no power over the available choices of features or options, while high customer influence allows for customer self-configuration of the product, e.g. using users tool kits, virtual platforms, and other technological mediums.

Kellogg and Nie (1995) discussed customer influence in the context of service management. They noted that the term encompasses the activities of customer contact, customer interaction and customer participation, and describes the way in which customers can affect product or service development processes. The exact level of customer influence corresponds to the particular way in which this influence is achieved: customers can exert influence through presence, interaction or participation, corresponding to low, medium and high levels of customer influence respectively.

Duray *et al.* (2000) identified customer influence and modularity as the two dimensions by which mass customisers could be categorised and their mass customisation capabilities assessed. They defined a high degree of customisation as one in which customers are involved in design stages of the production cycle, for example by requesting a unique design or specifying new product features. On the other hand, companies are said to only customise to a low degree when they involve customers only in the assembly and distribution phases. This may take the form of a list of features from which the customer can choose, assembly of the requested product from components in stock or provision of components with which the customer can assemble the product.

The mass customisation attribute of customer influence describes the extent to which the manufacturer is driven by customer need in product development. Customer influence can therefore, in a sense, be considered to be a marker of the degree of customisation, as described by the continuum of Lampel and Mintzberg (1996), for example. The importance of customer influence has long been understood (Rothwell, 1993, Cooper and Kleinschmidt, 1987), and continues to be of interest to academics (Callahan and Lasry, 2004, Enkel *et al.*, 2005b), who note that the principal method of ensuring high customer influence is to involve customers in the new product development processes – that is, to collaborate with them.

Customer influence has therefore been selected as one of the attributes by which mass customisation will be measured in this study. Customer influence will include the allowance for higher customer involvement at any of the stages of product development. In particular, three modes of customer influence will be considered: enabling customers to select product features, to self configure the product features, and the ability to design their own product features. Higher customer influence will be manifested by companies allowing the involvement of customers in all three modes.

4.3.1.4 Product Scope

Product scope represents the variety of products which are offered by a company. From the viewpoint of the customer, it corresponds to the possible range of products from which they can choose. From a manufacturing viewpoint, product scope represents the range of products existing at the end of the development or customisation process, and specifies the boundaries for a firm's product options. These include all variations of the product such as size and shape, and the different features that can be added or offered to customers.

The literature supports the use of either a linear (Hotelling, 1929) or circular (Salop, 1979) model, where distribution across the line or circle represents the variety of products. A company which practises no customisation will have a strategy represented by a single point, while a cluster of points along the line or circle signify high customisation. The mass customisation strategy of a company is represented by a continuous region of the line or circle, and the company offers the full range of product variety in this segment. This variety is referred to as the product scope (Mussa and Rosen, 1978).

Lancaster (1990) performed a comprehensive review of literature concerning product scope in industry, citing the beginnings of the theory of product variety in the 1920s and 1930s in response to deviations from the traditional models of market monopolies and competition. He noted that companies are driven to increase their product scope by one or more of a number of factors: individual consumers' desire for variety, different tastes amongst groups of consumers, increased profits enjoyed by firms as a result of variety and increased profits as a result of a firm making its products different from those of competitors.

Rumelt (1974) documented the dramatic increase in product scope over the three decades following World War II. He also noted that firms exhibited a wide range of product variety, and suggested that greatest profit was gained from companies who had a wide product range but with commonalities between their products. These observations were confirmed in a later study of five hundred companies (Rumelt, 1982). More recent studies have questioned the simplicity of this relationship: Palich *et al.* (2000), for example, reviewed fifty-five studies, and concluded that while performance initially increased with product variety, it reached a maximum point after which it decreased. This was confirmed by a subsequent study of Spanish manufacturing firms (Aleson and Escuer, 2002).

Product scope has long been recognised as an important attribute of mass customisation. When first writing about the paradigm, Pine (1993a) noted that mass customisers' achievement of "variety and customisation through flexibility and quick responsiveness" (p. 44) is the controlling focus of mass customisation. He also stated that while mass production focuses on economies of scale, the strength of mass customisation lies in its practise of economies of scope – that is, rapid production of a wide variety of products.

The product scope is limited by the extent of a manufacturer's capability to customise. For example, a factory may only be able to construct products up to a certain size, or with a certain number of added features. Product scope can limit customer influence, as a manufacturer can only generate products within its scope, and therefore cannot offer limitless possibilities to the customer.

Product scope is therefore selected as the final attribute of mass customisation for this research. In this study, product scope is defined along three dimensions: range of products (depth), scope of features (length), and number of product lines (width). Greater product scope is therefore manifested in increases in these three dimensions: a deeper product range, a broader scope of features and a wider number of product lines. The range of products relates to the various market segments to which an operation is aiming to sell its product and to the number of product variants in a line. The features of products offered refers to the minor variations that a company may offer in all production lines (for example colour, options, and accessories). Finally, the number of product lines describes the width of the product offering (such as different car models).

4.3.1.5 Characterising Mass Customisation and its Antecedents

These four attributes are appropriate for the study of mass customisation as they encompass the factors which differentiate the process from its two antecedents, mass production and craftsmanship, as shown in Table 4.1. While craftsmanship allows for very high customer influence, and very broad product scope, mass customisation offers significantly lower development costs and shorter development times. Conversely, while mass production already provides these low development costs and short (in many cases, negligible) development times, mass customisation can achieve the high customer influence and broad product scope that mass production lacks.

Table 4.1: Comparison of characteristic attributes of mass customisation and its antecedents

	Development Cost	Development time	Customer Influence	Product Scope
Craftsmanship	High	Long	High	Broad
Mass production	Low	Short	Low	Narrow
Mass customisation	Low	Short	High	Broad

4.4 Hypothesis Generation

As discussed above, the research question for this study is:

What are the relative effects of collaborating with suppliers and lead users in the product development processes on mass customisation?

The study therefore aims to gain information about supplier collaboration and lead user collaboration. The previous section described the section of four attributes to measure mass customisation performance. From these variables, eight relationships can be derived, describing the effect of each type of collaboration on each mass customisation attribute, as shown in Figure 4.2.

From this framework, eight hypotheses can be derived. This section describes the literature precedent for each hypothesis.

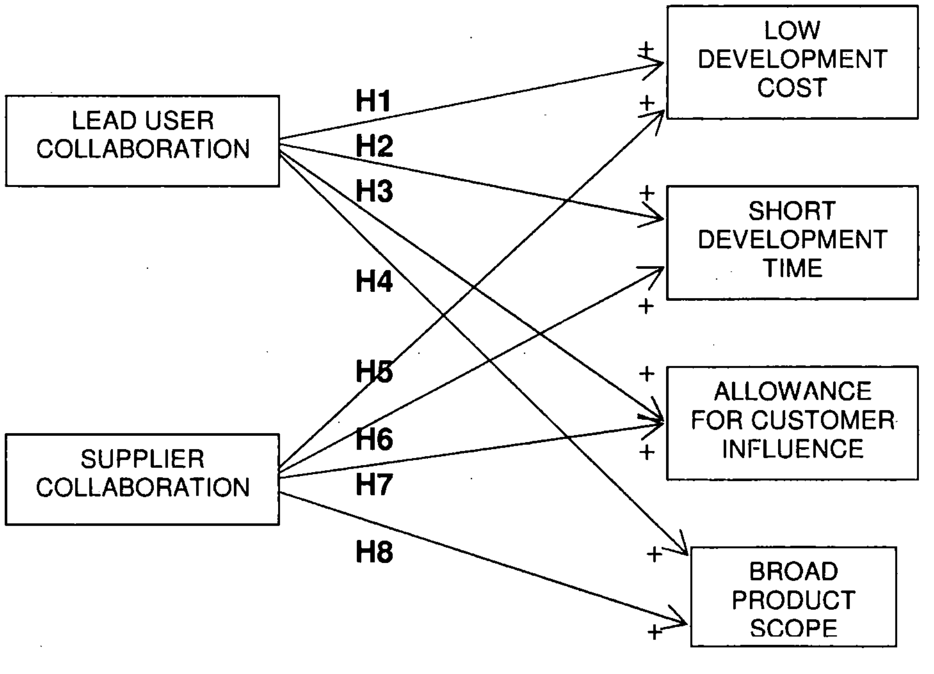


Figure 4.2: Conceptual model for the research

In general, while a number of studies have identified the effects of collaboration in product development processes, relatively fewer studies have addressed the importance of partnerships in mass customisation itself. Nevertheless, it is the belief of the researcher that general industrial trends are likely to also be reflected in the specific case of mass customisation, so this more general literature will therefore form the basis of the hypothesis generation. Similarly, while the focus of this study is on the effect of lead users, many studies have investigated users in general. This literature studying the broader category of customers will be considered in the generation of the hypotheses, but it is important to note that only lead users will be investigated in this study. What this relative lack of studies of mass customisation and lead users in specific does demonstrate, however, is the importance of this research. While the following discussion demonstrates that it has been shown that supplier collaboration is important in product development processes in general, it is important to understand this partnership in mass customisation in specific. Similarly, studies of customer involvement in both mass customisation and other new product development processes alike has typically focussed on the role of users in general, and not lead user collaboration in specific. Since lead users are an important partner in their own right, as discussed in Chapter Three, it is important to gain a specific understanding of this partnership. In addition, and just as significantly, this study aims to compare the importance of the contributions of suppliers and lead users.

4.4.1 Hypotheses Concerning Lead User Collaboration

The objectives of this research are to understand the effects of supplier and lead user collaboration on mass customisation performance, and to gain an indication of the relative importance of each partner. This section focuses on the role of lead user collaboration, and the hypotheses which have been generated to assist in the study of this factor.

This research attempts to gain an understanding of the effects of lead user collaboration in terms of the four attributes of mass customisation. These four attributes of – low development cost, short development time, customer influence and product scope – represent aspects of the success of a mass customisation venture, as explained in section 4.3 above. The benefits to the mass customisers of achieving these operational attributes take the form of increased competitiveness due to their ability to better satisfy their customers. But these attributes also represent benefits which are enjoyed by customers themselves. Low development cost and short development time, which lead to low product cost and short order-to-delivery time, are both desirable to the consumer. As discussed in Chapter Two, the foundation of mass customisation is based in a market response to customer's demand for personalisation, which is achieved through an allowance for customer influence, and a broad product scope. It is therefore in the interest of the lead users to spur companies on to the achievement of these four attributes, which will also benefit them as customers. It might therefore reasonably be assumed that collaboration with lead users will significantly and positively affect the four attributes of mass customisation. That is, there are strong conceptual grounds for presupposing a relationship between lead user collaboration and the four attributes of mass customisation, which forms the basis of the first four hypotheses of this research. Specific discussion of each attribute, with the literature basis for the generation of each hypothesis is provided below.

As discussed before, much of the literature discusses the broad group of customers as a whole, rather than lead users. This literature has, however, been used as the basis for exploring the hypotheses. This relative lack of research about the specific role of lead users is a significant driving force for this study.

4.4.1.1 Development Cost

The first four hypotheses describe the relationship between lead users and the four operational performance attributes of mass customisation, as shown in Figure 4.2. The first of these attributes is product development cost. The greatest advantages of lead user collaboration on product development cost are likely to be gained through decreased cost in the idea generation stages (Herstatt and von Hippel, 1992). The involvement of lead users should replace more widespread market research amongst general customers, which is more expensive and less efficient. In addition, a number of studies have identified that lead user generated ideas are more likely to result in successful products (Shah, 2000, Lilien *et al.*, 2002); this decreased failure rate will also be manifested in decreased product development cost.

As discussed above, lead users who collaborate with manufacturers are likely to suggest products which will bring benefit to them as customers. One of the most tangible of such benefits is low cost. That is, while the chief aim of lead users is to create product solutions for their needs, it is in their interest to innovate towards less expensive products. The interest of this study, however, is product development cost, rather than final product cost. It is therefore valuable to consider the putative effects of lead user collaboration on product development cost.

While no study has been performed to investigate the effect of lead user collaboration in mass customisation and low development cost, it has long been understood that the involvement of customers, and understanding of customers needs, leads to benefits to the customer, notably in the form of cost savings due to reduced expenditure on research and focused expenditure on the development of product processes based on their value creation (Utterback *et al.*, 1976, Buzzell and Gale, 1987, Cooper and Kleinschmidt, 1987). Decisions about product design have a high effect on the budgeted costs of the product development (Elfving, 2007). Failure to involve users in the design process will therefore increase the risks of design changes in the testing phase of the product, and might even lead to the failure of the design, particularly in beta testing. Since these testing phases involve tests carried out by customers, the prior involvement of users in the product design might be expected to increase the success rate of product testing. These effects are likely to be magnified in the case of lead users, whose product development input has been shown to be of even greater value (Lilien *et al.*, 2002).

These arguments are the rationale behind the first hypothesis:

H1: that there is a significant positive relationship between lead users' collaboration in product development processes of mass customisation and low development cost

4.4.1.2 Development Time

The second relationship of interest is that between lead user collaboration and development time. As for development cost, lead user collaboration is likely to afford greatest benefit during the idea generation stage of product development. Lead users are characterised by their ability to innovate (Luthje, 2000); in many cases they already have the idea for a new product prior to being requested to collaborate. As a result, the time spent on market research can be greatly decreased upon involvement of lead users (Harhoff *et al.*, 2003). Indeed, Herstatt and von Hippel (1992) indicated that companies experienced that concept development time occurred twice as fast in cases where lead users were involved.

The relationship between lead users and product development time has not previously been directly studied. Scott *et al.* (2001) suggested that involvement of customers in product development processes lead to greater impact of customer-driven demand for short lead times. As a result, companies seek to alter their practices to achieve such short production times. Whipple and Gentry's (2000) survey results indicated that manufacturers were motivated to collaborate with customers by the reduced cycle and lead times that they enjoyed as a result of such partnerships. The specific involvement of lead users would decrease the time spent on marketing research and focus the development efforts on specific ideas (Harhoff *et al.*, 2003). As discussed above, decreased product development time is also likely to be experienced as a result of user collaborations due to the decreased risk of design changes compared to situations in which there is no user involvement (Elfving, 2007). In particular, the input of lead users can be expected to generate product designs which more adequately fulfil customer desire, and therefore are more likely to pass the product testing phase, without increased time spent on excessive modifications or product redesign.

The above arguments lend support to the second hypothesis:

H2: that there is a significant positive relationship between lead users' collaboration in product development processes of mass customisation and short development time

4.4.1.3 Customer Influence

The third mass customisation attribute of interest in this study is customer influence, which describes the extent to which a company enables the end user to determine the product configuration. This ability to exercise control over the final product is likely to be an attractive property to most customers, particularly to lead users, who are characterised by a desire to find a solution to their needs: the ability to self-customise a product would cater for individual needs even further. It is therefore plausible to predict that lead users will suggest products which have the capacity for customer-determined product configuration.

Collaboration with lead users has been implicated as an important means of achieving customer influence. Herstatt and von Hippel (1992) found, in their study of a low technology industry, that 80% of consumers preferred the products influenced by lead users, suggesting that lead user collaboration is a good reflection of general customer demand. In particular, products designed by lead users involved modular components which could be self-assembled, and final products which could be combined in various configurations according to need. This suggests that lead user designs catered for a high level of customer influence. Shah (2000), in his study of sporting equipment manufacturers, made a similar finding, noting that new product ideas suggested by lead users had the greatest importance due to catering for the customer need to configure the final form of the product.

The above arguments form the rationale behind the third hypothesis:

H3: that there is a significant positive relationship between lead users' collaboration in product development processes of mass customisation and high allowance for customer influence

4.4.1.4 Product Scope

The final attribute of mass customisation operational performance which will be considered in this study is product scope. As discussed earlier, product scope describes the range of products developed by a company. There are three dimensions by which product scope may be described: the range of products, the scope of features and the number of product lines. As has previously been suggested, lead users aim to gain maximum benefit from their collaboration. Since they have the same desires of general customers, albeit with more urgent needs, lead users are therefore likely to collaborate in such a way that results in achievement of these desires. Lancaster (1990) argued that companies are strongly driven by a need to satisfy consumers desire for variety, and by the pressures of many consumers with a wide range of tastes. Lead users who are involved in product development are likely to add further impetus to this drive, and therefore result in increased product scope.

One essential method which is utilised by companies to increase their product scope is the development of new products, which both widen their product range, and increase the number of product lines. A number of studies have recognised the importance of lead users on the development of new products (Franke *et al.*, 2006, Luthje, 2004, Herstatt and von Hippel, 1992, Franke and Piller, 2003, Morrison *et al.*, 2004). Greater involvement of lead users is therefore likely to increase the product variety through a broader range of products.

The above arguments lend support to the fourth hypothesis:

H4: There is a significant positive relationship between lead users' collaboration in product development processes of mass customisation and broad product scope

4.4.2 Hypotheses Concerning Supplier Collaboration

The second collaborative partner investigated in this study is the supplier, which will be the focus of this section. While supplier collaboration has been somewhat better studied than lead user collaboration, as will be discussed below, it is nevertheless important to gain an understanding of the relative effects of supplier collaboration with respect to all four attributes of mass customisation. In addition, in order to weigh the contributions of supplier and lead user collaboration to mass customisation performance, it is necessary to develop a common platform by which to compare the two partners. In this study, as discussed in section 4.3, the platform will be the four mass customisation attributes. As a result, the following four hypotheses have been developed to mirror the hypotheses relating to lead user collaboration, and therefore to allow meaningful comparison of the relative contributions. Each hypothesis will be discussed below.

While it was important to develop these four hypotheses to enable comparison with lead user collaboration, there is nevertheless much literature to support the adoption of each hypothesis. This literature is reviewed in the following section.

4.4.2.1 Development Cost

There is much evidence that supplier involvement in product development processes results in the generation of many new ideas which either take the form of new products ideas, new production processes, new technological innovations, or the exchange of expertise and technological know-how (Afuah, 2000, Afuah and Bahram, 1995). These can lead to increased financial benefits for the manufacturer in the form of expenditure savings, decrease in cost centres such as elimination of low added value processes through process re-engineering and the introduction of more economic and efficient processes thus resulting in lower product development cost (Carr and Pearson, 1999). Ragatz *et al* (2002) discussed the involvement of suppliers in knowledge-sharing, and highlighted potential benefits of decreased capital and operational costs. Further decreases in cost can be experienced due to the fact that supplier involvement allows identification of potential problems in the product development process before production begins, which results in decreased costs associated with repair or redesign (Handfield, 1994, Dowlatshahi, 1997, Meyer, 1993). Collaboration with suppliers also involves shared costs between the two firms, resulting in a reduction in the product development costs of each firm.

Studies of mass customisation processes have also highlighted the link between supplier involvement and decreased cost. Tu *et al.* (2007) found that with careful selection of suppliers, and rigorous management of the levels to which they are involved, collaboration with suppliers can effectively lead to decreased cost in mass customisation ventures. These costs refer to the final cost to the consumer, rather than product development costs. However, on the basis of the literature described above which predicts decreased costs as a result of supplier collaboration, it can be expected that product development costs, which form a large part of total cost, will also be minimised.

As a result of these studies, it can be hypothesised:

H5: that there is a significant positive relationship between suppliers' collaboration in product development processes of mass customisation and low development cost

4.4.2.2 Development Time

Smith and Reinertsen (1991) suggest that decreased product development time could be achieved through incorporation of suppliers into product development teams to encourage them to add their information and expertise to the generation of new ideas. In a similar vein, Ragatz *et al* (2002) noted that companies which involve suppliers in activities of knowledge sharing and dissemination will experience decreases in both product development and concept-to-customer times. The early identification of potential problems in product development which is enhanced by supplier collaboration (Dowlatshahi, 1997) is also likely to lead to decreased cycle times. Decreased production cycle times arise from shortened critical path lengths which result from the shift from linear to branched manufacturing systems experienced by companies which involve suppliers (Clark and Fujimoto, 1991). Eisenhardt (1995) studied product development projects in the computer industry, and identified that early supplier involvement could effectively reduce product cycle time, but only for mature industries. Whipple and Gentry (Whipple and Gentry, 2000), from their survey of one hundred and eighty manufacturers, identified reduced cycle and lead times as principal motivations for companies to collaborate with material and service suppliers alike. Supplier involvement often also involves increased modularity (Alford *et al.*, 2000, Perez and Sanchez, 2001), which can further reduce development time.This leads to the sixth hypothesis:

H6: that there is a significant positive relationship between suppliers' collaboration in product development processes of mass customisation and short development time

4.4.2.3 Customer Influence

There is little evidence in the literature for a link between industrial supplier collaboration and customer influence. However, it has been shown that service suppliers have a role in facilitating customer influence. Alford *et al.* (2000) discuss supplier involvement in mass customisation among automotive manufacturers, and speculate that in order to facilitate customers to convey their needs, the manufacturer might utilise a third party (a supplier) to interact with the customer, thus indicating poor input from suppliers on that dimension. Whipple and Gentry (2000) noted that customer involvement was a motivator for companies to collaborate with suppliers, particularly with service suppliers: they found that it was in fact the most important motivator for collaboration with this group of suppliers, although this study did not focus on the manufacturing sector.

Despite the weak logical foundation behind the relationship between supplier collaboration and the allowance for customer influence, there is a literature basis for the proposition of the seventh hypothesis:

H7: that there is significant relationship between suppliers' collaboration in product development processes of mass customisation and higher allowance for customer influence

4.4.2.4 Product Scope

The final hypothesis relates to the relationship between supplier collaboration and product variety. Involving suppliers allows the use of sophisticated modularity (Alford *et al.*, 2000, Perez and Sanchez, 2001), which can increase an operation's ability to change the configuration of its products. Furthermore, closer involvement with suppliers may result in development of supplier capabilities, which increases flexibility and therefore product variety (Krause *et al.*, 2000, Day, 1994). Finally, suppliers who are more involved in the new product development process are more likely to be committed to the buyer firm for future business (Gassenheimer *et al.*, 1995). This commitment may in turn lead to openness to adaptations as circumstances change (Heide and Miner, 1992), which will result in higher product variety.

Therefore, the eighth hypothesis is:

H8: There is a significant positive relationship between suppliers' collaboration in product development processes of mass customisation and broad product scope.

4.5 Conclusions

The literature review which has been presented in this thesis has demonstrated the importance of mass customisation as a manufacturing paradigm, and the need to develop understanding of the ways in which mass customisation performance can be improved. Collaborative product development has been identified as a tool for achieving success in mass customisation, in particular through the partnership with suppliers and lead users, and notably in their early involvement from the concept development stages. This chapter has detailed the current understanding of the roles and advantages of collaborative product development in mass customisation, and has led to the generation of the research problem. This work seeks to gain an understanding of the effects of collaboration with suppliers and lead users, and to determine the relative value of each collaborative partner. An understanding of these factors would not only add valuable academic understanding to the literature concerning mass customisation, but could also be of value for industry, where it is important for companies to concentrate on strategies which will be of greatest advantage to their performance.

In order to study these research questions, a set of four attributes of mass customisation have been defined in order to measure the operational performance. These measures are development cost, development time, allowance for supplier involvement and product scope. It is one aim of this study, therefore, to determine the effects of each collaborative partner (suppliers and lead users) on each mass customisation attribute. This gives rise to eight hypotheses, describing each of these relationships. The final section of this chapter has outlined the conceptual basis for each set of hypothesis, and followed with current literature understanding which provides support, whether full or partial, for each. The next chapter describes and explains the research methodology which has been selected for the study of these hypotheses.

EMPIRICAL TESTING

CHAPTER FIVE

RESEARCH DESIGN AND METHODOLOGY

CHAPTER FIVE: RESEARCH DESIGN AND METHODOLOGY

5.1 Introduction

This chapter describes the methodology used to test the conceptual model proposed in Chapter Four and details the test instruments employed. Sekaran (2003) defined research as an organised, systematic, and data-based scientific enquiry or investigation into a specific problem with the aim of finding an appropriate solution. Similarly, Bryman and Bell (2003) and Collis and Hussey (2003) stressed the importance of a systematic process of inquiry in order to add to the library of knowledge, for theorists and practitioners alike. As a result, this research will address the existing problem by employing a rigorous, systematic and appropriate methodology explained herein.

A combination of theoretical and empirical approaches was employed in collecting the data, and a thorough study of literature was conducted as described in Chapters Two, Three and Four in order to identify key issues and to gain insight into the area of mass customisation, the role of suppliers/lead users in the development of new products, and current understanding of their effects on mass customisation characteristics (attributes). The arguments of different writers in the field of mass customisation have been critiqued and some of their conclusions relating to the main hypotheses of the research will be challenged through this research in order to reach the outcome derived from hypothesis testing. The testing and validation of the research instrument used to collect data from the chosen sample will be described later in this chapter.

Quantitative methods (exploratory factor analysis and regression analysis) were used to analyse the data collected from questionnaires and to test the hypotheses proposed. As a result, this research is expected to follow an inductive and deductive approach in testing the hypothesis and the theoretical framework (Bryman and Bell, 2003).

This chapter describes the development and implementation of the research tool which was selected to study the research problem. The following section contains discussion of the specific approach which was adopted.

5.2 Research Method

This study seeks to investigate the relationships between the key players in the mass customisation process, and to determine the relative effects each group has on the attributes of mass customisation. In order to draw meaningful conclusions, it is important to apply the most appropriate research methodology. This section outlines the rationale for the approach which was selected.

The aim of this research is to gain an understanding of the effects of partnership within the mass customisation industry as a whole, and the relationship between the various partners. In order to achieve this purpose, and to ensure the generisability of the findings, it was necessary to collect data from different industries of the consumer products manufacturing sector. This section discusses and provides the rationale for the selection of a mail survey as the research instrument.

Survey research is a useful research tool as it encompasses a number of research techniques, and has advantages of broad coverage and wide application (Campbell and Katona, 1953). Indeed, surveys form the basis of the data collection process of a majority of business studies (Ghauri and Gronhaug, 2002), and the application of survey techniques in production and operations management research has experienced success (Malhotra and Grover, 1998). In mass customisation literature, there is a lack of survey studies: most research is conducted using case studies (Comstock *et al.*, 2004, Kotha, 1996, Spring and Dalrymple, 2000, MacCarthy *et al.*, 2003b). The use of surveys as the main research method will lend meaningful input to the current literature of mass customisation as well as providing a powerful tool for generalising conclusions and deriving suggestions for application in industry, as will be discussed herein.

A survey involves collection of data by administering a standardised questionnaire to a sample of respondents. By its very nature, survey research requires particular care to be taken in the development of the survey tool. In order to be able to compare responses given by different subjects, surveys questions must be standardised, and carefully prepared to study relationships between variables. Since the information is being collected from a fraction of the population, this sample must be carefully selected so that findings can be meaningfully generalised to the population as a whole (Malhotra and Grover, 1998). The population of this study is the United Kingdom's consumer products manufacturers, which are a good representation of global products manufacturers. The sample determination is an integral and significant part of the survey development because it must be carefully chosen to represent the true distribution of the audience and respondents of the questionnaire, as will be shown in later sections.

Responses to questionnaires may be obtained in a written form, as for mail surveys, or orally, as in interviews. Surveying by mailed questionnaires has a number of advantages over other survey techniques: the method has low cost and high convenience, and enables sampling of a larger proportion of the population than would be possible for face-to-face interviews. Mail surveys also decrease the risk of personal bias as there is no personal contact between the subject and the researcher. It has also been shown that preserving respondents' anonymity increases the response rate of the survey (Faria and Dickinson, 1996). An added advantage of the written medium of the mail survey compared to oral questioning is that it allows for the use of scales, which will be discussed later. For these reasons, this study will utilise mail surveys to distribute the questionnaire to the UK consumer products manufacturing sectors.

One weakness of mail surveys lies in the low response rate compared to other techniques. Numerous studies have been performed to identify ways in which to increase this response rate, as reviewed by Kanuk and Berenson (1975) and Greer *et al.* (2000). Another disadvantage of the technique is the difficulties which might be faced by the respondent in understanding and answering the questions. These limitations and the possible procedures to overcome them will be addressed in the following sections.

5.2 Survey Design and Administration

5.3.1 Introduction

As discussed above, a mail survey was selected as the research tool. The following sections describe the methods used to develop and administer the questionnaire and the procedures followed to ensure the reliability and validity of the questionnaire.

Figure 5.1 overleaf shows the stages of survey development and implementation which were followed in this study. As shown throughout Chapters Two to Four, an extensive literature review was performed to develop the theoretical framework, and in particular, the research problem. Based on this research problem, and a further literature review of previous surveys, a preliminary questionnaire was developed. The questionnaire was first presented to focus groups of operations and product development managers, which led to refinement of the research tool. This modified questionnaire was then trialled in a pilot study. As a result of statistical testing and evaluation, further modifications were made to the survey. Based on a consideration of the research question, the sample population was determined, and it was to this group that the final version of the questionnaire was administered. Following the collation of responses, the resulting data was analysed, as will be described in Chapter Six. The following sections describe the various stages of survey development and implementation in more detail.

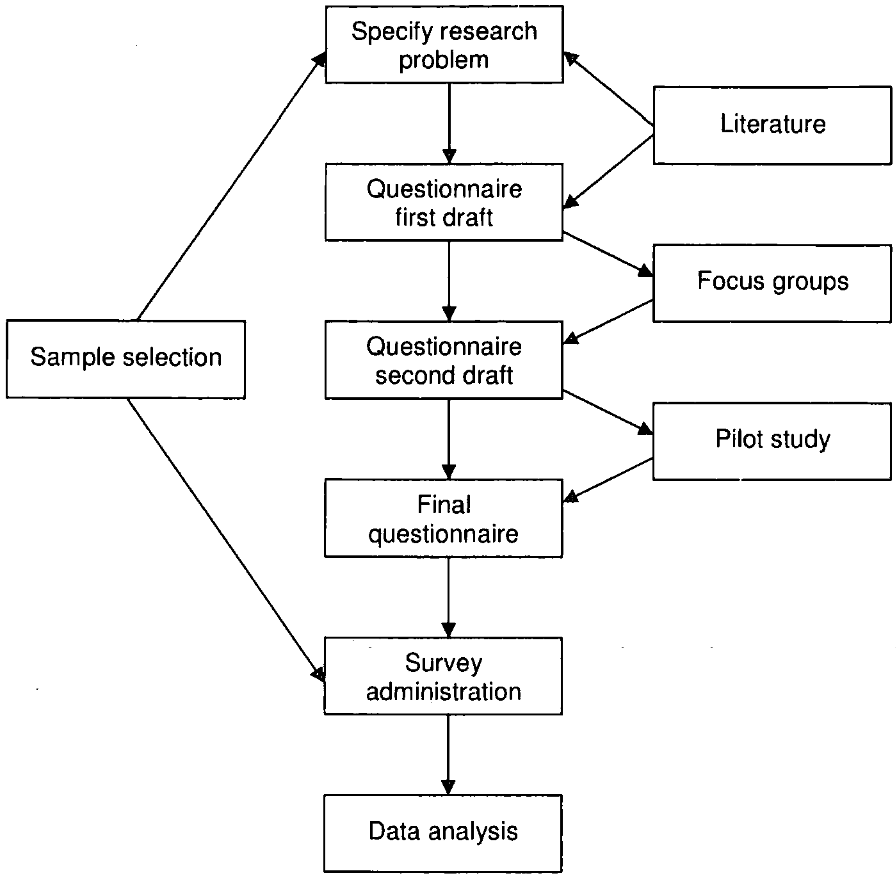


Figure 5.1: The stages of survey development and implementation

5.3.2 Scale Design and Development

The use of surveys as the research instrument generates large amounts of qualitative data. In order to make comparisons between responses, it is necessary to use a device to summarise the data, generalise the attitudes expressed, and perform statistical analysis. This can be achieved by utilisation of a scale. In the case of a survey, a scale attempts to quantify the intensity of the attitudes of the respondent (Moser and Kalton, 1971). Design of a scale involves selection of quantitative variables by which to characterise objects (in this case, responses) so that each element is a simple function of those variables (Guttmann, 1944).

Scales can be divided into three groups, as defined by Torgerson (1958) according to basis of the scale score. These classes are stimulus-centred scales, subject-centred scales and response scales. The term stimulus refers to the items (or questions), while the subject is the respondent. For stimulus-centred scales (or judgment scales), the stimuli are assigned scale values. Subject-centred scales, on the other hand, are based on the concept that variation in responses between subjects results from differences between the subjects themselves. As a result, scale values are assigned to the subjects. Importantly, for this class of scale, addition or removal of stimuli from the same group of stimuli does not have a significant effect on the results (Prieto and Sacristán, 2004). The final class, response scales, have scale scores that vary according to both subject and stimulus. Since this research attempts to compare the responses of different companies with respect to their mass customisation attributes and abilities, the most appropriate scales will be subject-centred.

There is a vast range of scale formats that may be adopted, resulting from the altering of many variables. The number of scale points can be varied (usually two, three or five), as can the degree of specificity or generality. There is also great variation in the description of the scale points through the use of anchors: it may be that each scale point is given a descriptor, or only those at the extremities. Furthermore, a broad range of anchors can be adopted (Dawis, 1987). Despite this spectrum of scale types, a number of scale methods have been developed which are commonly used in study of populations. One such method, five-point rating scale, has been adopted for this research, as described below.

The five-point rating scale, such as that described by Likert (1932), is the most commonly adopted method for the development of subject-centred scales (Dawis, 1987). The Likert procedure involves a number of stages. The first stage is the writing of a range of items that cover the array of content to be studied. Five-point rating scales are generally adopted, with scoring weights of 1 to 5 assigned to the points. Secondly, the items are presented to a large number of respondents ($N \geq 100$). In addition to the individual responses, a total score is calculated for each respondent by summing the scores for each item. Thirdly, an item-total score correlation is performed in order to screen items, and select only those which are able to discriminate between high and low scorers. This can be achieved through employment of an item-to-total reliability test. Cronbach's coefficient alpha (Cronbach, 1951), the widely employed test of the scale's internal consistency and reliability (Peterson, 1994), is also assessed at this stage. Finally, items which have proved to be the best discriminators are selected, and used to calculate overall scale scores.

As a result of its popularity in the development of scales for numerous surveys and studies, the Likert method has attracted some criticism. Fox *et al.* (1988) and Fowler (1993) contend that the method is left open to respondent bias, when the study participants attempt to create a certain impression, such as presenting their own companies in good light. Such bias is likely to result from wording of the items and anchors, and this effect can largely be overcome by careful selection of questions (Oppenheim, 1992).

The questionnaire used in this study involved items with a five-point rating scale. The odd-numbered scale is important as it allows for adoption of a neutral position –

the central point of the scale (Cox, 1980). The exact descriptors for each scale point varied between sets of questions according to the aspect of mass customisation being explored. The selection of the specific items for the scale is discussed in the following section.

5.3.3 Item Selection

The aim of the study reported here was to gain an understanding of the relationships between supplier and lead user collaboration, and the four measures of operational performance of mass customisation. An extensive literature review was performed, as discussed in Chapters Two, Three and Four, to identify items which have previously been used to study such factors. On the basis of this literature review, sixty-eight items were selected from previous studies, as will be discussed below. These items formed the theoretical base of the questionnaire, which was subsequently tested prior to widespread administration of the survey. The literature survey revealed a lack of specific items that correspond with the purpose of this study, particularly with respect to lead users, and some items therefore required alteration. This constituted the impetus for the two stages of testing which were subsequently performed.

The first stage of testing involved focus groups, which are discussed in more detail in section 5.3.4 below. As a result of the recommendations of the focus groups, some items were removed, some were amended to assist with clarity, and others were added. This resulted in a initial questionnaire which was completed by fifty-five production managers in a pilot study which will be discussed in section 5.3.6 below.

Items with low item-to-total correlation and low Cronbach α were removed from the questionnaire, giving rise to the questionnaire in its final form, as shown in Appendix 1.4.

In order to measure supplier collaboration, items were selected which referred to supplier involvement in the various product development processes. Twenty-four items were initially selected to measure the level of supplier collaboration in product development. Items were taken from a number of sources (Primo and Amundson, 2002, Li *et al.*, 2005, Song and Di Benedetto, 2008, Kayis and Kara, 2005, Dowlatshahi, 1997, Bidault *et al.*, 1998, Handfield *et al.*, 1999).

Lead user collaboration was measured by selecting items from the literature of customer involvement in product development (Kayis and Kara, 2005, Slaughter, 1993, Tomes *et al.*, 1996), in addition to studies on lead user methods of involvement (although not in product development) (Franke *et al.*, 2006, Morrison *et al.*, 2000, Urban and von Hippel, 1988, Luthje, 2004). Since there is little literature about lead user collaboration in product development, the generic model for product development processes which was selected to test supplier collaboration was also applied to test lead user collaboration. This is also necessary to allow for meaningful comparisons to be drawn. This item selection was further supported by the recommendations of the focus group. As a result of this process, sixteen items were initially selected.

A number of studies have presented items which can be used for the identification of lead users, as reviewed by Schreir and Prügl (2008). Specific lead user items were taken from a number of sources (Shah and Ward, 2007, Franke and Shah, 2003, Franke *et al.*, 2006, Morrison *et al.*, 2000, Urban and von Hippel, 1988, Luthje, 2004, Herstatt and von Hippel, 1992). At the end of this item selection, there were eight items referring to lead user identification. This lead user identification tool is discussed in section 5.4.5.

Finally, it was necessary to select items which measured the four attributes of mass customisation operation performance. These were selected from various sources (Kayis and Kara, 2005, Welborn, 2005, Tracey and Tan, 2001), and resulted in five items for each attribute.

As a result of this selection procedure, there were a total of sixty-eight items. These literature items provided a starting point for the preparation of the final questionnaire, and some items were subsequently modified or removed in order to ensure that the most valuable information was collected. As shown in Figure 5.1, items were changed as a result of two forms of validation: focus groups and the pilot study. The input of the focus groups is presented in the following section.

5.3.4 Focus Groups

Focus groups provide one method of obtaining qualitative data, in the form of group discussions exploring specific issues. They are differentiated from other forms of group interviews in that they are focused on a specific activity, whether viewing a video, examining a new product or providing feedback on a set of questions. In addition, focus groups generate data from group discussion rather than addressing specific questions to specific group members (Kitzinger and Barbour, 1999). In sharing and comparing their views, participants are able to generate new ideas.

Logistically, focus groups typically contain five to ten members, and studies are comprised of at least three focus groups. They take the form of a carefully-planned discussion led by the researcher, who raises topics or questions for consideration. The group meets on a single occasion for a period of one to two hours. The group should contain members who share common characteristics with respect to the discussion topic. This homogeneity may be specific, such as a particular job, or may be as general as any adults who live in certain community (Kreuger and Casey, 2000). Some differences between participants will, however, be effective in generating discussion and innovation (Kitzinger and Barbour, 1999). Focus groups can be used to obtain qualitative data for a number of purposes, and as such can be used at various stages of the research process.

Focus groups can be effectively combined with quantitative data collection techniques in order to maximise the information that is collected in a study. For example, these groups can be employed to assist with the designing of surveys, by providing broad feedback from key issues which should be examined to the phrasing of specific questions (Kitzinger and Barbour, 1999).

Focus groups were used in this study to provide feedback and suggestions concerning the initial form of the questionnaire. This was of particular importance due to the relatively new area investigated in this study: the items were collected from various sources and had not previously been utilised to study these specific relationships, particularly in the area of lead users. As a result, it was valuable to gain input from representatives of the respondents group as to the appropriateness of the items, and to gain suggestions as to any helpful modifications which might be made.

A sample of twenty-one production managers and product development managers were divided into four focus groups (three groups contained five and the remaining group comprised six participants). Managers for this study were contacted using the snowball sampling technique, in which a small number of subjects recruit other suitable subjects from amongst their acquaintances. The focus group procedure is provided in Appendix 1.1, and consisted of two main parts, which will be discussed below.

Session one involved discussion of the general concepts of mass customisation and collaborative partners. It was designed to allow collection of first-hand information from managers as to their understanding of the key issues of this research: operational performance, collaboration, and the concepts of lead users. This session confirmed the conceptual model proposed in Chapter Four, where general trend of the answers and the feedback indicated a positive relationship between the involvement of lead users and higher operational performance. The focus groups also confirmed the use of the four proposed attributes as the best indicators of the level of mass customisation performance.

In session two, participants were provided with a copy of the first draft of the questionnaire, and asked to comment on the items. In particular, they were asked to identify any problems with the items such as words or concepts which they found ambiguous or difficult to understand, and statements which were too complicated or cumbersome. As a result of these comments, changes were made to some questions. The focus groups were then asked to study each section closely and evaluate whether the items were relevant and sufficient to the topic of the section, and whether they had any ideas for other items which should be included or existing items which should be removed. Of greatest importance in this discussion was the section referring to lead user identification. On the basis of this discussion, two items were judged to be redundant, with confirmation of the remaining six items.

A general point of agreement from the focus groups was that the items selected from the literature to measure supplier and lead user collaboration did not reflect the product development processes as practised by operation managers. Interestingly, the most agreed alternative format for questions was satisfied by the adoption of a generic model for product development that was advised by all four focus groups and corresponded to the generic product development processes in the literature, such as those outlined by Handfield *et al.* (1999), Mikkola and Skjott-Larsen (2004) and Nambisan (2002), and shown in Figure 5.2 below.

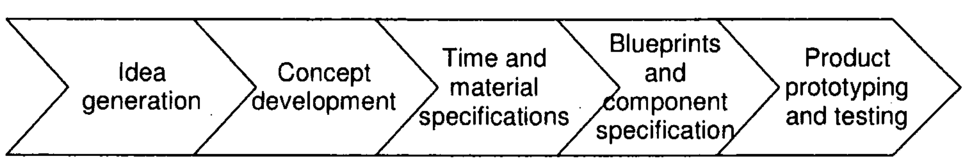


Figure 5.2: Product development processes

The suggestions of the focus groups allowed the development of the second draft of the questionnaire, containing thirteen items for supplier and lead user collaboration and a set of twenty items for measuring the operational performance of mass customisers. In addition, there were six items for the identification of lead users. The focus group discussions were therefore very helpful in clarifying the concepts proposed in the theoretical framework from an operational perspective – the interest of this study – and in refining the questionnaire. A particularly significant output from the study was the development of the lead user identification method, as described in the following section. The final form of the questions, based on the modifications arising from the focus group input, is shown in Appendix 1.4.

5.3.5 Lead User Identification Tool

One of the main outcomes of the focus groups was the refinement of the tool for the clear identification of lead users. As the term is not in widespread use, it could not be assumed that all survey respondents would understand it and allow for clear differentiation of lead users from general users. This was particularly important for companies that might have previous experience of collaboration with lead users without knowledge of the term. Most managers from the focus group agreed that it was incorrect to assume that companies would not have previous collaborations with lead users, on the simple basis of not being familiar with the term. On the contrary, lead users have often been used in product development, even without explicit identificaton. This provided further impetus for the development of a lead user identification tool, in order to assist survey respondents to correctly differentiate lead users from normal users.

From the literature, eight items had been identified as characteristics of lead users which set them apart from general users. These items referred to the various traits of lead users which have been described throughout the literature (Shah and Ward, 2007, Franke and Shah, 2003, Franke *et al.*, 2006, Morrison *et al.*, 2000, Urban and von Hippel, 1988, Luthje, 2004, Herstatt and von Hippel, 1992). Of particular importance to the identification of lead users is that they experience needs before the rest of the market, they have a particular interest in gain solutions to their problems, and an ability to suggest new ideas, which are beneficial to the company and the industry. Following consultation with academics and discussion within the focus groups, these eight items were refined and reduced to a total of six descriptive statements to which respondents were required to indicate on a Likert scale their level of agreement.

The value of this tool is that it allows the identification of companies which collaborated with lead users. This was particularly important for this study, in which the effects of lead user collaboration are being explored, and as a result, only companies which practice this partnership are of interest. The threshold for this division of companies which was agreed upon in the focus group discussions was a score of 4 or 5 on the Likert scale for each item in this section, corresponding to a positive response indicating experience with lead users. Any questionnaire which contained a score of 3 or less for any item in this section was removed, in order to maintain the internal and external validity of the study. This selection criterion will be further discussed in section 5.3.8. The final lead user identification tool is in section 2 of the questionnaire, which can be found in Appendix 1.4.

5.3.6 Pilot Study

A pilot study is a small-scale study which is performed before the full-scale research in order to identify any problems with the research design and to rectify them prior to implementation of the major study, which is often costly and time-consuming (Polit *et al.*, 2001). Typically, pilot studies are conducted on a small group of respondents who are as similar as possible to the target population. They can be performed for a number of different purposes, from assessing the likely success of a research approach, to testing the internal validity of a questionnaire, to providing evidence for a funding body that further, full-scale research is valuable (Holloway, 1997). The role of the pilot study in this research was to determine the reliability and internal validity of the questionnaire. This can assist in identification of ambiguous or unnecessary questions, as well as items which do not exhibit internal validity and which should therefore be discarded.

A group of one hundred operations and product development managers were randomly selected, and sent the second draft of the questionnaire, which had been developed as described above. Fifty-five completed questionnaires were received, and the responses were analysed using SPSS 15.1. Three main statistical tests were used to test the internal validity of the questionnaire, and the reliability of the constructs.

Reliability refers to the degree of consistency between a number measurements of a single variable (Hair *et al.*, 2006). There are a number of diagnostic measures of reliability (Robinson *et al.*, 1991). Item-to-total correlation is a univariate test, which measures the impact of each item on the summated scale score. An item-to-total correlation of above 0.50 is considered to indicate internal consistency. Cronbach's α measures the reliability coefficient which gives an indication of the consistency of the entire scale. It is generally agreed that a Cronbach's α value of above 0.70 is an acceptable measure of reliability. These two tests were performed on the pilot study. A summary of results is given below, and the tests themselves are discussed in more detail in Chapter Six.

In the pilot study, supplier collaboration in mass customisation was measured with thirteen items, and a similar thirteen items were used to investigate lead user collaboration in the mass customisation process. In order to study mass customisation attributes, five items were developed for each. The item-to-total reliability test on the responses to the pilot study indicated twelve items with corrected correlations below 0.4, which were therefore removed from the questionnaire. All other items had corrected correlations above 0.6 and were therefore retained (Churchill, 1979). As a result, the number of items concerning suppliers and lead users was reduced to nine each. The number of questions measuring each of low development cost, short development time, customer influence and product scope were decreased to four. Cronbach's α-value for all items in the pilot study ranged from 0.86 to 0.93, indicating the internal consistency of the items and confirming that the constructs employed were reliable (Cronbach, 1951).

This questionnaire was designed to test the conceptual model, and items were therefore selected to correspond to each construct. It was important to evaluate whether there is a good fit between the proposed model and the responses. In order to achieve this, the data was subjected to the measure of sample adequacy (MSA) for each variable (Hair *et al.*, 2006). Four variables (one each for supplier and lead user collaboration, product scope and customer influence) were identified to have correlations below 0.5, and these variables were subsequently dropped (Kaiser, 1974, Hair *et al.*, 2006). The Kaiser-Meyer-Olkin value for the remaining data was 0.882, which is higher than the recommended value of 0.80 (Kaiser, 1974), and it was therefore concluded that these items provided a better model fit, and a better representation of the constructs.

The pilot study of fifty-five operations and product development managers therefore allowed a trialling and subsequent refining of the questionnaire. A number of items were dropped, and the resulting final version of the questionnaire was confirmed to exhibit high internal validity and reliability as demonstrated in section 6.8.

5.3.7 Total Design Method

Prior to the distribution of the final questionnaire, it was necessary to consider the best methods by which to administer the survey in order to ensure highest response rate. This research applied the total design method (TDM) detailed by Dillman (1978) to plan and design the research instrument. The TDM was developed by Dillman in the early seventies to remedy the low response rates which were being experienced for surveys conducted in the USA at the time. In particular, he suggested that much emphasis needed to be placed on convincing potential respondents that their input is valuable and necessary.

Dillman divided the survey process into two main stages: questionnaire design and questionnaire administration, and advocated that suitable and equal consideration be given to accompanying techniques selected to help motivate respondents to complete the questionnaire and return it to the researcher. Such techniques include the use of rewards – both monetary, and non-monetary. Dillman claims that the total design method should aim to make the study relevant and urgent to the participants, and that their primary reward will therefore be the satisfaction that they have contributed to helping understand or solve problems faced by them or their community.

The use of the total design method was expected to ensure the reliability and validity of the research instrument, in addition to removing the potential errors and biases that commonly accompany the implementation of such surveys. One additional advantage of following such an approach is the expected increase in the response rate due to the rigour of the approach. The application of the total design method to this study will be outlined below.

Personalisation: it was important to ensure that the operations or product development manager at each company was personally contacted, by including the names and titles on each document sent. In order to increase the personalisation, all letters were signed by hand.

Initial contact was made prior to the distribution of the questionnaire. Two weeks before planned distribution of the questionnaire, an email was sent to one thousand companies explaining the nature of the research, with the purpose of gaining the commitment of the manager to completing and returning the questionnaire. A copy of this email is shown in Appendix 1.2. This correspondence asked managers to briefly reply as to whether or not they were prepared to complete the questionnaire. Six hundred and three affirmative answers were received, and it was to these managers that the surveys were sent. One reason for selecting this method of initial contact was to ensure that the questionnaire would be sent to companies for whom the area of study is relevant and applicable. It was also believed to contribute to a higher response rate.

First mailing: this involved sending the questionnaire package to the managers. In this package were a cover letter, the questionnaire itself, and a return envelope. All documents were printed on the official university letterhead, in order to increase the credibility. The total design method considerations of each document in the package will be considered in turn. An example of the cover letter and questionnaire are shown in Appendix 1.3.

Cover letter: this was attached to the questionnaire, in order to introduce the research aims and objectives, and to emphasise the importance of participation in the study. The cover letter also attempted to assure the confidentiality of responses by detailing the procedure of questionnaire handling, and to further encourage participation by providing the approximate length of time which would be required to complete the survey, and offering a results report as an incentive for completion, which has previously been shown to be helpful in increasing the response rate (Church, 1993, Yu and Cooper, 1983).

Questionnaire: this was designed according to the guidelines of Dillman (1978), with careful consideration taken to achieve clear layout of questions to allow for ease of comprehension and completion. This design process was assisted by the feedback from the focus group and pilot study phases as explained in sections 5.3.4 and 5.3.6.

Return envelope: a prepaid, self-addressed envelope was included with the questionnaire to assist with the ease of returning. This was intended to decrease the time and cost demands on the respondent in completing the questionnaire, conveying the importance of the response.

Reminder email: to those companies which had expressed an interest in the study following the initial contact, but did not return a completed questionnaire, a follow-up email was sent. The purpose of this email was to remind the manager that a questionnaire had been sent, and to request that it be completed and returned.

Dillman's total design method was carefully taken into consideration at a number of stages throughout the survey administration process. It was hoped that this would increase the response rate. The following section describes the selection of the sample prior to the launch of the survey.

5.3.8 Sample Determination

Sampling refers to the selection of the research units (elements) from a defined population based on specific criteria (Czaja and Blair, 2005). The rationale is to find a representative sample that could produce generalisable results, thus saving the researcher the costs of time, money and effort of studying the whole population. This is of utmost importance when studying populations of huge size, which can be difficult to manage and study, potentially affecting the quality of research. Therefore, the first step in determining the sample is to define the population from which the sample will be selected.

This study, as discussed in the introduction, aims to supplement the few empirical studies conducted on mass customisation (Duray *et al.*, 2000), by investigating, on a large, more substantial scale, the effects of suppliers and lead users on mass customisation attributes. To serve this purpose, a sample representing the different industrial sectors which possess the potential to mass customise was required. A combination of several databases and extensive phone research - as will be discussed later in the sampling frame section – was utilised to identify mass customising companies. Industries which cannot mass customise due to the nature of their activities, such as mining, were excluded from the population. The particular sampling unit which has been selected for this research is the manufacturing firms of consumer products. The reason behind this selection is twofold; the first is that this sector historically has the highest potential for mass customisation due to the nature of the customers and the second is derived from the objective of the research, which is to contribute to this area of literature which lacks empirical studies, particularly in the form of widespread surveys performed in the manufacturing sector (Ahlstrom and Westbrook, 1999).

The ideal target respondents to complete the questionnaires are knowledgeable of the company's product development processes, and should possess access to information not necessarily available at all levels of the company's hierarchy. The managers of product development processes, or the production or operations managers should possess this required knowledge and might be expected to provide the relevant necessary information in their answers. As a result, the survey was aimed at, and addressed to, these managers.

5.3.8.1 Sampling Frame

The sampling frame is the specific list and/or resource that includes the units of the defined population (Czaja and Blair, 2005). The criterion used to define the sampling frame is the European 1992 Standard Industrial Classification Codes (SIC). Classification codes for manufacturing companies (code D) DA15 through DN36 were included in the sample selection to include all manufacturing companies with the possibility to mass customise; namely manufacturers of consumer products. These included manufacturers from a variety of industries such as motor makers, electronics manufacturers, electrical and chemical industries, and health care/diet and specialist appliances. A random sample of manufacturers were sourced from the datasets of the London Stock Exchange and the International Configurator Database as well as internet sites for mass customisers operating in the UK.

Three main challenges were faced while determining the sampling frame. The first challenge was to find a list of potential the mass customisers in the UK. This proved to be difficult because no list found was comprehensive. As a result, a combination of different databases was utilised, in addition to the phone and internet research which was performed. Secondly, it was difficult to obtain complete information about the specific person being contacted at each company. It was not trivial to find the names and titles of current operations managers or product development managers, largely due to the great variation of organisational structures between companies, and the fact that different titles were given to the same jobs at different firms. The third challenge of defining the sampling frame was that many of the mailings lists available were not up-to-date, and therefore required a subsequent follow-up and filtering procedure prior to sending the questionnaires to ensure that the titles and names were correct and not obsolete, as some companies had restructured, or even ceased operations. Despite these difficulties, a list of two thousand manufacturing firms was obtained, which formed the basis of the sampling frame. A thorough phone and desk research was conducted to identify companies with the potential to mass customise. An initial email, described in section 5.3.7, was sent to one thousand companies which were thought to utilise mass customisation in their production. This email acted as a further checkpoint to ensure the suitability of the sample for investigation of the research question. Following the collection of email responses, a list of six hundred and three companies was compiled. In addition to a consideration of the appropriate sampling frame, it is also important to decide the minimum sample size required for meaningful hypothesis testing. The following section describes the consideration that was taken in determining the optimal sample size.

5.3.8.2 Sample Size

Determination of sample size requires consideration of both qualitative and quantitative factors. Quantitative determination of sample size involves calculations based on a number of factors: the precision required, the level of statistical significance desired and the number of variables. Each of these factors is directly proportional to the required sample size. In addition, the statistical techniques which will be employed to analyse the data will themselves dictate the sample size. Sophisticated multivariate analysis necessitates the use of a large number of responses (Hair *et al.*, 2006). From a qualitative viewpoint, deriving conclusions require high precision and large amounts of information, which can be achieved by increasing the sample size (Malhotra, 1999) . However, this must always be weighed against the costs of larger sample sizes. Other important qualitative considerations with respect to sample size are the nature of the research and the desired outcomes, the literature precedent for similar studies, the expected completion rate and the availability of resources to conduct the study.

It is important to ensure a sufficient sample size to perform the various statistical analyses. For factor analysis, sample size is important. While authors disagree about the absolute sample size required, it is generally suggested that larger sample sizes should be pursued (Pallant, 2006). Hair *et al.* (2006) recommend a minimum number of one hundred respondents to conduct factor analysis. Tabachnick and Fidell (2006) concluded that sample sizes of greater than three hundred are ideal, samples of one hundred and fifty are generally sufficient if some of the variables have high loadings. Other researchers argue that it is not the sample size itself which is of interest, but the ratio of responses to items. This ratio has been cited as 5:1 (Hair *et al.*, 2006, Tabachnik and Fidell, 2006) or 10:1 (Nunnally, 1978). For a study with thirty study items, this corresponds to an optimal sample size of between 150 and 300.

The second main statistical test performed in this study is multiple regression analysis. Hair *et al.* (2006) highlight the imperative for careful sample size selection for such analysis, for two main reasons. Sample size must be judiciously chosen to lend the desired power. In general, increasing the sample size will allow weaker relationships to be detected. Secondly, sample size is important in enabling generalisability of results. It is generally considered that the ratio of responses to independent variables should always be greater than 5:1, and ideally should be 15:1

(Stevens, 1996). In this study, there are two independent variables (supplier collaboration and lead user collaboration) and three control variables (company size, company age and sales level with suppliers), which corresponds to a recommended sample size as high as seventy-five.

The combination of the above considerations gives rise to an optimal sample size of approximately two hundred, in order to ensure the suitability of the data set for subsequent statistical analysis. It is important to note, however, that this represents the final sample size following collation of all completed questionnaires. As a result, it is important to distribute the questionnaire to as a large a sample as possible to ensure that this figure is met, even if a very low response rate is experienced.

As described in section 5.3.7, initial emails were sent to the product development or operations managers of one thousand consumer products manufacturing companies in the UK. Out of these, six hundred and three companies showed interest in receiving the questionnaire, of whom two hundred and ninety five responded with completed questionnaires. The received questionnaires were then subjected to a selection criterion including the lead user identification method, in which only the questionnaires with completed suppliers and lead users sections were accepted in order to satisfy the purpose of the research in studying companies that had previous projects with suppliers and lead users, which is a critical condition for the comparison between those two collaboration partners. By this method, thirty-five questionnaires were rejected. A small proportion of the remaining surveys had partially incomplete sections, and telephone contact was therefore made to follow up on this missing data. Six questionnaires were rejected due inability to obtain the missing data, and a further three were rejected as they were identified to be outliers as they represented extreme scoring, as will be described in Chapter Six.

Following these selection procedures, a total of two hundred and fifty-one questionnaires were accepted, corresponding to a response rate of 41.6%. This rate is considered acceptable for this research (Frohlich, 2002), and fulfils the requirements outlined above. A more detailed discussion of the sample size and the response rate will be given in section 6.1.1.

5.3.9 Potential Sources of Bias

While designing the questionnaire throughout the stages described in the previous sections, it was important to keep in consideration the potential sources of bias in the study, and to minimise them as far as possible. Bias was subsequently tested for through a number of statistical tests described throughout Chapter Six, but it was necessary to attempt to diminish the chances of such bias arising, and thus affecting the data.

The scales used in this study are perceptual: that is, they require respondents to give an assessment according to their own perception. Perceptual scales involve the translation of qualitative information based on the respondent's knowledge of the subject studied into the response categories available. For example, six of the items in this study required respondents to indicate their level of agreement with given statements using a five-point Likert scale, in which 1 corresponded to "strongly disagree" and 5 to "strongly agree". The use of perceptual scales may leave the survey data vulnerable to a number of biases, which are discussed in the following section. Nevertheless, perceptual scales are considered to provide good representation of objective data (Venkatraman and Ramanujan, 1986, Ward *et al.*, 1994) and have been used to assess performance in a number of previous studies (see Vickery *et al.*, 2003, Joshi *et al.*, 2003, Devaraj *et al.*, 2004 for example).

The use of Likert scales, and of perceptual scales in particular, may be affected by a number of forms of bias. Notable amongst these are acquiescence bias, central tendency bias and social desirability bias. Acquiescence bias is the tendency of respondents to agree with questions or indicate positive responses to a survey. Central tendency bias, on the other hand, results from respondents avoiding extreme responses, and instead preferring to indicate a neutral position. Social desirability bias describes the tendency of respondents to portray themselves, or their organisation, more favourably (Dawes, 2008). The possibility of the responses being affected by these biases has been minimised by three main strategies. Firstly, the study subjects were carefully selected based on their knowledge of the operations of the company, and in particular the product development and collaboration processes. In this way, a more holistic, and more objective, view of the company's operation can be obtained. It was anticipated that eliciting responses from senior members of the management team – in this case operations managers and product development managers – would result in more wise responses which were free from these biases. In fact, it has previously been demonstrated that senior managers' subjective ratings of their firms' performances were highly consistent with objective indicators of performance (Dess and Robinson Jr, 1984). Secondly, in the scale development process, items were phrased in as neutral a manner as possible, so as not to reflect values or favourable answers. Finally, strict measures were asserted to ensure that the respondents knew that their replies were only for academic use, and would have no effect on the company itself. In addition to the adoption of these strict measures, statistical tests were applied, as discussed in Chapters Six and Seven, in order to detect any bias.

An additional concern when designing a questionnaire is to account for common methods bias. Common methods bias arises when the instruments employed by the researcher affect the scores or measures which are being collected (Doty and Glick, 1998). This can result in false conclusions being drawn concerning the relationships between constructs. The principal way in which common methods bias can enter a data set is when two or more items in the questionnaire influence each other, and can arise from respondents' conscious or unconscious quest for internal consistency. In this way, the empirical relationships between two constructs can either be inflated or deflated (Fiske, 1982). It is necessary, therefore, to use comparative methods to test for common methods bias (Podsakoff *et al.*, 2003).

In this research, after adoption and employment of Dillman's Total Design Method, which should minimise the potential of common methods bias, the data was subsequently tested for common methods bias by using Harman's single –factor test (1976), which has been widely used for the detection of common methods bias (Aulakh, 2000, Andersson, 1997). However, it is important to remember that Harman's single-factor test is best treated as a diagnostic technique and the best remedy to deal with common methods variance is by attempting to eliminate the problem early in the design stage of the instrument through a thorough study of the framework and rigorous design of the methodology and instrument. This has been the impetus for the use of Dillman's Total Design Method, and the strict measures indicated throughout this chapter aim to increase the internal and external validity of the constructs. One specific strategy was the proximal separation of measurements in the questionnaire, in two main ways. The first technique involved separating the two independent variables with a section concerning the lead users identification tool, which will help to minimise the risk of respondents assuming a link between the two sections. A second proximal separation technique was to use different scale descriptors for different sections, so as not to create a similarity in the minds of the operation and product development managers (Podsakoff *et al.*, 2003). A second specific strategy was in the careful design of questionnaire items, including defining ambiguous or unfamiliar terms, avoiding vague concepts, keeping questions specific and concise, and decomposing complex questions into simpler questions (Tourangeau *et al.*, 1991).

The data collected in this research was analysed by the statistical package for social science (SPSS) software, in which all the variables were subsequently input into un-rotated Factor Analysis (EFA) to investigate whether or not the variables load on one factor. The rationale behind this approach is that if common method bias exists, then most covariance between the variables will be explained by one factor. In the case of common methods bias, the loadings might be distributed over two or three factors, but most, if not all, of the variables will load highly on one single factor. This was not found to be the case, as will be demonstrated in section 6.8.2. It can therefore be assumed based on the literature and previous experience that the proper procedures conducted by this research in designing the survey instrument have greatly diminished the possibility for common method bias.

Another potential source of bias is the collection of questionnaires from only a single respondent within each company. Such a practice has been noted to cause potential problems through respondents placing more emphasis on maintaining consistency in their answers than in conveying the true situation at their company (Podaskoff and Organ, 1986) and through the inability of an individual making broad inferences about the situation of a company (Bowman and Ambrosini, 1997). The possibility of the data being affected by single respondent bias has been minimised by targeting senior manufacturing managers who are best able to provide information about the practices and position of the firm.

In summary, there are a number of potential biases which might be introduced in the survey process. All attempts to minimise these biases have been taken throughout survey development and administration, but it is not until the data analysis stages that the presence or absence of any source of bias can be fully determined. This will be discussed further throughout Chapters Six and Seven.

5.4 Ethical Issues

While aiming to obtain the most meaningful and informative conclusions from this study, the researcher's main concern throughout the investigation was to ensure the ethical basis of the research from both theoretical and technical viewpoints. A theoretically-sound study is one which critically reviews current literature while acknowledging that the research builds on the foundations laid by others, and gives due credit to the academic property of other researchers. Good technical procedures involve attempts to increase the favourable attributes of best practice research such as high reliability and validity of the research design, or high response rate for the questionnaire. This has been thoroughly sought throughout the different stages of the research.

While these theoretical and practical concerns were held in high importance during the study, so too were the concerns of all parties involved with the investigation, particularly the survey subjects themselves. This included the maintenance of confidentiality of all responses – from focus groups and the pilot study, as well as from the main questionnaire. In addition, it was important to accurately describe the purposes of the study, and for what purposes responses would be used, as well as being willing to further discuss these aspects in more detail upon request.

In general, the researcher's commitment to the advancement of the body of knowledge and to the improving the world of academia has been always in the researcher's mind from the beginning of the project to the end.

5.5 Conclusions

This chapter has detailed the approach and the methodology which has been adopted for the investigation of the research question and hypotheses described in Chapter Four. A mail survey has been selected as the research method, and this choice was justified through a review of other literature. The body of this chapter details the considerations taken in the design and administration of the survey. The scale, and the items of which it comprised, were developed from a study of the literature, and the resulting questionnaire subjected to two rounds of refinement, through the involvement of focus groups and a pilot study. The resulting final form of the questionnaire was administered according to the total design method, which describes the best practices required to ensure a high response rate. This section also discusses how the sample population and the specific sample frame were determined.

The final section of this chapter has described the considerations taken to ensure a strong ethical stance. The following chapter presents the results of the questionnaire, and the subsequent data analysis which was performed on these responses.

CHAPTER SIX

DATA ANALYSIS

CHAPTER SIX: DATA ANALYSIS

6.1 Introduction

The aim of this study is to investigate the relative effects of supplier and lead user collaboration on the four attributes of mass customisation operational performance – development cost, development time, customer influence and product scope, as discussed in Chapter Four. A research methodology was carefully designed to collect data from consumer products manufacturers using surveys, in order to explore these relationships, as discussed in Chapter Five. This chapter presents the data which was obtained from these questionnaires, and describes the statistical analysis of these results. Discussion of results and hypothesis testing will be provided in Chapter Seven.

This chapter details how the data was screened for missing data and outliers, and tested for its adherence to the assumptions of important statistical tests. The use of exploratory factor analysis is then described, followed by the descriptive analysis of the derived independent and dependent variables. The principal statistical technique used to test the hypothesis of these studies is hierarchical multivariate regression, so the main section of this chapter focuses on this analysis, with an exploration of each model. Discussion then focuses on analysis of the data for anomalies such as variance and bias, as well as for confirmation of the validity and reliability of the data. The following section, however, begins with a discussion of the description of the sample.

6.1.1 Sample Size and Response Rate

In order to derive meaningful conclusions from the research and to fulfil the conditions of the various statistical tests which would be subsequently performed, it is important to ensure that an appropriate response is achieved both in terms of sample size and response rate. This has been a major consideration of the design of this study, with thorough planning of the distribution and follow-up of the survey instrument as devised by the total design method of Dillman (1978). Table 6.1 below presents the number of respondents and their proportion of the total initial sample.

Table 6.1: Questionnaire response rate

Questionnaires Sent	Questionnaires Received	Questionnaires Accepted	Response Rate
603	295	251	41.6%

Two hundred and fifty-one questionnaires were accepted on the basis of the selection criteria described in Chapter Five. This sample size is sufficient to run the main statistical tests of the study; factor analysis requires at least one hundred and fifty respondents (Tabachnik and Fidell, 2006). Furthermore, it has been suggested that the number of responses should be at least five times greater than the number of items to be tested. In this case, analysis was performed on thirty items, corresponding to a response to item ratio of greater than 8:1, which exceeds the minimum standard (Hair *et al.*, 2006).

Sample size is also crucial for multiple regression analysis, as discussed in Chapter Five. The number of responses obtained in this study is sufficient to measure even weak relationships. Hair *et al.* (2006) calculated that for a sample size of two hundred and fifty and with two independent variables, multiple regression analysis will detect statistically significant R^2 values as small as 5% with a significance level of 0.01 or 4% with significance of 0.05. In addition to providing statistical power, it is also important that the sample size provides sufficient generalisability. It is suggested by that the ratio of responses to independent variables should exceed 15:1 (Stevens, 1996), for this study, in which there are five independent variables, this ratio is more than 50:1. This provides further support for the suitability of data to be used in regression analysis.

In addition to the sample size, it is also important to ensure that the response rate is sufficiently high. Response rate is important due to its implications regarding the generalisability of the findings. In this study, of the six hundred and three questionnaires sent, two hundred and ninety-five were returned, of which two hundred and fifty-one questionnaires were accepted for analysis. This corresponds to a response rate of 41.6%, which exceeds the average of 32% observed in the operations management field (Frohlich, 2002).

6.1.2 Sample Description

Before analysis of responses, it is important to gain an understanding of the sample population as a whole. In order to achieve this, descriptive statistics can be used to summarise the characteristics of the respondents. Such analysis includes determination of the mean, standard deviation, range, skewness and kurtosis (Cohen and Holliday, 1996). The mean is the average score, and is a measure of central tendency. It is particularly valuable for the comparison of two data sets. Standard deviation measures the dispersion of data, and in particular, the variability about the mean. A lower standard deviation suggests that data is clustered around the average value. These measures will be discussed in this section, with the normality measures of skewness and kurtosis described in a subsequent section of this chapter.

As detailed earlier, questionnaires were directed to the production/operations managers or product development managers at the manufacturing companies. The companies involved in this study varied in their size, age, type of activity, number of products manufactured and relationship with suppliers as described below.

In terms of size, measured by the number of employees, the sample included companies of different sizes, ranging from 40 to over 2000. The average company size was 893, with a standard deviation of 507. In future statistical analysis, the actual company size was included, but in order to assist with discussion in this chapter, companies have been grouped into five categories. For the purposes of this discussion, small companies are defined as those with less than two hundred and fifty employees and large companies, as those with more than one thousand employees. The distribution of sizes is shown in Figure 6.1 overleaf. The frequencies analysis is included in Appendix 2.1. In this sample, the biggest participating category was the companies of medium size with 77 companies completing the questionnaire. However, this does not drastically exceed the number of large companies participating in this study; 57 large companies completed the survey. The sample covers the different sizes of companies which can be found throughout consumer products manufacturing industries, which increases the generisability of findings.

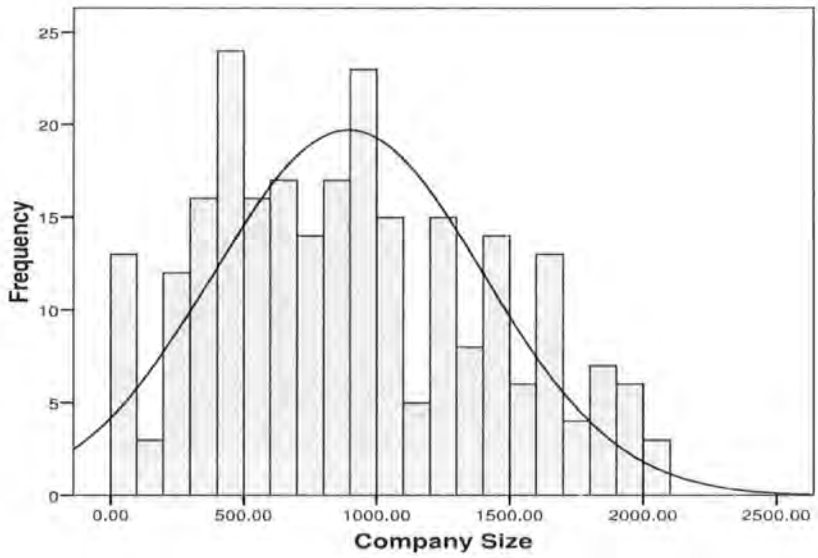


Figure 6.1: Normal probability plot for company size

Company age ranged from five to seventy-one years, with an average of 34 years and a standard deviation of 17. The distribution of companies according to age is shown in Figure 6.2 overleaf, with the frequencies analysis provided in Appendix 2.1. The largest group of companies (107) contained those which were more than forty years old, with the fewest companies (17) being less than ten years old.

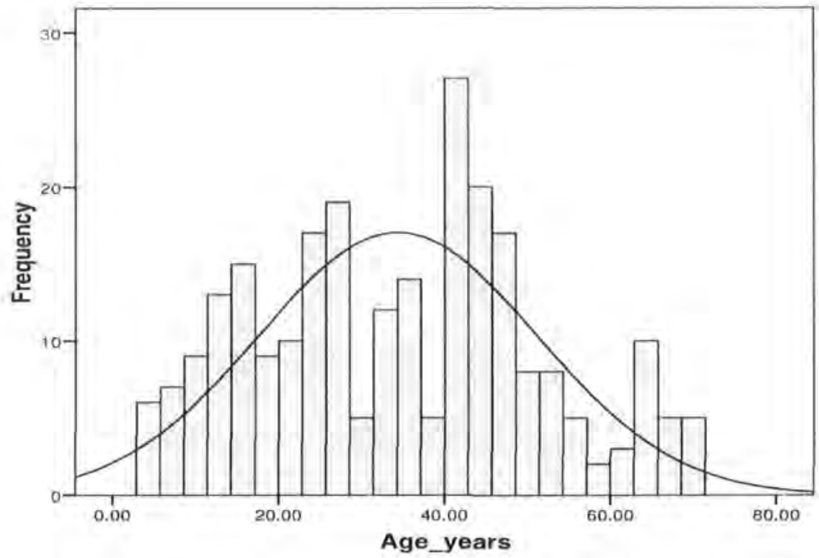


Figure 6.2: Normal probability plot for company age

Respondents were then asked to state the total number of product lines offered by their companies (Table 6.2). The responses varied considerably, with the most popular responses lying at either end of the scale. The greatest number of companies (102) had between one and fifty product lines, with 74 companies claiming more than two hundred product lines.

Table 6.2: Frequencies analysis of number of product lines

Number of Product Lines	Frequency	Percent	Cumulative Percent
1-50	102	40.6	40.6
51-100	38	15.1	55.8
101-150	15	6.0	61.8
151-200	22	8.8	70.5
more than 201	74	29.5	100.0
Total	251	100.0	

The questionnaire asked specifically for "number of product lines", which refers to a group of products with the same standard components, or which belong to the same product family. For example, identical products which are packaged differently are considered to be from the same product line. There is a possibility, however, that this item was misinterpreted by some respondents, who may instead have provided the total number of products manufactured by their companies. This does not adversely affect the analysis, as the same measure was subsequently tested in section 3 of the questionnaire, where respondents were asked to state how their number of product lines compared to those of their competitors. It was these values which were used for analysis purposes. Table 6.2 above shows the frequencies analysis of the number of product lines grouped into five categories, to give cursory information about the distribution of the companies studied.

This study was aimed at consumer products manufacturers across a range of industries, as shown in Table 6.3. The largest number of respondents (79) hailed from electronics and electrical companies, followed by specialist and other appliances with 58 responses. The industry type with fewest respondents (22) was the chemical industry.

Table 6.3: Frequencies analysis of industry type

Type of Industry	Frequency	Percent	Cumulative Percent
Motor industry	43	17.1	17.1
Chemical industry	22	8.8	25.9
Electronics and Electricals	79	31.5	57.4
Health care and diet	49	19.5	76.9
Specialist and other appliances	58	23.1	100.0
Total	251	100.0	

In order to gain an understanding of the relationships between each company and its suppliers, respondents were asked to indicate the length of time for which it had had relationships with its suppliers, and to rate the level of sales between the company and its suppliers with respect to its competitors. Frequencies analysis for the length of company-supplier relationship is shown in Table 6.4. The distribution of responses concerning the level of sales between suppliers and the company is shown in Figure 6.3, with the frequencies analysis presented in Appendix 2.1. The length of company-supplier relationships varied considerably. The largest group of responses (79) was for relationships of greater than twenty years, followed by 59 responses indicating relationships of between five and ten years. The smallest group (24 responses) corresponded to partnerships of between fifteen and twenty years. The frequencies of responses concerning relative levels of sales were normally distributed. The majority of participants indicated medium (99) or high (80) levels of sales, with fewer rating their sales levels as either very high (23) or very low (17).

Table 6.4: Frequencies analysis of length of company-supplier relationship

Length of Relationship	Frequency	Percent	Cumulative Percent
less than 5 years	42	16.7	16.7
5-10	59	23.5	40.2
10-15	47	18.7	59.0
15-20	24	9.6	68.5
more than 20 years	79	31.5	100.0
Total	251	100.0	

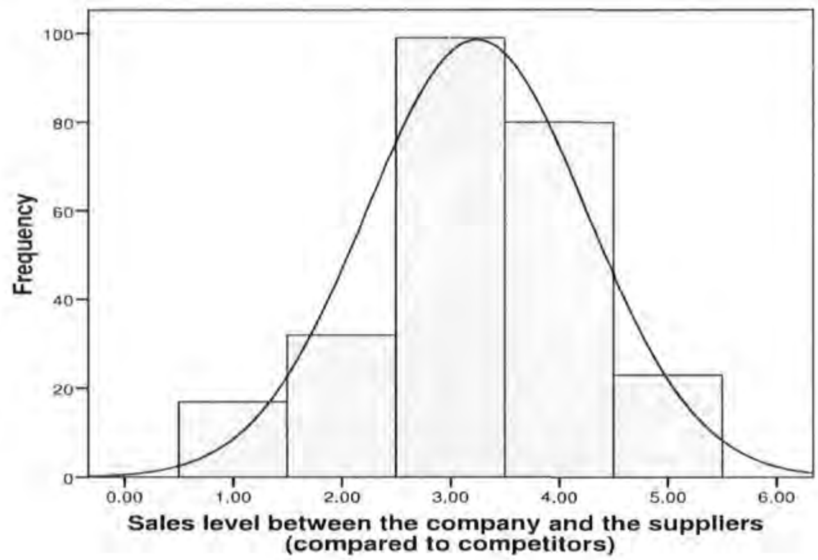


Figure 6.3: Normal probability plot for sales level between company and suppliers

From the above analysis of the sample descriptors, it can be seen that the survey respondents represented a diverse sample of companies which vary in their company size, age and industry type. In addition, the companies all exhibit varying length and strength of relationships with suppliers. This lends support to the selection of this sample as a representative sample of the consumer product manufacturing sector. In order to include some of these variables in statistical analysis, it is important that the scores meet specific statistical conditions. The following section describes the data screening which was performed to ensure these assumptions.

6.3 Screening the Data

In this research, the data collected from the companies will be used in various statistical tests. In order to subject data to these tests, it must meet some basic assumptions and conditions before it is deemed suitable for using. This section details the investigations which were performed to detect any breach of the main assumptions of factor analysis and hierarchical multivariate regression; namely the assumptions of normality and homoscedasticity and the determination of missing data or outliers. Other tests for linearity and multicollinearity were performed as part of the statistical analysis, and will be discussed in later sections. Any violation of these assumptions might lead to conclusions concerning non-significant relationships or to research bias (Hair *et al*, 2006). The following section describes the screen for missing data and outliers, and the tests for normality and homoscedasticity.

6.3.1 Missing Data and Outliers

During the design phase of the questionnaire, great emphasis was placed on the clarity and sequence of the questions in order to minimise the possibility of missing data. However, for the purpose of this research, which aims to compare and contrast the collaboration of suppliers and lead users in mass customisation, and due to the need for a complete set of data for the ensuing statistical analysis, a strict criterion was enforced in selecting questionnaires to accept. This required following up respondents for some questionnaires which contained random missing data, and rejecting others based on the failure of the company to provide such data, whether for security or confidentiality reasons. In addition, it was important to double check and cross check the entered data in the statistical software package against the original data to ensure correct data entry. While this rigour employed to ensure that only complete data sets are accepted has benefits in terms of the flexibility provided by the use of many statistical techniques and the potential to provide stronger indications for generalisability, the stringent requirement for completed questionnaires also raises the possibility of decreasing the statistical power due to the amputation of some of the cases (Hair *et al.*, 2006). This did not prove to be the case in this study, however, with only very low levels of missing data and a negligible amount of amputated data during the selection phase (only six cases were removed).

Outliers are data points with extreme values which are either too high or too low. The presence of outliers in any sample might skew the results, leading to false or unrepresentative conclusions. However, this is a rather simple view of outliers and they will instead be investigated within the context of the analysis. In this research, the questionnaire was designed using a Lickert 5-point scale which asked respondents to give a number between one and five. This restricts the range of possible answers, and therefore decreases the likelihood of outliers in the data set. Nevertheless, after data entry and scanning for missing data, the researcher applied the Mahalanobis D^2 measure, which is a method that enables identification of outliers in multivariate data sets. Higher D^2 values indicate greater variation from the general distribution, but this method can only give a measure of the overall variation, and is not useful in identifying errant variables (Hair *et al.*, 2006). As a result, a statistical significance test for the Mahalanobis D^2 was applied to each variable whether or not it was significant. Any variable returning a P value of greater than 0.001 was considered an outlier. Application of these procedures using SPSS 15.1 indicated no statistical significance for any variables, suggesting that none of these points was an outlier (due to the prior removal of three outliers during the selection phase).

6.3.2 Testing Assumptions of Factor Analysis and Multivariate Analysis

Before performing the statistical tests of factor analysis and multivariate analysis, it is important to test a number of assumptions to confirm the robustness of the data (Hair *et al.*, 2006). Testing of assumptions prior to statistical analysis is essential as statistical packages can often produce results even when assumptions are violated. This violation of assumptions can result in distortions and biases in the analysis and in the conclusions which can subsequently be drawn. There are four main assumptions which must be tested: normality, linearity, multicollinearity and homoscedasticity. The assumptions of normality and homoscedasticity will be discussed below; linearity and multicollinearity were tested as part of the multivariate analysis, and discussion of these assumptions can therefore be found in section 6.6.

6.3.2.1 Normality

Normality is the most fundamental assumption of multivariate analysis, and describes the shape of the data distribution in comparison to the normal distribution. In order to employ statistical techniques such as factor analysis and regression analysis, it is important that the distribution of data is normal (Pallant, 2006). Normality can be assessed by a number of measures, among which are skewness and kurtosis. Skewness is a measure of how symmetrically the responses are distributed about the mean. A skewness value of 0 indicates normality, with clustering to the left and right of the mean indicated by positive and negative skewness values respectively. Kurtosis describes how peaked or flat the distribution is. A normal distribution has a kurtosis of 0, with negative kurtosis values indicating relatively flat distribution, with many values towards the extremes. A positive kurtosis value is described as being peaked, and corresponds to many responses clustered around the mean.

Normal distribution is often determined by calculation of Z values, which are a measure of the kurtosis or skewness value divided by the standard error. Z values can be calculated by taking into account the skewness or kurtosis values and the number of responses (N), according to the following equations (Hair *et al.*, 2006):

$$z_{skewness} = \frac{skewness}{\sqrt{\frac{6}{N}}}$$

$$z_{kurtosis} = \frac{kurtosis}{\sqrt{\frac{24}{N}}}$$

Tabachnick and Fidell (2006) suggest that a critical value of z = 3.3 be adopted for the determination of normality for small samples. For larger samples, lower stringency may be appropriate, but in this study, the high stringency of 3.3 will be used to ensure that the assumption of normality can be confidently made. With the value of N = 251 for this study, these z values correspond to a critical skewness value of 0.51 and a critical kurtosis value of 1.02. It is these values which will be considered in subsequent discussion as the upper and lower limits to determine normality.

Another diagnostic test for normality is graphical analysis, in which the distribution of responses is visually compared to a normal curve. Normal probability plots for each set of variables are included in Appendix 2.1, and the findings discussed herein.

The normality of all variables must to be tested in order to perform statistical analysis. This included the control variables, which were the descriptors of variables as detailed in section 6.2, although some control variables will be used in statistical tests which do not require normality. These will be highlighted in subsequent discussion. The tests for normality of the control variables are shown in Table 6.5 below. The skewness values for company size, company age and number of products are positive values less than 0.51, which indicates normality, but skewed towards the lower end of the distribution. On the other hand, industry type, and the two measures of company-supplier relationships, length and strength, have negative skewness values which lie between 0 and -0.51. This suggests that the values are distributed towards the higher end of the scale, although their distribution can be considered to be normal. The kurtosis values for all descriptors are negative, indicating a flat distribution in which values are spread out towards the extremes. The kurtosis values for the number of products and the length of relationship between company and supplier have absolute values greater than 1.02, thus indicating abnormal distributions for these two control variables. This will be taken into consideration when analysing the data. Indeed, multivariate hierarchical regression analysis with robust standard error was used to account for this abnormality, as will be discussed later. In addition, the graphical plots of distribution (Figures 6.1 to 6.3) supports the above findings of normality.

Table 6.5: Normality of control variables

Control Variables	Mean	Std Dev	Skewness	Std Error	Kurtosis	Std Error
Company Size (no. employees)	893.09	507.56	.349	.154	-.782	.306
Company Age (years)	34.34	16.80	.177	.154	-.780	.306
Number of Products	2.71	1.72	.319	.154	-1.659	.306
Industry Type	3.23	1.36	-.274	.154	-.999	.306
Company Supplier Relationship	3.16	1.50	-.002	.154	-1.459	.306
Sales Level Between Company and Suppliers	3.24	1.02	-.355	.154	-.140	.306

The second set of variables which was tested was the dependent variables, which describe the four attributes of mass customisation, as will be discussed in a later section. The tests for normality of the dependent variables are shown in Table 6.6 below. The skewness values for all dependent variables are negative, indicating that the distribution is skewed towards smaller values. The skewness values for cost, development time and customer influence lie between 0 and -0.51, indicating normality. The skewness factor for product scope, however, is -0.821, which lies outside the defined range for normality. However, according to the central limit theorem which states that as sample size increases, the distribution of sample means will approach a normal distribution (Wild and Seber, 2000, Tijms, 2004). In this study, the large sample size will approximate normality, especially in this case where the deviation from normality is negligible.

This will be accounted for by use of multivariate hierarchical regression analysis with robust standard error. The kurtosis values for cost and product scope are positive, indicating a peaked distribution, with responses clustered about the mean. On the other hand, the kurtosis factors for time and customer influence are negative, in line with a flat distribution. The kurtosis factors for cost, time and customer influence lie between -1.02 and 1.02, suggesting normality. As observed for the skewness value, the kurtosis value obtained for product scope, of 1.027, lies just outside this critical range. Graphical analyses (Appendix 2.3a) also indicate normality, in confirmation of the skewness and kurtosis analyses.

Table 6.6: Normality of Dependent Variables

Dependent Variable	Mean	Std Dev	Skewness	Std Error	Kurtosis	Std Error
Cost	3.3078	0.8707	-0.177	0.154	0.119	0.306
Development Time	3.2470	0.8822	-0.072	0.154	-0.305	0.306
Customer Influence	3.1740	0.9579	-0.386	0.154	-0.040	0.306
Product Scope	3.6746	0.9008	-0.821	0.154	1.027	0.306

Finally, the independent variables, which correspond to the supplier and lead user collaboration, were tested, with the results shown in Table 6.7 below. Skewness values for both independent variables are negative, placing the data towards the right-hand side of the distribution. Both values lie comfortably within the region for normal distribution. The kurtosis values for both variables are also negative, indicating a flat distribution. Again, these values are well within the boundaries for normality. These observations of normality are further supported by graphical depiction of the distribution (Appendix 2.3b).

Table 6.7: Normality of Independent Variables

Independent Variable	Mean	Std Dev	Skewness	Std Error	Kurtosis	Std Error
Supplier Collaboration	3.0842	0.8952	-0.311	0.154	-0.354	0.306
Lead User Collaboration	2.9851	1.0132	-0.231	0.154	-0.656	0.306

6.3.2.2 Homogeneity of Variance:

It is important that the distribution of responses for one variable is not concentrated in a limited region of responses for another variable. This is particularly important for correlation of dependent and independent variables, and can be determined in the form of homoscedasticity. Variables are described as homoscedastic if the variance of the dependent variable is approximately equal across all values of the independent variable. When responses are grouped or the data is factored into composite constructs, homoscedasticity is referred to as homogeneity of variance. It is tested for by using Levene's test, which investigates whether the variability in the dependent variable is similar across the range of values of the independent variable. This is measured through this test, in which a significant value ($p < 0.05$) is interpreted as heterogeneity of variance (Tabachnik and Fidell, 2006, Hair *et al.*, 2006).

The homogeneity of variance and homoscedasticity of this dataset were evaluated by two methods. The results of Levene's test are shown in section 6.7, while scatter plots are provided in Appendix 2.4 and discussed in section 6.6. These tests confirmed that all the dependence relationships are homoscedastic and that the heterogeneity of variance is not existent.

6.3.3 Conclusions

This section has detailed the tests and measures to ensure that the data meets the requirements for and assumptions of subsequent statistical testing. These tests have confirmed that the final data set contains no missing data points or outliers which might skew the analysis or give misleading results. In addition, in order to perform factor analysis and regression analysis, it is important that data meet the assumptions of normality and homoscedasticity. These assumptions have been tested by various measures, and confirm that the data is indeed both normal and homoscedastic. Further statistical analysis can therefore be performed, as will be described in the following sections.

6.4 Exploratory Factor Analysis

Factor analysis is necessary to reduce a large number of unrelated items to a smaller number, which is more manageable. This is achieved by grouping similar items together, and combining the scores for these items. Following this, the reduced number of variables can then be subjected to other statistical tests. There are two types of factor analysis: exploratory factor analysis and confirmatory factor analysis, which differ in the inputs required. Exploratory factor analysis gathers information about the relationships between variables, and requires no input from the researcher. Confirmatory factor analysis, on the other hand, is used to confirm relationships between variables that are already specified. In the case of this study, these relationships had not been previously defined or determined, and therefore exploratory factor analysis has been employed. The main purpose of exploratory factor analysis is to identify the underlying relationships between variables (Hair *et al.*, 2006). Factor analysis is used to test the proposed conceptual framework and the underlying relationships in addition to reduce the data into composite factors which can then be included in further statistical tests, which is the main purpose of using this analysis in this study.

There are two exploratory factory analysis methods: principal components analysis (PCA) and factor analysis (FA), which have many similarities and are largely interchangeable. The two differ in the information which is retained for further statistical tests: in principal components analysis all the variance in the original variables is used, while in factor analysis only the shared variance is retained. A number of academics promote the use of principal components analysis for various reasons, such as the decreased indeterminacy in factors (Stevens, 1996) and the provision of an empirical summary of the data set (Tabachnik and Fidell, 2006). For this reason, principal components analysis has been adopted for this research.

Exploratory factor analysis will be primarily used in this research to reduce the data derived from the surveys to a manageable number of factors. Variables that load on one factor belong to one similar group and thus can be summated into one scale representing the construct. This will allow for proper use of these variables in subsequent multivariate regression analysis, and will guarantee more representation of the variables as the total group of variables will be used to represent the concept instead of only one of them. The procedure for the summation of variables will be achieved by averaging the values obtained for each variable. The resultant values will be used in the subsequent multivariate regression analysis. In addition, factor analysis will assist in the evaluation of the reliability, construct validity, and testing for common method bias, as discussed in Chapter Five.

6.4.1 Factor Analysis for Mass Customisation Attributes

The first step in factor analysis is to test for the factorability of the data, that is, the suitability of the data for factor analysis. This requires loading all the data into a statistical package - in this research SPSS 15.1 has been used - and running two main statistical tests, the Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) and the Bartlett's test of sphericity. These two statistical tests assess the factorability of the data: a Kaiser-Meyer-Olkin value of at least 0.6 and a Bartlett's significance value of $p < 0.05$ are conditions for factorability. The values obtained for analysis of the data in this study are shown in Table 6.8 below. These results confirm that the data is indeed suitable for factor analysis, as the Kaiser-Meyer-Olkin measure is 0.861, and the Bartlett's test of sphericity is significant ($p = 0.000$).

Table 6.8: Kaiser-Meyer-Olkin Measure of sampling adequacy (KMO) and Bartlett's test of sphericity for mass customisation attributes

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.861
Bartlett's Test of Sphericity	Sig.	0.000

An additional means of ensuring the factorability of the results is to determine the specific measure of sampling adequacy (MSA) for each variable. While the Kaiser-Meyer-Olkin measure of sampling adequacy gives an overall measure for all variables, the individual values for each variable can give more information about the factorability of each variable, and therefore can assist in the identification of individual variables which do not adhere to the requirements for analysis (Hair *et al.*, 2006). Again, an MSA value of greater than 0.7 is desired, with values of 0.8 being particularly meritorious. The results of variable-specific MSA analysis for the mass customisation attributes are shown in Table 6.9 overleaf. The values are all greater than 0.7, with all but one (the item concerning mix and match) greater than 0.8. This provides further confirmation of the factorability of results.

Table 6.9: Variable-specific MSA analysis for the mass customisation attributes.

Variable	Variable-specific MSA
(q3.1) Concept Development Costs	0.893
(q3.2) Product Design Costs	0.856
(q3.3) Product Manufacturing Costs	0.891
(q3.4) Total Costs of New Product Development	0.889
(q3.5) Concept Development Time	0.878
(q3.6) Product Designing Time	0.870
(q3.7) Product Manufacturing Time	0.907
(q3.8) Cycle Time (from concept to manufacturing)	0.896
(q3.9) Enabling customers to select from set menus/catalogs	0.813
(q3.10) Enabling customers to self configure features from tables (Mix and Match)	0.735
(q3.11) Enabling customers to design their products	0.843
(q3.12) range of items produced by existing facilities at the company	0.816
(q3.13) Scope of features offered to final customers (for each product)	0.883
(q3.14) number of products lines compared to competitors	0.886

Factorability requires that there are sufficient correlations between data: without this justification, factor analysis is inappropriate. This is computed by statistical packages in the form of the Bartlett test of sphericity, but can also be confirmed visually by inspection of the correlation matrix, as shown in Appendix 2.2. A majority of values below 0.3 would suggest that factor analysis is inappropriate (Hair *et al.*, 2006), but this is not the case for this data, providing further confirmation that factor analysis is an appropriate statistical method to be employed for this dataset.

Following confirmation of the factorability of this data, the next step in factor analysis is factor extraction. This describes the determination of the smallest number of factors required to suitably represent the relationships between variables. This can be achieved through the employment of Kaiser's criterion and Catell's scree test. A combination of the two methods is most helpful in determining the number of factors necessary to account for the variance in the data. The use of each method to analyse the data will be described here.

Kaiser's criterion, or the eigenvalue rule, separates factors into those which should be discarded and those which should be retained. The total amount of variance which is accounted for by the factor is calculated, and is called the eigenvalue. Kaiser's criterion states that only factors with an eigenvalue of greater than 1.0 can be retained for further factor analysis. The results of the eigenvalue test are demonstrated in Table 6.10 overleaf, which indicates the extraction of four dependent variables from the data. Bold type indicates the high loadings of each item on the corresponding extracted factor. These four factors had eigenvalues of greater than 1.0.

Table 6.10: Dependent variables factor extraction

Questionnaire Items	Component			
	Cost	Development Time	Product Scope	Customer Influence
(q3.1) Concept Development Costs	**0.807**	0.273	0.240	0.196
(q3.2) Product Design Costs	**0.845**	0.269	0.202	0.101
(q3.3) Product Manufacturing Costs	**0.773**	0.240	0.140	0.127
(q3.4) Total Costs of New Product Development	**0.813**	0.341	0.114	0.108
(q3.5) Concept Development Time	0.354	**0.826**	0.085	0.144
(q3.6) Product Designing Time	0.345	**0.802**	0.096	0.115
(q3.7) Product Manufacturing Time	0.171	**0.746**	0.296	0.057
(q3.8) Cycle Time (from concept to manufacturing)	0.262	**0.842**	0.135	0.114
(q3.9) Enabling customers to select from set menus/catalogs	0.149	0.114	0.153	**0.850**
(q3.10) Enabling customers to self configure features from tables (Mix and Match)	0.124	0.041	0.157	**0.917**
(q3.11) Enabling customers to design their products	0.110	0.158	0.131	**0.828**
(q3.12) range of items produced by exisiting facilities at the company	0.163	0.161	**0.855**	0.208
(q3.13) Scope of features offered to final customers (for each product)	0.206	0.130	**0.861**	0.192
(q3.14) number of products lines compared to competitors	0.156	0.173	**0.828**	0.083
Eigen values	3.110	3.024	2.475	2.464
Percentage of variation explained	22.21	21.60	17.68	17.60
Cumulative percentage	22.21	43.81	61.49	79.09

Extraction Method: Principal Component Analysis; **Rotation Method**: Varimax with Kaiser Normalization.

In order to assist in the interpretation of these factors, the component matrices were rotated as shown in Table 6.10 using VARIMAX orthogonal rotation. Factor rotation involves rotation of the axes about the origin, with the effect of redistributing the variance to achieve a simpler factor pattern. Orthogonal rotation maintains an angle of 90° between the axes, and is the most appropriate form of factor rotation for analysis of a set of uncorrelated measures. This is applicable in this study, as the underlying constructs are independent, as demonstrated in the correlation matrix in Appendix 2.2. VARIMAX is one method of achieving orthogonal rotation, which is based on simplification of the columns of the factor matrix, and is effective in maximising the sum of variances of loadings in the matrix. It has been shown to achieve clearer separation of factors than other orthogonal methods, although solutions are analytically more complex (Hair *et al.*, 2006).

The four extracted variables explain 79.09% of the total variance. The first factor, which relates to cost, contributes 22.2% of the variance, while the second factor, which relates to development time, contributes 21.60% of the variance. The third and fourth factors, of product scope and customer influence, each contribute 17.6% of the total variance. Inspection of Table 6.10 confirms that all variables load substantially on only one factor, highlighted in bold. This is consistent with the conceptual framework developed in Chapter Four, and allows the fourteen statements to be summated into four components to be included in future analysis.

Catell's scree test (Catell, 1966) is performed by plotting the eigenvalues for each factor and inspecting the resulting curve. In general, there is a steep drop before an "elbow", after which the values plateau. It is common to retain all factors with eigenvalues above this elbow, at which the curve changes shape, as these factors are those which contribute to most of the variance in the data set. The scree plot for the dependent variables is shown in Figure 6.4 overleaf. The elbow on this graph occurs between component numbers 4 and 5, suggesting that the first four factors be selected. This is consistent with the findings of Kaiser's criterion, which also found four factors.

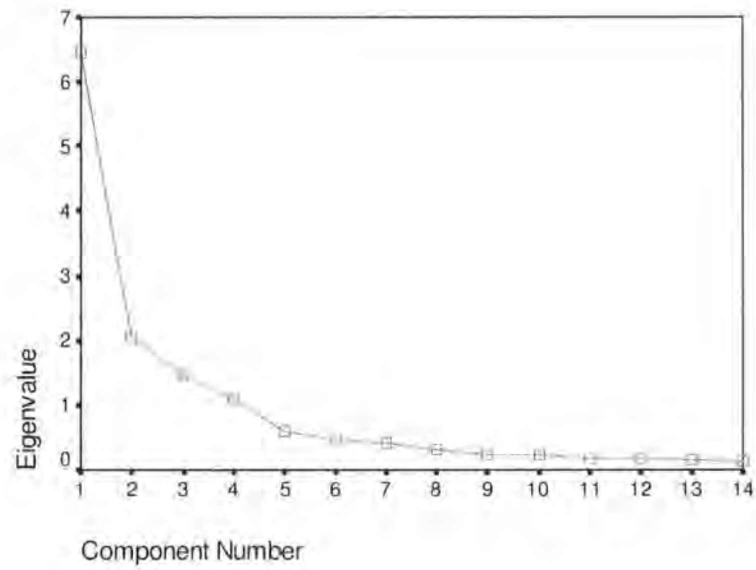


Figure 6.4: Scree plot for dependent variables

Factor analysis of the items relating to mass customisation attributes has therefore extracted from the fourteen original statements four factors: cost, development time, customer influence and product scope, which is in line with our conceptual framework, and provides further support that a structure does exist. These factors will henceforth be referred to as the dependent variables, and will be discussed in more detail in section 6.5.1.

6.4.2 Factor Analysis for Independent Variables

The above section describes the factor analysis which was performed with respect to the mass customisation attributes, that is, the dependent variables. This section describes the identical analysis of the items referring to supplier and lead user collaboration – the independent variables. Table 6.11 below shows the results of the Kaiser-Meyer-Olkin and Bartlett's tests. The Kaiser-Meyer-Olkin measure of 0.897 is greater than the required value of 0.6, and Bartlett's test of sphericity has a significance of $p = 0.000$, confirming the factorability of the data.

Table 6.11: Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) and Bartlett's test of sphericity for the independent variables

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.897
Bartlett's Test of Sphericity	Sig.	0.000

The results of variable-specific MSA analysis are shown in Table 6.12 overleaf. These show values of greater than 0.8 for all variables, signifying a very high degree of intercorrelation among the variables.

Table 6.12: Variable-specific MSA analysis for the collaboration variables.

Variable	Variable-specific MSA
(q1c.1)Supplier Collaboration setting General Product Definition	0.869
(q1c.2)Supplier Collaboration setting lead time requirements	0.880
(q1c.3)Supplier Collaboration setting product specifications	0.842
(q1c.4)Supplier Collaboration generating product's blueprint/drawings	0.932
(q1c.5)Supplier Collaboration designing product detailed component specification	0.876
(q1c.6)Supplier Collaboration product prototyping	0.885
(q1c.7)Supplier Collaboration product testing	0.922
(q1c.8)Supplier Collaboration overall NPD process	0.942
(q2.2.1) Lead User Collaboration setting General Product Definition	0.904
(q2.2.2) Lead User Collaboration setting lead time requirements	0.922
(q2.2.3) Lead User Collaboration setting product specifications	0.888
(q2.2.4) Lead User Collaboration generating product's blueprint/drawings	0.908
(q2.2.5) Lead User Collaboration designing product detailed component specification	0.885
(q2.2.6) Lead User Collaboration product prototyping	0.924
(q2.2.7) Lead User Collaboration product testing	0.901
(q2.2.8) Lead User Collaboration overall NPD process	0.922

Further justification of factorability was obtained through inspection of the correlation matrix, in Appendix 2.2. The table shows a majority of values above 0.3, which suggest that factor analysis can be appropriately employed on this sample.

Since the data has been shown to be factorable, factor extraction was performed, again using both Kaiser's criterion and the scree test. The sixteen items were subjected to principal component analysis, which presented two components with eigenvalues exceeding 1, as shown in Table 6.13 overleaf.

As explained in section 6.4.1, VARIMAX rotation was performed to aid in the interpretation of the two components. The resulting rotated matrix exhibited a simple structure, with both factors showing a number of strong loadings, and with each variable showing substantial loading on only one factor, highlighted in bold. The two extracted variables explain 65.83% of the total variance. The first factor, which relates to lead user collaboration, contributes 34.3% of the variance, while the second factor, which relates to supplier collaboration, contributes 31.5% of the variance. The two extracted factors are consistent with the conceptual framework developed in Chapter Four. The sixteen statements can be summated into two components to be included in future analysis.

Catell's scree test (Catell, 1966) was also performed on the factors relating to collaboration, as shown in Figure 6.5 below. By plotting the eigenvalues for each factor and inspecting the resulting curve. In this graph, the shoulder appears at component number 3, suggesting that two factors be selected. This is consistent with the above principal component analysis which suggested the two factors of supplier and lead user collaboration.

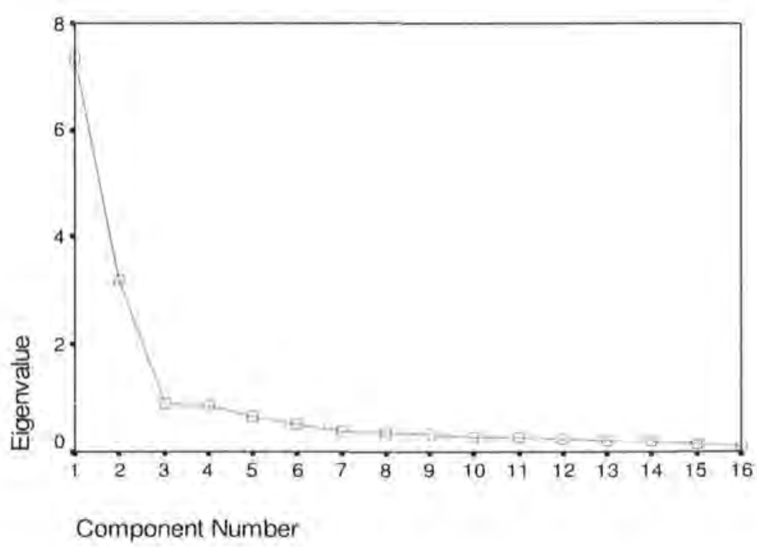


Figure 6.5: Scree plot for independent variables

Table 6.13: Independent variables factor extraction

Questionnaire Items	Lead User Collaboration	Supplier Collaboration
(q1c.1)Supplier Collaboration setting General Product Definition	0.211	**0.743**
(q1c.2)Supplier Collaboration setting lead time requirements	0.197	**0.687**
(q1c.3)Supplier Collaboration setting product specifications	0.098	**0.771**
(q1c.4)Supplier Collaboration generating product's blueprint/drawings	0.165	**0.814**
(q1c.5)Supplier Collaboration designing product detailed component specification	0.104	**0.821**
(q1c.6)Supplier Collaboration product prototyping	0.145	**0.749**
(q1c.7)Supplier Collaboration product testing	0.054	**0.796**
(q1c.8)Supplier Collaboration overall NPD process	0.292	**0.788**
(q2.2.1) Lead User Collaboration setting General Product Definition	**0.844**	0.091
(q2.2.2) Lead User Collaboration setting lead time requirements	**0.813**	0.116
(q2.2.3) Lead User Collaboration setting product specifications	**0.838**	0.101
(q2.2.4) Lead User Collaboration generating product's blueprint/drawings	**0.810**	0.262
(q2.2.5) Lead User Collaboration designing product detailed component specification	**0.802**	0.249
(q2.2.6) Lead User Collaboration product prototyping	**0.814**	0.196
(q2.2.7) Lead User Collaboration product testing	**0.742**	0.067
(q2.2.8) Lead User Collaboration overall NPD process	**0.812**	0.266
Eigen Values	5.487	5.047
Percentage of variation explained	34.29	31.54
Cumulative Percentage	34.29	65.83

Extraction Method: Principal Component Analysis. **Rotation Method**: Varimax with Kaiser Normalization.

As a result of this factor analysis, the sixteen items referring to collaboration have been reduced to two factors: supplier collaboration and lead user collaboration. These will be referred to as the independent variables, and will be discussed in more detail in section 6.5.2.

All the items were loaded at the same time, and subjected to factor analysis to test for any differences in results, as demonstrated in Table 6.14 overleaf. The resulting factor structure corresponds with the previously-derived structures for the dependent and independent variables, and is also consistent with the conceptual framework developed in Chapter Four. In the table below, components 1 and 2 correspond to the independent variables of lead user and supplier collaboration respectively, while components 3 to 6 represent the dependent variables of development cost, development time, product scope and customer influence respectively.

Table 6.14: Total variables factor extraction

Questionnaire Items	Component L	S	DC	DT	PS	CI
(q1c.1)Supplier Collaboration setting General Product Definition	0.226	**0.753**	0.108	-0.093	-0.037	0.073
(q1c.2)Supplier Collaboration setting lead time requirements	0.210	**0.699**	0.005	-0.072	0.137	0.004
(q1c.3)Supplier Collaboration setting product specifications	0.106	**0.779**	0.065	-0.032	0.023	0.020
(q1c.4)Supplier Collaboration generating product's blueprint/ drawings	0.141	**0.799**	0.078	0.149	-0.029	0.111
(q1c.5)Supplier Collaboration designing product detailed component specification	0.064	**0.801**	-0.001	0.212	0.101	0.107
(q1c.6)Supplier Collaboration product prototyping	0.107	**0.728**	0.053	0.184	0.140	0.017
(q1c.7)Supplier Collaboration product testing	0.032	**0.777**	0.197	0.123	0.009	-0.057
(q1c.8)Supplier Collaboration overall NPD process	0.255	**0.766**	0.136	0.124	0.136	0.084
(q2.2.1) Lead User Collaboration setting General Product Definition	**0.818**	0.077	0.148	0.008	0.255	0.044
(q2.2.2) Lead User Collaboration setting lead time requirements	**0.801**	0.114	0.073	-0.014	0.215	0.043
(q2.2.3) Lead User Collaboration setting product specifications	**0.820**	0.093	0.129	0.022	0.229	-0.004
(q2.2.4) Lead User Collaboration generating product's blueprint/drawings	**0.786**	0.250	0.124	0.130	-0.034	0.190
(q2.2.5) Lead User Collaboration designing product detailed component specification	**0.786**	0.243	0.046	0.169	-0.048	0.154
(q2.2.6) Lead User Collaboration product prototyping	**0.785**	0.179	0.081	0.229	-0.035	0.147
(q2.2.7) Lead User Collaboration product testing	**0.724**	0.055	0.080	0.196	0.029	0.006
(q2.2.8) Lead User Collaboration overall NPD process	**0.792**	0.257	0.069	0.121	0.021	0.155
(q3.1) Concept Development Costs	0.187	0.132	**0.785**	0.259	0.206	0.186
(q3.2) Product Design Costs	0.167	0.095	**0.822**	0.260	0.183	0.095
(q3.3) Product Manufacturing Costs	0.123	0.144	**0.771**	0.205	0.137	0.104
(q3.4) Total Costs of New Product Development	0.101	0.155	**0.809**	0.318	0.092	0.101
(q3.5) Concept Development Time	0.212	0.179	0.337	**0.789**	0.064	0.120
(q3.6) Product Designing Time	0.203	0.126	0.328	**0.777**	0.073	0.104
(q3.7) Product Manufacturing Time	0.094	0.041	0.202	**0.713**	0.325	0.035
(q3.8) Cycle Time (from concept to manufacturing)	0.199	0.128	0.270	**0.790**	0.124	0.090
(q3.9) Enabling customers to select from set menus/catalogs	0.101	0.054	0.147	0.114	0.161	**0.834**
(q3.10) Enabling customers to self configure features from tables (Mix and Match)	0.161	0.092	0.105	0.026	0.153	**0.898**
(q3.11) Enabling customers to design their products	0.168	0.062	0.121	0.114	0.120	**0.813**
(q3.12) range of items produced by exisiting facilities at the company	0.147	0.103	0.148	0.156	**0.832**	0.207
(q3.13) Scope of features offered to final customers (for each product)	0.150	0.139	0.197	0.118	**0.829**	0.183
(q3.14) number of products lines compared to competitors	0.103	0.090	0.159	0.167	**0.789**	0.092
Eigen Values	**5.536**	**5.104**	**3.172**	**3.028**	**2.539**	**2.496**
Percentage of variation explained	**18.46**	**17.01**	**10.57**	**10.09**	**8.46**	**8.32**
Cumulative Percentage	**18.46**	**35.47**	**46.04**	**56.13**	**64.60**	**72.92**

Extraction Method: Principal Component Analysis. **Rotation Method**: Varimax with Kaiser Normalization.
L = lead user collaboration; S = supplier collaboration; DC = development cost; DT= development time, PS = product scope; CI = customer influence

The resulting factors from this factor analysis represent the grouped variables that will be used in further analysis. The best method of including the results of the factor analysis is the use of summated scales. Summated scales use the grouped variables to reduce the dependence on any single variable as the only predictor of the construct (Hair *et al.*, 2006). By using factor analysis, variables that load on one factor belong to one similar group and are thus safe to summate into one scale representing the construct. This will allow for proper use of these variables in subsequent analysis. However, before conducting any further tests, primary descriptive analysis was performed on the data sets. This is discussed in the following section.

6.5 Descriptive Statistics and Analysis

The previous section described the factor analysis and the derivation of the four dependent and two independent variables. This section presents the descriptive statistics for each variable in the form of the frequencies analyses.

6.5.1 The Dependent Variables

The four dependent variables selected for this study were the attributes of mass customisation discussed in Chapter Four: cost, development time, customer influence and product scope. The aim of this study is to analyse the effect of the independent variables (supplier and lead user collaboration in mass customisation) on each of these attributes. This section presents the frequencies analysis for each dependent variable in order to gain an indication of how the companies view their performance in terms of the four attributes.

Development Cost

As discussed earlier in the scale development section, the dependent variable cost was measured by using four constructs. These were the concept development cost, product design cost and product manufacturing cost, in addition to the overall cost of the new product development, which was evaluated by the construct product development cost. These four constructs were represented by four statements asking the respondents to compare their costs with those of their competitors. Each construct was analysed separately to give deeper analysis of the underlying direction of results. Table 6.15 below shows the statistical analysis of the four constructs relating to cost, and allows comparison of their mean scores. Tables showing frequencies analysis of each construct are included in Appendix 2.5a.

Table 6.15: Frequencies analysis of dependent variable cost.

	(q3.1) Concept Development Costs	(q3.2) Product Design Costs	(q3.3) Product Manufacturing Costs	(q3.4) Total Cost of New Product Development
Mean	3.3108	3.2869	3.3506	3.2829
St. Dev.	0.9503	1.0067	0.9740	1.0018
Skewness	-0.207	-0.079	-0.149	-0.207
Std. Error	0.154	0.154	0.154	0.154
Kurtosis	-0.125	-0.443	-0.389	-0.436
Std. Error	0.306	0.306	0.306	0.306

Frequency analysis of the first construct, concept development costs, revealed that the majority of the companies studied view their concept development costs favourably with respect to their competitors. Respondents were asked to compare the costs of their concept development processes to those of their competitors, and report on their performance. Almost three quarters of those surveyed (72.9%) identified their concept development costs in the categories of equal to or better than those of their competitors, but only ten percent classed their performance as far superior.

The second construct studied related to product design costs. The frequency analysis revealed similar distribution to that observed for concept development costs, with distribution slightly more skewed towards the extremes. Fewer respondents (66.9%) categorised their performance as equal to or better than that of competitors, while more companies viewed their costs as being superior (12.4%) or below competition (17.1%).

Respondents were then asked to report on the third aspect of cost – product manufacturing cost. This corresponds to the expenditure associated with the fabrication and assembly stages of product development. The distribution of responses was similar to that observed for the concept development costs. The most popular response was that product manufacturing cost was equal to that of competition (37.5%) followed by the view that the cost was superior to that of competitors (32.3%). 12% of respondents answered that their performance in terms of product manufacturing costs far exceeded that of their competitors.

The fourth construct, the total cost of new product development, in effect encompasses the other three constructs. New product development refers to the entire process from concept to delivery, and therefore includes concept development, product design and product manufacturing. It might therefore be expected that the frequency analysis of this concept should mirror the average responses for the first three constructs. This did indeed appear to be the case, with the frequencies of responses lying within or close to the frequencies observed for the other constructs. Interestingly, slightly more (4%) respondents identified their performance as poor, compared to the lower percentages for concept development, product design and product manufacturing costs (3.6%, 3.6% and 2.8% respectively).

The overall direction of the cost constructs is towards better cost performance than competitors, with averages greater than 3 as shown in Table 6.15. The distribution for each construct is normal, confirmed by the skewness values between 0 and -0.5, and kurtosis values between 0 and -1. The skewness and kurtosis values are all negative, indicating that all curves tend towards the right-hand end of the distribution (larger scores) and are less peaked, with dispersion of scores across the range.

Development Time

The second dependent variable, development time, was studied as a combination of four constructs: concept development time, product designing time, product manufacturing time, and cycle time, which refers to the period from concept to manufacturing. Each construct was investigated by asking survey participants to respond to a statement to give a comparison of their times with respect to those of other companies. Table 6.16 overleaf shows the statistical analysis of the four constructs relating to development time, and allows comparison of their mean scores.

The frequencies analysis of each constructs can be found in Appendix 2.5b, and the chief findings are discussed below.

Table 6.16: Frequencies analysis of dependent variable development time.

	(q3.5) Concept Development Time	(q3.6) Product Designing Time	(q3.7) Product Manufacturing Time	(q3.8) Cycle Time (concept to manufacturing)
Mean	3.1594	3.1434	3.4542	3.2311
St. Dev.	1.0538	1.0096	0.9126	1.0557
Skewness	-0.096	-0.009	-0.166	-0.062
Std. Error	0.154	0.154	0.154	0.154
Kurtosis	-0.620	-0.521	-0.270	-0.651
Std. Error	0.306	0.306	0.306	0.306

The first construct referring to development time is concept development time, which corresponds to the period of time during which the product concept evolves. Frequencies analysis of this construct revealed that the majority of the companies studied view their concept development times favourably with respect to their competitors. When asked to compare the costs of their concept development processes to those of their competitors, and report on their performance, a majority of respondents (62.6%) identified their concept development costs in the categories of equal to or better than those of their competitors, but only ten percent classed their performance as far superior. Only a small number (5.6%) considered their concept development time to be far below those of competitors.

The second construct studied in order to gain an understanding of development time concerns product designing time, which corresponds to the process of developing the product concept into a definite product, with a clear manufacturing pathway. The frequency analysis revealed similar distribution to that observed for concept development time. Slightly more respondents (64.2%) categorised their performance as equal to or better than that of competitors, and slightly fewer companies viewed their costs as being superior (9.2%) or far below competition (4.4%).

Following product design, the next stage in the product development cycle is that of product manufacture, which covers fabrication and assembly processes. As a result, the third construct referring to lead time is that of product manufacturing time. The distribution of responses was somewhat different to those observed for the concept development and product designing times, with an overall more optimistic view of performance with respect to competitors. Almost three quarters (74.1%) of respondents described their performance as equal or better than competition, while 12.4% of companies answered that their performance in terms of product manufacturing costs far exceeded that of their competitors. Only a very small proportion (1.6%) believed that their performance was poor compared to that of their competitors.

The fourth construct, the total cycle time for new product development, in effect encompasses the other three constructs. The total cycle refers to the time from concept to manufacture, and therefore includes concept development, product design and product manufacturing. It is feasible to assume, therefore, that the frequency analysis of this concept should mirror the average responses for the first three constructs. It was found that the frequencies of responses were similar to those for the first two constructs. 62.2% of respondents cited their performance as lying in the categories of equal or better than that of their competitors, with 12.4% viewing their performance as superior. 4.4% of respondents believed that their overall cycle time was far inferior to that of competition.

Overall analysis of the constructs referring to development time is shown in Table 6.16, and demonstrates that the average response towards each construct is greater then 3, which signifies better time performance than competitors. The skewness values are between the critical values of 0.5 and -0.5 for each construct, and the kurtosis values are between the required 1 and -1, confirming a normal distribution of responses. As for the cost construct, all skewness and kurtosis factors are negative, indicating clustering of results towards the right of the mean and a flatter distribution of scores.

Customer Influence

In order to measure customer influence, three constructs were designed which refer to different levels of possible customer involvement. Listed from low to high levels of customer influence, these constructs are enabling customers to select from set menus or catalogues, enabling customers to self configure features from a given table and enabling customers to design their products. These three constructs were presented in the survey in the form of statements, and respondents were asked to compare their capacity for customer influence to that of competitors. Table 6.17 overleaf shows the statistical analysis of the three constructs relating to customer influence, and allows comparison of their mean scores. Each construct was analysed separately to give deeper analysis of the underlying direction of results. Tables showing frequencies analysis of each construct are included in Appendix 2.5c.

Table 6.17: Frequencies analysis of dependent variable customer influence

	(q3.9) Enabling customers to select from set menus/catalogs	(q3.10) Enabling customers to self configure features from tables (Mix and Match)	(q3.11) Enabling customers to design their products
Mean	3.2112	3.1355	3.1753
St. Dev.	1.0842	1.0907	1.0398
Skewness	-0.258	-0.365	-0.464
Std. Error	0.154	0.154	0.154
Kurtosis	-0.418	-0.509	-0.110
Std. Error	0.306	0.306	0.306

The first construct referring to customer influence describes the provision of a company for customers selecting desired products from set menus or catalogues. Frequency analysis of this construct revealed that the majority of the companies studied viewed that the levels to which they enabled customers to make selections favourably with respect to their competitors. Almost two thirds of those surveyed (65.8%) categorised their performance as equal to or better than those of their competitors, with 11.6% viewing their performance as far superior. On the other hand, 8% viewed their performance as far inferior.

The second construct studied described the performance of companies in enabling customers to self configure features from tables giving them possible choices. This has been referred to as the mix and match approach. The frequency analysis revealed a distribution skewed towards poorer performance compared to that for the first construct. A similar number of respondents (66.6%) classed their performance as equal to or better than that of competitors, but fewer (8.0%) viewed their performance as far superior and more (10%) believed that they had far inferior performance.

The final construct corresponding to customer influence describes the enabling of customers to design their products. Interestingly, respondents viewed their performance in this aspect more favourably than for the first two constructs. A majority of respondents (40.6%) viewed their performance as equal to competition, with a further 31.9% claiming better performance. The percentage of respondents claiming superior or inferior performance was slightly less than for the second construct (7.6% and 9.6% respectively).

The mean of each customer influence construct is greater than 3, indicating a tendency towards allowing customer influence better than competitors, as shown in Table 6.17 above. Normality of distribution is confirmed by the skewness and kurtosis values, which lie within the range considered acceptable for normal distributions (-0.5 to 0.5 for skewness, -1 to 1 for kurtosis). The negative skewness and kurtosis values are consistent with right-leaning, flat distributions.

Product Scope

The final dependent variable, product scope, was measured using three constructs which attempt to provide a gauge for the variety of products offered by the company. These constructs are the range of items produced by existing facilities, the scope of features which are offered for each product, and the number of product lines compared to competitors. In order to study product scope, these three constructs were presented in the survey in the form of statements, and respondents were asked to compare their product scope to that of competitors. The frequencies analysis of each constructs can be found in Appendix 2.5d, and the primary results are discussed below. The average frequency data for each construct is shown in Table 6.18 below.

Table 6.18: Frequencies analysis of dependent variable product scope

	(q3.12) range of items produced by exisiting facilities at the company	(q3.13) Scope of features offered to final customers (for each product)	(q3.14) number of products lines compared to competitors
Mean	3.6096	3.6932	3.7211
St. Dev.	0.9914	0.9703	1.0554
Skewness	-0.593	-0.782	-0.636
Std. Error	0.154	0.154	0.154
Kurtosis	0.211	0.636	0.119
Std. Error	0.306	0.306	0.306

The first construct measuring product scope is the range of items which are produced by existing facilities at the company. While this varies considerably across industries, respondents were asked to compare their performance to competitors within their industry. Frequency analysis of this construct revealed that most respondents believed they performed well in this area. The greatest number of respondents (40.2%) cited their performance as better than that of their competition, and 17.9% claimed they had far superior performance. A further 30.7% of respondents viewed their performance as equal to competition, and only 4% believed they performed far worse than their competitors.

The second construct studied explored the product scope by focussing on the range of features which were offered to final customers for each product. Frequencies were distributed similarly to the first construct. More respondents (45.4%) viewed their performance as better than that of their competitors, with 18.7% claiming superior performance. 26.3% of respondents rated their performance as equal to that of competition, and again 4% believed they had inferior performance.

The third construct for product scope describes the total number of product lines, as compared to the product lines offered by competitors. Respondents viewed their performance in this aspect more favourably than for the first two constructs. A total of 90.9% of respondents viewed their performance as equal to, better or far superior to competition, with frequencies distributed relatively evenly across the three categories (31.5%, 32.7% and 26.7% respectively).

The overall direction of the product scope constructs is towards better performance than competitors, with averages greater than 3 as shown in Table 6.18. Indeed, the mean responses for these three constructs were higher than for the other eleven constructs relating to the other dependent variables. The distribution of responses for these three constructs are slightly abnormal, indicated by the skewness values, -0.593, -0.782 and -0.636, which are outside the range for normality (0.5 to -0.5). However, the kurtosis values fall well within the range (1 to -1). This shows that the distribution curve is slightly skewed towards the right-hand side of the distribution. However, due to the large sample size, this small deviation from normality need not be considered problematic for subsequent statistical analysis, as discussed earlier with respect to the central limit theorem. In addition, the following statistical tests which have been employed are fairly robust and account for such deviation.

6.5.2 The Independent Variables

This study aims to understand the effect of collaborations on the new product development in mass customisation (measured by the dependent variables of cost, lead time, customer influence and product scope). In particular, the external partnerships with suppliers and lead users, and the differences between these two partnerships are being explored. In order to achieve this analysis, the two independent variables in this study are supplier collaboration in mass customisation, and lead user collaboration in mass customisation.

Supplier Collaboration

The first independent variable, supplier collaboration, was studied by assessing the role of suppliers in a number of key process in product development. Seven specific constructs were chosen to describe different aspects of product development, and an eighth construct measuring supplier collaboration in the overall new product development processes was also employed. In each case, respondents were asked to rate their supplier collaboration on a 5-point scale from very low to very high. Table 6.19 overleaf shows the statistical analysis of the four constructs relating to development time, and allows comparison of their mean scores. The frequencies analysis for each construct can be found in Appendix 2.5e and the findings for each are summarised below.

Table 6.19: Frequencies analysis of the independent variable supplier collaboration

	(q1c.1)Supplier collaboration setting general product definition	(q1c.2)Supplier collaboration setting lead time requirements	(q1c.3)Supplier collaboration setting product specifications	(q1c.4)Supplier collaboration generating blueprints	(q1c.5)Supplier collaboration designing component specification	(q1c.6)Supplier collaboration product prototyping	(q1c.7)Supplier collaboration product testing	(q1c.8)Supplier collaboration overall NPD
Mean	2.8725	3.2550	3.1474	2.9960	3.0757	3.1992	3.0837	3.0438
St. Dev.	1.1206	1.1094	1.1019	1.1042	1.1412	1.1559	1.1853	1.1323
Skewness	-0.176	-0.377	-0.259	-0.172	-0.198	-0.270	-0.163	-0.237
Std. Error	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154
Kurtosis	-0.843	-0.513	-0.613	-0.767	-0.683	-0.754	-0.793	-0.802
Std. Error	0.306	0.306	0.306	0.306	0.306	0.306	0.306	0.306

The first construct was supplier collaboration in setting the general product definition. Respondents were asked to evaluate the level to which they involved suppliers in the task of defining products. The largest group of respondents (31.9%) claimed medium supplier collaboration, followed by high collaboration (27.9%). Only a small proportion (4.8%) described their supplier collaboration as very high. The remaining respondents were distributed amongst the low (20.7%) and very low (14.7%) categories.

Respondents were then asked to assess their level of supplier collaboration in setting lead times. A larger number of participants identified their collaboration as high (34.3%) and very high (11.6%) compared to the responses for the first construct, with a similar number (30.7%) grading their collaboration as medium. As a result, fewer respondents measured their collaboration as low (15.1%) or very low (8.4%).

The third construct describes the supplier collaboration in setting the product specifications. The frequencies analysis of this construct reveals responses that are slightly more negative compared to the first construct. Fewer respondents identified their collaboration as high (31.5%) or very high (9.6%), with more rating their supplier involvement as low (18.3%) or very low (8.8%). The remaining 31.9% graded their collaboration as medium.

Following product specification, a blueprint of the product must be created in order to allow planning for assembly. As a result, the fourth construct for study was the supplier collaboration in generating the product's blueprint or drawings. The frequencies analysis for this construct revealed responses that were more similar to those for the first construct. The largest number of respondents (31.5%) claimed medium supplier collaboration, followed by high collaboration (28.3%). A further 8% described their supplier collaboration as very high. The remaining respondents were distributed between the low (19.9%) and very low (12.4%) categories.

The fifth construct which was studied as a measure of supplier collaboration describes supplier collaboration in designing the detailed component specification for a product. Almost one third (33.1%) of respondents identified their collaboration as medium, followed by 27.9% who rated their supplier involvement as high. A further 10% of participants regarded that they engaged in supplier collaboration to a very high degree. The remaining participants were distributed amongst the low (17.9%) and very low (11.2%) categories in a similar ratio to those observed for the other constructs (between 2:1 and 3:2).

Supplier collaboration was subsequently assessed in the area of product prototyping, which formed the basis of the sixth construct. The distribution of frequencies for this construct was more similar to those observed for the second construct, with the most popular response being that of high collaboration (32.3%), followed by medium collaboration (27.5%). 12.4% of respondents evaluated their supplier involvement in product prototyping as very high, while 18.7% measured their collaboration as low and the remaining 9.2%, as very low.

The final stage of product development in which supplier collaboration was assessed was product testing, which was the seventh construct. The frequencies analysis revealed a distribution of responses which most closely resembled those for the fifth construct, which measured supplier collaboration in determining component specifications. The largest number of respondents (31.1%) rated their supplier collaboration in product testing as medium, followed by those who ranked their performance as high (26.7%). 18.3% of respondents regarded their collaboration level as low, and the remaining responses were equally distributed between very low and very high categories (12% each).

The final construct was designed to measure the supplier collaboration in the overall new product development process. As this process involves all individual practices described in the first seven constructs, it might be expected that the responses for this construct reflected the average responses for the other constructs. This was indeed found to be the case. The largest group of respondents were those who rated their collaboration as high (32.3%), followed by a medium level (28.3%). 7.6% of respondents rated their supplier collaboration in overall NPD as very high. The remaining responses were distributed between low (20.7%) and very low (11.2%) levels of collaboration.

Overall analysis of the constructs referring to supplier collaboration is shown in Table 6.19, and demonstrates that the average response to most constructs is greater than 3, signifying better supplier collaboration than competitors. The anomalies to this are the average response to the first construct, supplier collaboration in setting the general product definition, with a mean of 2.87, and the average response to supplier collaboration in the generation of blueprints, with a mean which is very close to the central response of 3. The skewness values are between 0 and -0.5 for each construct, and the kurtosis values are between 0 and -1, confirming a normal distribution of responses. All skewness and kurtosis factors are negative, indicating clustering of results towards the right of the mean and a flatter distribution of scores.

Lead User Collaboration

This study attempts to compare the importance of supplier collaboration with that of lead users, and the second independent variable is lead user collaboration. The eight constructs selected to measure lead user collaboration are identical to those chosen for supplier collaboration, and were changed only in that they asked respondents to rate their level of lead user involvement in the various areas. The same five-point scale, from very low to very high, was employed for this study. The responses for each construct were subjected to frequencies analysis, the results of which are shown in found in Appendix 2.3f, and the observations for each construct are discussed here. Table 6.20 overleaf shows the statistical analysis of the four constructs relating to development time, and allows comparison of their mean scores.

Table 6.20: Frequencies analysis of the independent variable lead user collaboration

	(q1c.1)Lead user collaboration setting general product definition	(q1c.2) Lead user collaboration setting lead time requirements	(q1c.3) Lead user collaboration setting product specifications	(q1c.4) Lead user collaboration generating blueprints	(q1c.5) Lead user collaboration designing component specification	(q1c.6) Lead user collaboration product prototyping	(q1c.7) Lead user collaboration product testing	(q1c.8) Lead user collaboration overall NPD
Mean	3.1514	3.1116	3.1833	2.7809	2.7928	2.8167	3.0837	2.9602
St. Dev.	1.2104	1.2114	1.1959	1.2537	1.2605	1.2579	1.2054	1.2027
Skewness	-0.376	-0.297	-0.415	-0.021	-0.002	-0.087	-0.259	-0.090
Std. Error	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154
Kurtosis	-0.765	-0.858	-0.699	-1.095	-1.121	-1.104	-0.864	-0.889
Std. Error	0.306	0.306	0.306	0.306	0.306	0.306	0.306	0.306

The first construct measures lead user collaboration in setting the general product definition. The largest group of respondents (33.1%) claimed high supplier collaboration, followed by medium collaboration (28.3%). 11.6% described their supplier collaboration as very high. The remaining respondents were distributed relatively evenly between the categories of low (13.9%) and very low (13.1%) lead user collaboration.

In order to measure the second construct, respondents were asked to rate their level of lead user collaboration in the determination of requirements for lead times. A similar distribution of responses was observed as for the first construct, with 26.7% identifying their collaboration as medium, 32.3% as high and 11.2% as very high. Of the remaining participants, 16.3% described their level of lead user collaboration with respect to lead times as low and 13.5% as very low.

The third construct which was employed to measure lead user collaboration explores the process of defining product specifications. The frequencies analysis of this construct reveals similar responses to the first two constructs. The largest groups of respondents rated their collaboration as high (34.3%) and medium (28.3%). The remaining respondents were distributed between the other categories of very high (11.6%), low (12.7%) and very low (13.1%).

Frequencies analysis for the fourth construct, the lead user collaboration in the generation of blueprints or drawings of the product, revealed a different distribution of responses. Responses were generally more negative than for the first three constructs. While a similar number of respondents (27.1%) regarded their collaboration as medium, fewer ranked their performance in the high (25.1%) and very high (7.6%) categories. As a result, the proportion of responses in the low (18.3%) and very low (21.9%) classes increased.

The fifth construct which was studied describes lead user collaboration in designing the detailed component specification for a product. The distribution of frequencies is similar to that for the fourth construct. Responses were distributed relatively evenly between the categories of high (25.9%), medium (24.7%), low (20.3%) and very low (21.1%) collaboration. Only 8% of respondents rated their lead user collaboration for component specification as very high.

Lead user collaboration was then assessed in terms of involvement in product prototyping, the sixth construct. The most popular response was that of medium collaboration (27.5%), followed closely by high involvement (26.7%). Again, only a relatively small number (7.6%) described their collaboration levels as being very high. The remaining responses were distributed between low (16.3%) and very low (21.9%) categories.

The seventh construct, and the last which was employed to measure lead user collaboration at a specific stage of product development, was the lead user collaboration in product testing. The frequencies analysis revealed a distribution of responses which more closely resembled those for the first three constructs, The largest number of respondents (31.1%) rated their supplier collaboration in product testing as high, followed by those who ranked their performance as medium (27.5%). 17.1% of respondents regarded their collaboration level as low, and 13.5% described their lead user involvement as very low. The remaining 10.8% of responses lay in the very high category.

The final construct is the lead user collaboration in the overall new product development process, which encompasses all the stages of product development described by the first seven constructs. The frequencies analysis of responses revealed responses which lay within the frequencies observed for the other constructs, as might be expected. The largest group of respondents were those who rated their collaboration as medium (29.9%), followed by high (25.5%). 10% of respondents rated their lead user collaboration in overall NPD as very high. The remaining responses were distributed between low (19.9%) and very low (14.7%) levels of collaboration.

Overall analysis of the constructs referring to lead user collaboration is shown in Table 6.20, and inspection of the mean values shows that for some constructs, the average response indicates better performance than competitors (mean > 3) and for other constructs, there is a worse performance (mean < 3). The skewness values are between 0 and -0.5 for each construct, consistent with normal distribution. All skewness values are negative, which suggest clustering of results to the right of the mean. Interestingly, skewness values are much smaller in magnitude for those constructs for which the mean is less than 3: this low skewness value indicates a better fit for normality. On the other hand, the kurtosis values for the five constructs with means of greater than 3 lie between 0 and -1, confirming a normal distribution of responses with a flattened distribution. The kurtosis values for the remaining three constructs, however, are greater in magnitude than 1.02, which lies outside the boundary for normality. Since these constructs have such low skewness values, however, and since the kurtosis values lie between -1 and -1.2, normality can still be assumed, as is also supported by the central limit theorem.

6.6 Regression Analysis

In this study, two key partners (suppliers and lead users) in the product development process were used as predictors of four mass customisation attributes. Each partner was hypothesised to be a successful predictor of each of the four desired attributes. Section 6.4 above describes the factor analysis which was performed and which confirmed the categorisation of the survey items into groups which provided information for each of the variables: the two independent variables relating to supplier and lead user collaboration, and the four dependent variables describing the mass customisation attributes. In order to test the relationships between these two sets of variables, multivariate regression analysis was carried out. The following sections detail the procedures performed to test the proposed hypotheses, and explains the results of these statistical tests.

6.6.1 Hierarchical Multivariate Regression

Hierarchical multivariate regression is used to evaluate the relationships between a set of independent variables and the dependent variable, controlling for the impact of a different set of independent variables on the dependent variable. The rationale behind this is to determine whether the addition of the new set of proposed independent variables has increased the predictive power of the model beyond that afforded by the first or previous set. The hierarchical approach works by removing the effect of the first block of independent variables to check whether the next block is able to contribute in explaining the remaining variance in the dependent variable (Pallant, 2006) (Tabachnik and Fidell, 2006). This approach is appropriate for the purpose of this study where the aim is to test if the suppliers collaboration and lead users collaboration, whose effect is the main research focus, can predict some of the variance in the four mass customisation attributes (development cost, development time, customer influence and product scope). This effect is easier to test after separating it from the effect of the firm size, firm age, sales level between the supplier and the firm, which are thought to have some impact on the dependent variables.

In the regression function or model, the dependent variable must be a continuous variable and this has been achieved in the following models, in which all of the independent variables are also continuous.

In order to fulfil the assumptions of the multivariate regression, as discussed earlier in section 6.3.1, it was necessary to remove any outliers present in the data. This was achieved by the statistical test of the Mahalanobis D^2 measure, which indicated no statistical significance for any variables, suggesting that none of the responses was an outlier. The data set was therefore appropriate for multivariate regression, as demonstrated earlier. In addition, homoscedasticity was examined by performing visual inspection of scatter plots for each of the independent variables against each of the dependent variables, as described in section 6.3.2.

The hierarchical multiple regression requires that the there should be at least 5 valid cases for each independent variable to have a valid analysis. The ratio of valid cases to number of variables in this study is 50.2 (251/5) which is greater than the preferred ratio of 15:1 (Stevens, 1996).

In the following sections, each of the four models designed to test the relationships between supplier's collaboration and lead user's collaboration and the four mass customisation attributes will be presented in detail and the findings briefly examined. Discussion of results and conclusions are given in Chapter Seven.

6.6.2 Model 1: Development Cost

The first model tests for the effects of supplier collaboration and lead user collaboration on the costs of the product development process, and whether collaborating with suppliers and lead users would have any predictive power of the development costs. The following section details the regression function and model specification which has been designed in order to test this model.

6.6.2.1 Model specification

This section details how the relationship between the dependent variable (cost) and independent variables (supplier collaboration and lead user collaboration) was tested. The relationship is controlled by firm size (measured by the number of employees), firm's age in years, and the level of sales between supplier and the firm. The following regression model has been formulated to examine the research hypotheses:

$$C= \beta_0+ \beta_1 FS + \beta_2 FA + \beta_3 SL +\beta_4 SCMC +\beta_5 LUCMC + \varepsilon$$

Where:

C: Cost,

β_0: Constant,

$\beta_1, \beta_2, \beta_3, \beta_4,$ and β_5: Coefficients,

FS: Firm size,

FA: Firm age,

SL: Sales level,

SCMC: Suppliers' collaboration in mass customisation,

LUCMC: Lead users' collaboration in mass customisation, and

ε: error

6.6.2.2 Model Results

The model was tested by regressing the summated scores of the independent variables (suppliers collaboration and lead users collaboration) and the control variables (firm size, firm age, sales level) on development cost using hierarchical regression analysis. Initially, an inspection of the correlation matrix (Table 6.21) revealed correlations amongst the independent variables. Most correlations were positive, but small. Sales level correlated with firm age (0.108), firm size (0.125), supplier collaboration (0.38) and lead user collaboration (0.144), firm size correlated with supplier collaboration (0.196), and supplier collaboration correlated with lead user collaboration (0.395). In addition, there was a negative correlation between firm age and lead user collaboration (-0.276). However, all these correlations were small, ranging from 0.113 to 0.395, which indicates that multicollinearity between independent variables in the data set is unlikely to be a problem. Multicollinearity would be a problem if independent variables have a bivariate correlation higher than 0.90 (Tabachnick and Fidell (2001) recommend a more conservative limit of 0.70). There was also significant correlation between the control variables firm age and sales level with the dependent variable cost (-0.113 and 0.145 respectively), but this correlation was only very week. On the other hand, the two independent variables supplier collaboration and lead user collaboration correlated more significantly (*p* <0.01) with dependent variable cost (0.314 and 0.357 respectively). These correlations indicate that the data is suitable for reliable examination of the responses through hierarchical multiple linear regression.

The means and standard deviations for each variable are displayed in Table 6.21, cost has a mean of (3.31) and a standard deviation of 0.87 indicating good cost performance in comparison to competitors. The average firm size is 893 employees with a standard deviation of 507.6; this indicates that relatively medium and large firms are well represented in the sample. The average firm age was 34 years with a standard deviation of 17 years which suggests that the major part of the sample is of companies well situated and established in the market. The sales level between suppliers and the respondent companies is considered above average as the mean is (3.24) with a standard deviation of 1, which indicates fairly good relationship between the companies and their suppliers. Supplier collaboration and lead user collaboration summated factors indicated average collaboration levels with means of (3.08 and 2.98 respectively) with standard deviations of (0.89 and 1.01).

Table 6.21: Correlations matrix for development cost

	Mean	S.D.	Cost	Firm Size	Firm Age	Sales Level	SCMC	LUCMC
Cost	3.31	0.87	1.000					
Firm Size	893.1	507.6	0.098	1.000				
Firm Age	34.3	16.9	-0.113*	0.011	1.000			
Sales Level	3.24	1.01	0.145*	0.125*	0.108*	1.000		
SCMC	3.08	0.89	0.314**	0.196**	-0.068	0.380**	1.000	
LUCMC	2.98	1.01	0.357**	0.102	-0.276**	0.144*	0.395**	1.000

* $p < 0.05$, ** $p < 0.01$

While the correlation matrix is a good tool for inspecting multicollinearity, the recommended tests to assess multicollinearity are the tolerance limits and VIF tests. Simple correlations in the matrix reveals bivariate multicollinearity, whereas the tolerance limit and VIF asses by regressing each independent variable on all the other variables. As a rule of thumb if the tolerance coefficient for an independent variable is less than 0.10, this indicate that multiple correlation with the other independent variables is high therefore multicollinearity might be a problem (Pallant, 2006). Reciprocal of the tolerance test is the Variance inflation factor (VIF) (it is the inverse of the tolerance coefficient). When VIF is high (above 10) multicollinearity is present (Hair *et al*, 2006). Table 6.22 displays the statistics for multicollinearity, all of the independent variables tolerance coefficients are higher than 0.10 (ranging between 0.722 and 0.988) and the VIF statistics are less than 10 (ranging between 1.012 and 1.384) indicating the non existence of the inter-correlation between the independent variables, hence multicollinearity is unlikely to be a problem.

Another problem that might affect the predictive power of the model is the problem of autocorrelation. A major assumption in multivariate regression analysis is independence of observations which assumes that errors of prediction are independent from each other, that is they do not follow a pattern from one observation to another (Tabachnik and Fidell, 2006). The Durbin-Watson measure tests for the presence of this serial correlation amongst the residuals, if the statistic is between 1.5 and 2.5 then there is no serial autocorrelation and the independence of observations is assumed. Table 6.22 below shows that the Durbin-Watson statistic for this model (1.821) falls well within the acceptable range, and that the assumption of independence of errors has therefore been met.

Table 6.22: Multicollinearity and independence of errors tests for development cost

Model		Collinearity Statistics		Durbin-Watson
		Tolerance	VIF	
1	(Constant)			
	Company size	0.984	1.016	
	Age	0.988	1.012	
	Sales level between company and suppliers	0.973	1.028	
2	(Constant)			1.821
	Company size	0.952	1.050	
	Age	0.901	1.110	
	Sales level between company and suppliers	0.863	1.159	
	Suppliers collaboration in NPD	0.743	1.345	
	Lead users collaboration in NPD	0.774	1.291	

The regression results are shown in Table 6.23 overleaf. The model summary displays an R^2 value of the control variables (model 1), of 0.044, which, although significant ($p < 0.05$), is rather low. The adjusted R^2 of approximately 0.03 further lowers the predictive power of the first model, which has a low F statistic of 3.8. The standardised coefficients of the control variables are rather low: β_1, β_2, and β_3 are 0.081, -0.130, and 0.149 respectively. However, addition of the main independent variables of supplier collaboration and lead user collaboration in the second set of the regression model, resulted in a significant increase in R^2 by 12.1%. The R^2 (0.165) and adjusted R^2 (0.148) values are much larger than for set 1, and the F statistic (17.8) is also larger, which indicates much greater predictive power for the model. As for the first set, the standardised coefficients of the control variables are insignificant and very weak: β_1, β_2, and β_3 are 0.030, -0.031, 0.035. On the other hand, the standardised coefficients corresponding to supplier and lead user collaboration (β_4 and β_5 are 0.187 and 0.267 respectively) are higher and much more significant ($p = 0.007$ and 0.000 respectively). The differences between the two sets are evidenced in the change in the overall significance, which increased from a significance of $p < 0.05$ to $p = 0.000$. In hierarchical regression, each set is calculated with a different equation (Pallant, 2006), and as a result, the outputs for control variables in the two sets will differ. In this case, this is manifested in significance for company age and supplier sales level in the first model, but not in the second.

Table 6.23: Hierarchical Regression Model- Dependent Variable: Cost

	Unstdized Coeffs		Stdized Coeffs	t	Sig.
	B	Std Error	Beta		
Set 1					**0.011**
(Constant)	3.001	0.217		13.853	0.000
Company size (number of employees)	0.000	0.000	0.081	1.294	0.197
Company age	-0.007*	0.003	-0.130*	-2.074	0.039
Sales level between company and suppliers	0.128*	0.054	0.149*	2.360	0.019
r	0.210				
R^2	0.044				
Adjusted R^2	0.033				
Regression *F*-value	3.808				
Set 2					**0.000**
(Constant)	1.974	0.266		7.407	0.000
Company size (number of employees)	0.005	0.000	0.030	0.508	0.612
Company age	-0.002	0.003	-0.031	-0.498	0.619
Sales level between company and suppliers	0.030	0.055	0.035	0.548	0.584
Supplier Collaboration	0.182**	0.067	0.187**	2.723	0.007
Lead Users Collaboration	0.229**	0.057	0.267**	4.035	0.000
r	0.407				
R^2	0.165				
Adjusted R^2	0.148				
R^2 Change	0.121				
Regression *F*-value	17.798				

Note: *$p < 0.05$ ** $p < 0.01$

As discussed in section 6.3.2, it is important to ensure the validity of the results by testing for the homoscedasticity and normality of the dataset. A normal probability plot of the regression standardised residual and a residuals scatter plot were obtained during the model testing, and are shown in Appendices 2.4 and 2.5 respectively. The normal probability plot shows all values falling along the diagonal, suggesting that there is no substantial deviation from normality. The residuals scatter plots exhibits a centralised rectangular distribution, indicating homogeneity of variance (Pallant, 2006).

Hierarchical regression was used to evaluate the relationships between suppliers and lead users collaboration factor and the dependent factor cost, taking into account the impact of the company size, age and sales level on the cost. with suppliers employed to determine if the addition of the suppliers collaboration factor and the lead users collaboration factor improved the predictive ability of the model. The results, as discussed above, indicate a significant increase in the R^2 of the second model; the null hypothesis for the addition of suppliers and lead users factors to the control variables-firm size, firm age, and level of sales-to the analysis is that the change in R^2 is zero. Since the change in R^2 between the two models is 12.1% then the null hypothesis is rejected which indicates that the variables in the second model suppliers and lead users collaboration have a predictive power of lower product development cost after controlling for the relationship of the first model variables (firm size, firm age, and level of sales). The R^2 of the second model is 0.165 which indicates that 16.5% of the variance in product development costs is explained by this model. Therefore, in the light of the previous results, the fifth hypothesis of the research which assumes a positive relationship between supplier collaboration and low product development costs is supported. The results also support the first hypothesis of the research which assumes a positive relationship positive relationship between lead users collaboration and low product development costs, the results indicate that the relationship is stronger than that of the suppliers.

6.6.3 Model 2: Development Time

The first model focussed on the first dependent variable, development cost. The second model deals with the second dependent variable, development time, and tests for the effects of supplier collaboration and lead user collaboration on the product development time, and whether collaborating with suppliers and lead users would have any predictive power of the development time.

6.6.3.1 Model specification

This section details how the relationship between the dependent variable (time) and independent variables (supplier collaboration and lead user collaboration) was tested. The relationship is controlled by firm size (measured by the number of employees), firm's age in years, and the level of sales between supplier and the firm, which leads to the following regression model:

$$DT = \beta_0 + \beta_1 FS + \beta_2 FA + \beta_3 SL + \beta_4 SCMC + \beta_5 LUCMC + \varepsilon$$

Where:

DT: Development time,

β_0: Constant,

$\beta_1, \beta_2, \beta_3, \beta_4,$ and β_5: Coefficients,

FS: Firm size,

FA: Firm age,

SL: Sales level,

SCMC: Suppliers' collaboration in mass customisation,

LUCMC: Lead users' collaboration in mass customisation, and

ε: error

6.6.3.2 Model Results

The model was tested by the regression of the summated scores of the independent variables (suppliers collaboration and lead users collaboration) and the control variables (firm size, firm age, sales level) on development time using hierarchical regression analysis. An intial inspection of the correlation matrix (Table 6.24) revealed correlations amongst the independent variables as noted in section 6.8.1.2. There is also significant correlation between the control variables firm age and sales level with the dependent variable cost (-0.115 and 0.140 respectively), but this correlation was only very weak. On the other hand, the two independent variables supplier collaboration and lead user collaboration correlated more significantly (p <0.01) with dependent variable cost (0.309 and 0.396 respectively). These correlations indicate that the data is suitable for reliable examination of the responses through hierarchical multiple linear regression.

The means and standard deviations for each variable are displayed in Table 6.24. The mean response for time is 3.25 with a standard deviation of 0.88, indicating an overall trend towards better time performance than competitors. The other descriptive statistics have been presented in Section 6.8.1.2.

Table 6.24: Correlations matrix for development time

	Mean	S.D.	Time	Firm Size	Firm Age	Sales Level	SCMC	LUCMC
Time	3.25	0.88	1.000					
Firm Size	893.1	507.6	0.120*	1.000				
Firm Age	34.3	16.9	-0.115*	0.011	1.000			
Sales Level	3.24	1.01	0.140*	0.125*	0.108*	1.000		
SCMC	3.08	0.89	0.309**	0.196**	-0.068	0.380**	1.000	
LUCMC	2.98	1.01	0.396**	0.102	-0.276**	0.144*	0.395**	1.000

* $p < 0.05$, ** $p < 0.01$

Multicollinearity was assessed by measurement of the tolerance and VIF values, as shown in Table 6.25. The independent variables tolerance coefficients range from 0.722 to 0.988, well above the threshold of 0.10. The VIF statistics range from 1.012 to 1.384, again well below the upper threshold of 10. These two sets of results confirm that multicollinearity is unlikely to affect the data analysis. In order to test for autocorrelation, the Durbin-Watson statistic was determined, and found to be 1.868. This falls well within the required range of 1.5 to 2.5, and demonstrates that there is no autocorrelation which might affect the predictive power of the model.

Table 6.25: Multicollinearity and independence of errors tests for development time

Model		Collinearity Statistics		Durbin-Watson
		Tolerance	VIF	
1	(Constant)			
	Company size	0.984	1.016	
	Age	0.988	1.012	
	Sales level between company and suppliers	0.973	1.028	
2	(Constant)			1.868
	Company size	0.957	1.045	
	Age	0.901	1.110	
	Sales level between company and suppliers	0.835	1.198	
	Suppliers collaboration in NPD	0.722	1.384	
	Lead users collaboration in NPD	0.780	1.283	

The regression results are shown in Table 6.26. The model summary displays an R^2 value of the control variables (in model 1) of 0.047, which, although significant ($p < 0.01$), is rather low. The adjusted R^2 of 0.036 further lowers the predictive power of the first model, which has a low F statistic of 4.1. The standardised coefficients of the control variables are rather low: β_1, β_2, and β_3 are 0.103, -0.131 and 0.142 respectively. In the second set of the regression model, in which the main independent variables of supplier collaboration and lead user collaboration have been added, there is a significant increase in R^2 by 14.1%. The R^2 (0.188) and adjusted R^2 (0.172) values are much larger than for set 1, and the F statistic (21.2) is also larger, which indicates much greater predictive power for the model. As for the first set, the standardised coefficients of the control variables are insignificant and very weak: β_1, β_2, and β_3 are 0.052, -0.020, 0.029. On the other hand, the standardised coefficients corresponding to supplier and lead user collaboration (β_4 and β_5 are 0.167 and 0.317 respectively) are higher and much more significant (p = 0.018 and 0.000 respectively). The differences between the two sets are evidenced in the change in the overall significance, which increased from a significance of p = 0.007 to p = 0.000.

Table 6.26: Hierarchical Regression Model- Dependent Variable: Development Time

	Unstdized Coeffs		Stdized Coeffs	t	Sig.
	B	Std. Error	Beta		
Set 1					**0.007**
(Constant)	2.925	0.219		13. 348	0.000
Company size (number of employees)	0.000	0.000	0.103	1.651	0.100
Company age	-0.007*	0.003	-0.131*	-2.102	0.037
Sales level between company and suppliers	0.123*	0.055	0.142*	2.249	0.025
r	0.218				
R^2	0.047				
Adjusted R^2	0.036				
Regression *F*-value	4.090				
Set 2					**0.000**
(Constant)	1.806	0.266		6.784	0.000
Company size (number of employees)	0.000	0.000	0.052	0.885	0.377
Company age	-0.001	0.003	-0.020	-0.332	0.740
Sales level between company and suppliers	0.025	0.055	0.029	0.462	0.644
Supplier Collaboration	0.159*	0.067	0.161*	2.379	0.018
Lead Users Collaboration	0.276**	0.057	0.317**	4.865	0.000
r	0.234				
R^2	0.188				
Adjusted R^2	0.172				
R^2 Change	0.141				
Regression *F*-value	21.238				

Note: $*p < 0.05$ $**p < 0.01$

As for model 1, visual inspection of the normal probability plot of the regression standardised residual and the residuals scatter plot shown in Appendices 2.4 and 2.5 respectively confirm the assumptions of normality and homoscedasticity.

Hierarchical regression was used to evaluate the relationships between suppliers and lead users collaboration factor and the dependent variable development time, while accounting for the impact of company size, age and sales level on this time. In the regression model, it was determined whether the addition of the suppliers collaboration factor and the lead users collaboration factor improved the predictive ability of the model. The results, as discussed above, indicate a significant increase in the R^2 of the second model of 14.1%, providing evidence for the rejection of the null hypothesis, which states that the addition of the contribution of supplier and lead user collaboration will result in no change in R^2. As a result, the sixth hypothesis, which assumes a positive relationship between supplier collaboration and low product development time is supported. The results also support the second hypothesis of the research, which assumes a positive relationship between lead users collaboration and low product development time. In fact, the results indicate that this relationship is stronger than that with suppliers.

6.6.4 Model 3: Customer Influence

The third model to be studied by regression analysis concerns the third dependent variable, customer influence, and tests for the effects of supplier collaboration and lead user collaboration on this attribute, and whether collaborating with suppliers and lead users would have any predictive power of the customer influence.

6.6.4.1 Model Specification

The relationship between the dependent variable (customer influence) and independent variables (supplier collaboration and lead user collaboration) were tested through the following regression model, in which the relationship is controlled by firm size (measured by the number of employees), firm's age in years, and the level of sales between supplier and the firm:

$$CI= \beta_0 + \beta_1 FS + \beta_2 FA + \beta_3 SL + \beta_4 SCMC + \beta_5 LUCMC + \varepsilon$$

Where:

CI: Customer Influence,

β_0: Constant,

β_1, β_2, β_3, β_4, and β_5: Coefficients,

FS: Firm size,

FA: Firm age,

SL: Sales level,

SCMC: Suppliers' collaboration in mass customisation,

LUCMC: Lead users' collaboration in mass customisation, and

ε: error

6.6.4.2 Model Results

The model was tested by the regression of the summated scores of the independent variables (suppliers collaboration and lead users collaboration) and the control variables (firm size, firm age, sales level) on customer influence using hierarchical regression analysis. An initial inspection of the correlation matrix (Table 6.27) revealed correlations amongst the independent variables as noted in section 6.8.1.2. There is also significant correlation between the control variables firm size, firm age and sales level with the dependent variable cost (0.144, -0.131 and 0.109 respectively), but this correlation was only very weak. On the other hand, the two independent variables supplier collaboration and lead user collaboration correlated more significantly (p <0.01) with dependent variable customer influence (0.197 and 0.317 respectively). These correlations indicate that the data is suitable for reliable examination of the responses through hierarchical multiple linear regression

The means and standard deviations for each variable are displayed in Table 6.27. The mean response for customer influence is 3.17 with a standard deviation of 0.96, indicating an overall trend towards greater allowance for customer influence than competitors. The other descriptive statistics have been presented in Section 6.8.1.2.

Table 6.27: Correlations matrix for customer influence (CI)

	Mean	S.D.	CI	Firm Size	Firm Age	Sales Level	SCMC	LUCMC
CI	3.17	0.96	1.000					
Firm Size	893.1	507.6	0.144*	1.000				
Firm Age	34.3	16.9	-0.131*	0.011	1.000			
Sales Level	3.24	1.01	0.109*	0.125*	0.108*	1.000		
SCMC	3.08	0.89	0.197**	0.196**	-0.068	0.380**	1.000	
LUCMC	2.98	1.01	0.317**	0.102	-0.276**	0.144*	0.395**	1.000

* $p < 0.05$, ** $p < 0.01$

Multicollinearity was assessed by measurement of the tolerance and VIF values, as shown in Table 6.28. The independent variables tolerance coefficients range from 0.722 to 0.988, well above the threshold of 0.10. The VIF statistics range from 1.012 to 1.384, again well below the upper threshold of 10. These two sets of results confirm that multicollinearity is unlikely to affect the data analysis. In order to test for autocorrelation, the Durbin-Watson statistic was determined, and found to be 1.791. This falls well within the required range of 1.5 to 2.5, and demonstrates that there is no autocorrelation which might affect the predictive power of the model.

Table 6.28: Multicollinearity and independence of errors tests for customer influence

Model		Collinearity Statistics		Durbin-Watson
		Tolerance	VIF	
1	(Constant)			
	Company size	0.984	1.016	
	Age	0.988	1.012	
	Sales level between company and suppliers	0.973	1.028	
2	(Constant)			1.791
	Company size	0.957	1.045	
	Age	0.901	1.110	
	Sales level between company and suppliers	0.835	1.198	
	Suppliers collaboration in NPD	0.722	1.384	
	Lead users collaboration in NPD	0.780	1.283	

The regression results are shown in Table 6.29. The model summary displays an R^2 value of the control variables (in model 1) of 0.050, which, although significant ($p < 0.01$), is rather low. The adjusted R^2 of 0.038 suggests even lower predictive power for this set, with a low F statistic of 4.3. The standardised coefficients of the control variables are rather low: β_1, β_2, and β_3 are 0.132, -0.144 and 0.108 respectively. In the second set of the regression model, in which the main independent variables of supplier collaboration and lead user collaboration have been added, there is a significant increase in R^2 by 7.1%, although this change is lower than the increase observed for models 1 and 2. The R^2 (0.121) and adjusted R^2 (0.103) values are much larger than for set 1, and the F statistic (10.0) is also larger, which indicates much greater predictive power for the model. As for the first set, the standardised coefficients of the control variables are insignificant and very weak: β_1, β_2, and β_3 are 0.102, -0.061, 0.045. In this case, the standardised coefficient corresponding to supplier collaboration (β_4 = 0.052) is not significant, while the coefficient describing lead user collaboration (β_5 = 0.263) is larger, and is significant (p = 0.000). The differences between the two sets are evidenced in the change in the overall significance, which increased from a significance of p = 0.007 to p = 0.000.

Table 6.29: Hierarchical Regression Model- Dependent Variable: Customer influence

	Unstdized Coeffs		Stdized Coeffs	t	Sig.
	B	Std. Error	Beta		
Set 1					**0.006**
(Constant)	2.901	0.238		12.209	0.000
Company size (number of employees)	0.000*	0.000	0.132*	2.118	0.035
Company age	-0.008*	0.004	-0.144*	-2.303	0.022
Sales level between company and suppliers	0.102	0.059	0.108	1.721	0.087
r	0.223				
R^2	0.050				
Adjusted R^2	0.038				
Regression F-value	4.306				
Set 2					**0.000**
(Constant)	2.068	0.301		6.876	0.000
Company size (number of employees)	0.000	0.000	0.102	1.671	0.096
Company age	-0.003	0.004	-0.061	-0.960	0.338
Sales level between company and suppliers	0.043	0.062	0.045	0.693	0.489
Supplier Collaboration	0.056	0.075	0.052	0.739	0.460
Lead Users Collaboration	0.248**	0.064	0.263**	3.872	0.000
r	0.348				
R^2	0.121				
Adjusted R^2	0.103				
R^2 Change	0.071				
Regression F-value	9.961				

Note: *$p < 0.05$ ** $p < 0.01$

As for the previous two models, visual inspection of the normal probability plot of the regression standardised residual and the residuals scatter plot shown in Appendices 2.4 and 2.5 respectively confirm the assumptions of normality and homoscedasticity.

The results demonstrate the use of hierarchical regression to evaluate the relationships between suppliers and lead users collaboration factor and the dependent variable customer influence, while accounting for the impact of company size, age and sales level on this time. Through this analysis, it was demonstrated that there was a significant increase in the R^2 of the second model of 7.1%, in rejection of the null hypothesis. As a result, it can be seen that there is a positive relationship between customer influence and collaboration, but these results show that it is lead user collaboration which is important. The seventh hypothesis which assumes a positive relationship between supplier collaboration and high allowance for customer influence is rejected. The results do, however, support the third hypothesis of the research, which assumes a positive relationship between lead users collaboration and high allowance for customer influence.

6.6.5 Model 4: Product Scope

The fourth model to be studied by regression analysis concerns the final dependent variable, product scope, and tests for the effects of supplier collaboration and lead user collaboration on this attribute, and whether collaborating with suppliers and lead users would have any predictive power of the product scope.

6.6.5.1 Model Specification

The relationship between the dependent variable (product scope) and independent variables (supplier collaboration and lead user collaboration) were tested through the following regression model, in which the relationship is controlled by firm size (measured by the number of employees), firm's age in years, and the level of sales between supplier and the firm:

$$PS= \beta_0+ \beta_1 FS + \beta_2 FA + \beta_3 SL +\beta_4 SCMC +\beta_5 LUCMC + \varepsilon$$

Where:

PS: Product Scope,

β_0: Constant,

$\beta_1, \beta_2, \beta_3, \beta_4,$ and β_5: Coefficients,

FS: Firm size,

FA: Firm age,

SL: Sales level,

SCMC: Suppliers' collaboration in mass customisation,

LUCMC: Lead users' collaboration in mass customisation, and

ε: error

6.6.5.2 Model Results

The model was tested by the regression of the summated scores of the independent variables (suppliers collaboration and lead users collaboration) and the control variables (firm size, firm age, sales level) on product scope using hierarchical regression analysis. An initial inspection of the correlation matrix (Table 6.30) revealed correlations amongst the independent variables as noted in section 6.8.1.2. There is also significant correlation between the control variables firm size and sales level with the dependent variable cost (0.131 and -0.013 respectively), but this correlation was only very weak. On the other hand, the two independent variables supplier collaboration and lead user collaboration correlated more significantly ($p < 0.01$) with dependent variable customer influence (0.253 and 0.315 respectively). These correlations indicate that the data is suitable for reliable examination of the responses through hierarchical multiple linear regression.

The means and standard deviations for each variable are displayed in Table 6.30. The mean response for customer influence is 3.67 with a standard deviation of 0.90, indicating an overall trend towards wider product scope than competitors. The other descriptive statistics have been presented in Section 6.8.1.2.

Table 6.30: Correlations matrix for product scope (PS)

	Mean	S.D.	PS	Firm Size	Firm Age	Sales Level	SCMC	LUCMC
CI	3.67	0.90	1.000					
Firm Size	893.1	507.6	0.131*	1.000				
Firm Age	34.3	16.9	-0.013	0.011	1.000			
Sales Level	3.24	1.01	0.144*	0.125*	0.108*	1.000		
SCMC	3.08	0.89	0.253**	0.196**	-0.068	0.380**	1.000	
LUCMC	2.98	1.01	0.315**	0.102	-0.276**	0.144*	0.395**	1.000

* $p < 0.05$, ** $p < 0.01$

Multicollinearity was assessed by measurement of the tolerance and VIF values, as shown in Table 6.31. The independent variables tolerance coefficients range from 0.722 to 0.988, well above the threshold of 0.10. The VIF statistics range from 1.012 to 1.384, again well below the upper threshold of 10. These two sets of results confirm that multicollinearity is unlikely to affect the data analysis. In order to test for autocorrelation, the Durbin-Watson statistic was determined, and found to be 1.692. This falls well within the required range of 1.5 to 2.5, and demonstrates that there is no autocorrelation which might affect the predictive power of the model.

Table 6.31: Multicollinearity and independence of errors tests for product scope

Model		Collinearity Statistics		Durbin-Watson
		Tolerance	VIF	
1	(Constant)			
	Company size	0.984	1.016	
	Age	0.988	1.012	
	Sales level between company and suppliers	0.973	1.028	
2	(Constant)			1.692
	Company size	0.957	1.045	
	Age	0.901	1.110	
	Sales level between company and suppliers	0.835	1.198	
	Suppliers collaboration in NPD	0.722	1.384	
	Lead users collaboration in NPD	0.780	1.283	

The regression results are shown in Table 6.32. The model summary displays an R^2 value of the control variables (in model 1) of 0.034, which, although significant ($p <$ 0.01), is rather low. The adjusted R^2 of 0.023 suggests even lower predictive power for this set, with a low F statistic of 2.9. The standardised coefficients of the control variables are rather low: β_1, β_2, and β_3 are 0.115, -0.028 and 0.132 respectively. In the second set of the regression model, in which the main independent variables of supplier collaboration and lead user collaboration have been added, there is a significant increase in R^2 by 8.7%. The R^2 (0.122) and adjusted R^2 (0.104) values are much larger than for set 1, and the F statistic (12.2) is also larger, which indicates much greater predictive power for the model. As for the first set, the standardised coefficients of the control variables are insignificant and very weak: β_1, β_2, and β_3 are 0.064, 0.052, 0.040. In this case, the standardised coefficient corresponding to supplier collaboration (β_4 = 0.177) is significant ($p <$ 0.05), while the coefficient describing lead user collaboration (β_5 = 0.209) is larger, and more significant (p = 0.002). The overall significance of the two sets increased, with a change from p = 0.034 to p = 0.000.

Table 6.32: Hierarchical Regression Model- Dependent Variable: Product Scope

	Unstdized Coeffs		Stdized Coeffs	t	Sig.
	B	Std. Error	Beta		
Set 1					**0.034**
(Constant)	3.163	0.225		14.043	0.000
Company size (number of employees)	0.000*	0.000	0.115*	1.827	0.069
Company age	-0.002	0.003	-0.028	-0.445	0.657
Sales level between company and suppliers	0.117*	0.056	0.132*	2.088	0.038
r	0.186				
R^2	0.034				
Adjusted R^2	0.023				
Regression *F*-value	2.941				
Set 2					**0.000**
(Constant)	2.240	0.285		7.852	0.000
Company size (number of employees)	0.000	0.000	0.064	1.051	0.294
Company age	0.003	0.003	0.052	0.825	0.410
Sales level between company and suppliers	0.035	0.057	0.040	0.620	0.536
Supplier Collaboration	0.188*	0.074	0.177*	2.544	0.012
Lead Users Collaboration	0.187**	0.061	0.209**	3.076	0.002
r	0.349				
R^2	0.122				
Adjusted R^2	0.104				
R^2 Change	0.087				
Regression *F*-value	12.205				

Note: $*p < 0.05$ $** p < 0.01$

As discussed for previous models, visual inspection of the normal probability plot of the regression standardised residual and the residuals scatter plot shown in Appendices 2.4 and 2.5 respectively confirm the assumptions of normality and homoscedasticity.

The results demonstrate the use of hierarchical regression to evaluate the relationships between suppliers and lead users collaboration factor and the dependent variable product scope, while accounting for the impact of company size, age and sales level on this time. Through this analysis, it was demonstrated that there was a significant increase in the R^2 of the second model of 9.6%, in rejection of the null hypothesis. The eighth hypothesis which assumes a positive relationship between supplier collaboration and high product scope is supported. The results also support the fourth hypothesis of the research, which assumes a positive relationship between lead users collaboration and product scope.

6.6.6 Validation of Results

To further validate the results of the regression analysis a split-sample cross-validation test was conducted using a random number generator. This test randomly divides the sample into two groups, with one group representing 75% of responses and the other group, the remaining 25%. The results are considered to valid if the results of the 75% split sample are similar to the statistical results for the full data set. The results of these tests are shown in Table 6.33.

Table 6.33: Cross-validation statistics for each model

Model	R		R^2	Change statistics			Durbin-Watson statistic	
	Split = 1.00 selected	Split ≅1.00 unselected		ΔR^2	ΔF	Sig. ΔF	Split = 1.00 selected	Split ≅1.00 unselected
Development Cost	0.426	0.294	0.181	0.151	17.283	0.000	1.801	2.010
Development Time	0.469	0.305	0.220	0.185	22.166	0.000	1.815	1.478
Customer Influence	0.332	0.322	0.110	0.092	9.642	0.000	1.921	2.244
Product Scope	0.393	0.273	0.155	0.137	15.170	0.000	1.742	1.894

From Table 6.33 above, each of the four models demonstrated significant (all with $p = 0.000$) comparable R^2 values for the random 75% sample (0.181, 0.220, 0.110 and 0.155 respectively) as for the full data set. This suggests that the fit of this random sample is similar to that for the full sample, and implies therefore that the regression model could be utilised to predict outcomes for data sets other than those used here. The Durbin-Watson statistics range from 1.7 and 1.9 for the four models, which lies comfortably between the recommended values of 1.5 and 2.5, demonstrating the independence of the models from errors, that is that there is no autocorrelation which might affect the predictive power of the model.

The relationships between the independent variables (supplier and lead user collaborations) and the four dependent variables did not change in the cross-validation test, with each model showing the same pattern of significance as was observed above, as shown in Table 6.34 below. Every relationship is significant ($p < 0.05$) except for the effect of supplier collaboration on customer influence ($p = 0.351$).

Table 6.34: Cross-validation statistics for relationships between independent and dependent variables

	Unstdized Coeffs		Stdized Coeffs	t	Sig.
	B	Std. Error	Beta		
Development Cost					
Supplier Collaboration	0.263	0.072	0.285	3.647	0.000
Lead Users Collaboration	0.188	0.060	0.236	3.119	0.002
Development Time					
Supplier Collaboration	0.200	0.074	0.206	2.696	0.008
Lead Users Collaboration	0.300	0.062	0.200	4.828	0.000
Customer Influence					
Supplier Collaboration	0.080	0.086	0.076	.934	0.351
Lead Users Collaboration	0.267	0.072	0.294	3.728	0.000
Product Scope					
Supplier Collaboration	0.178	0.079	0.179	2.253	0.025
Lead Users Collaboration	0.262	0.066	0.305	3.977	0.000

The results of these tests indicate external validity of the model, as it supports the assumption that the findings of this study can be generalised to the wider population represented by the sample in this study.

6.6.7 Conclusions

Hypothesis testing in this study has been achieved by the use of hierarchical regression analysis, which has enabled the study of the effects of each collaboration type on each mass customisation attribute. By designing four models, each corresponding to one attribute of mass customisation operational performance, the significance of supplier and lead user collaboration has been assessed. The regression analysis has revealed that there is a positive relationship between supplier and lead user collaboration and each of the mass customisation attributes, except for a weaker, not significant relationship between supplier collaboration and the allowance for customer influence. These findings will be further discussed in section 7.3 in the following chapter.

The R^2 values for each model range from 0.121 to 0.188, which are good for models with only two main independent variables accounting for the variance in the respective dependent variables. The R^2 are also considered to be well within the limits reported for other studies in this field (Cagliano *et al.*, 2006, Petersen *et al.*, 2005, Carr and Pearson, 2002, Curkovic *et al.*, 2000). The validity of analysis has also been performed by cross-validation studies, which demonstrate the external validity of the model.

Following this regression analysis, it is important to perform a number of tests to confirm that the relationships derived here are real, and do not reflect constraints placed by the data set itself. These include analysis of variance, and testing for validity, reliability and bias, and will be discussed in the following sections.

6.7 Analysis for Variance

This study has focussed on the effects of the two independent variables – supplier and lead user collaboration – as well as the control variables – company age, company size and sales level with suppliers – on the dependent variables. There are also other factors, however, which could affect the distribution of responses, most notably the categorical factors of industry type and the length of the supplier-manufacturer relationship. Analysis of variance allows for the study of the effect of these factors on the data set, to determine whether these characteristics of companies significantly affected the responses.

6.7.1 Industry Effect

The sample has been drawn from several consumer product industries. Responses were gathered from five main industries, namely the motor industry (which includes manufacture of all motorised appliances), chemical industry, electronics and electricals manufacture, health care and diet, and specialist and other appliances. The frequencies analysis for the responses is shown in Table 6.3, and the results discussed in section 6.1.2. It is conceivable that surveys collected from different industries will show different responses. For example, the experience of collaboration with lead users might vary between two very different industry types such as the motor industry and the chemical industry. However, it is the assumption of this study that the collaboration with lead users or suppliers in product development is independent of industry type, because the mechanisms and processes of product development are generic and supposed to be constant across industries (Mikkola and Skjoett-Larsen, 2003).

In order to confirm this assumption, it is necessary to test whether the responses vary according to industry type. This can be achieved by analysis of variance, or ANOVA, which is a comparison of the variability of scores between different groups with the variability within each group. If industry type does not affect response, it would be expected that the variance between different industry types reflect the variance within the industry groupings.

It is important, before conducting analysis of variance, to test for the homogeneity of variance, which tests whether the variability in the dependent variable is similar across the range of values of the independent variable. This is achieved through application of Levene's test, in which a significant value ($p < 0.05$) is interpreted as heterogeneity of variance. The results of Levene's test for the four dependent variables are shown in Table 6.35 below. Each variable has a significance value of $p > 0.15$, indicating that there is homogeneity of variance, and that this requirement for analysis of variance is therefore fulfilled.

Table 6.35: Test of homogeneity of variances

Dependent Variable	Levene Statistic	Sig.
Cost	1.243	0.293
Development Time	0.528	0.715
Customer Influence	1.656	0.161
Product Scope	0.231	0.921

After confirming the appropriateness of analyses of variance by testing the homogeneity of variances, an one-way between-groups analysis of variance was conducted to explore the impact of industry type on each dependent variable. The results are shown in Tables 6.36. For each variable, analysis of variance reveals no statistically significant difference (p = 0.935, 0.137, 0.312 and 0.813 respectively) between the groups. This suggests that development costs, development time, customer influence and product scope do not differ across these industry types. From this analysis of variance, it can therefore be concluded that the type of industry has no influence on the dependent variables. This justifies the concurrent use of all data for statistical analysis, rather than the separation of responses into industry type.

Table 6.36: Analysis of variance across industry type

Variable		Sum of Squares	Mean Square	F	Sig.
Development Cost	Between Groups	0.633	0.158	0.206	0.935
	Within Groups	188.904	0.768		
	Total	189.537			
Development Time	Between Groups	5.427	1.357	1.765	0.137
	Within Groups	189.133	0.769		
	Total	194.560			
Customer Influence	Between Groups	4.384	1.096	1.198	0.312
	Within Groups	225.019	0.915		
	Total	229.403			
Product Scope	Between Groups	1.289	0.322	0.393	0.813
	Within Groups	201.584	0.819		
	Total	202.873			

6.7.2 Effect of Supplier Relationship

As for industry, the sample contains a heterogeneous representation of companies with respect to the length of their interaction with suppliers. The frequencies analysis for the responses is shown Appendix 2.1, and the results discussed in section 6.1.2. It is necessary, therefore, to determine whether the survey responses are dependent on the length of supplier involvement, or whether all responses are equally distributed across this measure. In order to achieve this, analysis of variance (ANOVA) was performed on the data set.

This study includes a test for the supplier relationship with the company in order to determine whether this relationship has any effect on collaboration. The same analysis is not performed for lead users as these players have no formal ties with the companies. This is in contrast to suppliers, who exist in a formal relationship with the company. This may impact the collaboration process.

Prior to the analysis of variance, the homogeneity of variance was determined, with the result shown in Table 6.37 below. Each variable has a significance value of $p > 0.2$, which indicates that there is homogeneity of variance, and that analysis of variance can therefore be performed on this dataset.

Table 6.37: Test of homogeneity of variances

Dependent Variable	Levene Statistic	Sig.
Cost	0.923	0.451
Development Time	1.369	0.245
Customer Influence	0.816	0.516
Product Scope	0.358	0.839

Since the homogeneity of variances test has revealed that the data can be analysed for variance, analysis of variance was conducted to explore the impact of supplier involvement on each dependent variable, with the results shown in Table 6.38 overleaf. For each variable, there is no statistically significant difference ($p = 0.293$, 0.646, 0.059 and 0.323 respectively) between the groups. From this analysis of variance, it can be concluded that the length of supplier relationship has no influence on the dependent variables. The dataset can therefore be analysed in its entirety, rather than first requiring division into groups according to supplier relationship length.

Table 6.38: Analysis of variance across length of supplier relationship

Variable		Sum of Squares	Mean Square	F	Sig.
Development Cost	Between Groups	3.755	0.939	1.243	0.293
	Within Groups	185.783	0.755		
	Total	189.537			
Development Time	Between Groups	1.955	0.489	0.624	0.646
	Within Groups	192.606	0.783		
	Total	194.560			
Customer Influence	Between Groups	8.267	2.067	2.299	0.059
	Within Groups	221.136	0.899		
	Total	229.403			
Product Scope	Between Groups	3.802	0.950	1.174	0.323
	Within Groups	199.071	0.809		
	Total	202.873			

From this analysis of variance, it can be concluded that the length of supplier relationship has no influence on the dependent variables. The dataset can therefore be analysed in its entirety, rather than first requiring division into groups according to supplier relationship length.

6.8 Validity, Reliability and Bias Testing

After cross-validating the regression analysis, it is important to confirm the validity and reliability of the data, and to test for the presence of any bias.

6.8.1 Validity and Reliability

Validity is a measure the extent to which the scale represents the concepts of the study. One aspect is the reliability, which is a measure of the internal consistency of the questionnaire. High reliability is marked by a strong correlation of items to other items, and to the scale. Two main measures of reliability are the item-to-total correlation, and Cronbach's α. Item-to-total correlation is the measure of the correlation of each item to the total scale score. Correlations of greater than 0.50 are considered to indicate reliability (Robinson *et al.*, 1991). Cronbach's α is a function of number of items, the variance of the overall test scores, and the variance of each component. This value will increase with increasing correlations between items. It is agreed that a lower limit of Cronbach's α of 0.70 be adopted for the assessment of reliability (Robinson *et al.*, 1991).

The results of the Cronbach's α and item-to-total correlation tests are shown in Table 6.39 overleaf. The item-to-total correlation for each item is greater than 0.60, which exceeds the lower limit of 0.50, indicating that each item exhibits reliability. This is further confirmed by the measurement of Cronbach's α for each construct. All calculated α values are greater than 0.80, which again is greater than the 0.70 limit for reliability.

Table 6.39: Statistical measures of reliability of the constructs

Construct	Items	Item-to-total correlation	Cronbach's α
Supplier Collaboration	SC1: Supplier collaboration setting general product definition	0.6954	0.9128
	SC2: Supplier collaboration setting lead time requirements	0.6394	
	SC3: Supplier collaboration setting product specifications	0.7023	
	SC4: Supplier collaboration generating product's blueprint/drawings	0.7595	
	SC5: Supplier collaboration designing product detailed component specification	0.7557	
	SC6: Supplier collaboration product prototyping	0.6857	
	SC7: Supplier collaboration product testing	0.7162	
	$SC_{overall}$: Supplier collaboration overall PD process	0.7668	
Lead User Collaboration	LUC1: Lead user collaboration setting general product definition	0.7829	0.9340
	LUC2: Lead user collaboration setting lead time requirements	0.7509	
	LUC3: Lead user collaboration setting product specifications	0.7775	
	LUC4: Lead user collaboration generating product's blueprint/drawings	0.7966	
	LUC5: Lead user collaboration designing product detailed component specification	0.7873	
	LUC6: Lead user collaboration product prototyping	0.7876	
	LUC7: Lead user collaboration product testing	0.6704	
	$LUC_{overall}$: Lead user collaboration overall PD process	0.7999	
Development Cost	CDC: Concept development costs	0.8197	0.9082
	PDC: Product design costs	0.8291	
	PMC: Product manufacturing costs	0.7209	
	TCPD: Total time of product development	0.8018	
Development Time	CDT: Concept development time	0.8325	0.8959
	PDT: Product design time	0.7918	
	PMT: Product manufacturing time	0.6648	
	CT: Cycle time (concept to manufacturing)	0.8009	
Customer Influence	CI1: Enabling customers to select from set menus/catalogues	0.7424	0.8736
	CI2: Enabling customers to self configure features from tables (mix and match)	0.8417	
	CI3: Enabling customers to design their products	0.6950	
Product Scope	PS1: Range of items produced by existing facilities at the company	0.7757	0.8776
	PS2: Scope of features offered to final customers (for each product)	0.8030	
	PS3: Number of products lines compared to competitors	0.7095	

Throughout this study, every effort has been made to ensure the validity and reliability of the research. The above discussion has demonstrated the reliability (internal consistency) of the scales. This research uses summated scales, in which the items that load on one factor are averaged into one representative value. Table 6.14 shows the loading of variables on different factors. In this model, eight items loaded on each of supplier collaboration and lead user collaboration. Four items loaded on development cost and development time, with three each on customer influence and product scope. It is therefore important to assess the validity in terms of two other measures. Convergent validity describes the extent to which two measures of the same concept are correlated. Discriminant validity, on the other hand, measures the degree to which two concepts which bear similarities are distinct from each other. Convergent and discriminant validity can be assessed from inspection of the exploratory factor analysis in Table 6.14. For each item loading on a single factor, it can be observed that the loadings for that one factor are high – confirming convergent validity for that scale – and the loadings for other factors are low – an indication of discriminant validity compared to other scales. This can be noticed from inspection of items 1 to 8, which load strongly on the same factor and show very low loadings for all other factors, thus indicating high convergent validity and high discriminant validity. This is in line with the theoretical foundations of the summated scale, which was based on the conceptual model. The same observations can be made for the other sets of items.

6.8.2 Common Methods Bias

As demonstrated earlier in section 5.3.9, the questionnaire has been thoroughly designed and tested to minimise the possibility of common method bias. Harman's single-factor test (1976) has been used to test for the existence of the common methods variance. The un-rotated factor analysis has generated six different factors with eigenvalues greater than one. Importantly, the covariance was not accounted for by one single variable, but loadings were distributed across the six factors, as can be seen in Table 6.14. This demonstrates that, although the study was based on a single respondent survey, the effect of the common methods bias on the data is minimal. This reflects the care that was taken in the survey design: the assurance of anonymity, the fact that the questions did not follow a pattern that biased respondents towards a certain answer, and the use of distinct items.

6.8.3 Non-Response Bias

Non-response bias can be manifested in various ways. It may be observed as a marked difference between responses with time, that is, that immediate responses are different from those which are returned later. To evaluate for possible non-response bias, the responses were categorised into early responses (within the first month: n=100) and late responses (within the second month, n=151) (Armstrong and Overton, 1977). It was then necessary to test for the presence of a significant difference between the two sets of responses. This was achieved through the use of two tests, which were selected due to their robustness and statistical power.

The Kolmogorov-Smirnov test assesses the equality of a probability distribution with a reference probability distribution, or allows comparison of two samples, as in this case. The test involves the calculation of *Z*, the distance between the two functions, with the null hypothesis that the samples are drawn from the same distribution. A significant *Z* value ($p < 0.05$) is therefore evidence for rejecting the null hypothesis. The Mann-Whitney *U* test allows assessment of whether two sets of data belong to the same distribution. The null hypothesis is that the two sets do have equal probability distributions, that is, they are derived from the same population. The test involves the calculation of *U*, which has a known distribution under the null hypothesis. Again, a significant *U* value ($p < 0.05$) will result in rejection of the null hypothesis.

The statistics for these two tests are shown in Table 6.40 below. For each dependent and independent factor, and for both tests, the significance value is greater than 0.05, indicating that there is not evidence to reject the null hypothesis. This suggests that the two sets of data can be considered to arise from the same population, indicating that the non-response bias is minimal

Table 6.40: Test statistics for Kolmogorov-Smirnov and Mann-Whitney *U* test for non-response bias

	Development Cost	Development Time	Customer Influence	Product Scope	Supplier Collaboration	Lead User Collaboration
Kolmogorov-Smirnov *Z*	1.107	1.067	.341	.761	.826	.67
Significance (2-tailed)	0.172	0.205	1.000	0.609	0.502	0.740
Mann-Whitney *U*	7182	6488	7485	6648	7235	7282
Significance (2-tailed)	0.511	0.060	0.907	0.105	0.575	0.634

6.9 Conclusions

This chapter has described the results of the data analysis of the questionnaire responses. The descriptive statistics relating to the sample confirmed that the companies surveyed represent a good cross-section of the population of interest. Assumption testing confirmed that the data was suitable for subsequent statistical analysis. Exploratory factor analysis could then be performed to reduce the data to factors, which corresponded to the dependent and independent variables proposed in the conceptual model. Based on these factors, models were determined to test the effect of supplier and lead user collaboration by hierarchical regression analysis. This analysis allowed the study of the relationships of these independent variables on the dependent variables of development cost, development time, customer influence and product scope. The final section of this chapter has focussed on the analysis for variance, validity, reliability and bias in the data set, all of which demonstrated that the instrument is appropriate for this study, and that conclusions drawn from the data can be considered to be valid.

The following chapter contains discussion of the results presented in this chapter, and compares these findings to those reported in the literature. Notably, these results allow for conclusions to be drawn regarding the eight hypotheses, as well as a comparison of the effects of supplier and lead user collaboration.

CHAPTER SEVEN

DISCUSSION OF RESULTS

CHAPTER SEVEN: DISCUSSION OF RESULTS

7.1 Introduction

This thesis is concerned with understanding the relationships between lead user and supplier collaborations and mass customisation operational performance. In order to test these relationships, a survey was designed as described in Chapter Five, and responses collected from UK consumer product manufacturing companies. The data obtained was subjected to statistical analysis detailed in Chapter Six. This chapter contains a discussion of results from these analyses.

The chapter begins with an evaluation of the methodology selected for this study in the light of the results, which are subsequently discussed. The main body of the chapter is concerned with the hypothesis testing, and a comparison of the results to previous literature findings.

7.2 Evaluation of Methodology

Chapter Five details the selection of the particular methodological tools for this study. This selection was based on extensive research into previous studies, and the theoretical bases of the various methods. It is important, however, to re-evaluate these choices in the light of the data collection and analysis phases of the study. In particular, this section discusses the selection of the survey method and scale, the use of focus groups and the method of sample selection.

The selection of the mail survey as the research tool is described in section 5.2.3. Testing the research model required the collection of data from a large number of companies across a range of industries, in order to ensure the generalisability of findings. Given the time and financial constraints of this study, surveys were deemed to be the most appropriate method to achieve this. The relative lack of empirical studies in mass customisation literature provided further impetus for the use of a survey tool (Comstock *et al.*, 2004, Kotha, 1996, Spring and Dalrymple, 2000, Chandra and Grabis, 2004). Mail surveys were selected over other forms of surveys, such as field visits and phone interviews, as they allowed contact with a larger sample size with lower cost and time demands.

The mail survey was also selected as it enabled the collection of large amounts of data without the risk of personal bias due to direct interaction of researcher with respondent. This was indeed found to be the case, with straightforward data entry and subsequent processing. However, mail surveys are associated with a number of disadvantages, such as low response rates (Greer *et al.*, 2000). In this study, the rigorous survey design following Dillman's total design method (1978) resulted in a sufficient, above-average response rate of 41.6%, as discussed in section 6.1.1. A second potential drawback is ambiguity or over-complications in the survey items. This was minimised by refining the questions based on feedback from the focus groups, and the pilot study – it was anticipated that in this way, any unclear or overly-complicated questions were removed from the questionnaire prior to administration. In addition, any respondent who left questions blank or indicated difficulty in answering was personally contacted. In most cases, following explanation of the question, an answer was provided.

Successful data collection from a survey requires careful consideration of the questionnaire. In this study, items were selected from previously-validated studies in the literature. This assisted in the design of a valid research tool. While the exact descriptors for each scale point varied between items, in each case the central descriptor (corresponding to a score of 3) represented a neutral position. This contributed to the standardisation of the survey, and hence a straightforward analysis of results.

One valuable tool in the survey preparation was the input from focus groups, as discussed in section 5.3.4. The input of focus groups was valuable in the development of the survey tool. In particular, they provided a clear indication of the operational definition of lead users from the management point of view. This concept could therefore be more clearly conveyed to the survey participants, and questions phrased in such a way as to gain the greatest information about these collaborators.

Another important aspect of survey design is the sample determination One potential source of bias in the sample determination was that the one thousand manufacturers were emailed to ask for their interest in participating in this study. Only those who were interested in the study were sent the final questionnaire. In the email, managers were told that the questionnaire was concerned with lead user and supplier collaboration in mass customisation. It is possible, therefore, that those who believed they did not involve lead users (due to their unfamiliarity with the term, for example) might not have responded positively to the email. This could possibly skew the sample towards those companies who have prior knowledge of the lead user concept. This is inconsistent with the view of this research that many companies unknowingly utilise lead users, to whom they might refer to by a different name, however this might not cause a problem for this study as it is the intention of the research to study mass customisers operating in UK. It can be argued that the group that did not reply positively to the email corresponds well to those who would not have returned the questionnaire, in which case the cross-section of responses would not have differed greatly from that obtained. This non-response bias has indeed been tested for, and found to be non-existent, as shown in section 6.11.

A consideration of the research methods in the light of the analysis of results therefore confirms the validity of this methodology. The following section contains a discussion of the findings presented in Chapter Six.

7.3 Overview of Findings

The principal aim of the data collection and analysis was to test the hypotheses. Prior to this, however, it is important to gain a holistic view of the direction of the data. This section contains a general discussion of the responses gained from the questionnaire. Frequencies analysis of the sample population, described in section 6.1.2, indicated a good distribution of responses across the entire range. This shows that the sample is a good representation of the population of consumer product manufacturing companies (the focus of this study), which further supports the external validity of the research.

The frequencies analysis of the dependent and independent variables is detailed in section 6.5. It can be noted that almost all of the average responses for the questions referring to each of the variables (Tables 6.20 to 6.25) are greater than 3 (the median response), which indicates that respondents consider their performance in these six aspects better than that of their competitors. It might be expected that, for a sample which completely represents the spread of companies, the mean response should be 3. This increase in the reported performance may be due to a tendency for companies to over-report their performance, although this is only slight, as all results lie comfortably within one standard deviation of 3. The possibility of over-reporting has been minimised by surveying senior management with sufficient knowledge and experience, and by ensuring that the respondents know that the questionnaires are being used in the strictest confidence, for academic purposes alone. In addition, it has previously been demonstrated that the senior managers' perceptual ratings of their firms' performances were strongly consistent with objective indicators of performance (Dess and Robinson Jr, 1984). This use of perceptual scales is well documented in the literature, and the scales have been shown to be representative of objective data (Venkatraman and Ramanujan, 1986, Ward *et al.*, 1994). The fact that the mean responses are so close to the mode (3) suggests that acquiescence bias and social desirability bias have been minimal, which further adds to the validity of the scale used. In addition, the fact that responses were spread well across the range of possible answers gives further assurance of the unlikely occurrence of central tendency bias.

In order to test the underlying structure of the data, it was necessary to perform factor analysis, which also aided in confirming the proposed conceptual model. This analysis revealed four dependent variables relating to the mass customisation attributes, and two independent variables describing supplier and lead user collaboration. This demonstrates that the questionnaire designed as the research tool was appropriate for the study of the eight hypotheses composed of the six variables, which further affirms the construct validity of the research tool.

While the aim of the data collection and analysis was to test the relationship between the dependent and independent variables, it is important to briefly consider the patterns observed for the control variables, and to test for their effects on the hypotheses. Throughout the analysis presented in Chapter Six, control variables were tested for their effects on the regression models, and on the dependent variables. In the four regression models tested in this thesis, the control variables of firm size, firm age and sales level between suppliers and the firm, were found to have no effect on the regression relationships. This suggests that supplier and lead user collaboration in mass customisation is not affected by these control variables, as demonstrated in Tables 6.23, 6.26, 6.29 and 6.32. In addition, the effects of industry type and length of the supplier-company relationship on the dependent variables were evaluated by analysis of variance tests, as described in section 6.7. This analysis revealed that the four mass customisation attributes do not vary significantly according to industry type or the length of supplier relationship. These findings are important, as it has previously been argued that firm age and industry type would have an effect on product development (Eisenhardt and Tabrizi, 1995, Spring and Dalrymple, 2000). This was not found to be the case, however, in this study of mass customisers.

The following section contains discussion of the eight hypotheses, and presents the results from the regression analysis, which formed the basis of the hypothesis testing.

7.4 Hypothesis Testing

This study developed eight main hypotheses to test the conceptual model that has been developed through Chapters Two, Three and Four to answer the main research question of the comparative effects of collaboration with lead users and suppliers on mass customisation operational performance. The eight hypotheses, which are described in section 4.4, operationalised the conceptual framework in eight dimensions, each describing the relationship between a collaborative partner and a mass customisation attribute. The hypotheses were tested by the use of multivariate regression analysis. Chapter Six describes the tests which were performed to confirm that the data met the assumptions for this analysis. This section interprets the findings of the analysis and discusses these findings with respect to previous literature. The effect of each collaborator – lead user and supplier – will be considered in turn.

7.4.1 Lead User Effect

This research is interested in the effect of lead user collaboration on the product development processes of mass customisation. As discussed in section 3.3.2, the concept of lead users is relatively novel, and arose in response to a growing need for customer-active product development (von Hippel, 1986). Few studies have investigated the effects of lead users in product development (Urban and von Hippel, 1988, Herstatt and von Hippel, 1992), and even fewer have discussed the role that lead users might play in mass customisation (Franke and Piller, 2004). These existing studies have investigated lead users from the point of view of innovation, and were concerned with measuring the novelty of the products developed as a result of lead user input, regardless of the effects on operational performance. No study has investigated the effect of lead user collaboration on operational performance in mass customisation, as is described here.

This study has been designed to investigate the effect of lead user collaboration on the four attributes of mass customisation performance which have been derived from the literature, as discussed in section 4.3. In order to test the relationships between lead users and these four attributes, four hypotheses have been developed, as described in section 4.4.1. The following sections discuss the literature understanding of each relationship, the results generated from this study and the implications of these findings.

As noted in section 4.4.1, there is relatively little literature focussed on the effects of lead user collaboration, particularly on any one of the four attributes used in this study. Most of the literature instead describes studies of collaboration with the broader group of customers. Therefore, in the following discussion, this literature concerning customer collaboration will be mentioned as a means for establishing consistency between the results of this study and other findings, but is important to remember that the focus of this study remains lead users.

7.4.1.1 Relationship with Development Cost

H1: that there is a significant positive relationship between lead users' collaboration in product development processes of mass customisation and low development cost.

The first hypothesis is concerned with the relationship between lead user collaboration and low development cost. An initial indication of the relationship was gained through bivariate correlation between the lead user collaboration and cost, which showed moderately high correlation (0.357) between the two variables. However, the much stronger statistical test of regression analysis was subsequently used, taking into consideration the various control variables that might affect or moderate the relationship. Regression analysis of the development cost construct on lead user collaboration indicated a highly significant ($p = 0.000$) correlation between these two variables. The standardised β coefficient of 0.267 indicated that for each unit increase in lead user collaboration, there is a 26.7% unit increase in low development cost, which corresponds to a 26.7% unit decrease in development cost. This is further supported by the significant R^2 value of 0.165 ($p = 0.000$) calculated for the entire model, which indicates good predictive power for this model.

These results provide evidence to reject the null hypothesis, suggesting that there is a significant positive relationship between lead user collaboration and low development cost. This is the first study which has linked lead user collaboration and cost, but these findings are in keeping with the literature concerning customer collaboration. Various studies (Utterback *et al.*, 1976), (Buzzell and Gale, 1987), (Cooper and Kleinschmidt, 1987) have indicated that customer involvement in product development leads to reduced research and development costs. This is due to more cost effective market research and more focused expenditure on valuable processes. A further documented advantage of customer involvement is the decreased risks enjoyed following involvement of users. Failure to involve users in the design process can increase the risks of design changes in the testing phase of the product, which will have a high effect on the budgeted costs of product development (Elfving, 2007).

This study is, however, interested in lead users, rather than general customers. The effects of customer collaboration described above are likely to be heightened in the case of lead users, whose contribution means less cost must be allocated to market research and whose involvement is likely to be more productive than that of the average customer due to the fact that lead users are selected for their merit and innovativeness in the specific industry (Lilien *et al.*, 2002). It has previously been observed that lead user collaboration leads to decreased cost in the initial idea generation stages of product development (Herstatt and von Hippel, 1992). The research reported here has demonstrated that such cost benefits extend throughout the product development processes, and are not only restricted to the idea generation stage. This study has therefore provided evidence for a positive significant relationship between lead user collaboration and decreased development cost.

7.4.1.2 Relationship with Development Time

H2: that there is a significant positive relationship between lead users' collaboration in product development processes of mass customisation and short development time.

The second hypothesis of this study proposes the relationship between lead user collaboration and short development time. Firstly, the relationship between lead user collaboration and time was investigated by the bivariate correlation, which indicated moderately high correlation (0.396) between the two variables. The more robust test of regression analysis was then performed to factor in the effects of the various control variables. Regression analysis of the development time construct on lead user collaboration indicated a highly significant ($p = 0.000$) correlation between these two variables. The standardised β coefficient of 0.317 indicated that for each unit increase in lead user collaboration, there is a 31.7% unit increase in short development time (which is physically manifested in a decrease in development time). This is further supported by the significant R^2 value of 0.188 ($p = 0.000$) calculated for the entire model, which indicates that this model has good predictive power.

These results provide evidence to reject the null hypothesis, suggesting that there is a significant positive relationship between lead user collaboration and short development time. This study is valuable in exploring the effects of lead user collaboration and product development time. It is important, however, to evaluate the findings in terms of existing literature which has explored similar relationships.

A number of studies have observed a positive relationship between customer involvement and short development times. Dell Computers found that collaboration with customers reduced their lead times (McWilliams, 1997), and Sport Obeymeyer similarly enjoyed decreased product lead times as a result of customer involvement (Fisher *et al.*, 1994). In these two cases lead times refer to the entire time period from order to delivery, a significant part of which is the time taken for product development. Whipple and Gentry (2000) conducted a survey of manufacturers and noted that companies were motivated towards collaboration with customers due to the reduced cycle and lead times that they experienced as a result of such collaborations. Scott *et al.* (2001) account for this effect by suggesting that customer collaboration heightens the customer-driven demand for short product development times, which results in greater efforts being made by companies to decrease these times. In this research, in which lead user collaboration is specifically studied, it might be expected that since lead users are characterised by the fact that they already have ideas for new products, less time will be spent on marketing research (Harhoff *et al.* 2003), which should be manifested in decreases in the overall development time.

One study which has provided contrary evidence is that of Squire *et al.* (2006), who surveyed five hundred manufacturing firms based in the UK to determine the effects of mass customisation on manufacturing practices. They observed a negative relationship between customer collaboration and short production times. The study of Squire *et al.* utilises a similar research tool and sample as the study described in this thesis, and so is an important comparison. One reason for this difference is that the partners of this study are customers in general, who were selected from the centre of the market to be representative of market trends, rather than from the leading edge of the market, where lead users lie. This could provide indication of the value of lead user collaboration as distinct from customer collaboration, as has been demonstrated in this study. An additional reason for these differing results is that customer collaboration may require long periods of time spent in familiarising the customers with the manufacturing processes and practices of the company prior to the specific contribution of the customers. By definition, lead users, on the other hand, come with a better knowledge of the specific industry, and with matured product ideas (Herstatt and von Hippel, 1992). This is evident in the findings of this study, which highlight a significant positive relationship between lead user collaboration and short development time.

7.4.1.3 Relationship with Customer Influence

H3: that there is a significant positive relationship between lead users' collaboration in product development processes of mass customisation and high allowance for customer influence.

The third hypothesis is concerned with the relationship between lead user collaboration and the allowance for customer influence. An initial indication of the relationship was gained through bivariate correlation between the lead user collaboration and the allowance for customer influence. This analysis revealed a moderately high correlation (0.317) between the two variables. However, the much stronger statistical test of regression analysis was subsequently used, taking into consideration the various control variables that might affect or moderate the relationship. Regression analysis of the customer influence construct on lead user collaboration indicated a highly significant (p = 0.000) correlation between these two variables. The standardised β coefficient of 0.263 indicated that for each unit increase in lead user collaboration, there is a 26.3% unit increase in the allowance for customer influence. This is further supported by the significant R^2 value of 0.121 (p = 0.000) calculated for the entire model, which indicates good predictive power for this model.

These results provide evidence to reject the null hypothesis, suggesting that there is a significant positive relationship between lead user collaboration and allowance for customer influence. This finding is consistent with studies (Callahan & Lasry, 2004; Enkel *et al*, 2005) which note that high customer influence can be best achieved by the collaboration of customers in product development processes. Lead users are a subset of customers, and might therefore be expected to have great importance in the generation of high customer influence.

Studies of lead user collaboration have indicated a role in achieving high customer influence. Herstatt and von Hippel (1992) found that 80% of consumers preferred the products designed by lead users. Similarly, Shah (2000), in his study of sporting equipment manufacturers, noted that products suggested by lead users had the greatest importance due to being more customer specific. In both cases, the emphasis is on the ability of the product to cater for the specific needs of customers. This is evident in the customisation of the product, where lead users understand better the needs of the customers than the company. As a result, the product development processes yield products which can be much more easily customised by the end user.

The findings of this study provide a more definitive link between lead user collaboration and the allowance for customer influence.

This study has found therefore demonstrated that lead user collaboration has a positive effect on customer influence. This may be due to the fact that the ability to exercise control over exact form of the final product is a desirable property for customers. For lead users, who are themselves customers, this is likely to be even more attractive, as lead users are characterised by a desire to find solutions to their needs (von Hippel, 1986) – such solutions would be enhanced by the ability to self-customise a product. Lead users might therefore be expected to identify product solutions with the capacity for customer influence. This rationale is in keeping with the findings of this study: that lead user collaboration has a positive effect on customer influence.

7.4.1.4 Relationship with Product Scope

H4: There is a significant positive relationship between lead users' collaboration in product development processes of mass customisation and broad product scope.

The fourth hypothesis of this study proposes the relationship between lead user collaboration and broader product scope. Firstly, the relationship between lead user collaboration and product scope was observed through the bivariate correlation, which indicated moderately high correlation (0.315) between the two variables. The more robust test of regression analysis was then performed to factor in the effects of the various control variables. Regression analysis of the product scope construct on lead user collaboration indicated a highly significant (p = 0.000) correlation between these two variables. The standardised β coefficient of 0.209 indicated that for each unit increase in lead user collaboration, there is a 20.9% unit increase in product scope. This is further supported by the significant R^2 value of 12.2% (p = 0.000) calculated for the entire model, which indicates that this model has good predictive power.

These results provide evidence to reject the null hypothesis, suggesting that there is a significant positive relationship between lead user collaboration and broader product scope. This research is provides a valuable study in exploring the effects of lead user collaboration and product scope. The discussion below compares the results of this study to findings in the existing literature which has explored similar relationships.

The lead user approach to product development collects information about both the needs and solutions of users. Reports on their formal integration to the product development process advocate a four stage process (goal generation and team formation, trend research, pyramid networking, and workshop and idea generation) (Lilien *et al.*, 2002). Although the development and integration of such a formal process with current product development processes is relatively rare (Olson *et al.*, 2001), informal or tacit processes for identifying and integrating ideas from this group of users are frequently employed, as evidenced by several studies who have explored these groups in various industrial contexts (Franke *et al.*, 2006, Luthje and Herstatt, 2004, Herstatt and von Hippel, 1992, Franke and Hippel, 2003, Morrison *et al.*, 2004). These studies have also established that lead users have a profound impact on the development of new products. This might be expected to lead to an increased product offering for a company, and therefore be reflected in greater product variety. Until now, however, no study has definitively drawn the link between lead user collaboration and product scope.

The research described in this thesis has determined that lead user collaboration has a significant positive effect on product scope. This is likely to be due to three main reasons. Firstly, as discussed above, lead users possess the ability to generate new products (Lilien *et al.*, 2002). Secondly, lead users are characterised by heightened needs, and thus the generation of high product variety is in their interests (von Hippel, 1986). They are therefore likely to spur the company on towards product development processes which satisfy these needs. Finally, by suggesting modifications to existing products, lead users can be effective in increasing the number of features offered for a product, or increasing the modularity of a product, which will increase the product scope. Lead users undoubtedly have great potential to make contributions to increased product variety, as is confirmed by the findings of this study, which identified the positive effect of lead user collaboration on broader product scope.

7.4.2 Supplier Effect

The second collaborative partner with which this study is concerned is the supplier. This research aims to investigate the effect of supplier collaboration on the operational performance of mass customisation. As discussed in section 3.2, the value of supplier collaboration in product development has long been understood (Dowlatshahi, 1997, Bidault *et al.*, 1998). Supplier collaboration has also been identified as an important facilitator of mass customisation (Meixell and Wu, 2004, Yassine *et al.*, 2004). While a number of studies have investigated the effects of supplier collaboration on various aspects of mass customisation, no study has analysed the effect of the collaboration on mass customisation performance in terms of the four attributes described here, nor has any study explored the comparative effects of supplier and lead user collaboration, as will be discussed in section 7.2.3.

In order to test the relationships between suppliers and the four attributes of mass customisation, four hypotheses have been described. The following sections discuss the literature understanding of each relationship, the results generated from this study and the implications of these findings.

7.4.2.1 Relationship with Development Cost

H5: that there is a significant positive relationship between suppliers' collaboration in product development processes of mass customisation and low development cost.

The first hypothesis relating to supplier collaboration is concerned with the relationship between supplier collaboration and low development cost. An initial indication of the relationship was gained through bivariate correlation between supplier collaboration and cost, which showed a high correlation (0.314) between the two variables. However, the much stronger statistical test of regression analysis was subsequently used, taking into consideration the various control variables that might affect or moderate the relationship. Regression analysis of the development cost construct on supplier collaboration indicated a highly significant (p = 0.007) correlation between these two variables. The standardised β coefficient of 0.187

indicated that for each unit increase in supplier collaboration, there is a 18.7% unit increase in low development cost, which corresponds to a 18.7% unit decrease in development cost.

These results provide evidence to reject the null hypothesis, suggesting that there is a significant positive relationship between supplier collaboration and low development cost. This finding is supported by a number of reported findings. Afuah *et al.* (Afuah, 2000, Afuah and Bahram, 1995) claim that supplier involvement in product development processes results in the generation of many new ideas which can take the form of new products ideas, new production processes, new technological innovations, or the exchanging of expertise and technological know-how. These can lead to increased financial benefits for the manufacturer in the form of expenditure savings, elimination of low-added value processes through process re-engineering, and the introduction of more economic and efficient processes. These result in a lowered product development cost (Carr and Pearson, 1999). Handfield *et al.* (1999) noted that early supplier involvement in mass manufacturing enabled the manufacturer to reduce the cost of production, and to deliver lower cost to the customer. This was confirmed by Ragatz *et al.* (2002), who surveyed companies about the effect of supplier integration in new product development, and identified decreased capital and operational costs as potential benefits of the involvement of suppliers in knowledge-sharing. Further decreases in cost might also be enjoyed due to the fact that early supplier involvement allows identification of potential problems in the product development process before production begins, which results in decreased costs associated with repair or redesign (Handfield, 1994, Dowlatshahi, 1997, Meyer, 1993). These studies, however, generally investigate mass manufacturing in general, and are not restricted to mass customisation.

Studies of mass customisation processes have also highlighted this link between supplier involvement and decreased cost. Tu *et al.* (2007) observed that collaboration with suppliers can effectively lead to decreased cost in mass customisation ventures if suppliers are judiciously selected, and if their levels of involvement are carefully managed. Swedish retailer IKEA found that close collaboration with suppliers led to reduced supplier costs, which in turn gave rise to decreased product cost (Margonelli, 2002). Monczka *et al.* (1997) also found that firms that integrate suppliers in design stages of the product development process enjoy reduced material costs, which can translate into decreased overall product costs.

From above, it can be seen that there is much literature support for the relationship between supplier collaboration and low cost. Most of these studies, however, focus on the total cost delivered to the customer. The overall aim of this study is to develop a greater understanding of the benefits of collaboration in the product development processes of mass customisation. As a result, the attributes investigated here refer to outputs of product development alone, and the interest in this case is therefore product development cost. The findings of this study are therefore valuable as they provide an indication of the positive effect of supplier collaboration on product development costs in mass customisation, which has not previously been evaluated.

Such benefits in terms of cost may be due to a number of factors. Companies which collaborate with suppliers enjoy many advantages, such as greater access to knowledge, improved flow of information and better working relationships (Clark and Fujimoto, 1991, Ragatz *et al.*, 2002, Primo and Amundson, 2002). These will result in decreased expenditure in these areas, which will, in turn, lead to decreased cost. The information input from suppliers, and their technical knowledge, will decrease the need to financially invest in processes to obtain this knowledge from other sources. In addition, manufacturers should enjoy reduced cost as a result of supplier involvement as the two companies will share some costs of the product development processes. Supplier collaboration is therefore likely to result in decreased product development cost, as confirmed in this study.

7.4.2.2 Relationship with Development Time

H6: that there is a significant positive relationship between suppliers' collaboration in product development processes of mass customisation and short development time.

The sixth hypothesis of this study proposes the relationship between supplier collaboration and short development time. The relationship between supplier collaboration and time was first indicated by the bivariate correlation, with moderately high correlation (0.309) between the two variables. The more robust test of regression analysis was then performed to take into account the effects of the various control variables. Regression analysis of the development time construct on lead user collaboration indicated a significant ($p = 0.018$) correlation between these two variables. The standardised β coefficient of 0.161 indicated that for each unit increase in lead user collaboration, there is a 16.1% unit increase in short development time (which is physically manifested in a decrease in development time).

These results provide evidence to reject the null hypothesis, suggesting that there is a significant positive relationship between supplier collaboration and short development time. This study is valuable in exploring the effects of supplier collaboration and product development time. It is important, however, to evaluate the findings in terms of existing literature which has explored similar relationships.

Handfield *et al.* (1999) noted that early supplier involvement gives rise to reduced product development time, which is manifested in decreased lead time. This phenomenon was also noted by Smith and Reinertsen (1991), who suggested that decreased product development time could be achieved through incorporation of suppliers into the product development team to encourage them to add their information and expertise to the generation of new ideas. In a similar vein, Ragatz *et al.* (2002) believe that companies which involve suppliers in activities of knowledge-sharing and dissemination will experience decreases in both product development and concept-to-customer times. The early identification of potential problems in product development which is enhanced by supplier collaboration (Dowlatshahi, 1997) is also likely to lead to decreased cycle times.

A number of other studies have likewise implicated supplier collaboration in reducing product lead times for a variety of reasons. Decreased product development times arise from shortened critical path lengths, which result from the shift from linear to branched manufacturing systems experienced by companies which involve suppliers (Clark and Fujimoto, 1991). The effect of supplier collaboration in improving communication in the supply chain also leads to decreased delays and lower product lead times (Meyer, 1993).

The computer company Dell found that collaboration with suppliers resulted in decreased development time (McWilliams, 1997), while Sport Obeymeyer similarly enjoyed greater flexibility and reduced lead time as a result of supplier collaboration. Monczka *et al.* (1997) also found that integration of suppliers in the design process led to the benefits of reduced product development time. Whipple and Gentry (2000) identified reduced cycle and lead times as principal motivators for companies to collaborate with material and service suppliers alike. In contrast to these findings, several studies (Littler *et al.*, 1995; Sako and Helper, 1998) noted that without careful management of levels of cooperation, companies could experience unproductive collaboration, which could result in longer development times. This could be due to organizational culture and human factors, and does not contradict the findings of this and other studies, which state that supplier collaboration shortcuts many processes which would lead to increased development times. What has been demonstrated in this study, however, is that supplier collaboration has a positive effect on decreased product development time.

Eisenhardt and Tabrizi (1995) studied product development projects in the computer industry, and identified that early supplier involvement could effectively reduce product cycle time, but only for mature industries. In contrast, the results from this study show that company age has no effect on the product development time: in fact, there was a significant ($p < 0.05$), although weak ($r = -0.115$) negative correlation between firm age and product development time. This could be due to the recent increase in understanding the methods of supplier involvement, which have been readily adopted by young firms. In addition, the age of the firm is not expected to affect supplier collaboration outcomes as the information and infrastructure gap between old and new firms can be easily bridged as a result of the information revolution. Instead, it might be expected that the length of company-supplier relationship has a greater impact on the outputs of the relationship than the age of the company. The analysis of variance described in section 6.7.2, however, has shown that this is not true, with development time not significantly varying across different lengths of company-supplier relationships. Indeed, the results of this study show that supplier collaboration has a positive effect on shorter product development time irrespective of either the age of the company or the length of its relationship with its suppliers.

7.4.2.3 Relationship with Customer Influence

H7: that there is a significant positive relationship between suppliers' collaboration in product development processes of mass customisation and high allowance for customer influence.

The seventh hypothesis is concerned with the relationship between supplier collaboration and the allowance for customer influence. An initial indication of the relationship, through bivariate correlation between the supplier collaboration and the allowance for customer influence, showed good correlation (0.197) between the two variables. However, this analysis did not take into account the effect of any other variables included in the study. For this reason, regression analysis was critically important. Regression analysis of the customer influence construct on supplier collaboration did not indicate a significant correlation between these two variables ($p = 0.460$). The standardised β coefficient of 0.052 was very weak, indicating little effect of supplier collaboration on customer influence.

These results do not provide evidence to reject the null hypothesis, suggesting that there is not a significant relationship between supplier collaboration and the allowance for customer influence. This is in contrast to the literature studies of Alford *et al.* (2000) and Whipple and Gentry (2000), who both suggested a positive relationship between the involvement of service suppliers and customer influence. This could be due to the fact that these two studies are referring to service suppliers, whereas this study solely focussed on industrial suppliers.

The lack of a relationship between supplier collaboration and customer influence may be due to the lack of motivation for suppliers to collaborate towards this result. Suppliers do not directly deal with end users, nor is their main aim to satisfy customer demand. That is, suppliers primarily focus on their direct buyers (the companies) rather than the second-tier buyers (the customers). Suppliers therefore do not derive great benefit from customers enjoying great influence, and there is therefore less impetus for focus on this dimension. Indeed, from the point of view of the supplier, increasing the allowance for customer influence might lead to increased cost and time, as building in the ability for customers to self-configure their products can require the implementation of more complex infrastructure at early stages of product development. This might be further reason for suppliers to not invest in an increased allowance for customer influence. This reasoning is consistent with the findings of this study, which indicated no relationship between supplier collaboration and the allowance for customer influence.

7.4.2.4 Relationship with Product Scope

H8: There is a significant positive relationship between suppliers' collaboration in product development processes of mass customisation and broad product scope.

The final hypothesis of this study proposes the relationship between supplier collaboration and broader product scope. Firstly, the relationship between supplier collaboration and product scope was investigated by the bivariate correlation, which indicated moderately high correlation (0.253) between the two variables. However, it was necessary to perform the more robust test of regression analysis to factor in the effects of the various control variables. Regression analysis of the product scope construct on supplier collaboration indicated a correlation between these two variables, with a β coefficient of 0.177, which was significant ($p = 0.012$).

These results provide evidence to reject the null hypothesis, suggesting that there is a significant positive relationship between supplier collaboration and broader product scope. This is consistent with a number of studies which demonstrate that supplier collaboration leads to increased modularity (Alford *et al.*, 2000, Perez and Sanchez, 2001) and increased flexibility (Krause *et al.*, 2000, Day, 1994), both of which lead to broader product scope. It has also been shown that suppliers who are more involved in the new product development process are more likely to be committed to the buyer firm for future business (Gassenheimer *et al.*, 1995), which may lead to an openness to adaptations as circumstances change (Heide and Miner, 1992), and in turn result in higher product variety.

In contrast to these results, Tracey and Tan (2001) explicitly examined product variety as one of the measures of product performance when examining supplier involvement, but they did not find any direct link. However, this could be due to the fact that the study is focussing on delivery as the medium of interaction between supplier and manufacturer rather than direct collaboration.

As discussed above, suppliers are likely to be motivated by the direct benefits which they enjoy as a result of their collaboration, rather than the benefits to the end users, of which increased product scope is one. Supplier collaboration, however, might be expected to increase product scope as a corollary of other benefits. The discussion above has highlighted that supplier collaboration can lead to increased flexibility and modularity. Suppliers can therefore feed product scope by these means. This is consistent with the findings of this study, which identify a positive relationship between supplier collaboration and product scope.

7.4.3 Summary of Hypothesis Testing

The multivariate regression analysis has allowed for the testing of the eight proposed hypotheses which describe the relationships between collaboration and mass customisation operational performance. As this discussion has highlighted, such links have not previously been conclusively drawn. The results of the multivariate regression analysis reveal that there is evidence to reject the null hypothesis for the four hypotheses relating to lead user collaboration. That is, there is a significant positive relationship between lead user collaboration and lower development cost, shorter development time, higher allowance for customer influence and broader product scope. This indicates that lead user collaboration has a positive effect on the overall operational performance. Similar analysis was performed regarding supplier collaboration. This analysis revealed that there is a significant positive relationship between supplier collaboration and lower development cost, shorter development time and broader product scope. There was no evidence, however, to reject the null hypothesis regarding supplier collaboration and its effect on customer influence, suggesting that there is no relationship between supplier collaboration and the allowance for increased customer influence.

In addition to enabling hypothesis testing, the regression analysis also allows for a comparison of the relative effects of supplier and lead user collaboration. This will form the basis of the discussion in the following section.

7.5 Suppliers or Lead Users: Comparing the Effects

This study aimed not only to determine the significance of the effect of each collaborative partner on each mass customisation attribute, but also to gain an understanding of the relative value of each collaborative partner. This will have implications in management and academia alike, as will be discussed below. The nature of the statistical tests utilised allows for easy comparison of partners, as the model describing each attribute simultaneously evaluates the effect of both suppliers and lead users. The findings of each model will be discussed in turn.

7.5.1 Model 1: Development Cost

In the first step of this model, only control variables (firm size, age and sales level with suppliers) were entered into the equation (R^2 = 0.044, F = 3.8, p = 0.011). The addition of supplier and lead user collaboration to the regression equation resulted in a significant improvement of the model fit (R^2 = 0.165, ΔR^2 = 0.121, F = 17.8, p = 0.000). Both suppliers and lead users showed significant contribution in predicting the variance in development cost. However, the positive relationship between lead users and development cost (β = 0.267) was stronger than that of suppliers (β = 0.187). This indicates the importance of involving lead users in the product development processes of mass customisation.

The comparative cost advantages of lead user collaboration over supplier collaboration could be due to the savings in expenditure in a number of areas, including market research, joint engineering teams with suppliers, training and orientation of supply chain partners, and changes in design techniques due to technical incompatibilities between suppliers and manufacturers. In addition, individual lead users might be more motivated than suppliers towards cost-reducing collaborations as they have a direct interest in lowering the final costs, and as they reap more immediate benefits of such achievements. It could also be argued that lead users see the bigger product picture than suppliers, as they are interested in the final product, and not in the construction of an individual module, therefore enabling the company to make a more informed decision about product details which are important and those which can be more cheaply manufactured.

The results of this study indicate that lead user collaboration has a greater effect on decreased product development cost than supplier collaboration. This is the first study which has compared the two collaborative partners in terms of their effects on this aspect of operational performance.

7.5.2 Model 2: Development Time

The first set of this model involved the use of an equation which contained firm size, age and sales level with suppliers (R^2 = 0.047, F = 4.0, p = 0.007). In the second set, supplier and lead user collaboration were added to the regression equation, which gave rise to a significant improvement of the model fit (R^2 = 0.188, ΔR^2 = 0.141, F = 21.2, p = 0.000). Supplier collaboration (β = 0.161, p = 0.018) and lead user collaboration (β = 0.317, p = 0.000) were both positively related to development time, however lead user collaboration showed a greater, and more significant, relationship. This again indicates the importance of involving lead users in the product development processes of mass customisation.

The time advantages of collaborating with lead users over suppliers could result from a number of factors. The collaboration point itself is likely to be an area of relative differences in time, with supplier collaboration requiring the establishment of formal agreements involving the formation of official relationships, joint engineering teams and the transfer of knowledge between supplier and manufacture, while lead user collaboration is less formal, and requires only transient relationship. This difference in the nature of the collaborative relationships also extends to the product development, as suppliers are closely bound to manufacturers and therefore any unproductive relationships, rather than being rapidly dissembled, would instead lead to increased product development times (Littler *et al.*, 1995, Sako and Helper, 1998). Unproductive relationships with lead users, on the other hand, are less formal, and can therefore be quickly ended, rather than having a harmful effect on product development times.

The relative advantage of lead users over suppliers in terms of product development time could also be due to the greater motivation for lead users to reduce this time: suppliers do not directly feel the effects of the length of product development times, as they are involved at a relatively early stage of the process. Lead users, on the other hand, desire solutions to their problems in the shortest possible time. While these arguments indicate that it is feasible to assume a greater effect of lead users than suppliers with respect to development time, this is the first time such a comparison has been directly made. The findings of this study do indeed confirm that lead user collaboration has a greater effect on product development time than supplier collaboration.

7.5.3 Model 3: Customer Influence

In the first set of third model, only control variables (firm size, age and sales level with suppliers) were entered into the equation (R^2 = 0.050, F = 4.3, p = 0.006). Addition of supplier and lead user collaboration to the regression equation resulted in a significant improvement of the model fit (R^2 = 0.121, ΔR^2 = 0.071, F = 10.0, p = 0.000). In this case, however, only lead users showed significant contribution in predicting the variance in customer influence (β = 0.263, p = 0.000). Supplier collaboration was found to have a weak ($\beta = 0.052$), and not significant ($p = 0.460$) effect. These results indicate that, in terms of the output indicator of customer involvement, it is valuable to collaborate with lead users in the product development processes of mass customisation, but not with suppliers.

This difference in the effects of lead user and supplier collaboration on customer involvement has an intuitive basis. Lead users, as customers themselves, are likely to contribute to the product development process in such a way as to best facilitate the customisation process. Suppliers, on the other hand, do not directly interact with second-tier customers, and so are less likely to be concerned with the allowance for customer influence, as discussed in section 7.4.2.3 above.

This provides a very valuable indication of the difference between supplier and lead user collaboration, which has not previously been directly demonstrated. While lead users have been shown to have a positive effect on the allowance for customer influence, supplier collaboration was not found to exhibit this effect.

7.5.4 Model 4: Product Scope

The first set of this model involved the use of an equation which contained firm size, age and sales level with suppliers ($R^2 = 0.034$, $F = 2.9$, $p = 0.034$). In the second set, supplier and lead user collaboration were added to the regression equation, which gave rise to a significant improvement of the model fit ($R^2 = 0.122$, $\Delta R^2 = 0.087$, $F = 12.2$, $p = 0.000$). Supplier collaboration ($\beta = 0.177$, $p = 0.012$) and lead user collaboration ($\beta = 0.209$, $p = 0.002$) were both positively related to product scope, with lead user collaboration showing a slightly greater, and more significant, relationship. The difference in standardised coefficients, however, is not large enough to definitively state that lead user collaboration is more valuable than supplier collaboration on the performance indicator of product scope. This may be due to the fact that both suppliers and lead users possess great, albeit differing, abilities to increase flexibility and product variety, and therefore broaden product scope, as discussed in sections 7.4.1.4 and 7.4.2.4. This study is the first time the relative effects of supplier and lead user collaboration on product scope have been determined. The findings reported here suggest that collaboration with both suppliers and lead users are valuable with respect to the achievement of broad product scope.

7.5.5 Summary and Overall Comparison

The four regression models proposed and tested in this research examined the relationships between the operational attributes of mass customisation and the two key collaboration partners in the product development processes. The models indicated significant positive relationships between lead users and all of the four attributes, with a stronger statistical significance than those of suppliers in each case. These four models thus served not only to test the individual relationships, but also acted as a comparative tool between the two key partners. It is also valuable to consider the relative effects of supplier and lead collaboration on the overall operational performance.

The relative effects of supplier and lead user collaboration on mass customisation operational performance have not previously been investigated. Frohlich and

Westbrook (2001) did investigate the performance outputs of companies which focussed on supplier integration in the supply chain compared with those whose main interest was integrating customers into the supply chain, observing that supplier-integrating companies had greater association with different performance measures than customer-integrating companies. While these results are in contradiction to those reported here, it is important to note that Frohlich and Westbrook were studying the involvement of customers, rather than lead users. This difference in effect can be accounted for by the significant benefits of lead user collaboration over supplier collaboration (von Hippel, 1986). Indeed, the fact that the findings of this study are so different from those noted by Frohlich and Westbrook emphasises the great value of collaboration with this particular subset of customers – the lead users.

This study has demonstrated that external collaboration results in an increase in the various aspects of the operational performance of the company. In order for the formation of strong and effective partnerships, however, the external partners must also be motivated to collaborate. The interests of the lead users in participating in product development processes also lies in an achievement of the four attributes, as they stand to directly benefit from each. Suppliers, on the other hand, only indirectly feel the effects of achievement of any one of the four attributes, and are therefore likely to be less highly motivated than lead users. This relative lack of motivation could be manifested in less fruitful partnership. This provides further weight to the argument that lead users are the more valuable collaborative partner: companies need exert less effort in motivation to meaningful collaboration.

The predictive powers, and the ability of these models to predict the variation in the mass customiser's operational performance, are indicated by the R^2 values (0.165, 0,188, 0.121 and 0.122 respectively). Taking into consideration that for each model, only the two main variables studied were considered significant, this range of R^2 values is considered acceptable, if not good. There are many other, as yet unknown, variables whose effect was not been investigated by this analysis, and which could potentially contribute to the variation. To have a predictive power of approximately 1/6 of the total variation with only two variables is significant enough to lead to the conclusion that both supplier collaboration and lead user collaboration are important. This can form an effective starting point for further studies investigating other effects on the mass customisation operational performance. In addition, the R^2 values observed in this study are considered to be in a good range for relationships which have not previously been investigated, and are well within the limits reported for other studies in the area of operations management (Cagliano *et al.*, 2006, Petersen *et al.*, 2005, Carr and Pearson, 2002, Bhaduri, 2002, Curkovic *et al.*, 2000).

7.6 Conclusions

This chapter has discussed the findings of this study. In the light of the data analysis, the selection of the methodology was affirmed, and a holistic view of the data was described. The bulk of this chapter concerned the hypothesis testing. On the basis of the statistical analysis, each hypothesis has been accepted or rejected, and the conclusions about each were discussed in the light of previous studies. This work has enabled the direct study of the eight relationships described by the hypotheses, which has not previously been performed. The results also allow for a comparison of the relative merits of lead user and supplier collaboration, providing evidence that lead user collaboration has a greater effect on mass customisation operational performance than supplier collaboration.

This work has immediate application for both theory and practice, as will be discussed in the following chapter. The scope for future research will also be outlined, along with the limitations of the study. Chapter Eight will end with general conclusions from this work.

CHAPTER EIGHT

CONCLUSIONS

CHAPTER EIGHT: CONCLUSIONS

8.1 Introduction

As discussed in Chapter Two, mass customisation has proved to be an important manufacturing paradigm of the current age, and worthy of the academic attention it has received. Vast numbers of studies have attempted to understand the mechanisms of mass customisation, both in the ways through which it is achieved and the features which characterise it. Much current attention is focussed on gaining an understanding of the ways in which mass customisation performance may be optimised, to decrease the number of reported failures, and to allow companies and customers alike to reap the greatest possible benefits which the strategy can offer. This study attempts to contribute to such an understanding, through the study of collaboration within the product development process.

Product development describes the essential set of activities involving the design and manufacture of products, which is important not only for mass customisers but for all manufacturers. Chapter Three describes how product development processes can be enhanced through collaboration. Mechanisms for the achievement of collaboration include the use of knowledge management through communities of practice and process networks. Principal collaborative partners for product development are suppliers, notably through the employment of the early supplier involvement strategy, and users, especially the class of lead users. Both collaborative partners have great importance in product development processes, but the relative merits of each are not well understood.

Chapter Four completes the theoretical framework of the study. In accordance with the great importance of both mass customisation and collaborative product development demonstrated throughout Chapters Two and Three, this study is focussed on gaining an understanding of collaboration in mass customisation. Current literature suggests great benefit of supplier collaboration on mass customisation, but the area of lead user collaboration has been less well characterised. This lead to the research question: *What are the relative effects of collaborating with suppliers and lead users in the product development processes on mass customisation?* In order to investigate this question, four attributes of mass customisation have been selected as markers of operational performance: development cost, development time, allowance for customer influence and product scope. These four attributes lead to the generation of eight hypotheses, each of which describes the relationship between supplier or lead user collaboration and one of the four attributes.

On the basis of these eight hypotheses, a mail survey was selected as the method for collecting data, as described in Chapter Five. A preliminary questionnaire was compiled from items in the literature, and refined through focus groups and a pilot study. The survey was then administered to product development and operations managers of consumer products manufacturing companies throughout the UK.

Following data collection and collation, results were subjected to a number of statistical tests, as described in Chapter Six. The first principal statistical analysis which was performed was exploratory factor analysis, which allowed the testing of the proposed conceptual framework and the underlying relationships, as well as a reduction of the data into composite factors for further analysis. The major statistical test of this study was exploratory factor analysis, through which the effects of supplier and lead user collaboration on each of the attributes of mass customisation could be studied.

Chapter Seven contains a discussion of the results presented in Chapter Six. The selection of methodology is evaluated in the light of the data analysis, and concluded to be appropriate. A holistic discussion of the data is provided, followed by a more detailed discussion of the hypothesis testing. This data analysis supported the four hypotheses referring to lead user collaboration, signifying a positive relationship between this collaborative partner and each of the four mass customisation attributes. Three of the four hypotheses referring to supplier collaboration were supported, but the other – concerning customer influence – was rejected. Chapter Seven also contains a discussion of the relative effects of the two collaborative partners, with the conclusion that lead user collaboration has greater effect on mass customisation operational performance than supplier collaboration.

This chapter contains an overview of the results presented in this study, and general discussion of the meaning of these findings. The chapter ends with a discussion of the limitations of the study, the implications for both academia and industry, and the scope for future research.

8.2 Overview

This study has focussed on gaining and understanding the relative effects of collaborating with suppliers and lead users in the product development processes of mass customisation. This has been achieved by measuring the outputs of mass customisation using four attributes which measure mass customisation operational performance: development cost, development time, customer influence and product scope. On the basis of the theoretical framework developed through Chapters Two to Four, eight hypotheses were proposed which described the relationships between supplier or lead user collaboration and the four operational performance attributes. Data was collected by conducting a survey of consumer products manufacturing companies. The eight hypotheses were tested by hierarchical regression analysis of the survey results, which confirmed the four hypotheses relating to lead user collaboration, and three of the four hypotheses describing the effects of supplier collaboration, as depicted in Figure 8.1 overleaf. The results of this hypothesis testing allow identification of a number of benefits of supplier and lead user collaboration.

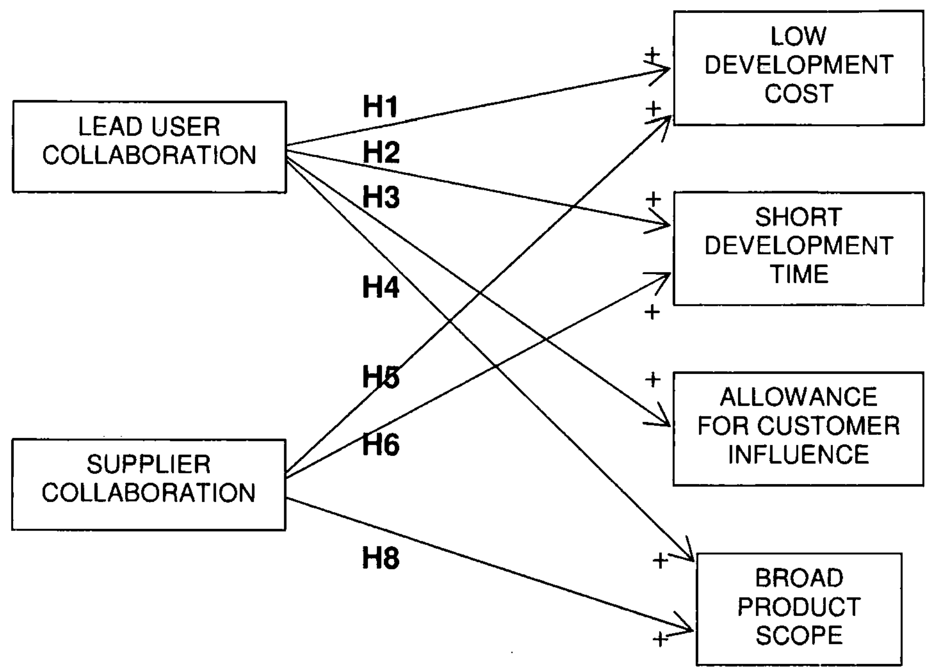


Figure 8.1: Findings of hypothesis testing

As discussed in Chapter Three, supplier advantage has previously been shown to demonstrate a number of benefits for product development: the supplier can bring to the company specific access to technology, research and development expertise and the ability to efficiently use equipment and to increase the manufacturing capabilities of the company. As a result, supplier involvement in product development is expected to benefit the mass customiser significantly, with their contributions to the product development processes resulting in improved quality and decreased costs, among other benefits (Dixon and Porter, 1994).

This study has been able to identify three main benefits of collaborating with suppliers: decreased product development cost, reduced product development time and broader product scope. While these benefits specifically describe the product development process, they are likely to have broader implications for the customer, such as reduced final price, shorter lead time and increased variety of choice. The combination of these factors will help the company to achieve core competency, and competitive advantage.

The other collaborative partner investigated in this study was the lead user. Since the concept was first introduced by von Hippel, lead users have gained much attention and praise, not least for their ability to generate new products which can be regarded as breakthroughs (Morrison *et al.*, 2000, Luthje and Herstatt, 2004), and for the appeal of these products to customers (Herstatt and von Hippel, 1992). This study has identified four specific advantages of lead user collaboration: reduced product development time, decreased product development cost and broader product scope. Notably, lead user collaboration, but not supplier collaboration, was identified as achieving greater allowance for customer influence, which is likely to result in increased customer satisfaction, and therefore a larger market share. Again, as a result of lead user collaboration, companies will enjoy competitive advantage.

This study has therefore been able to demonstrate the value of both supplier and lead user collaboration. A comparison of the significance of the effects of each has also provided meaningful results. As well as having a significant positive effect on customer influence where supplier collaboration did not, lead user collaboration demonstrates more significant and more positive effects on each of the other three attributes: cost, time and product scope. This suggests that, from consideration of the four measures of mass customisation operational performance, lead user collaboration is more valuable than supplier collaboration.

The four attributes used in this study to measure operational performance form an operational definition of mass customisation, as discussed in Chapter Four. Mass customisation, by its very name, combines the merits of mass production, which is characterised by low cost and short product time, with those of customisation, in which high allowance for customer influence and broad product scope are key. Achieving high success in one of these attributes, therefore, will reduce the number of failures in mass customisation ventures. This study has shown that lead user collaboration has a positive effect on all four attributes, and supplier collaboration, on three, highlighting the enormous potential for these collaborations in enhancing mass customisation performance.

This study has clearly demonstrated the importance of lead users in mass customisation. This research is not based, however, on the view that lead users are a novel player in product development, introduced only when the term gained widespread use in academia. Instead, lead users have often been used in new product development, although they might have been labelled as active users or developers.

Mass customisation takes many and various forms, as discussed throughout Chapter Two. This study has investigated mass customisation which allows for the involvement of the collaborator in the early stages of the product development process. A consideration of the stage and length of collaboration is also helpful. It is unlikely that companies entering into a partnership or starting a new product development project with external partners such as suppliers and lead users, would desire these partners to be involved in their product development processes at only one stage, as the costs of establishing partnerships will not be justified, particularly in the case of suppliers. If, on the other hand, the external partner was involved from the beginning until the end, this would guarantee consistency and higher control over the processes of the product development from concept development through design and manufacturing to delivery of the final products to the customers. This may explain why loadings were high on product development as a single factor, although there was some, less than significant, evidence of set-wise (or stage-dependent) effects on the loadings of some responses. This could be further investigated, as it might lead to a new variable which could affect the relationship. In this study, the respondents' loadings indicated that suppliers and lead users were either highly involved in the product development, or showed minimal or no involvement. There was no indication that these partners were involved at any one stage more than another. In particular, high involvement from the first stage (concept development) appeared to be followed by consistent involvement.

This study has therefore revealed a number of important results concerning the effects of supplier and lead user collaboration, particularly through determination of the benefits of each partnership, and a comparison of the two partners. The following sections describe the implications of these findings, both for theory and for practice. Limitations of the study will be described, and suggested future studies outlined.

8.3 Implications of this Study

The theoretical framework of this study, presented in Chapters Two to Four, and based on extensive literature research, has demonstrated the great importance of gaining greater understanding of collaborative product development as an enabler of mass customisation. This is the impetus of this research, and is of interest for both academia – for the development of knowledge in these crucial area – and management – through extension of the relationships observed into practice. The following two sections discuss the implications of this work for theory and for practice.

8.3.1 Implications for Theory

In considering implications for theory, it is important to consider the unique contributions of this study to the body of academic understanding, and the future research which may be carried out to further this understanding. The former will be discussed here, and the latter, in section 7.6.

This is an inter-disciplinary study, which links the literature of collaborative product development, mass customisation, supply chain management and the lead user concept, and therefore makes several valuable contributions to the body of understanding. The direct implication of this inter-disciplinary study is the demonstration that there are indeed significant relationships between these separate concepts. The background to the study was the increased interest in both mass customisation and lead user theory, described throughout Chapters Two and Three. This interest has not been far developed in the domain of operations management, and in particular in empirical studies: very few studies of mass customisation performance have involved the use of surveys (Chandra and Grabis, 2004a).

Another contribution of this research is that it takes the lead user concept and displays its utility in the contexts of both product development and mass customisation. Of particular interest is the role of lead users on customer influence and product scope, and the value of the comparison with the investigated effect of suppliers on these two operational objectives. This comparison has indicated that lead users are in fact valuable enablers of mass customisation ventures, and are therefore worthy of attention in future studies.

This study investigates for the first time the relationships between suppliers and lead users on the one hand, and the four attributes of mass customisations on the other, and allows for a unique comparison of suppliers and lead users. Supplier collaboration was found to impact product development cost, product development time and product scope, but to a lesser extent than lead user collaboration. Lead user collaboration, but not supplier collaboration, had a positive effect on customer influence. In the only other comparison of external partners, Frohlich and Westbrook (2001) did investigate the relative value of the integration of suppliers and customers in the supply chain, but their focus was on supply chain integration, and the importance of customer as opposed to lead users. In addition, Frohlich and Westbrook evaluated performance on the basis of financial and service as well as operational outputs.

Empirically, previous research has determined direct positive relationships between suppliers and decreases in total costs and total time (Carr and Pearson, 1999, Tu *et al.*, 2007, Dowlatshahi, 1997, Smith and Reinertsen, 1991), and indirect indications of the relationships between supplier collaboration and increased allowance for customer influence and product variety (Alford *et al.*, 2000, Krause *et al.*, 2000, Day, 1994). This study has investigated direct links of supplier collaboration with all four attributes, and has therefore been able to provide valuable confirmation of previous studies with regard to cost, time and product scope. This study has, however, provided evidence that there is no significant relationship between supplier collaboration and customer influence.

With regard to the literature understanding of lead user collaboration in mass customisation, there are relatively fewer extant studies, and most focus on the role of customers as opposed to lead users: for example, customer involvement has been shown to lead to decreased cost and time and product variety (Franke and Piller, 2003). This study has shown that there are indeed direct links between lead user collaboration and each of the four attributes of operational performance, which is a valuable contribution to the literature. In general, this research contributes to the operations management literature by extending the concept of lead users into collaborative product development and mass customisation, and by supporting the argument that trade-offs are not necessary between the operational performance objectives of manufacturing performance. Instead, it has been demonstrated that all four operational objectives can be simultaneously improved.

The conceptual model which has been developed in this thesis has proposed and tested a scheme based on collaborative product development and the performance indicators of mass customisation. This model has proved to be valid and helpful in evaluating the value of partnerships, and can therefore form the basis of further work to extend the understanding of collaborative product development in mass customisation. For example, different partners or alternative performance indicators could be tested using this same model. Of particular significance in this conceptual model is the employment of the four mass customisation attributes in an empirical study and the lead users identification tool, which will be discussed below.

8.3.1.1 Measuring Mass Customisation Operational Performance

As has been discussed throughout Chapters Two and Four, there is a need for research into ways to improve mass customisation processes, and to reduce the failures of such ventures. There is no dominant way, however of achieving mass customisation (Pine, 1993a, Gilmore and Pine, 1997, Ahlstrom and Westbrook, 1999). As a result, there is a need in the literature for empirical research into understanding the operational performance of mass customisation ventures (Kotha, 1996, Ahlstrom and Westbrook, 1999).

This study contributes to the literature by developing a better understanding of the end results which MC manufacturers should seek to achieve, which could provide a standard or performance index that might be of use to academics and managers alike. Notably, this has been one of the first empirical studies carried out with a concise set of measures of mass customisation operational performance. On the basis of this work, a performance index could be derived which incorporates and weights each attribute to give an overall measure of performance, such as that suggested by Welborn (2005).

8.3.1.2 Lead User Identification Method

This research aimed to investigate the comparative effects of lead users' and suppliers' collaboration on the mass customisation operational performance. In order to do so, it was of crucial importance that the subjects of the study had previous experience of collaboration with both lead users and suppliers. As a result, it was necessary to ensure that only data was collected from companies that had experience of lead user collaboration, and could therefore provide information about the effects of such partnerships. In order to achieve this requirement, a lead user identification method was developed with the assistance of senior production and operations managers, and subsequently validated and tested, to allow for separation of companies which did collaborate with lead users from those which did not (and which were subsequently removed from the study). The development of this method is described in Section 5.3.5.

The lead user identification method involves six items which describe the various characteristics of a lead user as distinct from other users. Only companies which answered 4 or 5 (agree or strongly agree) for each statement were considered to practise lead user collaboration, and were retained for the study. This method further develops the lead user identification methods reported by other studies (Shah and Ward, 2007, Franke and Shah, 2003, Franke *et al.*, 2006, Morrison *et al.*, 2000, Urban and von Hippel, 1988, Luthje, 2004, Herstatt and von Hippel, 1992). In this study, it has proved to be a simple and effective tool for investigating lead users in an empirical study. It therefore contributes to the literature in its potential for use in other similar studies of the effects of lead users.

8.3.2 Implications for Practice

The role of management is to utilise, develop and organise internal and external capabilities in order to best meet customer needs. For mass customisation companies, these needs are met by providing a wide variety of products which allow for customer influence, at a low cost and within a short time. The external capabilities which are utilised by companies include supplier and lead user collaboration. This study, in investigating the ways in which collaboration impacts upon mass customisation operational performance, therefore provides valuable implications for management. The findings of this study emphasise the importance of early involvement of suppliers and lead users in the product development processes. Involvement from the concept development stage gives the collaborator a sense of ownership, and thus more commitment towards the project at latter stages. Companies are therefore well advised to actively seek the involvement of both suppliers and lead users. In addition to the academic benefits of the lead user identification method described above, this method is also a valuable tool for practical use, allowing companies to quickly assess whether they are making use of lead user collaboration.

It has previously been shown, however, that it is important to carefully select supply chain partners in order to gain maximum benefit from the partnership (Tracey and Tan, 2001). This study supports that this is also the case for the choice of collaborative partners. This study gives some indication of where manufacturers should begin to build collaborations. Such an understanding is also important in the light of the costs associated with collaboration – there is expenditure in establishing the relationship, whether formal or informal, and in implementing mechanisms for the transfer of information. As a result, although this study has shown the great benefit of collaboration, it is neither practical nor effective to form the maximum possible number of collaborations. As a result, collaborative partners must be judiciously selected, a process which may be assisted by the findings of this study.

Both suppliers and lead users had a differing effect on the four mass customisation attributes, with lead users showing a greater positive relationship with all four attributes than supplier collaboration. This suggests that manufacturers should give more attention and consideration to lead users than they have previously done. Such focus has implications for the quality and success of mass customisation initiatives, and the appeal of products for consumers. Traditionally, manufacturers have focussed on suppliers, but a shift is needed towards lead users. While it is the finding of this research that suppliers have a positive effect on operational aspects of production and cost savings due to their input such as sophisticated technology, it is likely to be valuable to devote more time and effort in the identification of and collaboration with lead users. Such efforts might be expected to complement the benefits of existing supplier collaborations, and lead to more successful mass customisation ventures.

It is important, however, to avoid emphasis on one collaborative partner at the expense of all else. While this study has concluded that lead user collaboration has a greater effect on mass customisation operational performance, it would be dangerous to collaborate with lead users alone, and to completely disregard suppliers. Frohlich and Westbrook (2001), in their study of supply chain integration of suppliers and general users, observed that while integration of both suppliers and users had a significant positive effect on a firm's performance, integration of either one or the other had no added benefit over situations where there was no integration. It is likely that the same is also true in the context of collaboration with suppliers and lead users, and therefore both partnerships should be retained wherever possible. The fact that hypothesis testing showed that both suppliers and lead users had positive effects on most operational performance outputs – all four attributes, in the case of lead users – supports the retention of both collaborative partners.

Chapter Four discussed the four attributes of mass customisation, dividing them into those which describe customisation (product variety and customer influence) and the attributes of mass production (low cost and short time). The challenge of mass customisation is to balance the two to best cater to customers needs. This study has shown that integrating lead users in product development does not imply a trade-off between these two sets of attributes; the focus on wider product scope and higher customer influence do not compromise the desired low cost or short development time. Instead, there is a positive effect on these outcomes. Accordingly, one of the practical aspects that might be extended to manufacturing practice is that the involvement of lead users might have an exponential effect on the four dimensions of mass customisation operational performance.

This study not only provides operations managers and product development managers with a better understanding of the collaboration processes which impact the performance of their product development projects, but also the overall mass customisation initiatives. This might be of greatest assistance to those managers seeking to reengineer their product development processes to achieve more desirable outputs. In particular, the findings from the study offer directions for operation and product development managers who aim to achieve high performance in one of the four objectives (lower product cost, shorter product development time, greater allowance for customer influence or broader product scope). This study has used and validated seven different items which describe collaboration with suppliers or lead users. Focussing on these items might result in more focused collaboration activities.

8.4 Limitations of the Research

It is important to keep in mind the limitations of the chosen research design, in order to avoid inappropriate interpretation or generalisation of results, and to provide a clear picture of experimental changes which could be made for future research. One limitation of the study lies in the nature of the problem: both collaborative product development and mass customisation describe vast processes, which encompass all industries and countries. This study has only investigated a small aspect of both subjects, and has therefore been able to contribute relatively a modest amount of knowledge to this vast field. As a result, there is a very broad scope for further research.

This research included firm size, firm age and level of sales with suppliers as control variables. These three control variables provide only an attempt to account for the effects on the dependent variables. There are many more factors that could have an influence, such as the level of technology, the nature of competition, and the organisational structure. Accordingly, the results must be judiciously interpreted in order to avoid generalisations, which may prove to be false.

This study only focussed on product manufacturing firms in the United Kingdom: although many firms were international, only the practices at the UK firm were considered. There are literature indications that product development practices differ across countries, with findings in North America, Europe and Asia differing considerably (Nakata and Sivakumar, 1996). It is possible, therefore, that the generalisability of this survey might be affected, and the findings may only describe relationships that are true within the UK or Europe. An additional limitation of the sample is that only one respondent was surveyed from each company, which may result in the single respondent bias described in section 5.3.9. This was minimised as far as possible by selecting individuals who were very knowledgeable about the operations of the plant.

The method of data collection in this study was a survey, which is consistent with a number of survey studies of mass customisation (see Duray *et al.*, 2000, Chiou *et al.*, 2002 and Randall and Ulrich, 2001 for example). This method is a cost-effective way of collecting large quantities of data that avoids interview bias (Roberts, 1999). The main weakness of the survey method, however, is the lack of the ability to clarify items to respondents. For example, the use of sophisticated terms may be misunderstood. This was minimised by using focus groups to provide feedback on the questionnaire items, and was also evaluated in the responses to the pilot study. It is also hard to control for external factors such as the knowledge limitations of the survey respondents.

8.5 Directions for Future Research

There is much value in broadening the specific understanding that has been gained in this study. This study has demonstrated a causal relationship between supplier and lead user collaboration and increased mass customisation performance. Much remains to be investigated, however, about this relationship. Future research lies in three main areas: collaborations, mass customisation operational performance and the increasing of generality. Each aspect will be discussed in turn.

This study has provided information about the effects and relative merits of suppliers and lead users as broad categories, but has not considered the most valuable suppliers or lead users with whom to collaborate. It has been established that operational performance will be enhanced if supply chain partners are carefully selected based on a consideration of a number of factors (Vonderembse and Tracey, 1999, Tracey and Tan, 2001). As a result, it would be valuable to identify desirable characteristics in a supplier, or a lead user, in order to maximise the operational gains from collaboration. In addition to identifying the desirable properties of a collaborator, it could also be helpful to determine the level of collaboration which derives the greatest benefit. This study has measured the extent of collaboration in a relative manner: a more quantitative understanding could provide better guidance for management.

As well as investigating supplier and lead user collaboration, there is great value in extending the understanding to other collaborators. This study has built on other work in the development of an index for measuring mass customisation performance. It has studied the supplier and lead user collaboration by measuring their effect on the operational success of mass customisation. Based on these findings, it is imperative that future research investigate other forms of collaboration, and other potential collaborative partners, and to relate these to mass customisation performance.

This study has demonstrated the great value of collaborative product development on operational performance in mass customisation. The mechanisms by which this collaboration achieves these outcomes have not been fully elucidated, nor have the ways in which valuable collaboration can be facilitated. For example, more sophisticated information technology may be important in the achievement of fruitful relationships. A study could be performed to understand the factors that positively affect supplier and lead user collaboration.

Supplier collaboration and lead user collaboration can be initiated at any stage throughout product development, although this did not appear to be the case in this study, where suppliers and lead users were shown to participate throughout the product development processes. This supports the argument in the literature of early supplier involvement (Bidault *et al.*, 1998). However, it would be interesting to investigate whether there is variance of the level of collaboration at different stages of product development, and whether this variance affects the mass customisation outputs, as an intermediate variable. In addition to deepening the understanding of collaborative product development, further studies could also investigate mass customisation operational performance.

This study has suggested a framework for mass customisation operational performance, based on the four attributes of development cost, development time, customer influence and product scope. While this study has revealed the value and utility of this framework, further studies could confirm the use of these four indicators, and could enhance the ways in which each attribute is measured. For example, further study might reveal more constructs for each descriptor, which could lead to more sensitivity in future surveys.

This research has demonstrated that both supplier and lead user collaboration positively affect operational performance. Future studies could identify other factors which may have greater, more easily regulated effects. Furthermore, future studies of the features of successful mass customisation ventures could lead to the identification of further attributes which enhance the measurement of operational performance.

Because the nature of quantitative research necessitates the drawing of some form of boundary around the studies, there is commonly scope for increasing the generalisability of the study. This research could be extended to other industry types, such as service providers, to determine whether supplier and lead user collaboration similarly affect mass customisation operational performance. It could also be valuable to determine whether organisational or national culture could play a determinate role in favouring suppliers over lead users, or vice versa, and whether this will affect the mass customisation attributes.

Another valuable broadening of scope is to other processes of mass customisation. Mass customisation is a combination of many different managerial processes, of which operations and product development are only two. The findings of this study will have implications for other processes, such as distribution and delivery, marketing and the supply chain, and these should be investigated further.

A more general study might involve analysis of other factors which affect mass customisation operational performance. Da Silviera *et al.* (2001), identified six enablers of mass customisation: agile manufacturing, lean manufacturing, supply chain management, customer-driven design and manufacturing, advanced technologies and communication and networking. A study could be performed in which the relative effects of these enablers on mass customisation operational performance (measured by the mass customisation attributes) are compared to those of supplier and lead user collaboration.

8.6 Concluding Remarks

In the current market climate of competition and customer demand, it is becoming increasingly difficult for companies, particularly mass customisers, to retain competitiveness while acting alone. Instead, collaboration with various external partners can enable improvements in performance through shared knowledge and capabilities. Supplier collaboration is one tried and true method of such a beneficial partnership. Lead users have been hailed as the bearers of a new age of market research, in which not only are customer needs presented to the company, but also product ideas for possible solutions. This study has shown that this is indeed the case, with lead users having a significant positive effect on the mass customisation performance. The old favourite partner, suppliers, have also been shown to be beneficial, although with less breadth and weight. These findings show that it is valuable for companies to pursue these partnerships as a way of ensuring mass customisation operational performance. In this case, therefore, through collaboration comes success.

REFERENCES

REFERENCES

Adamson, R. E. (1952) Functional fixedness as related to problem solving: a repetition of three experiments. *Journal of Experimental Psychology,* 44, 288-291.

Adamson, R. E. & Taylor, D. W. (1954) Functional fixedness as related to elapsed time and to set. *Journal of Experimental Psychology,* 47, 122-126.

Afuah, A. N. (2000) How much do your competitors' capabilities matter in the face of a technological change? *Strategic Management Journal,* 21, 387-404.

Afuah, A. N. & Bahram, N. (1995) The hypercube of innovation. *Research Policy,* 24, 51-76.

Agarwal, S., Erramilli, M. K. & Dev, C. S. (2003) Market orientation and performance in service firms: role of innovation. *Journal of Services Marketing,* 17, 68-82.

Agrawal, M., Kumaresh, T. V. & Mercer, G. A. (2001) The false promise of mass customization. *The McKinsley Quarterly,* 2001, 62-71.

Ahlstrom, P. & Westbrook, R. (1999) Implications of mass customization for operations management: an exploratory survey. *International Journal of Operations and Production Management,* 19, 262-274.

Akkermans, H. A., Bogerd, P., Yucesan, E. & Van Wassenhove, L. N. (2003) The impact of ERP on supply chain management: exploratory findings from a European Delphi study. *European Journal of Operational Research,* 146, 284-301.

Aleson, M. R. & Escuer, M. E. (2002) The impact of product diversification strategy on the corporate performance of large Spanish firms. *Spanish Economic Review,* 4, 119-137.

Alfnes, E. & Strandhagen, J. O. (2000) Enterprise design for mass customization: the control model methodology. *International Journal of Logistics: Research and Application,* 3, 111-125.

Alford, D., Sackett, P. & Nelder, G. (2000) Mass customization - an automotive perspective. *International Journal of Production Economics,* 65, 99-110.

Allen, T. J. & Marquis, D. G. (1964) Positive and negative biasing sets: the effects of prior experience on research performance. *IEEE Trans. Engineering Management,* EM-11, 158-161.

Amaro, G., Hendry, L. & Kingsman, B. (1999) Competitive advantage, customization and a new taxonomy for non make-to-stock companies. *International Journal of Operations and Production Management,* 19, 349-371.

Andel, T. (2002) From common to custom: the case for make-to-order. *Material Handling Management,* 24-31.

Anderson, D. M. (1990) *Design for Manufacturability: Optimising Cost, Quality and Time-to-Market,* Lafayette, CA, CIM Press.

Anderson, D. M. (1998) *Agile product development for mass customization,* New York, McGraw-Hill.

Anderson, D. M. (2003) *Built-to-Order and Mass Customization,* Cambria, CA, CIM Press.

Anderson, D. M. P. E. (1997) *Agile product development for mass customization,* Chicago, Irwin Professional Pub.

Anderson, J. C. (1995) Relationships in business markets: exchange episodes, value creation, and their empirical assessment. *Journal of the Academy of Marketing Science,* 23, 346-350.

Andersson, L. M., & Bateman, T.S. (1997) Cynicism in the workplace: some causes and effects. *Journal of Organizational Behavior,* 18, 449-469.

Armstrong, S. & Overton, T. (1977) Estimating nonresponse bias in mail surveys. *Journal of Marketing Research,* 14, 396-402.

Atkins, R. G. & Slywotzky, A. J. (2001) You can profit from a recession. *Wall Street Journal,* February 5, A22.

Auerswald, P. E. & Kauffman, S., (2000) The production recipes approach to modeling technological innovation : an application to learning by doing. *Journal of Economic Dynamics and Control,* 24, 389-451.

Aulakh, P. S., & Gencturk, E.F. (2000) International principal-agent relationships-control, governance and performance. *Industrial Marketing Management,* 29, 521-538.

Aviv, Y. & Fredergruen, A. (2001) Design for postponement: a comprehensive characterization of its benefits under unknown demand distribution. *Operations Research,* 49, 578-598.

Baldwin, C. Y. & Clark, K. B. (1994) Modularity-in-design: an analysis based on the theory of real options. Boston, MA, Harvard Business School.

Baldwin, C. Y. & Clark, K. B. (1997) Managing in an age of modularity. *Harvard Business Review,* Sept-Oct, 84-93.

Berger, C., Moslein, K., Piller, F. T. & Reichwald, R. (2005) Cooperation between manufacturers, retailers, and customers for user co-design: learning from exploratory research. *European Management Review,* 1, 70-87.

Berman, B. (2002) Should your firm adopt a mass customization strategy? *Business Horizons,* 45, 51-60.

Bhaduri, S. N. (2002) Determinants of Corporate Borrowing: some evidence from the indian corporate structure. *Journal of Economics and Finance,* 26, 200-215.

Bidault, F., Despres, C. & Butler, C. (1998) New product development and early supplier involvement (ESI): the drivers of ESI adoption. *International Journal of Technology Management,* 15, 49-69.

Biemans, W. (1992) *Managing innovation within networks,* London, Routledge.

Birch, H. G. & Rabinowitz, H. J. (1951) The negative effect of previous experience on productive thinking. *Journal of Experimental Psychology,* 41, 121-125.

Blackburn, J. (1991) *Time Based Competition: The Next Battleground in American Manufacturing,* Homewood, Illinois, Business One Irwin.

Bonney, M., Ratchev, S. & Moualek, I. (2003) The changing relationship between production and inventory examined in a concurrent engineering context. *International Journal of Production Economics,* 81-82, 243-254.

Bowersox, D. J. & Closs, D. J. (1996) *Logisiical Management, the Integrated Supply Chain Process,* New York, McGraw-Hill.

Bowman, C. & Ambrosini, V. (1997) Using Single Respondents in Strategy Research. *British Journal of Management,* 8, 119-131.

Boynton, A. C. & Victor, B. (1991) Beyond flexibility: building and managing the dynamically stable organization. *California Management Review,* Fall, 53-66.

Bozgodan, K., Deyst, J., Hoult, D. & Lucas, M. (1998) Architectural innovation in product development through early supplier integration. *R&D Management,* 28, 163-173.

Brouthers, K. D., Brouthers, L. E. & Wilkinson, T. J. (1995) Strategic alliances: choose your partners. *Long Range Planning,* 28, 18-25.

Brown, J. S., Durchslag, S. & Hagel, J. I. (2002) Loosening up: How process networks unlock the power of specialization. *McKinsey Quarterly,* 58-69.

Brown, S. & Bessant, J. (2003) The manufacturing strategy-capabilities links in mass customization and agile manufacturing – an exploratory study. *International Journal of Operations and Production Management,* 23, 707-730.

Brown, S. L. & Eisenhardt, K. M. (1995) Product development: pas research, present findings, and future directions. *Academy of Management Review,* 20, 343-378.

Bruce, M., Leverick, F. & Littler, D. (1995) Complexities of collaborative product development. *Technovation,* 15, 535-552.

Bryman, A. & Bell, E. (2003) *Business research methods,* Oxford, Oxford University Press.

Bucklin, L. P. (1965) Postponement, speculation and the structure of distribution channels. *Journal of Marketing Research,* 2, 26-31.

Buzzell, R. D. & Gale, B. T. (1987) *The PIMS Principles: Linking Strategy to Performance,* New York, Free Press.

Cagliano, R., Caniato, F. & Spina, G. (2006) The linkage between supply chain integration and manufacturing imrpovements programmes. *International Journal of Operations and Production Mangement,* 26, 282-299.

Callahan, J. & Lasry, E. (2004) The importance of customer input in the development of very new products. *R & D Management,* 34, 107-120.

Campbell, A. A. & Katona, G. (1953) The Sample Survey: A Technique for Social Science Research. IN Newcomb, T. M. (Ed.) *Research Methods in Behavioral Sciences.* New York, Dryden Press.

Campbell, A. J. & Cooper, R. G. (1999) Do customer partnerships improve new product success rates. *Industrial Marketing Management,* 28, 507-519.

Carr, A. S. & Pearson, J. N. (1999) Strategically managed buyer-supplier relationships and performance outcomes. *Journal of Operations Management,* 17, 497-519.

Carr, A. S. & Pearson, J. N. (2002) The impact of purchasing and supplier involvement on strategic purchasing and its impact on firm's performance. *International Journal of Operations and Production Mangement,* 22, 1032-1053.

Catell, R. B. (1966) The scree test for number of factors. *Multivariate Behavioural Research,* 1, 245-276.

Cavusoglu, H., Cavusoglu, H. & Raghunathan, S. (2007) Selecting a customization strategy under competition: mass customization, targeted mass customization, and product proliferation. *IEEE Transactions on Engineering Management,* 54, 12-28.

Chandra, C. & Grabis, J. (2004a) Logistics and supply chain management for mass customization. IN Chandra, C. & Kamrani, A. (Eds.) *Mass Customization: A Supply Chain Approach.* New York, Plenum.

Chandra, C. & Grabis, J. (2004b) Managing logistics for mass customization: the new production frontier. IN Chandra, C. & Kamrani, A. (Eds.) *Mass Customization: A Supply Chain Approach.* New York, Plenum.

Cheng, F., Ettl, M., Lin, G. & Yao, D. D. (2002) Inventory-service optimization in configure-to-order systems. *Manufacturing and Service Operations Management,* 4, 114-132.

Chiou, J.-S., Wu, L.-Y. & Hsy, J. C. (2002) The adoption of form postponement strategy in a global logistics system: the case of Taiwanese information technology industry. *Journal of Business Logistics,* 23, 107-124.

Church, A. H. (1993) Estimating the effect of incentives on mail survey response rates: A meta-analysis. *Public Opinion Quarterly,* 57, 62-79.

Churchill, G. A. J. (1979) A paradigm for developing better measures of marketing constructs. *Journal of Marketing Research (JMR),* 16, 64-73.

Ciccantelli, S. & Magidson, J. (1993) Consumer-idealized design: involving consumers in the product development process. *Journal of Product Innovation Management,* 10, 341-347.

Clark, K. B. & Fujimoto, T. (1990) *Product development performance : strategy, organization, and management in the world auto industry,* Boston, MA, Harvard Business School.

Clark, K. B. & Fujimoto, T. (1991) *Product development performance,* Boston, MA, Harvard Business School Press.

Cohen, L. & Holliday, M. (1996) *Practical Statistics for Students,* London, Sage Publications.

Collis, J. & Hussey, R. (2003) Business research : a practical guide for undergraduate and postgraduate students. 2nd ed., Palgrave Macmillan.

Comstock, M., Johansen, K. & Winroth, M. (2004) From mass production to mass customization: enabling perspectives from the Swedish mobile telephone industry. *Production Planning & Control,* 15, 362-372.

Contractor, F. J. & Lorange, P. (2002) The growth of alliances in knowledge-based economy. *International Business Review,* 11, 485-502.

Cooper, R. G. & Kleinschmidt, E. J. (1987) New products: what separate winners from losers? *Journal of Product Innovation Management,* 4, 169-184.

Court, A. W., Culley, S. J. & McMahon, C. A. (1997) The influence of information technology in new product development: Observations of an empirical study of the access of engineering design information. *International Journal of Information Management,* 17, 359-375.

Court, A. W., Ullman, G. D. & Culley, S. J. (1998) A comparison between the provision of information to engineering designers in the UK and the USA. *International Journal of Information Management,* 18, 409-425.

Cox, E. P. (1980) The optimal number of response alternatives for a scale: A review. *Journal of Marketing Research,* 17, 407-422.

Cox, M. W. & Alm, R. (1998) *The Right Stuff. America's Move to Mass Customization,* Dallas, Federal Reserve Bank of Dallas.

Cravens, D. W. & Piercy, N. F. (1994) Relationship marketing and collaborative networks in service organizations. *International Journal of Service Industry Management,* 5, 39-53.

Cronbach, L. J. (1951) Coefficient alpha and the internal structure of tests. *Psychometrika,* 16, 297-334.

Curkovic, S., Vickery, S. K. & Droge, C. (2000) An empirical analysis of the competitive dimensions of quality performance in the automative supply industry. *International Journal of Operations and Production Mangement,* 20, 386-403.

Czaja, R. & Blair, J. (2005) *Designing Surveys: A Guide to Decisions and Procedures,* London, Sage.

Da Silveira, G., Borenstein, D. & Fogliatto, F. S. (2001) Mass customization: Literature review and research directions. *International Journal of Production Economics,* 72, 1-13.

Das, A., Narasimhan, R. & Talluri, S. (2006) Supplier integration: finding an optimal configuration. *Journal of Operations Management,* 24, 563-582.

Daugherty, P. J., Sabath, R. E. & Rogers, D. S. (1992) Competitive advantage through customer responsiveness. *Logistics and Transportation Review,* 28, 257-271.

Davis, S. (1989) From future perfect: mass customizing. *Planning Review,* 17, 16-21.

Davis, S. M. (1987) *Future perfect,* Reading, MA, Addison-Wesley.

Dawes, J. (2008) Do data characteristics change according to the number of scale points used? An experiment using 5-point, 7-point and 10-point scales. *International Journal of Market Research,* 50, 61-77.

Dawis, R. V. (1987) Scale construction. *Journal of Counseling Psychology,* 34, 481-489.

Day, G. S. (1994) The capabilities of market-driven organizations. *Journal of Marketing,* 58, 37-52.

De Toni, A. & Nassimbeni, G. (1999) Buyer-supplier operational practices, sourcing policies and plant performances: results of an empirical research. *International Journal of Production Research,* 37, 597-619.

Dertouzos, M. L., Lester, R. K. & Solow, R. M. (1989) *Made in America: Regaining the Productive Edge,* New York, Harper Perennial.

Dess, G. G. & Robinson Jr, R. B. (1984) Measuring Organizational Performance in the Absence of Objective Measures: The Case of the Privately-Held Firm and Conglomerate Business Unit. *Strategic Management Journal,* 5, 265-273.

Devaraj, S., Hollingworth, D. G. & Schroeder, R. G. (2004) Generic Manufacturing Strategies and Plant Performance. *Journal of Operations Management,* 22, 313-333.

Dewan, R. M., Jing, B. & Seidmann, A. (2001) Product customization and price competition on the internet. Simon Business School Working Paper No. CIS 01-03.

Dibona, C., Ockman, S. & Stone, S. (1999) *Open Sources: Voices from the Open Source Revolution,* Cambridge, MA, O'Reilly.

Dillman, D. A. (1978) *Mail and Telephone Surveys: The Total Design Method,* New York, John Wiley and Sons.

Dixon, L. & Porter, A. M. (1994) *JIT II: Revolution in Buying and Selling,* Newton, MA, Cahners.

Doty, D. H. & Glick, W. H. (1998) Common methods bias: does common methods variance really bias results? *Organizational Research Methods,* 1.

Dowlatshahi, S. (1997) The role of product design in designer-buyer-supplier interface. *Production Planning and Control,* 8, 522-532.

Duguay, C. R., Landry, S. & Pasin, F. (1997) From mass production to flexible/agile production. *International Journal of Operations and Production Management,* 17, 1183-1195.

Duncker, K. (1945) On problem-solving. *Psychological Monographs,* 58, 270.

Duray, R., Ward, P. T., Milligan, G. W. & Berry, W. L. (2000) Approaches to mass customization: configurations and empirical validation. *Journal of Operations Management,* 18, 605-625.

Easton, G. (1992) Industrial networks: a review. IN Axelsson, B. & Easton, G. (Eds.) *Industrial Networks: A New View of Reality.* London, Routledge.

Eastwood, M. A. (1996) Implementing mass customization. *Computers in Industry,* 30, 171-174.

Edwards, K. L. (2002) Towards more strategic product design for manufacture and assembly: priorities for concurrent engineering. *Materials and Design,* 23, 651-656.

Efstathiou, J. & Zhang, T. (2004) Future direction on mass customization research and practices: a research agenda. IN Chandra, C. & Kamrani, A. (Eds.) *Mass Customization: A Supply Chain Approach.* New York, Kluwer Academic.

Eisenhardt, K. M. & Tabrizi, B. (1995) Accelerating adaptive processes: product innovation in the global computer industry. *Administrative Science Quartely,* 40, 84-110.

Elfving, S. (2007) Managing Collaborative Product Development. *Innovation Design and Product Development.* Malardalen, Malardalen University.

Eliashberg, J., Lilien, G. L. & Rao, V. (1997) Minimizing technological oversights: a marketing research perspective. IN Garud, R., Nayyar, P., Rattah, P. & Shapira, Z. B. (Eds.) *Technological Innovation: Oversights and Foresights.* New York, Cambridge University Press.

Elliman, T. & Orange, G. (2000) Electronic commerce to support construction design and supply chain management. *International Journal of Physical Distribution and Logistics Management,* 30, 345-360.

Elliman, T. & Orange, G. (2003) Developing distributed design capabilities in the construction supply chain. *Construction Innovation,* 3, 15.

Ellram, L. (1990) The supplier selection decision in strategic partnerships. *Journal of Purchasing and Materials Management,* 26, 8-14.

Ellram, L. (1991) A managerial guideline for the development and implementation of purchasing partnerships. *International Journal of Purchasing and Materials Management,* 27, 2-8.

Ellram, L. & Cooper, M. C. (1990) Supply chain management partnerships and the shipper-third party relationship. *International Journal of Logistics Management,* 1, 1-10.

Enkel, E., Kausch, C. & Gassman, O. (2005a) Managing the risk of customer integration. *European Management Journal,* 23, 203-213.

Enkel, E., Perez-Freije, J. & Gassmann, O. (2005b) Minimizing Market Risks Through Customer Integration in New Product Development: Learning from Bad Practice. *Creativity & Innovation Management,* 14, 425-437.

Erens, F. J. & Hegge, H. M. H. (1994) Manufacturing and sales co-ordination for product variety. *International Journal of Production Economics,* 37, 83-99.

Fagerstrom, B. (2003) Managing suppliers in the distributed product development project. *Project Management: Dreams, Nightmares, and Realities.* NORDNET.

Faria, A. J. & Dickinson, J. R. (1996) The effect of reassured anonymity and sponsor on mail survey response rate and speed with a business population. *Journal of Business and Industrial Marketing,* 11, 66-76.

Feitzinger, E. & Lee, H. L. (1997) Mass customization at Hewlett Packard: the power of postponement. *Harvard Business Review,* 75, 91-101.

Fine, C. H. (1998) *Clockspeed - Winning Industry Control in the Age of Temporary Advantage,* Reading, MA, Perseus Books.

Fisher, M. L., Hammond, J., Obermeyer, W. & Raman, A. (1994) Making supply meet demand in an uncertain world. *Harvard Business Review*, 83-93.

Fisher, M. L. & Ittner, C. D. (1999) The impact of product variety on automobile assembly operations: empirical evidence and simulation analysis. *Management Science,* 45, 771.

Fiske, D. W. (1982) Convergent-discriminant validation in measurements and research strategies. IN Brinberg, D. & Kidder, L. (Eds.) *New directions for methodology of social and behavioural science: Forms of validity in research.* San Francisco, Jossey-Bass.

Ford, D. (1997) *Understanding Business Markets,* London, Dryden Press.

Foster, R. N. (1986) *Innovation: The Attacker's Advantage,* New York, Summit Books.

Fowler, F. J., Jr. (1993) *Survey Research Methods,* London, Sage Publications.

Fox, R. J., Crask, M.R. And Kim, J. (1988) Mail survey response rate: a meta-analysis of selected techniques for including response. *Public Opinion Quarterly,* 52.

Foxall, G. & Johnston, B. (1987) Strategies of user-initiated product innovation. *Technovation,* 6, 77-102.

Foxall, G., Murphy, F. & Tierney, J. D. (1985) Business development in practice: a case study of user initiated innovation. *Journal of Marketing Management,* 1, 201-211.

Foxall, G. R. & Tierney, J. D. (1984) From CAP1 to CAP2: user-initiated innovation from the user's point of view. *Management Decision,* 22, 3-15.

Franke, N. & Hippel, E. V. (2003) Satisfying heterogeneous user needs via innovation toolkits: the case of Apache security software. *Research policy.,* 32, 1199.

Franke, N. & Piller, F. T. (2003) Key research issues in user interaction with user toolkits in a mass customization system. *International Journal of Technology Management,* 26, 578-599.

Franke, N. & Piller, F. T. (2004) Value creation by toolkits for user innovation and design: the case of the watch market. *Product Innovation Management,* 21, 401-415.

Franke, N. & Shah, S. (2003) How communities support innovative activities: an exploration of assistance and sharing among end-users. *Research Policy,* 32, 157-178.

Franke, N., Von Hippel, E. & Schreier, M. (2006) Finding commercially attractive user innovations: a test of lead-user theory. *Journal of Product Innovation Management,* 23, 301-315.

Frohlich, M. T. (2002) Techniques for improving response rates in OM survey research. *Journal of Operations Management,* 20, 53-62.

Frohlich, M. T. & Westbrook, R. (2001) Arcs of integrations: an international study of supply chain strategies. *Journal of Operations Management,* 19, 185-200.

Fulkerson, B. & Shank, M. (1999) The new economy electronic commerce, and the rise of mass customization. IN Shaw, M., Blanning, R. & Strader, T. (Eds.) *Handbook on Electronic Commerce.* New York, Springer.

Fulkerson, F. (1997) A response to dynamic change in the market place. *Decision Support Systems,* 21, 199-214.

Furst, K. & Schmidt, T. (2001) Turbulent markets need flexible supply chain communication. *Production Planning and Control,* 12, 525-533.

Gardiner, S. C., Hanna, J. B. & Latour, M. S. (2002) ERP and the reengineering of industrial marketing processes: a prescriptive overview for the new-age marketing manager. *Industrial Marketing Management,* 31, 357-365.

Garud, R. & Kotha, S. (1994) Using the brain as a metaphore to model flexible product units. *Academy of Management Review,* 19, 671-698.

Gassenheimer, J. B., Calantone, R. J. & Scully, J. I. (1995) Supplier involvement and dealer satisfaction: implications for enhancing channel relationships. *Journal of Business and Industrial Marketing,* 10, 7-19.

Ghauri, P. & Gronhaug, K. (2002) *Research Methods in Business Studies: A Practical Guide,* Harlow, England, Prentice Hall: Financial Times.

Ghiassi, M. & Spera, C. (2003) Defining the Internet-based supply chain system for mass customized markets. *Computers in Industrial Engineering,* 45, 17-41.

Gilmore, J. H. & Pine, B. J. I. (1997) The four faces of mass customization. *Harvard Business Review,* Jan-Feb, 91-101.

Goldhar, J. & Jelinek, M. (1983) Plans for economies of scope. *Harvard Business Review,* 61, 141-148.

Gomory, R. E. & Schmitt, R. W. (1988) Step-by-step innovation. *Across the Board.* November.

Gooley, T. B. (1998) Mass customization: how logistics makes it happen. *Logistics,* 4, 49-53.

Greer, T. V., Chuchinprakarn, N. & Seshadri, S. (2000) Likelihood of participating in mail survey research - business respondents' perspectives. *Industrial Marketing Management,* 29, 97-109.

Griffin, A. & Hauser, J. R. (1996) Integrating R&D and marketing: a review and analysis of literature. *Journal of Product Innovation Management,* 13, 191-215.

Griffiths, J. & Margetts, D. (2000) Variation in production schedules - implications for both the company and its suppliers. *Journal of Materials Processing Technology,* 103, 155-159.

Gruner, K. E. & Homburg, C. (2000) Does customer interaction enhance new product success? *Journal of Business Research,* 49, 1-14.

Gupta, A. K., Raj, S. P. & Wilemon, D. (1985) The R&D-marketing interface in high technology firms. *Journal of Product Innovation Management,* 2, 12-24.

Guttmann, L. (1944) A Basis for Scaling Qualitative Data. *American Sociological Review,* 9, 139-150.

Hagel, J. I. & Brown, J. S. (2005) *The Only Sustainable Edge: Why Business Strategy Depends on Productive Friction and Dynamic Specialization,* Harvard, MA, Harvard Business Press.

Hair, J. F., Tatham, R. L., Anderson, R. E. & Black, W. C. (2006) *Multivariate data analysis,* New York, Prentice Hall.

Hakansson, H. (1987) *Industrial Technological Development: A Network Approach,* London, Croom Helm.

Handfield, R. (1994) Effects of concurrent engineering on make-to-order products. *IEEE Trans. Engineering Management,* 41, 1-11.

Handfield, R., Ragatz, G. L., Petersen, K. J. & Monczka, R. (1999) Involving suppliers in new product development. *California Management Review,* 42, 59-82.

Hargadon, A. (2003) How Breakthroughs Happen - The Surprising Truth About How Companies Innovate. *Harvard Business Review,* 80, 72-9.

Harhoff, D., Henkel, J. & Von Hippel, E. (2003) Profiting from voluntary information spillovers: how users benefit by freely revealing their innovations. *Research Policy,* 32, 1753-1769.

Harman, H. A. (1976) *Modern Factor Analysis,* Chicago, University of Chicago Press.

Hart, C. W. L. (1995) Mass customization: conceptual underpinnings, opportunities and limits. *International Journal of Service Industry Management,* 6, 36-45.

He, Q.-M. & Jewkes, E. M. (2000) Performance measures of a make-to-order inventory-production system. *IIE Transactions,* 32, 409-419.

Heide, J. B. & Miner, A. S. (1992) The shadow of the future: effects of anticipated interaction and frequency of contact on buyer-seller cooperation. *Academy of Management Journal,* 35, 265-291.

Helander, M. G. & Jiao, J. (2002) Research on E-product development (ePD) for mass customization. *Technovation,* 22, 717-724.

Hendrick, T. & Ellram, L. (1993) Strategic Supplier Partnering: An International Study. Tempe, AZ, Centre for Advanced Purchasing Studies.

Herstatt, C. & Von Hippel, E. (1992) From experience: developing new product concepts via the Lead User Method: a case study in a "low tech" field. *Journal of Product Innovation Management,* 9, 213-221.

Hillebrand, B. & Biemans, W. (2004) Links between internal and external cooperation in product development: a exploratory study. *Journal of Product Innovation Management,* 21, 110-121.

Hirschhorn, L., Noble, P. & Rankin, T. (2001) Sociotechnical systems in an age of mass customization. *Journal of Engineering and Technology Management,* 18, 241-252.

Holloway, I. (1997) *Basic Concepts for Qualitative Research,* Oxford, Blackwell Science.

Hoogeweegen, M. R., Teunissen, W. J. M., Vervest, P. H. M. & Wagenaar, R. W. (1999) Modular network design: using information and communication technology to allocate production tasks in a virtual organization. *Decision Sciences,* 30, 1073-1103.

Hotelling, H. (1929) Stability in competition. *Economic Journal,* 39, 41-57.

Hounsell, D. A. (1984) *From the American System to Mass Production, 1800-1932,* Baltimore, John Hopkins University Press.

Industry Week (1995) *Complete Guide to America's Best Plants,* Cleveland, OH, Penton Publishing.

Istook, C. L. (2002) Enabling mass customization: computer-driven alteration methods. *International Journal of Clothing,* 14, 61-76.

Joshi, M. P., Kathuria, R. & Porth, S. J. (2003) Alignment of Strategic Priorities and Performance: An Integration of Operations and Strategic Management Perspectives. *Journal of Operations Management,* 21, 353-369.

Kahn, K. B. (2005) Department Status: An Exploratory Investigation of Direct and Indirect Effects on Product Development Performance. *Journal of Product Innovation Management,* 22, 515-526.

Kaiser, H. F. (1974) An index of factorial simplicity. *Psycometrika,* 39, 31-36.

Kakati, M. (2002) Mass customization - needs to go beyond technology. *Human Systems Management,* 21, 85-93.

Kamali, N. N. & Loker, S. (2002) Mass customization: On-line consumer involvement in product design. *Journal of Computer Mediated Communication,* 7.

Kamath, R. R. & Liker, J. K. (1994) A second look at Japanese product development. *Harvard Business Review,* 72, 154-170.

Kamrani, A. & Salhieh, S. M. (2002) *Product Design for Modularity,* Norwell, MA, Kluwer Academic.

Kane, C. L. (1983) New product development: a systematic approach. *Journal of Consumer Marketing,* 1, 53-57.

Kanuk, L. & Berenson, C. (1975) Mail surveys and response rates: a literature review. *Journal of Marketing Research,* 12, 440-453.

Karlsson, A. (2002) Assembly-initiated production - a strategy for mass customization utilizating modular, hybrid automatic production systems. *Assembly Automation,* 22, 239-247.

Karsak, E. E. & Kuzgunkaya, O. (2002) A fuzzy multiple objective programming approach for the selection of flexible manufacturing system. *International Journal of Production Economics,* 79, 101-111.

Katz, R. & Allen, T. J. (1985) Project performance and the locus of influence in teh R&D matrix. *Academy of Management Journal,* 27, 67-87.

Kayis, B. & Kara, S. (2005) The supplier and customer contribution to manufacturing flexibility: Australian manufacturing industry's perspective. *Journal of Marketing Technology Management,* 16, 733-752.

Kellogg, D. L. & Nie, W. (1995) A framework for strategic service management. *Journal of Operations Management,* 13, 323-337.

Kim, J. (1998) Hierarchical structure of intranet functions and their relative importance: using the analytic hierarchy process for virtual organization. *Decision Support Systems,* 23, 59-74.

Kirzner, I. (1973) *Competition and Entrepreneurship,* Chicago, Chicago University Press.

Kitzinger, K. & Barbour, R. (1999) *Developing focus group research: Politics, theory and practice,* London, Sage Publications.

Kotha, S. (1995) Mass customization: Implementing the emerging paradigm for competitive advantage. *Stategic Management Journal,* 16, 21-42.

Kotha, S. (1996) From mass production to mass customization: the case of the National Industrial Bicycle Company of Japan. *European Management Journal,* 14, 442-450.

Kotler, P. (1988) *Marketing Management - Analysis Planning, Implementation and Control,* Englewood Cliffs, NJ, Prentice-Hall.

Kotler, P. (1989) From mass marketing to mass customization. *Planning Review,* 17, 10-13.

Krause, D. R., Scannell, T. V. & Calantone, R. J. (2000) A structural analysis of the effectiveness of buying firms' strategies to improve supplier performance. *Decision Sciences,* 31, 33-55.

Kreuger, R. A. & Casey, M. A. (2000) *Focus groups: a practical guide for applied research,* London, Sage Publications.

Lamming, R. (1996) Squaring lean supply with supply chain management. *International Journal of Operations and Production Management,* 16, 183-196.

Lampel, J. & Mintzberg, H. (1996) Customizing customization. *Sloan Management Review,* 38, 21-30.

Lancaster, K. (1990) The economics of product variety: a survey. *Marketing Science,* 9, 189-206.

Lau, R. S. M. (1995) Mass customization: the next industrial revolution. *Industrial Management,* 37, 18-19.

Lave, J. & Wenger, E. (1991) *Situated Learning: Legitimate Peripheral Participation,* Cambridge, Cambridge University Press.

Lee, C.-H. S., Barua, A. & Whinston, A. B. (2000) The complementarity of mass customization and electronic commerce. *Economics of Innovation and New Technology,* 9, 81-110.

Lee, H. L. & Billington, C. (1995) The evolution of supply-chain-management models and practice at Hewlett Packard. *Interfaces,* 25, 42-63.

Lei, D. (1993) Offensive and defensive uses of alliances. *Long Range Planning,* 26, 32-41.

Li, S., Rao, S. S., T.S., R.-N. & Ragu-Nathan, B. (2005) Development and validation of a measurement instrument for studying supply chain management practices. *Journal of Operations Management,* 23, 618-641.

Likert, R. (1932) A Technique for the Measurement of Attitudes. *Archives of Psychology,* 140, 1-55.

Lilien, G. L., Morrison, P. D., Searls, K., Sonnack, M. & Von Hippel, E. (2002) Performance assessment of the lead user idea-generation process for new product development. *Management Science,* 48, 1042-1059.

Littler, D., Leverick, F. & Bruce, M. (1995) Factors Affecting the Process of Collaborative Product Development: A Study of UK Manufacturers of Information and Communications Technology Products. *Journal of Product Innovation Management,* 12, 16-32.

Luchins, A. S. (1942) Mechanization in problem solving: The effect of einstellung. *Psychological Monographs,* 54, 248.

Luthje, C. (2004) Characteristics of innovating users in a consumer goods field. An empirical study of sport-related product consumers. *Technovation,* 24, 683-695.

Luthje, C. & Herstatt, C. (2004) The Lead User method: an outline of empirical findings and issues for future research. *R & D management,* 34, 553-568.

Ma, S., Wang, W. & Liu, L. (2002) Commonality and postponement in multistage assembly sustems. *European Journal of Operational Research,* 142, 523-538.

MacCarthy, B., Brabazon, P. G. & Bramham, J. (2003a) Examination of mass customization through field evidence. IN Tseng, M. M. & Piller, F. T. (Eds.) *The Customer Centric Enterprise: Advances in Mass Customization and Personalization.* Berlin, Springer.

MacCarthy, B., Brabazon, P. G. & Bramham, J. (2003b) Fundamental modes of operation for mass customization. *International Journal of Production Economics,* 85, 289-214.

Malhotra, M. K. (1999) *Marketing Research: An Applied Orientation,* New Jersey, Prentice Hall.

Malhotra, M. K. & Grover, V. (1998) An assessment of survey research in POM: from constructs to theory. *Journal of Operations Management,* 16, 407-425.

Maltz, A. B. (1994) The relative importance of cost and quality in the outsourcing of warehousing. *Journal of Business Logistics,* 15, 45-62.

Mansfield, E. (1968) *Industrial Research and Technological Innovation: An Econometric Analysis,* New York, W.W. Norton.

Margonelli, L. (2002) How IKEA designs its sexy price tags. *Business 2.0,* 3, 106.

Marx, R., Zilbovicius, M. & Salerno, M. S. (1997) The modular consortium in a new VW truck plant in Brazil: new forms of assembler and supplier relationship. *Integrated Manufacturing Systems,* 8, 292-298.

Mather, H. F. (1987) Logistics in manufacturing: a way to beat the competition. *Assembly Automation,* 7, 175-178.

McCarthy, I. (2004) Special issue editorial: the what, why and how of mass customization. *Production Planning and Control,* 15, 347-351.

McCutcheon, D. M., Raturi, A. S. & Meredith, J. R. (1994) The customization responsiveness squeeze. *Sloan Management Review,* 35, 89-99.

McFarlan, F. W. & Nolan, R. L. (1995) How to manage an IT outsourcing alliance. *Sloan Management Review,* 36, 9-23.

Mcivor, R., Humphreys, P. & Huang, G. (2000) Electronic commerce: reengineering the buyer-supplier interface. *Business Process Management Journal,* 6, 122-138.

Mcivor, R., Humphreys, P. & Mcaleer, W. (1997) The implications of the trend towards partnership sourcing on buyer-supplier relations. *Journal of General Management,* 23, 53-70.

Mcwilliams, G. (1997) Whirlwind on the Web. *Business Week,* April, 132-136.

Meixell, M. J. & Wu, S. D. (2004) Collaborative manufacturing for mass customization. IN Chandra, C. & Kamrani, A. (Eds.) *Mass Customization - A Supply Chain Approach.* New York, Kluwer Academic.

Meyer, C. (1993) *Fast cycle time: how to align purpose, strategy and structure for speed,* New York, Free Press.

Mikkola, J. H. & Skjoett-Larsen, T. (2003) Early supplier involvement: implications for new product development outsourcing and supplier-buyer interdependence. *Global Journal of Flexible Systems Management,* 4, 31-41.

Mikkola, J. H. & Skjott-Larsen, T. (2004) Supply-chain integration: implications for mass customization, modularization and postponement strategies. *Production Planning and Control,* 15, 352-361.

Millson, M. R., Raj, S. P. & Wilemon, D. (1992) A survey of major approaches for accelerating new product development. *Journal of Product Innovation Management,* 9, 53-69.

Mintzberg, H. & Lampel, J. (1996) Customizing customization. *Sloan Management Review,* 38, 21-30.

Monczka, R. & Morgan, J. (1997) What's wrong with supply chain management? *Purchasing,* 122, 69-73.

Monczka, R., Ragatz, G. L., Handfield, R., Trent, R. & Frayer, D. (1997) Supplier integration into new product development: a strategy for competitive advantage - the global procurement and supply chain benchmarking initiative. East Lansing, Michigan, The Eil Broad Gradate School of Management, Michigan State University.

Monczka, R. & Trent, R. (1997) *Purchasing and sourcing 1997: trends and implications,* Greenwich, CT (CAPS).

Monplaisir, L. F. & Salhieh, S. M. (2000) Integrated CSCW/QFD to support distributed product development. *4th International Conference on Engineering Design and Automation.* Orlando, Florida.

Morash, E. A. (2000) Supply chain strategies, capabilities and performance. *Transportation Journal,* 41, 37-54.

Morrison, P. D., Roberts, J. H. & Hippel, E. V. (2000) Determinants of User innovation and Innovation Sharing in a Local Market. *Management science.,* 46, 1513.

Morrison, P. D., Roberts, J. H. & Midgley, D. F. (2004) The nature of lead users and measurement of leading edge status. *Research Policy,* 33, 351-362.

Moser, C. A. & Kalton, G. (1971) *Survey Methods in Social Investigation,* London, Glower.

Mussa, M. & Rosen, S. (1978) Monopoly and product quality. *Journal of Economic Theory,* 18, 301-317.

Myers, S. & Marquis, D. G. (1969) Successful Inudstrial Innovations. Washington DC, National Science Foundation.

Nakata, C. & Sivakumar, K. (1996) National culture and new product development: an integrative review. *Journal of Marketing,* 60, 61-72.

Nambisan, S. (2002) Designing virtual customer environments for new product development: toward a theory. *Academy of Management Review,* 27, 392-413.

Noori, H. (1990) *Managing the dynamics of new technology : issues in manufacturing management,* Englewood Cliffs, N.J., Prentice Hall.

Nunnally, J. O. (1978) *Psychometric Theory,* New York, NY, McGraw Hill.

Oleson, J. D. (1998) *Pathways to Agility: Mass Customization in Action,* New York, Wiley.

Olson, E. M., Walker Jr., O. C., Ruekert, R. W. & Bonner, J. M. (2001) Patterns of cooperation during new product development among marketing, operations and R&D: Implications for project performance. *Journal of Product Innovation Management,* 18, 258-271.

Oppenheim, A. N. (1992) *Questionnaire design, interviewing and attitude measurement,* London, Pinter Publishers.

Palich, L. E., Cardinal, L. B. & Miller, C. C. (2000) Curvilinearity in the diversification-performance linkage: an examination of over three decades of research. *Strategic Management Journal,* 21, 155-174.

Pallant, J. (2006) *SPSS survival manual,* Berkshire, Open University Press.

Partanen, J. & Haapasalo, H. (2004) Fast production for order fulfillment: Implementing mass customization in electronics industry. *International Journal of Production Economics,* 90, 213-222.

Penya, Y. K., Bratoukhine, A. & Sauter, T. (2003) Agent-driven distributed-manufacturing model for mass customization. *Integrated Computer-Aided Engineering,* 10, 139.

Perez, M. P. & Sanchez, A. M. (2001) Supplier relations and flexibility in the Spanish automotive industry. *Supply Chain Management: An International Journal,* 6, 29-38.

Petersen, K. J., Handfield, R. B. & Ragatz, G. L. (2005) supplier integration into new product development: coordinating products, process, and supply chain design. *Journal of Operations Management,* 23, 371-388.

Peterson, R. A. (1994) A meta-analysis of Cronbach's coefficient alpha. *Journal of Consumer Research,* 21, 381-391.

Piller, F. T. (2002) Customer interaction and digitizablitiy: a strucutral approach. IN Rautenstrauch, C., Seelmann-Eggbert, R. & Turowski, K. (Eds.) *Moving Towards Mass Customization.* Berlin, Springer.

Pine, B. J. I. (1993a) *Mass Customization: The New Frontier in Business Competition,* Cambridge, MA, Harvard University Press.

Pine, B. J. I. (1993b) Mass customizing products and services. *Planning Review,* 21, 6-13.

Pine, B. J. I. (1998) Mass customization: the new imperative in business. IN Anderson, D. M. (Ed.) *Agile Product Development for Mass Customization.* New York, McGraw-Hill.

Pine, B. J. I., Peppers, D. & Rogers, M. (1995) Do you want to keep your customers forever? *Harvard Business Review,* 72, 103-114.

Pine, B. J. I., Victor, B. & Boynton, A. C. (1993c) Making mass customization work. *Harvard Business Review,* 71, 108-119.

Podaskoff, P. M. & Organ, D. W. (1986) Self-Reports in Organizational Research: Problems and Prospects. *Journal of Management,* 12, 531-544.

Podsakoff, P. M., Mackenzie, S. B., Lee, J.-Y. & Podsakoff, N. P. (2003) Common method biases in behavioral research: A critical review of the literature and recommended remedies. *Journal of Applied Psychology,* 88, 879-903.

Polit, D. F., Beck, C. T. & Hungler, B. P. (2001) *Essentials of Nursing Research: Methods, Appraisal and Utilization,* Philadelphia, Lippincott Williams & Wilkins.

Prieto, L. & Sacristán, J. A. (2004) What is the value of social values? The uselessness of assessing health-related quality of life through preference measures. *BMC Medical Research Methodology,* 4, 10-18.

Primo, M. A. M. & Amundson, S. D. (2002) An exploratory study of the effects of supplier relationships on new product development outcomes. *Journal of Operations Management,* 20, 33-52.

Rackham, N., Friedman, L. & Ruff, R. (1996) *Getting Partnering Right,* New York, McGraw-Hill.

Ragatz, G. L., Handfield, R. & Petersen, K. J. (2002) Benefits associated with supplier integration into new product development under conditions of technology uncertainty. *Journal of Business Research,* 55, 389-400.

Ragatz, G. L., Handfield, R. & Scanell, T. V. (1997) Success factors for integrating suppliers into new product development. *Journal of Product Innovation Management,* 14, 190-202.

Randall, T. & Ulrich, K. (2001) Product variety, supply chain structure, and firm performance: analysis of the U.S. bicycle industry. *Management Science,* 47, 1588-1604.

Rifkin, G. (1994) Digital blue jeans pour data and legs into customized fit. *The New York Times,* Nov. 8.

Roberts, E. S. (1999) In defence of the survey method: an illustration from user information satisfaction. *Accounting and Finance,* 39, 53-78.

Robinson, J. P., Shaver, P. R. & Wrightman, L. S. (1991) Criteria for scale selection and evaluation. IN Robinson, J. P., Shaver, P. R. & Wrightman, L. S. (Eds.) *Measures of Personality and Social Psychological Attitudes.* San Diego, CA, Academic Press.

Ross, A. (1996) Selling uniqueness. *Manufacturing Engineer,* December, 260-263.

Ross, A. (1998) Mass customization: the dirty reality. *Manufacturing Engineer,* 77, 79-80.

Rostow, W. W. (1978) *The World Economy: History and Prospect,* Austin, Texas, University of Texas Press.

Rothwell, R. (1993) The changing nature of the innovation process. *Technovation.,* 13, 1-2.

Rothwell, R., Freeman, C., Horseley, A., Jervis, V.T.P., Robertson, A.B. & Townsend, J. (1974) SAPPHO updated - project SAPPHO phase II. *Research Policy,* 3, 258-291

Roy, R. & Potter, S. (1996) Managing engineering design in complex supply chains. *International Journal of Technology Management,* 12, 403-420.

Roy, U. & Kodkani, S. S. (1999) Product modeling within the framework of the World Wide Web. *IIE Transactions,* 31, 667-677.

Rubenstein, A. H., Chakrabarti, A. K., O'keefe, R. D., Souder, W. E. & Young, H. C. (1976) Factors influencing innovation success at the project level. *Research Management,* May.

Rudberg, M. & Wikner, J. (2008) Mass customization in terms of the customer order decoupling point. *Production Planning and Control,* 15, 445-458.

Rumelt, R. P. (1974) *Strategy, Structure and Economic Performance,* Boston, Harvard University Press.

Rumelt, R. P. (1982) Diversification strategy and profitability. *Strategic Management Journal,* 3, 359-369.

Sahin, F. (2000) Manufacturing competitiveness: different systems achieve the same results. *Production & Inventory Management Journal.* American Production and Inventory Control Society.

Saisse, M. C. P. & Wilding, R. D. (1997) Short term strategic management in mass customization markets. *Logistics Information Management,* 10, 199-207.

Sako, M. & Helper, S. (1998) Determinants of Trust in Supplier Relations: Evidence from the Automotive Industry in Japan and in the United States. *Journal of economic behavior & organization.,* 34, 387-417.

Salhieh, S. M. & Kamrani, A. K. (1999) Macro level product development using design for modularity. *Robotics & Computer-Integrated Manufacting,* 15, 319-329.

Salop, S. C. (1979) Monopolistic competition with outside goods. *Bell Journal of Economics,* 10, 141-156.

Salvador, F., Forza, C. & Rungtusanatham, M. (2002a) How to mass customize: product architectures, sourcing configurations. *Business Horizons,* 45, 61-69.

Salvador, F., Forza, C. & Rungtusanatham, M. (2002b) Modularity, product variety, production volume, and component sourcing: theorizing beyond generic prescriptions. *Journal of Operations Management,* 20, 549-575.

Salvador, F., Rungtusanatham, M. & Forza, C. (2004) Supply-chain configurations for mass customization. *Production Planning and Control,* 15, 381-397.

Sanchez, R. & Mahoney, J. T. (1996) Modularity, flexibility and knowledge management in product and organization design. *Strategic Management Journal.*

Schilling, M. A. (2000) Toward a general modular systems theory and its application to interfirm product modularity. *Academy of Management Review,* 25, 312-334.

Schmookler, J. (1966) *Invention and Economic Growth,* Cambridge, MA, Harvard University Press.

Schreier, M. & Prugl, R. (2008) Extending Lead-User Theory: Antecedents and Consequences of Consumers' Lead Userness. *Journal of Product Innovation Management,* 25, 331-346.

Scott, J. P., Rishel, T. D. & Stenger, A. J. (2001) Managing information in a service industry to enhance buyer/supplier relationships. *International Conference on e-Business.*

Sekaran, U. (2003) Research methods for business : a skill-building approach. 4th ed., John Wiley & Sons.

Seungwha, C. & Gyeong, M. K. (2003) Performance effects of partnerships between manufacturers and suppliers for new product development: the suppliers standpoint. *Research Policy,* 32, 587-603.

Shah, R. & Ward, P. T. (2007) The Effect of Contextual Factors on the Implementation of Lean Manufacturing Practices. *Journal of Operations Management,* 25, 785-805.

Shah, S. (2000) Sources and patterns of innovation in a consumer products field: innovations in sporting equipment. *Sloan Working Paper,* #4105.

Shimbun, N. K. (1987) *Poka-Yoke, Improving Product Quality by Preventing Defects,* Portland, OR, Productivity Press.

Skjelstad, L., Hagen, I. & Alfnes, E. (2005) Guidelines for achieving a proper mass customization system. *Euroma International Conference on Operations and Global Competitiveness.* Budapest.

Slaughter, S. (1993) Innovation and learning during implementation: A comparison of user and manufacturer innovations. *research Policy,* 22, 81-95.

Smirnov, A. V., Pashkin, M., Chilov, N. & Levashova, T. (2003) Agent-based support of mass customization for corporate knowledge management. *Engineering Applications of Artificial Intelligence,* 16, 349-364.

Smith, R. & Reinertsen, D. (1991) *Developing products in half the time,* New York, Van Nostrand.

Sokolov, M. (2001) Technology's impact on society: the issue of mass-customized education. *Technological Forecasting and Social Change,* 68, 195-206.

Song, M. & Di Benedetto, C. A. (2008) Supplier's involvement and success of radical new product development in new ventures. *Journal of Operations Management,* 26, 1-22.

Souder, W. E. & Chakrabarti, A. K. (1978) The R&D/Marketing Interface: results from an empirical study of innovation projects. *IEEE Trans. Engineering Management,* 25, 88-93.

Souder, W. E. & Chakrabarti, A. K. (1979) Industrial innovations: a demographical analysis. *IEEE Trans. Engineering Management,* 25, 101-109.

Spekman, R. E. (1988) Strategic supplier selection: understanding long-term buyer relationships. *Business Horizons,* 131, 75-81.

Spira, J. S. (1993) Mass customization through training at Lutron Electronics. *Strategy and Leadership,* 21, 23-24.

Spring, M. & Dalrymple, J. (2000) Product customization and manufacturing strategy. *International Journal of Operations & Production Management,* 20, 441-467.

Squire, B., Brown, S., Readman, J. & Bessant, J. (2006) The impact of mass customization on manufacturing trade-offs. *Production and Operations Management Journal,* 15, 10-21.

Stankosky, M. (2004) *Creating the Discipline of Knowledge Management: The Latest in University Research,* Boston, MA, Butterworth-Heinemann.

Starr, M. (1965) Modular production - a new concept. *Harvard Business Review,* 131-142.

Stevens, J. (1996) *Applied Multivariate Statistics for the Social Sciences,* Mahway, NJ, Lawrence Erlbaum.

Stigler, G. J. (1958) The economies of scale. *Journal of Law and Economics,* 1, 54-71.

Tabachnik, B. G. & Fidell, L. S. (2006) *Using Multivaraite Statistics,* Boston, Pearson Education.

Takeichi, A. (2001) Bridging inter- and intra-firm boundaries: managing of suppliers in automobile product development. *Strategic Management Journal,* 22, 403-433.

Thomke, S. & Von Hippel, E. (2002) Customers as innovators: a new way to create value. *Harvard Business Review,* 80, 74-81.

Thorelli, H. B. (1986) Networks: between markets and hierarchies. *Strategic Management Journal,* 7, 37-51.

Tijms, H. (2004) *Understanding Probability: Chance Rules in Everyday Life,* Cambridge, Cambridge University Press.

Tomes, A., Armstrong, P. & Clark, M. (1996) User groups in action: the management of user groups in the NPD process. *Technovation,* 16, 541-551.

Torgerson, W. S. (1958) *Theory and Methods of Scaling,* New York, Wiley.

Tourangeau, R., Rainski, K. & D'andrade, R. (1991) Attitude structure and belief accessibility. *Journal of Experimental Social Psychology,* 27, 48-75.

Tracey, M. & Tan, C. L. (2001) Empirical analysis of supplier selection and involvement, customer satisfaction, and firm performance. *Supply Chain Management,* 6, 174-188.

Tseng, M. M. & Jiao, J. (1997) Case-based evolutionary design for mass customization. *Computers and Industrial Engineering,* 33, 319-323.

Tseng, M. M., Jiao, J. & Su, C. J. (1998) Virtual prototyping for customized product development. *Integrated Manufacturing Systems,* 9, 334-343.

Tu, Q., Vonderembse, M. A., Ragu-Nathan, T. S. & Ragu-Nathan, B. (2004) Measuring Modularity-Based Manufacturing Practices and Their Impact on Mass Customization Capability: A Customer-Driven Perspective. *Decision Sciences 35, no,* 2, 147-168.

Tu, Y. L., Xie, S. Q. & Fung, R. Y. K. (2007) Product development cost estimation in mass customization. *IEEE Transactions on Engineering Management,* 54, 29-40.

Turowski, K. (2002) Agent-based e-commerce in case of mass customization. *International Journal of Production Economics,* 75, 69-81.

Twede, D., Clarke, R. H. & Tait, J. A. (2000) Packaging postponement: a global packaging strategy. *Packaging Technology and Science,* 13, 105-115.

Ulrich, K. (1992) The role of product architecture in the manufacturing firm. MIT, Sloan School of Managment.

Ulrich, K. & Tung, K. (1991) Fundamentals of product modularity. *Proceedings of the 1991 ASMA Winter Annual Meeting Symposium on Issues in Design/Manufacturing Integration.* Atlanta.

Urban, G. L. & Von Hippel, E. (1988) Lead user analyses for the development of new industrial products. *Management Science,* 34, 569-582.

Utterback, J. M., Allen, T. J., Holloman, J. H. & Sirbu, M. A., Jr (1976) The process of innovation in five industries in Europe and Japan. *IEEE Trans. Engineering Management,* 23, 3-9.

Van Hoek, R. I. (1996) VAL, the functional and spatial organization of businesses. *Journal of Economic and Social Geography,* 87, 32-43.

Van Hoek, R. I. (2000) The role of third-party logistics providers in mass customization. *International Journal of Logistics Management,* 11, 37-46.

Van Hoek, R. I. (2001) The rediscovery of postponement: a literature review and directions for future research. *Journal of Operations Management,* 19, 161-184.

Van Hoek, R. I., Vos, B. & Commandeur, H. R. (1999) Restructuring European supply chains by implementing postponement strategies. *Long Range Planning,* 32, 505-518.

Varadarajan, P. R. & Cunningham, M. H. (1995) Strategic alliances: a synthesis of conceptual foundations. *Journal of the Academy of Marketing Science,* 23, 282-296.

Veloso, F. & Fixson, S. (2001) Make-Buy Decisions in the Auto Industry: New Perspectives On the Role of the Supplier as an Innovator. *Technological Forecasting and Social Change,* 67, 239-257.

Venkatraman, N. & Ramanujan, V. (1986) Measurements of business performance in strategy research: a comparison of approaches. *Academy of Management Review,* 11, 801-814.

Verwoerd, W. (1999) Value-added logistics: the answer to mass customization. *Hospital Material Management Quarterly,* 21, 31-36.

Vickery, S. K., Jayarm, J., Droge, C. & Calantone, R. (2003) The Effects of an Integrative Supply Chain Strategy on Customer Service and Financial Performance: An Analysis of Direct Versus Indirect Relationships. *Journal of Operations Management,* 21, 523-539.

Von Hippel, E. (1977) Has a customer already developed your next product? *Sloan Management Review,* 18, 63-74.

Von Hippel, E. (1978) Successful industrial products from customer ideas. *Journal of Marketing,* 42, 39-49.

Von Hippel, E. (1979) A customer-active paradigm for industrial product idea generation. IN Baker, M. J. (Ed.) *Industrial Innovation.* London, Macmillan.

Von Hippel, E. (1986) Lead users: A source of novel product concepts. *Management Science,* 32, 791-805.

Von Hippel, E. (1988) *The sources of innovation,* Oxford, Oxford University Press.

Von Hippel, E. & Katz, R. (2002) Shifting Innovation to Users via Toolkits. *Management science.,* 48, 821.

Vonderembse, M. A. & Tracey, M. (1999) The impact of supplier selection criteria and supplier involvement on manufacturing performance. *Journal of Supply Chain Management,* 35, 33-39.

Voordijk, H., Meijboom, B. & De Haan, J. (2006) Modularity in supply chains: a multiple case study in the construction industry. *International Journal of Operations and Production Management,* 26, 600-618.

Vyas, N. M., Shelburn, W. L. & Rogers, D. C. (1995) An analysis of strategic alliances: forms, functions and framework. *Journal of Business and Industrial Marketing,* 10, 47-60.

Walsh, J. & Godfrey, S. (2000) The Internet: A new era in customer service. *European Management Journal,* 18, 85-92.

Ward, P. T., Leong, G. K. & Boyer, K. K. (1994) Manufacturing proactiveness and performance. *Decision Sciences,* 25, 337-358.

Welborn, C. (2005) Mass customization performance index. *Faculty of the Graduate School.* Arlington, University of Texas at Arlington.

Wenger, E. (1998) *Communities of Practice: Learning, Meaning and Identity,* Cambridge, Cambridge University Press.

Wenger, E. (2004) Knowledge management as a doughnut: shaping your knowledge strategy with communities of practice. *Ivey Business Journal,* Jan-Feb, 1-8.

Wenger, E., Mcdermott, R. & Snyder, W. (2002) *Cultivating communities of practice: a guide to managing knowledge,* Harvard, MA, Harvard Business School Press.

Wenger, E. & Snyder, W. (2000) Communities of practice: the organizational frontier. *Harvard Business Review,* 78, 139-145.

Westbrook, R. & Williamson, P. J. (1993) Mass customization: Japan's new frontier. *European Management Journal,* 11, 38-45.

Wheelwright, S. C. & Clark, K. B. (1992) Creating project plans to focus product development. *Harvard Business Review,* 70, 67-83.

Wheelwright, S. C. & Sasser, W. E., Jr (1989) The new product development map. *Harvard Business Review,* 67, 112-125.

Whipple, J. S. & Gentry, J. J. (2000) A network comparison of alliance motives and achievements. *Journal of Business and Industrial Marketing,* 15, 301-322.

Wild, C. & Seber, G. (2000) *Chance encounters: a first course in data analysis and inference,* New York, John Wiley and Sons.

Womack, J. P. (1993) A book review of mass customization. *Sloan Management Review,* 34, 121-122.

Womack, J. P. & Jones, D. T. (1997) *Lean Thinking,* London, Simon & Schuster Ltd.

Womack, J. P., Jones, D. T. & Roos, D. (1990) *The Machine that Changed the World,* New York, Rawson Associates.

Worren, N., Moore, K. & Cardona, P. (2003) Modularity, strategic flexibility, and firm performance: a study of the home appliance industry. *Strategic Management Journal,* 23, 1123-1140.

Yang, S. L. & Li, T. F. (2002) Agility evaluation of mass customization product manufacturing. *Journal of Materials Processing Technology,* 129, 640-644.

Yao, A. C. & Carlson, J. G. H. (2003) Agility and mixed-model furniture production. *International Journal of Production Economics,* 81-82, 95-102.

Yassine, A. (2004) Investigating the role of IT in customized product design. *Production Planning and Control.*

Yassine, A., Kim, K.-C., Roemer, T. & Holweg, M. (2004) Investigating the role of IT in customized product design. *Production Planning and Control,* 15, 422-434.

Yu, J. & Cooper, H. (1983) A quantitative review of research design effects on response rates to questionnaires. *Journal of Marketing Research,* 20, 36-44.

Zipkin, P. (2001) The limits of mass customization. *Sloan Management Review,* 42, 81.

APPENDICES

APPENDICES

Appendix 1.1: Focus group procedure

Focus group subject:	Collaborative product development in mass customisation
Function:	Questionnaire item development
Focus group participants:	Operations and product development managers of consumer products manufacturing firms
Time required:	2 hours

Introduction (10 minutes)

- Welcome participants and introduce yourself.
- Explain the general purpose of the discussion and why the participants were chosen.
- Discuss the purpose and process of focus groups
- Outline general ground rules and form which discussion will take
- Review break schedule and location of facilities
- Assure confidentiality
- Notify the group that discussion will be used for academic purposes only, in a holistic manner, and names will not be used in any analysis

Session 1 (45 minutes) – General Concepts

- Introduction – *purpose of this session is to explore general concepts of mass customisation and collaborative partners from your experiences in your companies*
- Discussion guided by the following questions:
  - ➢ How do you measure the operational performance of your company?
  - ➢ How does your company collaborate with its suppliers?
  - ➢ How do you know your lead users?
  - ➢ Do you use the same mechanisms for collaborating with lead users as with suppliers?
- Summary of discussion, draw together ideas

Break / Refreshments (10 minutes)

Session 2 (50 minutes) – Questionnaire Analysis

- Introduction – *purpose of this session is to go through the following questionnaire, which has been designed to test the general concepts that we discussed in question one. Please take 10 minutes to read through the questionnaire, and try to answer the following six questions on the board:*
    - ➢ Are there any words or concepts which are ambiguous or which you do not understand?
    - ➢ Which statements do you feel are badly worded or too complicated? How can they be improved?
    - ➢ Do you feel that the statements in section 1 adequately and helpfully encapsulate the concepts of supplier collaboration? Is anything missing? Should any questions be removed?
    - ➢ Do you feel that the statements in section 2.1 adequately and helpfully identify your lead users? Is anything missing? Should any questions be removed?
    - ➢ Do you feel that the statements in section 2.2 adequately and helpfully encapsulate the concepts of lead user collaboration? Is anything missing? Should any questions be removed?
    - ➢ Do you feel that the statements in question 3 adequately and helpfully encapsulate the operational attributes of mass customisation? Is anything missing? Should any questions be removed?
- Summary of discussion, draw together ideas

Closing (5 minutes)

- Closing remarks
- Thank the participants

Appendix 1.2: Email of initial contact

Dear Mr Smith,

My name is Zu'bi Al-Zu'bi, and I am a doctoral researcher from Durham Business School (DBS) at Durham University. As part of my doctorate, I am conducting a study investigating the factors that affect the ability of companies to mass customise. I am studying the comparative effects of suppliers and lead users on the mass customisation operational performance. A major part of my study is to investigate collaboration in the product development processes in consumer products manufacturing firms in the UK. The results of this study will also provide insights into ways of improving the performance of companies by enhancing their mass customisation ability, which will lead to operational, managerial, financial and economic gains. Your company has been selected as an appropriate source of information for this study.

The study will take the form of a questionnaire, which should not take more than ten minutes of your time. The survey will be launched in June 2007, and if you agree to participate, the questionnaire will be mailed to you within the coming fortnight. All replies will be treated with the strictest confidence. A summary of results will be sent to all companies that request it upon completion of the study.

If you are willing to assist me in this important study, and feel that this study is applicable to your company, please reply to this email with the word AGREE in the subject heading.

If you require any further information, please do not hesitate to contact me.

Yours faithfully,

Zu'bi Al-Zu'bi

077384 23901
zubi.zubi@durham.ac.uk
Durham Business School
Mill Hill Lane
Durham DH1 3LB
United Kingdom

Appendix 1.3: Survey cover letter

Durham University

Durham Business School
Mill Hill Lane
Durham DH1 3LB
United Kingdom

Mass Customisation Research

Dear Mr Smith,

I am a doctoral researcher from Durham Business School (DBS) conducting a study investigating factors that affect the ability of companies to mass customise. In particular, I am focusing on the collaboration between companies and their suppliers and/or lead users in the new product development process. An understanding of these relationships will assist companies to better utilise inputs from suppliers and lead users. The results of this study will also provide insights into ways of improving the performance of companies by enhancing their mass customisation ability, which will lead to operational, managerial, financial and economic gains.

Enclosed is a questionnaire that has been designed to collect information about companies' collaboration with suppliers and/or lead users and how this affects their ability to mass customise. I do hope that you can put aside ten minutes to assist with research into this important topic; your views will enable my study to be more comprehensive. It is important to hear from the widest range of experts possible.
All replies will be treated in the strictest confidence. In order to maintain confidentiality, the first page will be detached from this questionnaire on its receipt and the information on this page will be used only to send participants a summary of the results. My intention is to complete the analysis by October 2007.
If you require any further information, please do not hesitate to contact me.

I look forward to receiving your completed questionnaire and very much appreciate your support of my research.

Yours faithfully,

Zu'bi Al-Zu'bi

(077384 23901) or e-mail (zubi.zubi@durham.ac.uk)

Appendix 1.4: Final form of questionnaire

Company Information:

Contact Name: ______________________________

Company Name: ______________________________

Position: ______________________________

Postal Address: ______________________________

____

____

Telephone Number: ______________ Fax: ______________

Email Address: ______________________________

Size of Company: (Personnel)

Less than 250 O 250 – 500 O 501 – 750 O 751– 1000 O more than 1000 O

Company Age:

Less than 10 years O 10-20 O 20-30 O 30-40 O 40+ years O

Number of product lines: ______________________________

Description of final products: ______________________________

____

____

1- Supplier Collaboration:

1a- On average, how long has your company been collaborating with its key suppliers in New Product Development?
Less than 5 years O 5-10 years O 10-15years O 15-20 years O 20+ years O

1b- How would you rate the level of sales between your company and the supplier/s involved in the product development compared to your competitors?
Very Low O Low O Medium O High O Very High O

1c- Please rate the extent to which your key suppliers are involved in the following activities:

Activity:		**Very low**	**Low**	**Medium**	**High**	**Very high**
1c.1	Setting general product definition.	1	2	3	4	5
1c.2	Setting lead-time requirements	1	2	3	4	5
1c.3	Setting product specifications	1	2	3	4	5
1c.4	Generating products' blueprints/drawings	1	2	3	4	5
1c.5	Designing product detailed component specification	1	2	3	4	5
1c.6	Product prototyping	1	2	3	4	5
1c.7	Product testing	1	2	3	4	5
1c.8	Sourcing of unique parts	1	2	3	4	5
1c.9	Designing manufacturing processes	1	2	3	4	5
1c.10	Providing technical support for manufacturing processes	1	2	3	4	5
1c.11	Overall new product development (NPD) process	1	2	3	4	5

2- Lead Users Collaboration:

This section explores your company's collaboration with a special group of your products' users often called "lead users". These are a group of users (companies or individuals) who experience needs unknown to your company and to your other customers, but use your products to develop bespoke solutions to satisfy their needs (e.g. making adjustments and/or adding features or options to your products)

Please rate the extent to which you believe the following statements are reflective of your company's experience with these particular users:

Statement:		**Disagree Strongly**	**Disagree**	**Neutral**	**Agree**	**Agree Strongly**
2.1.1	Lead Users' suggestions were new (never used in your company or industry before)	1	2	3	4	5
2.1.2	Lead Users' ideas were used in improving new products or the development new products	1	2	3	4	5
2.1.3	Lead Users' ideas were ahead on the trends in the marketplace	1	2	3	4	5
2.1.4	Lead Users' ideas proved beneficial for your company in improving existing products or developing new products	1	2	3	4	5
2.1.5	Lead Users ideas proved beneficial for the industry in which your company operates (i.e. improvement in the current trend in the market place)	1	2	3	4	5
2.1.6	Lead Users' demonstrated great interest in improving the existing products and/or the development of the new products	1	2	3	4	5

2.2-Lead Users Collaboration:

Please rate the extent to which users described above are involved in the following activities:

Activity:		Very Low	Low	Medium	High	Very High
2.2.1	Setting general product definition.	1	2	3	4	5
2.2.2	Setting lead-time requirements	1	2	3	4	5
2.2.3	Setting product specifications	1	2	3	4	5
2.2.4	Generating products' blueprints or drawings	1	2	3	4	5
2.2.5	Designing product detailed component specification	1	2	3	4	5
2.2.6	Product prototyping	1	2	3	4	5
2.2.7	Product testing	1	2	3	4	5
2.2.8	Sourcing of unique parts	1	2	3	4	5
2.2.9	Designing manufacturing processes	1	2	3	4	5
2.2.10	Providing technical support for manufacturing processes	1	2	3	4	5
2.2.11	Overall new product development (NPD) process	1	2	3	4	5

3- Mass Customisation Attributes:

Please indicate your opinion of how your company compares to its competitors in your industry in terms of:

Comparison:	Poor	Below Competition	Equal to Competition	Better than Competition	Superior
3.1 Concept development costs	1	2	3	4	5
3.2 Product design costs	1	2	3	4	5
3.3 Product manufacturing costs	1	2	3	4	5
3.4 Total cost of new product development	1	2	3	4	5
3.5 Concept development time	1	2	3	4	5
3.4 Product designing time	1	2	3	4	5
3.5 Product manufacturing time	1	2	3	4	5
3.6 Cycle time (from concept to manufacturing)	1	2	3	4	5
3.9 Enabling customers to select product features from menus/catalogs	1	2	3	4	5
3.10 Enabling customers to self configure the final features of the product from (Mix and Match) tables	1	2	3	4	5
3.11 Enabling customers to design their own product	1	2	3	4	5
3.12 Range of products produced by existing facilities	1	2	3	4	5
3.13 Scope of features offered to final customers	1	2	3	4	5
3.14 Number of product lines	1	2	3	4	5

Please return by using the stamped addressed envelope enclosed.

Many thanks for your time !

Appendix 2.1: Frequencies analyses for control variables

Frequencies analysis of company size (number of employees)

	Frequency	Percent	Cumulative Percent
less than 250	54	21.5	21.5
250-500	77	30.7	52.2
501-750	34	13.5	65.7
751-1000	29	11.6	77.3
more than 1000	57	22.7	100.0
Total	251	100.0	

Frequencies analysis of company age

	Frequency	Percent	Cumulative Percent
less than 10 years	17	6.8	6.8
10-20	42	16.7	23.5
20-30	50	19.9	43.4
30-40	35	13.9	57.4
more than 40 years	107	42.6	100.0
Total	251	100.0	

Frequencies analysis of relative level of sales between company and suppliers

	Frequency	Percent	Cumulative Percent
very low	17	6.8	6.8
low	32	12.7	19.5
medium	99	39.4	59.0
high	80	31.9	90.8
very high	23	9.2	100.0
Total	251	100.0	

Appendix 2.2: Correlation matrices

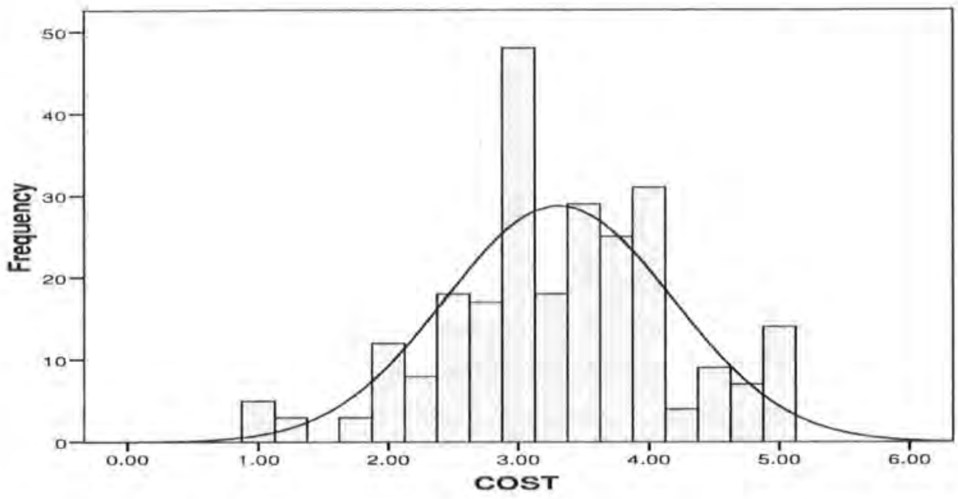
Correlation matrix for dependent variables

Questionnaire Items	(q3.1)	(q3.2)	(q3.3)	(q3.4)	(q3.5)	(q3.6)	(q3.7)	(q3.8)	(q3.9)	(q3.10)	(q3.11)	(q3.12)	(q3.13)	(q3.14)
(q3.1) Concept Development Costs	1.000													
(q3.2) Product Design Costs	.847	1.000												
(q3.3) Product Manufacturing Costs	.634	.635	1.000											
(q3.4) Total Costs of New Product Development	.710	.732	.714	1.000										
(q3.5) Concept Development Time	.565	.560	.452	.590	1.000									
(q3.6) Product Designing Time	.554	.577	.400	.561	.828	1.000								
(q3.7) Product Manufacturing Time	.445	.402	.450	.406	.598	.554	1.000							
(q3.8) Cycle Time (from concept to manufacturing)	.470	.461	.493	.547	.743	.701	.671	1.000						
(q3.9) Enabling customers to select from set menus/catalogs	.363	.285	.248	.265	.293	.235	.226	.251	1.000					
(q3.10) Enabling customers to self configure features from tables (Mix and Match)	.322	.241	.249	.228	.232	.207	.159	.185	.781	1.000				
(q3.11) Enabling customers to design their products	.313	.235	.271	.267	.266	.269	.211	.287	.592	.720	1.000			
(q3.12) range of items produced by exisiting facilities at the company	.431	.405	.312	.265	.301	.308	.413	.297	.330	.341	.338	1.000		
(q3.13) Scope of features offered to final customers (for each product)	.420	.369	.351	.357	.287	.298	.375	.308	.332	.338	.315	.777	1.000	
(q3.14) number of products lines compared to competitors	.374	.343	.259	.336	.306	.289	.327	.327	.258	.245	.220	.652	.686	1.000

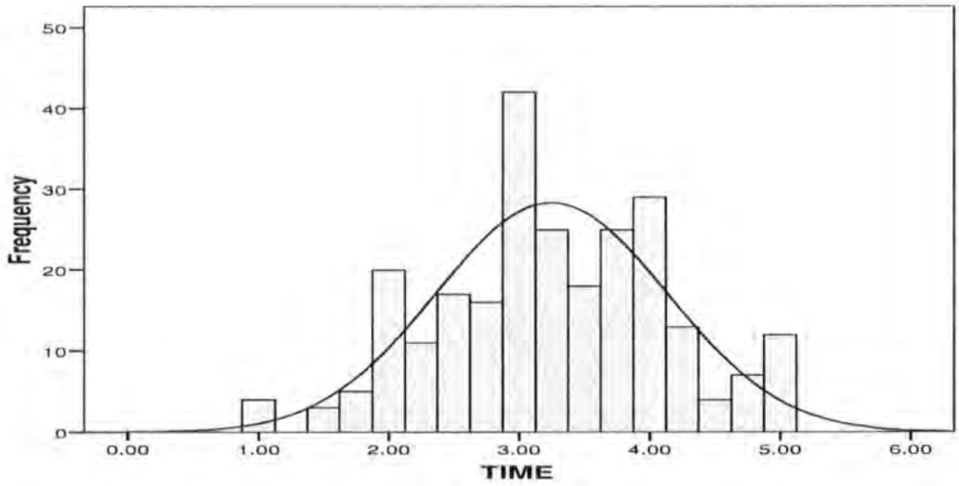
Correlation matrix for independent variables

Questionnaire Items	q1c.1	q1c.2	q1c.3	q1c.4	q1c.5	q1c.6	q1c.7	q1c.8	q2.2.1	q2.2.2	q2.2.3	q2.2.4	q2.2.5	q2.2.6	q2.2.7	q2.2.8
(q1c.1) Supplier Collaboration setting General Product Definition	1.000															
(q1c.2) Supplier Collaboration setting lead time requirements	.605	1.000														
(q1c.3) Supplier Collaboration setting product specifications	.699	.601	1.000													
(q1c.4) Supplier Collaboration generating product's blueprint/drawings	.551	.507	.554	1.000												
(q1c.5) Supplier Collaboration designing product detailed component specification	.464	.500	.538	.729	1.000											
(q1c.6) Supplier Collaboration product prototyping	.421	.447	.432	.574	.689	1.000										
(q1c.7) Supplier Collaboration product testing	.535	.437	.523	.595	.616	.633	1.000									
(q1c.8) Supplier Collaboration overall NPD process	.607	.504	.565	.672	.623	.617	.629	1.000								
(q2.2.1) Lead User Collaboration setting General Product Definition	.230	.254	.172	.212	.171	.201	.150	.322	1.000							
(q2.2.2) Lead User Collaboration setting lead time requirements	.223	.318	.161	.238	.205	.221	.122	.332	.769	1.000						
(q2.2.3) Lead User Collaboration setting product specifications	.244	.260	.195	.206	.172	.228	.139	.319	.843	.767	1.000					
(q2.2.4) Lead User Collaboration generating product's blueprint/drawings	.419	.259	.258	.397	.308	.229	.225	.463	.607	.609	.624	1.000				
(q2.2.5) Lead User Collaboration designing product detailed component specification	.389	.250	.313	.336	.256	.273	.202	.435	.550	.550	.559	.804	1.000			
(q2.2.6) Lead User Collaboration product prototyping	.301	.237	.173	.301	.288	.265	.201	.399	.565	.580	.549	.748	.806	1.000		
(q2.2.7) Lead User Collaboration product testing	.189	.217	.159	.125	.126	.206	.180	.191	.573	.509	.525	.542	.567	.614	1.000	
(q2.2.8) Lead User Collaboration overall NPD process	.332	.352	.246	.353	.291	.348	.263	.439	.650	.604	.659	.671	.720	.696	.629	1.000

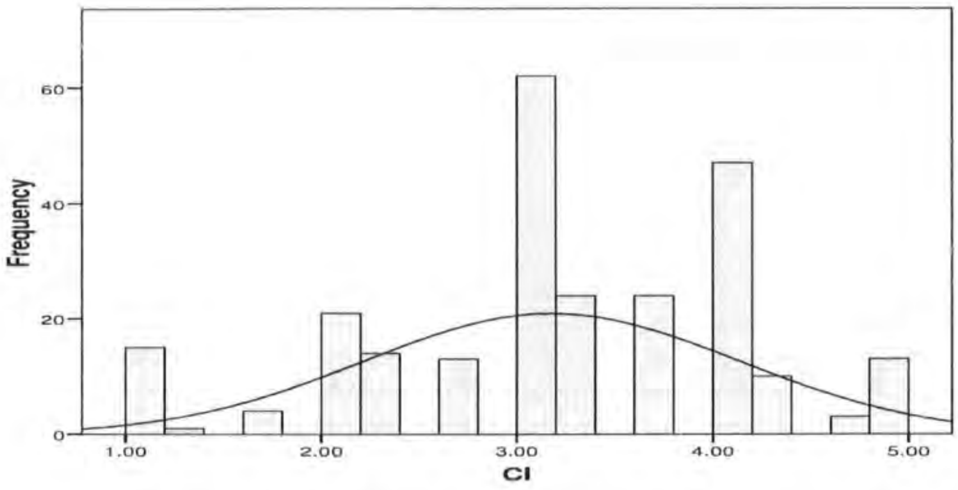
Appendix 2.3a: Normal probability plots for dependent variables



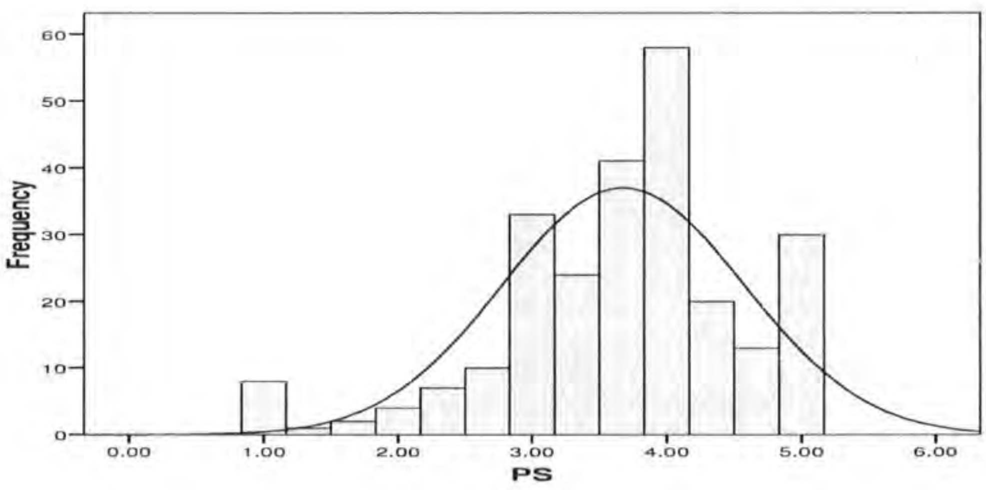
Normal probability plot for product development cost



Normal probability plot for product development time

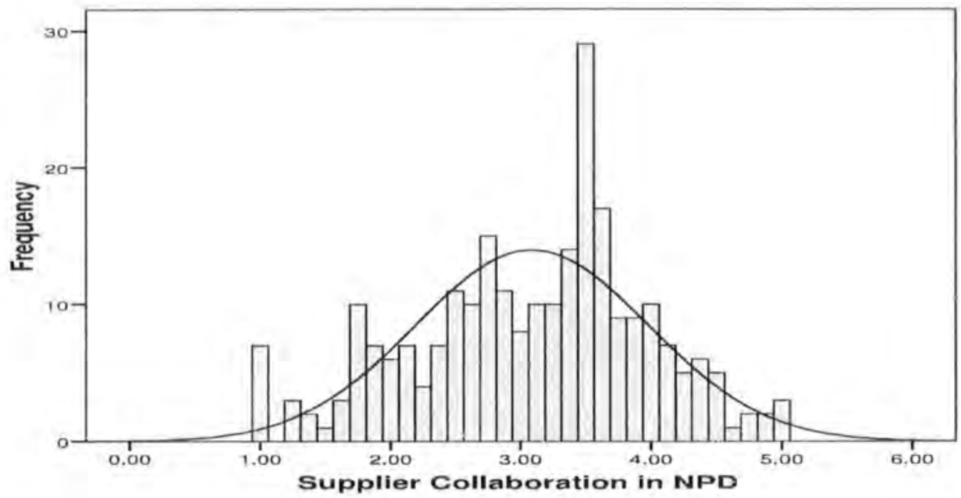


Normal probability plot for customer influence

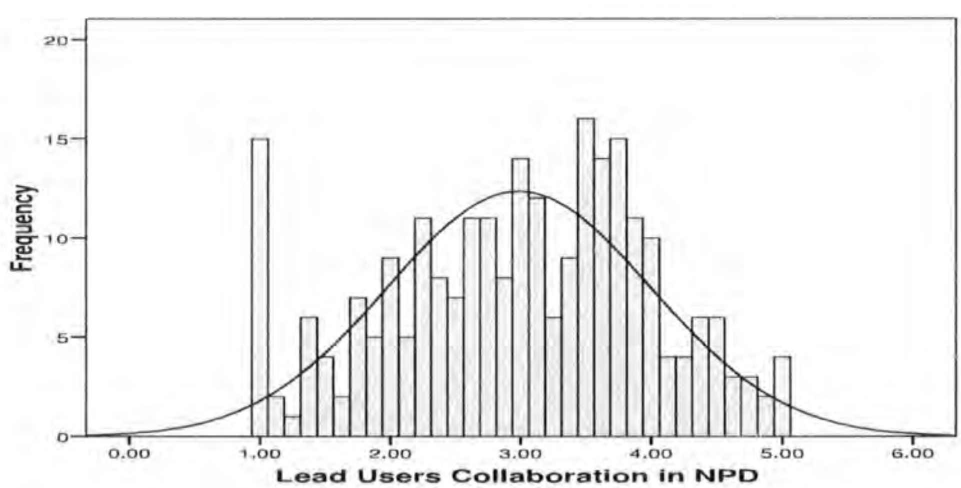


Normal probability plot for product scope

Appendix 2.3b: Normal probability plots for independent variables

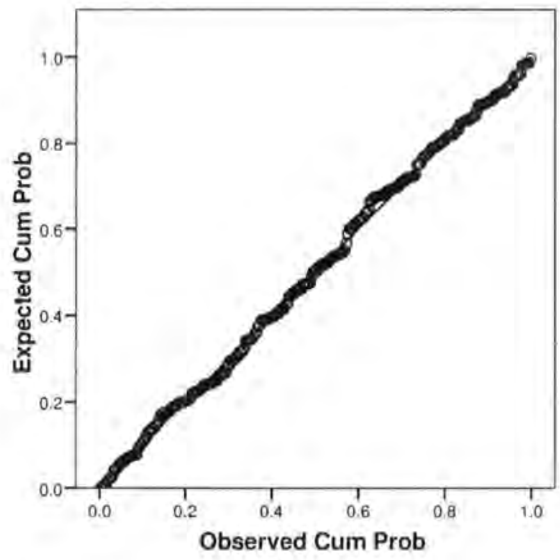


Normal probability plot for supplier collaboration

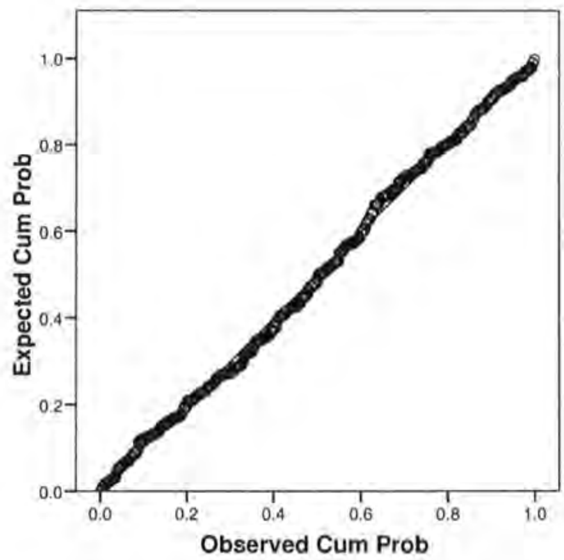


Normal probability plot for lead user collaboration

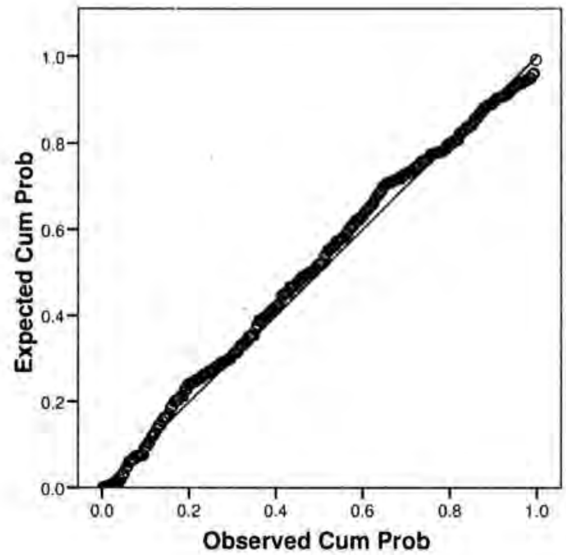
Appendix 2.4: Normal probability plot of the regression standardised residual for each model



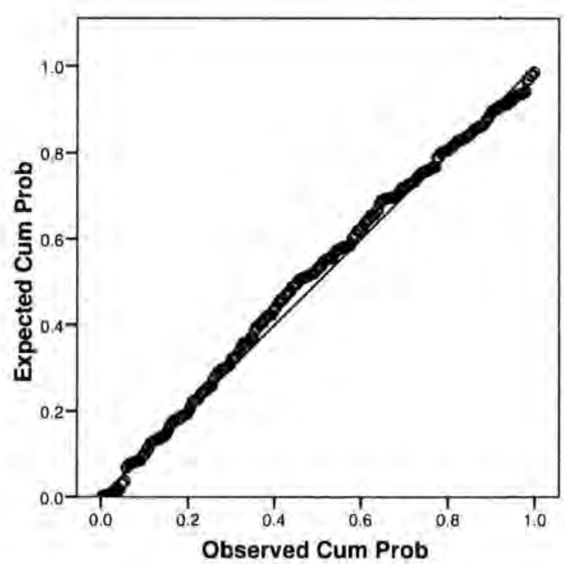
Normal P-P plot of regression standardised residual for dependent variable development cost



Normal P-P plot of regression standardised residual for dependent variable development time

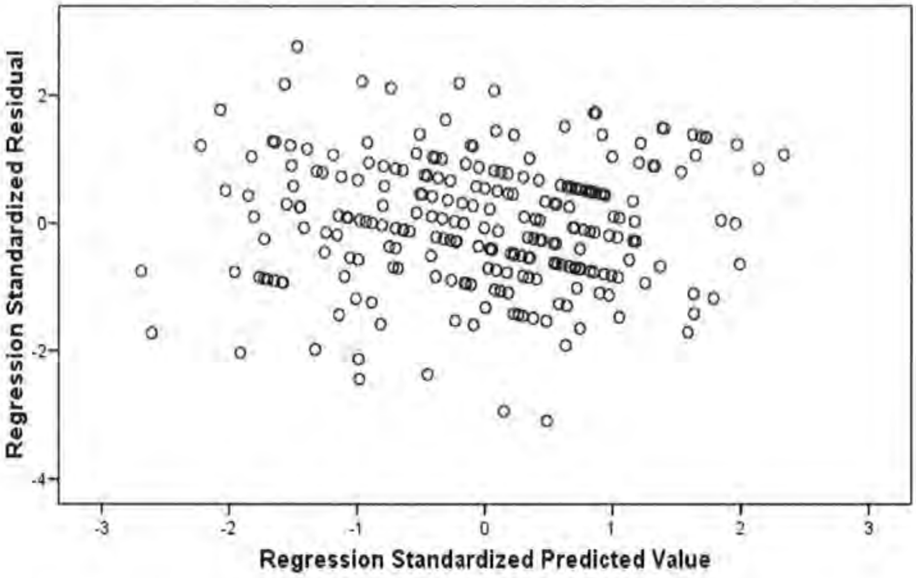


Normal P-P plot of regression standardised residual for dependent variable customer influence

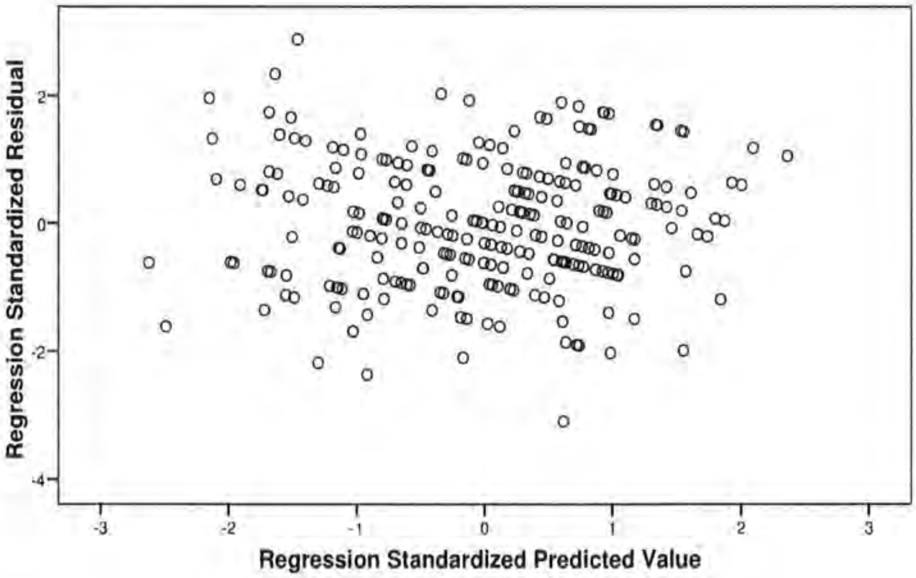


Normal P-P plot of regression standardised residual for dependent variable product scope

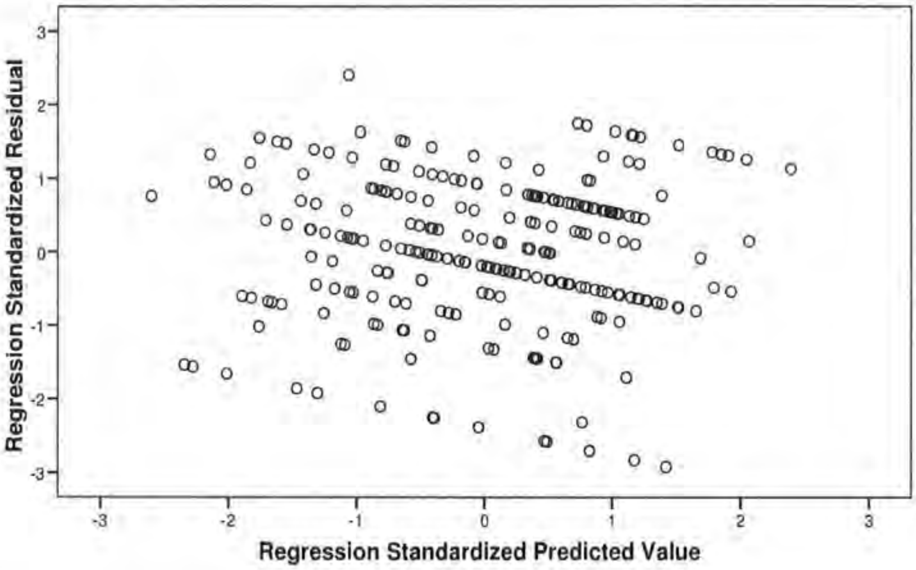
Appendix 2.5: Residuals scatter plots for each model



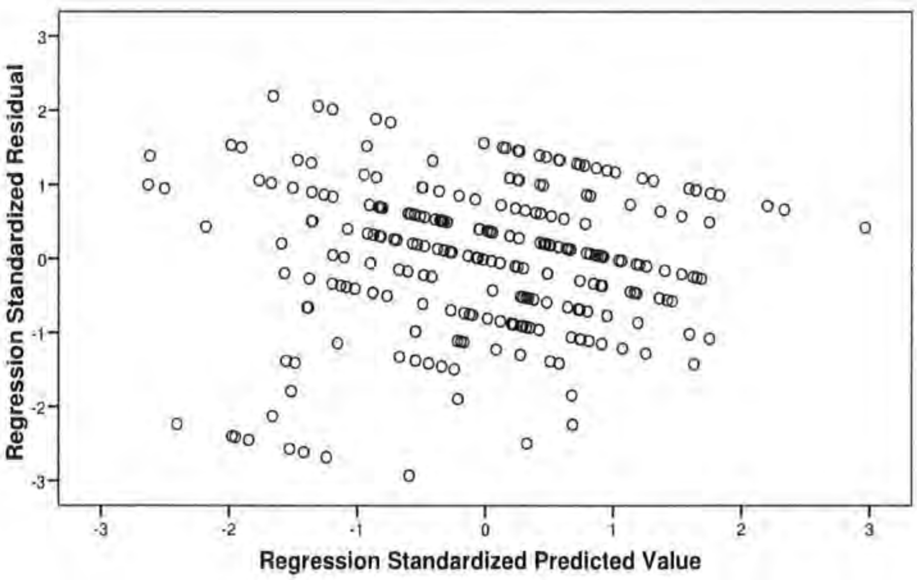
Residuals scatter plot for dependent variable development cost



Residuals scatter plot for dependent variable development time



Residuals scatter plot for dependent variable customer influence



Residuals scatter plot for dependent variable product scope

Appendix 2.5a: Frequencies analysis of each construct relating to development cost

Frequencies analysis for concept development costs

		Frequency	Valid Percent	Cumulative Percent
Valid	poor	9	3.6	3.6
	below competition	34	13.5	17.1
	equal to competition	103	41.0	58.2
	better than competition	80	31.9	90.0
	superior	25	10.0	100.0
	Total	251	100.0	

Frequencies analysis for product design costs

		Frequency	Valid Percent	Cumulative Percent
Valid	poor	9	3.6	3.6
	below competition	43	17.1	20.7
	equal to competition	97	38.6	59.4
	better than competition	71	28.3	87.6
	superior	31	12.4	100.0
	Total	251	100.0	

Frequencies analysis for product manufacturing costs

		Frequency	Valid Percent	Cumulative Percent
Valid	poor	7	2.8	2.8
	below competition	39	15.5	18.3
	equal to competition	94	37.5	55.8
	better than competition	81	32.3	88.0
	superior	30	12.0	100.0
	Total	251	100.0	

Frequencies analysis for total costs of new product development

		Frequency	Valid Percent	Cumulative Percent
Valid	poor	10	4.0	4.0
	below competition	44	17.5	21.5
	equal to competition	88	35.1	56.6
	better than competition	83	33.1	89.6
	superior	26	10.4	100.0
	Total	251	100.0	

Appendix 2.5b: Frequencies analysis of each construct relating to development time

Frequencies analysis for concept development time

		Frequency	Valid Percent	Cumulative Percent
Valid	poor	14	5.6	5.6
	below competition	55	21.9	27.5
	equal to competition	84	33.5	61.0
	better than competition	73	29.1	90.0
	superior	25	10.0	100.0
	Total	251	100.0	

Frequencies analysis for product designing time

		Frequency	Valid Percent	Cumulative Percent
Valid	poor	11	4.4	4.4
	below competition	56	22.3	26.7
	equal to competition	93	37.1	63.7
	better than competition	68	27.1	90.8
	superior	23	9.2	100.0
	Total	251	100.0	

Frequencies analysis for product manufacturing time

		Frequency	Valid Percent	Cumulative Percent
Valid	poor	4	1.6	1.6
	below competition	30	12.0	13.5
	equal to competition	96	38.2	51.8
	better than competition	90	35.9	87.6
	superior	31	12.4	100.0
	Total	251	100.0	

Frequencies analysis for cycle time

		Frequency	Valid Percent	Cumulative Percent
Valid	poor	11	4.4	4.4
	below competition	53	21.1	25.5
	equal to competition	85	33.9	59.4
	better than competition	71	28.3	87.6
	superior	31	12.4	100.0
	Total	251	100.0	

Appendix 2.5c: Frequencies analysis of each construct relating to customer influence

Frequencies analysis for enabling customers to select from set menus / catalogues

		Frequency	Valid Percent	Cumulative Percent
Valid	poor	20	8.0	8.0
	below competition	37	14.7	22.7
	equal to competition	93	37.1	59.8
	better than competition	72	28.7	88.4
	superior	29	11.6	100.0
	Total	251	100.0	

Frequencies analysis for enabling customers to self-configure features from tables

		Frequency	Valid Percent	Cumulative Percent
Valid	poor	25	10.0	10.0
	below competition	39	15.5	25.5
	equal to competition	84	33.5	59.0
	better than competition	83	33.1	92.0
	superior	20	8.0	100.0
	Total	251	100.0	

Frequencies analysis for enabling customers to design their products

		Frequency	Valid Percent	Cumulative Percent
Valid	poor	24	9.6	9.6
	below competition	26	10.4	19.9
	equal to competition	102	40.6	60.6
	better than competition	80	31.9	92.4
	superior	19	7.6	100.0
	Total	251	100.0	

Appendix 2.5d: Frequencies analysis of each construct relating to product scope

Frequencies analysis of range of items produced by existing facilities

		Frequency	Valid Percent	Cumulative Percent
Valid	poor	10	4.0	4.0
	below competition	18	7.2	11.2
	equal to competition	77	30.7	41.8
	better than competition	101	40.2	82.1
	superior	45	17.9	100.0
	Total	251	100.0	

Frequencies analysis for scope of features offered to final customers

		Frequency	Valid Percent	Cumulative Percent
Valid	poor	10	4.0	4.0
	below competition	14	5.6	9.6
	equal to competition	66	26.3	35.9
	better than competition	114	45.4	81.3
	superior	47	18.7	100.0
	Total	251	100.0	

Frequencies analysis for number of product lines

		Frequency	Valid Percent	Cumulative Percent
Valid	poor	12	4.8	4.8
	below competition	11	4.4	9.2
	equal to competition	79	31.5	40.6
	better than competition	82	32.7	73.3
	superior	67	26.7	100.0
	Total	251	100.0	

Appendix 2.5e: Frequencies analysis of each construct relating to supplier collaboration

Frequencies analysis for supplier collaboration in setting general product definition

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	37	14.7	14.7
	low	52	20.7	35.5
	medium	80	31.9	67.3
	high	70	27.9	95.2
	very high	12	4.8	100.0
	Total	251	100.0	

Frequencies analysis for supplier collaboration in setting lead time requirements

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	21	8.4	8.4
	low	38	15.1	23.5
	medium	77	30.7	54.2
	high	86	34.3	88.4
	very high	29	11.6	100.0
	Total	251	100.0	

Frequencies analysis for supplier collaboration in setting product specifications

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	22	8.8	8.8
	low	46	18.3	27.1
	medium	80	31.9	59.0
	high	79	31.5	90.4
	very high	24	9.6	100.0
	Total	251	100.0	

Frequencies analysis for supplier collaboration in generating product blueprints

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	31	12.4	12.4
	low	50	19.9	32.3
	medium	79	31.5	63.7
	high	71	28.3	92.0
	very high	20	8.0	100.0
	Total	251	100.0	

Frequencies analysis for supplier collaboration in designing component specification

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	28	11.2	11.2
	low	45	17.9	29.1
	medium	83	33.1	62.2
	high	70	27.9	90.0
	very high	25	10.0	100.0
	Total	251	100.0	

Frequencies analysis for supplier collaboration in product prototyping

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	23	9.2	9.2
	low	47	18.7	27.9
	medium	69	27.5	55.4
	high	81	32.3	87.6
	very high	31	12.4	100.0
	Total	251	100.0	

Frequencies analysis for supplier collaboration in product testing

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	30	12.0	12.0
	low	46	18.3	30.3
	medium	78	31.1	61.4
	high	67	26.7	88.0
	very high	30	12.0	100.0
	Total	251	100.0	

Frequencies analysis for supplier collaboration in overall NPD process

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	28	11.2	11.2
	low	52	20.7	31.9
	medium	71	28.3	60.2
	high	81	32.3	92.4
	very high	19	7.6	100.0
	Total	251	100.0	

Appendix 2.5f: Frequencies analysis of each construct relating to lead user collaboration

Frequencies analysis for lead user collaboration in setting general product definition

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	35	13.9	13.9
	low	33	13.1	27.1
	medium	71	28.3	55.4
	high	83	33.1	88.4
	very high	29	11.6	100.0
	Total	251	100.0	

Frequencies analysis for lead user collaboration in setting lead time requirements

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	34	13.5	13.5
	low	41	16.3	29.9
	medium	67	26.7	56.6
	high	81	32.3	88.8
	very high	28	11.2	100.0
	Total	251	100.0	

Frequencies analysis for lead user collaboration in setting product specifications

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	33	13.1	13.1
	low	32	12.7	25.9
	medium	71	28.3	54.2
	high	86	34.3	88.4
	very high	29	11.6	100.0
	Total	251	100.0	

Frequencies analysis for lead user collaboration in generating product blueprints

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	55	21.9	21.9
	low	46	18.3	40.2
	medium	68	27.1	67.3
	high	63	25.1	92.4
	very high	19	7.6	100.0
	Total	251	100.0	

Frequencies analysis for lead user collaboration in designing component specification

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	53	21.1	21.1
	low	51	20.3	41.4
	medium	62	24.7	66.1
	high	65	25.9	92.0
	very high	20	8.0	100.0
	Total	251	100.0	

Frequencies analysis for lead user collaboration in product prototyping

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	55	21.9	21.9
	low	41	16.3	38.2
	medium	69	27.5	65.7
	high	67	26.7	92.4
	very high	19	7.6	100.0
	Total	251	100.0	

Frequencies analysis for lead user collaboration in product testing

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	34	13.5	13.5
	low	43	17.1	30.7
	medium	69	27.5	58.2
	high	78	31.1	89.2
	very high	27	10.8	100.0
	Total	251	100.0	

Frequencies analysis for lead user collaboration in overall NPD process

		Frequency	Valid Percent	Cumulative Percent
Valid	very low	37	14.7	14.7
	low	50	19.9	34.7
	medium	75	29.9	64.5
	high	64	25.5	90.0
	very high	25	10.0	100.0
	Total	251	100.0	