Competition and collaboration in supply chains: An agent-based modelling approach

By

Niniet Indah Arvitrida

A Doctoral Thesis submitted in partial fulfilments of the requirements for the award of Doctor of Philosophy of Loughborough University

School of Business and Economics
May 2017

Dedicated to my parents for their unconditional love and prayers

Table of Contents

Glossary of Terms and Variables vi
List of Figures viii
List of Tables xii
Acknowledgement xiv
Declaration of Authorship xv
Abstract xviii
Chapter 1 Introduction 1
1.1 Introduction 1
1.2 Overview of this thesis 1
1.3 The aim and objectives of this study 5
1.4 The findings and contributions 7
1.5 Thesis outline 10
Chapter 2 Competition and collaboration studies in supply chains: What is missing? 12
2.1 Introduction 12
2.2 Overview of supply chain management (SCM) 13
2.3 Competition in supply chains 15
2.3.1 Competition strategies in SCM 15
2.3.2 Literature gap in competition 20
2.4 Supply chain collaboration between supplier and manufacturer 28
2.4.1 Collaboration features in supply chain 28
2.4.2 Collaboration studies in SCM 32
2.4.3 Main topics in supplier-manufacturer collaboration 34
2.5 Summary of the literature gap 46
2.6 Conclusions: The missing points from existing literature 50
2.7 Summary 52
Chapter 3 Research opportunity of agent-based modelling for studying competition and collaboration in supply chains 54
3.1 Introduction 54

3.2 Overview of agent-based modelling (ABM) approach 55
3.2.1 The agent 57
3.2.2 The environment 58
3.2.3 The interactions and autonomy (the rules) 58
3.2.4 The schedule 58
3.2.5 Emergent behaviour 59
3.3 Existing ABM work 60
3.3.1 Supply chain management context 60
3.3.2 Strategic management context 65
3.4 ABM validation 69
3.5 Conclusions and summary 71
Chapter 4 Methodology 74
4.1 Introduction 74
4.2 Overview of the research aims and objectives 74
4.3 Research hypotheses 77
4.3.1 *Hypothesis A* aimed to objective number 2: To explore the effect of competition on supply chains and market structure, with regards to the demand fulfilment and survivability of supply chains for the long-term 78
4.3.2 *Hypotheses B* aimed to objective number 3: To explore the effect of firm competitive and collaborative behaviour on supply chains, in terms of demand fulfilment and survivability of supply chains over the long-term 78
4.4 The modelling approach 83
4.4.1 Conceptual modelling 85
4.4.2 Computer modelling (coding) 86
4.4.3 Experimentation 88
4.5 Analysis method 88
4.5.1 Analysis method for *Hypothesis A* 89
4.5.2 Method of analysis for *Hypotheses B* 91
4.6 Commentary on the results 97
4.7 Summary 98
Chapter 5 The agent-based model of supply chain competition and collaboration 99
5.1 Introduction 99
5.2 Conceptual model 100

5.2.1 Model contents: Scope and level of detail 100
5.2.2 Inputs or experimental factors...114
5.2.3 Outputs 119
5.2.4 Assumptions and simplifications 120
5.3 Computer model...123
5.3.1 The model setup 124
5.3.2 Model testing..135
5.3.3 The generic emergent outcomes: formation of the market structure 146
5.4 Summary 148
Chapter 6 Model results and analysis 149
6.1 Introduction..149
6.2 Effect of competition on supply chains and market structure (*Hypothesis A*)...149
6.2.1 Positive effect: Strategic alignment within supply chain..............................150
6.2.2 Negative effect: Extreme *shakeouts*..153
6.3 Effect of competition and collaboration strategy on supply chains (*Hypotheses B*) 158
6.3.1 *Hypothesis B.1*: *Duration of collaboration* 159
6.3.2 *Hypothesis B.2*: *Number of partnerships* 167
6.3.3 *Hypothesis B.3*: *Trust* 174
6.3.4 *Hypothesis B.4*: Individual *firm survivability* 190
6.3.5 *Hypothesis B.5*: Manufacturer *strategic mutation* 196
6.3.6 Results summary for *Hypotheses B*...201
6.4 Summary 203
Chapter 7 Discussion of the findings 204
7.1 Introduction..204
7.2 The agent-based model of competition and collaboration in supply chains (Objective 1). 204
7.3 The long-term impact of competition on supply chains and market structure (Objective 2 – *Hypothesis A*). 209
7.3.1 Strategic alignment within supply chain 210
7.3.2 Extreme *shakeouts* 212
7.4 The exploration of competition and collaboration strategy on supply chains (Objective 3) 214

7.4.1 The effect of the *duration of collaboration* (*Hypothesis B.1*)........................216
7.4.2 The effect of *number of partnerships* of both manufacturer and supplier (*Hypothesis B.2*)..219
7.4.3 The effect of *trust* (*Hypothesis B.3*)..223
7.4.4 The effect of individual *firm survivability* (*Hypothesis B.4*) 228
7.4.5 Manufacturer *strategic mutation* (*Hypothesis B.5*).......................................230
7.4.6 Summary of the results and input characteristics for *Hypotheses B* 231
7.5 Study limitations 235
7.5.1 Modelling approach limitations 236
7.5.2 Model setup limitations...237
7.5.3 Analysis limitations...237
7.6 Summary 238
Chapter 8 Conclusions...240
8.1 Introduction..240
8.2 Research objectives, hypotheses, and the findings 240
8.2.1 Summary of research objectives 241
8.2.2 Summary of hypotheses 242
8.2.3 Summary of findings..244
8.2.4 Achievement of objectives...251
8.3 Thesis contributions 253
8.3.1 Implications to knowledge and practice...254
8.3.2 Agent-based model of competition and collaboration with an advancement of the Hotelling's model 258
8.4 Research limitations...259
8.5 Future work 260
8.5.1 Optimising the use of current model feature...260
8.5.2 Relaxing the current study limitations 261
8.6 Summary and final comments..261
References...263
Appendix A: The ineffective use of parametric statistics and common random numbers in inferential analysis...283
Appendix B: The computer model 290
Appendix C: Variable description in NetLogo...292
Appendix D: Base run and behavioural setup 297

Appendix E: The logic flow for each procedure in NetLogo 301
Appendix F: Unexplored features in the computer model - a further research 318
Appendix G: Example of verification procedure...320
Appendix H: Computer code 324
Appendix I: Decay rate of demand fulfilment for each experimental factor 349
Appendix J: The Mann-Whitney U-Test results..350

Glossary of Terms and Variables

customer trust/loyalty	-	a variable/experimental factor to represent customer *loyalty* towards the manufacturer. In the model, it is defined as the probability that a customer will choose the same manufacturer as selected previously.
dual-sourcing	-	a supply chain collaboration strategy where a firm has two suppliers at the same time.
manufacturer trust	-	a variable/experimental factor to represent manufacturer *trust* towards supplier. It is described as the probability that a manufacturer would choose the same supplier as selected previously.
manufacturer survivability	-	the duration of the manufacturer to survive when it collaborates with less efficient and/or responsive (undesired) supplier/s.
multi-sourcing	-	a supply chain collaboration strategy where a manufacturer has more than two suppliers at the same time.
shakeouts	-	a term used in business and management studies to describe a phenomenon when massive exits of a number of companies from a market due to competition.
single-sourcing	-	a supply chain collaboration strategy where a manufacturer has a single supplier.
strategic mutation	-	a variable/experimental factor to reflect an extreme competition strategy where a firm drastically change its strategic position to a market segment that has not being served by the competitors.
supplier trust	-	a variable/experimental factor to represent supplier *trust* towards the manufacturer. In the model, it is defined as the probability

		that a supplier would follow the manufacturer strategic movement to maintain its current relationships.
supplier survivability	-	the length of the supplier to survive, defined in *time unit* when it does not have a link with the manufacturer agent at all.
supply chain fill rate	-	a term used in this Thesis to represent supply chain's ability to meet the demand (demand fulfilment) in the market, described by the percentage of customers served by all supply chains in the simulation model.
survivability	-	a term used in this Thesis to describe a company's or supply chain's ability to survive when it is losing profits due to having no collaboration partner or collaborating with an undesired supplier. In this Thesis, this term represents a company's or supply chain's robustness to withstand or cope with adverse situation.
time unit	-	the simulation time unit, where one *time unit* is assumed to be a period (between 3 and 18 months) for the firms to make a slight strategic change.
two-stage supply chain	-	a supply chain scope that consists of two stages of firms in the supply chain, such as supplier-manufacturer supply chain.
willingness to compromise	-	a term used in this Thesis to refer to the selection radius of agents to decide which agent that is closest to their preference. The radius is represented as a percentage of the diagonal length of the simulation space in NetLogo.

List of Figures

Figure 2.1 Supply chain complexity (Chopra and Meindl 2007) 13
Figure 2.2 Strategic fit in supply chain (Chopra and Meindl 2007) 17
Figure 2.3 Illustration of the applicability of supply chain strategy: efficiency and responsiveness 20
Figure 2.4 The pattern of performance improvement, considering the level of supplier development and the length of partnership (Wagner 2011)........................37
Figure 3.1 ABM role in this research: to merge the gap between the related research domains...73
Figure 4.1 The structure of *Hypotheses* B...82
Figure 4.2 The modelling approach of this study (adapted from Robinson 2008)...........85
Figure 4.3 The basis for commentary on the results of this study 98
Figure 5.1 The attributes and behaviour of the customer agents 103
Figure 5.2 The attributes and behaviour of the manufacturer agents.............................106
Figure 5.3 The attributes and behaviour of the supplier agents 107
Figure 5.4 An abstraction of the agents within their environment.................................109
Figure 5.5 The abstraction of link direction and border of customer and manufacturer preference, with a degree of *willingness to compromise* 111
Figure 5.6 Agent's interactions and movements..113
Figure 5.7 The expected effect of the individual experimental factor to the outputs 135
Figure 5.8 The simulation procedure with the related experimental factors in each step 137
Figure 5.9 An illustration of Hotelling's competition model 138
Figure 5.10 The convergence of the firms' positions, which is similar to Hotelling's prediction...140
Figure 5.11 Competition can lead to one supply chain moving to domination: 142
Figure 5.12 The *number of supply chains in the market* of the base run 143
Figure 5.13 The market structure driven by the competition:..147
Figure 6.1 The relationship between the *gap between firms in supply chains* and *the number of supply chains in the market*..151
Figure 6.2 An illustration of measuring the gap between firms in a supply

chain in Euclidean distance 151
Figure 6.3 Competition does not assist strategic alignment for all supply chains 152
Figure 6.4 Illustration of the occurrence of zero supply chain in the manufacturer *strategic mutation* – with 2% *manufacturer probability of mutation*...156
Figure 6.5 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of *duration of collaboration* with *single-link firms* 160
Figure 6.6 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of *duration of collaboration* with *single-link firms*..162
Figure 6.7 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of *duration of collaboration* with *dual-link suppliers* 163
Figure 6.8 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of *duration of collaboration* with *dual-link firms* 164
Figure 6.9 The *supply chain fill rate* comparison between *single-link* suppliers and *dual-link* suppliers with various *duration of collaboration*.............................165
Figure 6.10 The comparison of the *number of supply chains in the market* between *single-link* suppliers and *dual-link* suppliers with different *duration of collaboration* 166
Figure 6.11 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *number of partnerships* in *short-term* partnerships............168
Figure 6.12 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of *number of partnerships* in *short-term* partnerships 169
Figure 6.13 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of *number of partnerships* in *long-term* partnerships..................170
Figure 6.14 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of *number of partnerships* in *long-term* partnerships 171
Figure 6.15 The comparison of *supply chain fill rate* between *short-term* and *long-term collaboration*, with different levels of *duration of collaboration* 172
Figure 6.16 The comparison of the *number of supply chains in the market* between *short-term* and *long-term collaboration*, with different levels of

duration of collaboration 173
Figure 6.17 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *manufacturer trust* 176
Figure 6.18 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of the *manufacturer trust* with *short-term* collaboration 177
Figure 6.19 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *manufacturer trust* with *long-term* collaboration....................178
Figure 6.20 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of the *manufacturer trust* with *long-term* collaboration..179
Figure 6.21 The comparison of *supply chain fill rate* between *short-term collaboration* and *long-term collaboration*, with different levels of *duration of collaboration* 180
Figure 6.22 The comparison of the *number of supply chains in the market* between the *short-term collaboration* and the *long-term collaboration*, with different levels of *duration of collaboration* 181
Figure 6.23 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *supplier trust*, with *short-term collaboration* 182
Figure 6.24 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of the supplier *trust*, with *short-term collaboration* 183
Figure 6.25 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *supplier trust* with *long-term* collaboration 184
Figure 6.26 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of the *supplier trust* with *long-term* collaboration...185
Figure 6.27 The comparison of *supply chain fill rate* between *short-term collaboration* and *long-term collaboration*, with different levels of *duration of collaboration* 185
Figure 6.28 The comparison of *supply chain fill rate* between *short-term collaboration* and *long-term collaboration*, with different levels of *duration of collaboration* 186
Figure 6.29 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *customer trust/loyalty*..188

Figure 6.30 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of the *customer loyalty*..189
Figure 6.31 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *manufacturer survivability*...192
Figure 6.32 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of the *manufacturer survivability* 193
Figure 6.33 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *supplier survivability*...195
Figure 6.34 Boxplots of the *number of supply chains in the market* and a line representing mean values for each scenario of the *supplier survivability* 196
Figure 6.35 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of manufacturer *strategic mutation* 199
Figure 6.36 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of manufacturer *strategic mutation* 199
Figure 7.1 The model mechanism that makes micro behaviour emerge as system level behaviour 207

List of Tables

Table 2.1 Efficient and *responsive supply chains* (adapted from Chopra and Meindl, 2007) 17
Table 2.2 Different recommendations on competition in SCM literature..........23
Table 2.3 Recommendation on competition in strategic management literature..........24
Table 2.4 Supply chain elements that influence supply chain collaboration and competition 31
Table 2.5 Summary of various perspectives on long-term partnerships..........38
Table 2.6 Various suggestions on number of sourcing..........41
Table 2.7 Summary of conflicting perspectives on supply chain collaboration..........46
Table 2.8 Important behavioural factors of competition and collaboration and the hypotheses..........52
Table 3.1 Previous work of supply chain competition and collaboration that employ ABM 66
Table 5.1 The conceptual model..........101
Table 5.2 The inputs or experimental factors..........115
Table 5.3 Assumptions and simplifications applied in the model scope..........123
Table 5.4 The non-input variables and the constants for the simulation setup..........127
Table 5.5 Variables' feature in the simulation setup..........130
Table 5.6 The base run and the behaviour space..........131
Table 5.7 The scenarios for the *manufacturer collaborative and competitive behaviour* 132
Table 6.1 The experimental design and the hypothesis..........158
Table 6.2 The scenarios for the *duration of collaboration*..........159
Table 6.3 The Mann-Whitney U test of *supply chain fill rate* between all scenarios of the *duration of collaboration* with *single-link firms* (with critical value -2.33 for Z_{stat}) 161
Table 6.4 The scenarios for the *number of partnerships*..........168
Table 6.5 The scenarios for the *manufacturer trust*..........175
Table 6.6 The scenarios for the *supplier trust*..........182

Table 6.7 The scenarios for the *customer loyalty*..187
Table 6.8 The scenarios for the *manufacturer survivability* 191
Table 6.9 The scenarios for the *supplier survivability* 194
Table 6.10 The scenarios for the manufacturer *strategic mutation*.................................198
Table 6.11 The proportion of extreme numbers of supply chains in the experiment of the manufacturer *strategic mutation* 201
Table 6.12 Summary of the resulting experiments for *Hypotheses B* 202
Table 7.1 Summary of the results...215
Table 7.2 Summary of the effect of each experimental factor for *Hypotheses set A* 233
Table 7.3 Main limitation of each experiment for *Hypotheses set A* 235

Acknowledgement

In the name of Allah, the Most Gracious and the Most Merciful.

Completion of a doctorate is no small achievement to me. It is a substantial an individual research project - requires enormous effort, greatest time, a high degree of patience and also persistence. Thus, it is an honour to express my deepest appreciation to those who involved, either direct or indirect.

First, I would like to gratefully thank my lovely parents: Johnny Arifin Mertosono and Tutty Prawiraningsih, and my loveliest twin sisters, Titiet Indah Arviyenny and Tutut Indah Arviyetty. Without their great support, I would not be able to complete this arduous journey, let alone to survive the bumpy ride. Their incredible support has made me stronger.

I definitely would like to thank my supervisors. They are so amazingly patient, supportive, and professional. I feel so lucky having the opportunity to be supervised by them. To my previous first supervisor, Professor Stewart Robinson, he is a great role model to me. His great supervisions have led me to learn how to be a professional academic. He supported me to participate in many academic events and winning many awards both in the UK and US during my PhD journey.

I would like to express my deepest appreciation to my first supervisor, Dr. Antuela Tako. She has patiently assisted me in shaping my research, improving my papers, structuring this Thesis, finding opportunities to attend a conference in Thailand, preparing the Viva presentation, and completing the thesis corrections. She has furthermore supported me in my decisions in my career path in academia after PhD.

To my second supervisor, Dr. Duncan Robertson, he is great in helping me to find inspirations and ideas. His ideas are always innovative, and his critical perspective is highly useful to reshape my Thesis to be more comprehensive, detail, and insightful.

I am so grateful for the opportunity given by the Indonesian Directorate General of Higher Education. The financial support has accommodated my journey to seek for the wider knowledge beyond national border.

Finally, I should not miss mentioning my friends who persistently provided practical assistance and willing to lend their ears for listening and their words for encouragement. They are always ready to give me a hand sincerely without asking any return. I am so indebted to them.

Declaration of Authorship

I, Niniet Indah Arvitrida, declare that this thesis entitled:

“Competition and collaboration in supply chains: An agent-based modelling approach” and the work presented are my own. I confirm that:

- This work was done wholly while in candidature for this research degree;
- This thesis contains no material which has been accepted for the award of any other degree or diploma in any university;
- I have acknowledged all primary sources of help;
- The work described in this thesis has served the material for several published papers and conference presentations which are listed below.

Journal paper:

(*accepted*) Arvitrida, N.I, Tako, A.A., Robertson, D.A., and Robinson, S., 2017. Duration of collaboration in supply chains from a market perspective: An agent-based modeling approach. *Operations and Supply Chain Management: An International Journal*, 10.

Refereed conference proceedings:

Arvitrida, N.I, Tako, A.A., Robertson, D.A., and Robinson, S., 2016. Duration of collaboration in supply chains from a market perspective: An agent-based modeling approach. In *Proceedings of the 7th International Conference on Operations and Supply Chain Management*.

Arvitrida, N.I., Robinson, S., Tako, A.A., and Robertson, D.A., 2015. Collaboration in supply chains: An agent-based modelling approach. In *Proceedings of the Operational Research Society Simulation Workshop 2016 (SW16)*. A.Anagnostou, K. Hoad, M. Kunc, eds.

Arvitrida, N.I., Robinson, S., and Tako, A.A., 2015. How do competition and collaboration affect supply chain performance? An agent-based modeling approach. In *Proceedings of the 2015 Winter Simulation Conference*. L. Yilmaz, W.K.V. Chan, I. Moon, T.M.K. Roeder, C. Macal, and M.D. Rossetti, eds. IEEE.

Arvitrida, N.I, Robinson, S., Tako, A.A., and Robertson, D.A., 2015. An agent-based model of competition and collaboration in supply chains. In *Conference Proceedings of Loughborough University*.

Conferences and presentations:

Presentation at School of Business and Economics, Loughborough University Doctoral Conference – 14 September 2016.

Presentation at 3rd Annual Research Workshop, Cranfield Indonesian Scholars Community (Criscom) on 20 May 2016, at Cranfield University, UK.

Presentation at Café Academique – a postgraduate event at Loughborough University, UK, on 18 May 2016.

Poster presentation at 2nd East Midlands Networking and Project Showcase Event (EMiNePSE) - East Midlands Operational Research Society (EMORG), at Loughborough University, UK, 12 May 2016.

Presentation at 8th Simulation Workshop (SW16) - OR Society, in Stratford, Worcestershire, UK, 11-13 April 2016.

Presentation and Poster Presentation at the Winter Simulation Conference 2015, on 6-9 December 2015, in Huntington Beach, California.

Presentation at PhD colloquium of the Winter Simulation Conference 2015, on 6th-9 December 2015, in Huntington Beach, California.

Presentation at Simulation Practice Research Group, School of Business and Economics, Loughborough University, on 26 November 2015.

Presentation at the Young Operational Research (YoungOR), OR Society, UK, on 22-24 September 2015, at Aston Business School, Birmingham

Presentation at School of Business and Economics, Loughborough University Doctoral Conference – 16 September 2015.

Short presentation at 3 Minute Thesis (3MT) competition in the final heat on 17 June 2015, Loughborough University.

Presentation at the 1st Doctoral Conference: 'Your Research...What's the point?' 29 May 2014, Loughborough University.

Presentation at the first Annual Research Workshop of Cranfield Indonesian Short presentation at 3 Minute Thesis (3MT) competition in the first heat on 2 December 2014, Loughborough University.

Scholar Community (CRISCOM) on 3-4 May 2014, Cranfield University.

Poster presentation at the 7th Simulation Workshop (SW14) – OR Society (via a poster presentation) on 1-2 April 2014, in The Abbey Hotel Golf and Country Club, Worcestershire, England.

Awards:

2016 – The Best Presentation, School of Business and Economics PhD Conference, Loughborough University.

2015 – The Winter Simulation Conference (WSC) Diversity Award, INFORMS-Simulation Society, USA.

2015 – The Santander Mobility Award, Loughborough University.

2015 - The Simpson Award, the OR Society Young OR Conference.

2014 - People's Choice Award in the 1st Heat of Three Minute Thesis Competition, Loughborough University.

Signed:

Date: 8th May 2017

Abstract

Competition has been considered as an effective means to improve business and economic competitiveness. However, competition in supply chain management (SCM) can be viewed as a source of uncertainty. Most recommended collaboration strategies in SCM literature tend to avoid the emergence of competition inside the supply chain, but, in reality, these strategies do not lead all supply chains to success. In addition, from strategic management perspective, these collaboration strategies are not believed to encourage firms to improve their performance. Both competition and collaboration are critical issues in achieving business success, but the effect of both factors on the market has not been explored concurrently in the literature. The complexity of this issue should be investigated using a comprehensive perspective, and it is hard to undertake by using an empirical approach.

This study develops an agent-based model of supply chain competition and collaboration. It focuses on partnerships between supplier and manufacturer, which are particularly critical in innovative product markets, such as automobile and high brand apparels. A model representing two-stage supply chains is modelled, involving customers, manufacturers and suppliers. It assumes a simplified strategic landscape where the agents (customer, manufacturer, and supplier) attempt to reach the best strategic fit on two dimensions (criteria), defined as responsiveness and efficiency. A theory-driven approach is adopted to develop the model and observe the emerging outcome as a result of the agents' intrinsic behaviour. Instead of focusing on a particular single supply chain, the problem is examined at market-level, taking a system perspective. Thus, the performance measured is the rate of demand fulfilment and the number of supply chains which can survive in the market.

The results indicate that competition can have both positive and negative impacts on supply chains. Competition can assist strategic alignment between collaborating firms (the supplier and the manufacturer), whereas it can lead to a massive exits of a number of companies from the market, known as *shakeouts*. Furthermore, not all competition and collaboration approaches recommended in SCM and strategic management field have significant better demand fulfilment and survivability of supply chains for the long-term. These findings are counterintuitive with the existing literature and offer new insights on operations strategy. This study suggests that a strategy that is advantageous for a single company could be detrimental when it applies to all firms in the market. The market-level perspective adopted in the modelling approach also provides a novel approach that has not been implemented by previous studies.

CHAPTER 1 INTRODUCTION

1.1 Introduction

This chapter provides the general outlook for this thesis. An overview of this study is presented, followed by the aim and general objectives of the research as well as the related body of knowledge, which is supply chain management (SCM), strategic management, and agent-based modelling (ABM). This overview ends with the outline of thesis structure.

1.2 Overview of this thesis

Competition is an effective approach to improve business and economic performance. It results in lower prices and costs with better quality, more options, more innovation, higher efficiency and productivity, and furthermore. These benefits not only support wider business opportunities but also enhance a nation's performance (Stucke 2013). Competition could also be viewed as an essential trigger to firm performance improvement through innovation development, such as offering service extension as an addition to a product. This extension adds the firm's competitive advantage, which is the key driver to corporate success (Walley 1998).

Nevertheless, competition can be a potential source of uncertainty in supply chain management (SCM). It can increase operational costs (Walker and Weber 1987; Altug and van Ryzin 2013) and makes the collaboration harder (Rice and Hoppe 2001). Therefore, most collaboration strategies in SCM are intended to minimise the emergence of competition, particularly within the supply chain.

SCM practices have been widely accepted as a fundamental determinant of business success. It shifts the conventional perspective from individual firm competition to supply chain competition. This SCM point of view makes collaboration between companies along the supply chains crucial in achieving business success (Christopher 2000; Sahay 2003; Lee 2004; Chopra and Meindl 2007).

The most popular collaboration strategies suggested in SCM are maintaining long-term collaboration and having a single supplier (known as a *single-sourcing* strategy). These strategies are trusted to optimise the supply chain's competitive advantage for the long-term, particularly for the innovative product supply chains. The longer duration of collaboration is considered to promote better communication between collaborating firms and accelerate the innovation process along the supply chain (Boddy et al. 1998). Meanwhile, the *single-sourcing* strategy, which applies along with long-term collaboration, can minimise uncertainties in the supply side because it can secure the supply flow (Kraljic 1983). This strategy can also dramatically lessen the lead time to market as the intensive partnerships enable supplier involvement to rapid the product innovation process (Christopher 2000). *Single-sourcing* is also believed to be able to reduce the emergence of competition (Lee 2004). These claims are also supported by a successful SCM practices in several large companies, such as Toyota and Benetton.

However, these supply chain strategies do not always lead every supply chain to success. Many firms have failed to establish successful collaborations even though they have imitated the collaboration practices of the successful enterprises, by implementing long-term collaboration and *single-sourcing* strategy. This failure makes their SCM practices to be ineffective and inefficient (Barratt, 2004; Cao and Zhang, 2011; Holweg et al. 2005; Lambert and Cooper, 2000). Moreover, several studies find that these suggested supply chain approaches do not always lead to a better supply chain performance, such as examined by Anderson and Jap (2005), Burke et al. (2007), Leeuw and Fransoo (2009), Squire et al. (2009), and Sun and Debo (2014).

Other factors that are often highlighted in business partnerships are *trust* and *loyalty* among the companies. In SCM, *trust* has been understood as the core enabler to collaboration success (Dapiran 1992; Dyer and Ouchi 1993; Ganesan 1994; Nyaga et al. 2010). As well as *trust*, *loyalty* is considered substantial for maintaining profitable relationships in other domain of business studies, such as Singh and Sirdeshmukh (2000), Alhabeeb (2007), Horppu et al. (2008), and O'Cass and Carlson (2012) in marketing research. *Trust* is often considered to describe relationships between corporates, while *loyalty* is used for describing customer. Both refer to behavioural-related aspects in which businesses strive to maintain. These factors tend to have a positive linear relationship (O'Cass and Carlson 2012), so these terms can be taken into account concurrently.

On the other hand, a good collaboration practice does not guarantee a supply chain to have a sustainable profitability. For example, Nokia's collaboration with its supplier was considered as a best practice of supply chain partnerships (Fourtane 2015; Johnson and Lauritzen 2015; Collin and Lorenzin 2006). It won the Supply Chain Management Award in 2015 for Excellence in Supply Chain Operations at the EXCHAiNGE conference. However, other supply chain experts and researchers regard that Nokia's profit in mobile phone industries is declining compared to its main competitors, such as Apple and Korean manufacturers (McCray et al. 2011; Reeves and Deimler 2011). Another example of decreasing business with an appropriate practice of supply chain collaboration is the Japanese electronics industries, such as Sony, Panasonic, and Sharp. Similar to Nokia, these firms have declining profit as Apple and Korean manufacturers have a growing market share. This unexpected business pattern attracts many discussions between business reviewers, such as Hall (2009), Ihlwan (2009), Morris (2012), Fingleton (2012), and Wingfield-Hayes (2013).

In addition, from strategic management view, these strategies can hinder firms to innovate and improve their performance. Experts in strategic management, such as Porter (1990; 1997), believe that cooperation or collaboration without competition will not enhance the quality of the relationship between firms.

These contradicting suggestions indicate that understanding the effect of competition and collaboration on supply chains is complicated. It requires a comprehensive point of view that elaborates the conflicting perspectives, which involve SCM and strategic management. Furthermore, the behaviour of all companies in the market contributes to the demand fulfilment and survivability of supply chains in the competition. This complex issue is difficult to investigate by using an empirical approach. Hence, this study aims to provide a better understanding of the effect of competition and collaboration on supply chains, by observing the problem from market-level perspective.

In this study, an agent-based modelling (ABM) approach is adopted to incorporate market-level perspective in analysing supply chain competition and collaboration strategies. This approach employs a non-aggregated method; it starts with modelling the individual entities - called agents, allowing them to interact with each other, and then analyse the resulting emergent behaviour in the system. This approach offers a comprehensive perspective on understanding the effect of individual firm-level behaviour on supply chains at market-level outcomes.

An agent-based model of competition and collaboration in supply chains is developed in this Thesis. It models two-stage supply chains, involving manufacturer and supplier, in innovative product markets. The agents act in a two-dimension strategic landscape, which is defined based on the basic supply chain competitive strategies, known as efficiency and responsiveness (Chopra and Meindl 2007). The experimental factors are described to represent the suggested collaborative behaviour in SCM and competition strategy in strategic management. As the problem and the modelling approach are based on literature in SCM and strategic management, this study is considered as a theory-driven research.

1.3 The aim and objectives of this study

The main motivation of this research is to understand the effect of competition and collaboration on supply chains from a system-level perspective. Existing literature in SCM and strategic management have contradictory views about the benefits of competition and collaboration strategies. Most conflicting opinions are led by different perspectives used in the previous work. SCM studies apply an operational perspective to analyse supply chain competition and collaboration issues without considering the emergent behaviour of a particular SCM strategy in the market. Meanwhile, strategic management considers a market-level perspective without regarding partnerships and operational issues in supply chains to the analysis. To obtain better insights on understanding these current conflicting perspectives on competition and collaboration in supply chains, this study adopts a market-level perspective which has not been considered in SCM studies. Hence, the aim of this study is:

> "To explore the impact of competition and collaboration strategies on supply chains from a market perspective".

Based on this overall aim, the objectives are described as follows.

Objective 1: To develop an agent-based model that explores the effect of competition and collaboration on supply chains.

As the aim is difficult to achieve using an empirical approach, an agent-based modelling approach is employed. The model is developed based on the literature review on competition and collaboration issues. The resulting behaviour of the model is then compared with a theoretical competition model to enhance the confidence of the agent-based model. For example, several case studies in *shakeouts* (a situation where a massive number of companies exit from a market) are applied to explain the plausibility of the model results.

The model investigates several well-known strategies in competition and collaboration, particularly those applied in the manufacturer-supplier partnerships in innovative product markets. The collaboration strategies that are observed are duration of collaboration, number of partnerships, and trust. These strategies are believed essential in SCM literature. Meanwhile, the competition strategies examined are individual firm's *survivability* and strategic *mutation*. The firm's *survivability* depicts the individual firm robustness to cope with losses, and strategic movement is an extreme competition strategy that is popular in strategic management. The emergent effect of these competition and collaboration strategies are assessed based on two measures: the market ability to fulfil the demand (market demand fulfilment rate), and the overall supply chain's *survivability*, which is represented by the number of supply chains which can survive in the long-term competition.

Objective 2: To explore the effect of competition on supply chains and market structure, with regards to the demand fulfilment and survivability of supply chains for the long-term.

This objective considers the overall effect of competition on supply chains. It describes the emergent patterns that are consistently resulted in every experiment and have never been expected to appear. The effect represents the benefit and the downside of competition on the supply chains, observed from a market perspective.

Objective 3: To explore the effect of competition and collaboration strategy on the market, in terms of demand fulfilment and survivability of supply chains over the long-term. The following factors are considered to describe the competition and collaboration strategies:

1) *Duration of collaboration*
2) *Number of partnerships*
3) *Trust*
4) Individual firm's *survivability*
5) Strategic movement, i.e. *strategic mutation*

The model is used to explore the firm behaviour in competition and collaboration through a set of experiments. The factors are first observed in isolation, and then several experimental scenarios are investigated under two different *duration of collaboration*, with respect to the *number of partnerships* and *trust.* This experimental design allows the author to obtain general intuitions about interaction among these factors as discussed in the literature.

1.4 The findings and contributions

The simulation results indicate that competition can have both positive and negative impacts on supply chains. The positive effect is that competition can assist strategic alignment within supply chains, while the drawback is that competition can lead to extreme *shakeouts*, with regards to monopoly. It means that competition is not always detrimental to supply chains as it could offer benefit in supply chain strategic alignment.

Moreover, the model outputs show that the recommended competition and collaboration strategies are not always beneficial to supply chains when it is investigated under long-term competition. The *manufacturer trust* of the supplier, *customer loyalty* towards manufacturer, *manufacturer survivability* to work with less efficient and/or less responsive supplier, and manufacturer strategic movement (*strategic mutation*) have a significant effect on supply chains. This finding is counter-intuitive with the popular recommendations in SCM, which focuses more on the *duration of collaboration*, the *number of partnerships*, and *trust,* particularly from supplier to manufacturer.

This study contributes to three research domains: SCM, strategic management, and ABM. SCM and strategic management drive the description of the problem situation, the modelling process, and the analysis perspective. Meanwhile, ABM is the main approach used to achieve the aim and objectives of this study.

SCM is the primary point of view that affects the agent-based model development in this study. The agent's characteristics and its interactions are constructed and analysed based on theory and findings in SCM literature. The market-level perspective employed in this study offers a novel approach that provides new insights in SCM. Instead of observing a single supply chain, the competition and collaboration issue is examined from market-level point of view. An essential insight obtained from this approach is that "what is good for a single company may be detrimental for the market". This finding suggests insights on the fundamental or sensitive factors for supply chain collaboration and understanding the dynamic problem in supply chains.

This study shows that the use of market-level perspective to study SCM could provide a building block to improve the current suggested collaboration strategies. The insight generated by this point of view can encourage academics, business managers, and market regulators to consider the system (the market) to rethink about the strategic relations inside a supply chain as well as deciding the appropriate competitive approach. To the best of the author's knowledge, the market-level viewpoint has not been used to analyse competition and collaboration in the literature. Hence, this study offers a novel approach in SCM.

In addition to SCM theory, previous works on business competition are employed to support the modelling process. Several theoretical models and cases in business competition, which are often discussed under strategic management field, are employed to define the agent's competitive features. A strategic management point of view is also adopted in concluding the resulting emergent behaviour.

With respect to the adoption of strategic management perspective on analysis, this research provides a new approach to analyse business dynamics by taking SCM perspective into account. The emerging outcome of the simulation model reflects the similar output as predicted by Hotelling (1929) even though this study applies different modelling assumptions. It suggests that the agent-based model proposed in this study can be considered as an extension of Hotelling's competition model in ABM, by incorporating two-layer competition and allowing SCM features to the firm behaviour. Moreover, the adoption of SCM perspective to the modelling and analysis allows a new insight on understanding *shakeouts* in strategic management studies.

SCM and strategic management are related to operations management (OM), particularly for the analysis and discussions. Thus, OM can be considered as the general domain of the perspective used in this research. As for the contributions for OM, this research not only allows a new insight on strategy in both SCM and strategic management context, but also providing new insights on understanding the effect of competition and collaboration.

Meanwhile, the use of ABM to study competition and collaboration in supply chains is still limited to date. Studies that use ABM to study SCM issues focus primarily on software architecture than supply chain analysis, such as Barbuceanu et al. (1997), Parunak et al. (1998), Barbuceanu (1999), García-Flores et al. (2000), Jiao et al. (2006), Kwon et al. (2007, 2011), and Siebers and Onggo (2014). In addition, ABM research that has addressed collaboration issues in SCM, such as Zhu (2008) and Chen et al. (2013), only focuses on a single supply chain. Thus, this study provides a new implementation of ABM as a novel approach to modelling supply chain issues by consolidating the different perspectives between SCM and strategic management. The model also offers an advancement of the existing agent-based model of Hotelling's model.

1.5 Thesis outline

This Thesis is organised into eight chapters. While the first chapter is about the introduction of this Thesis, the remaining chapters are described as follows.

Chapter two provides a review of the previous works that discuss the extent of competition and collaboration impact on supply chain. The contradicting views on this issue, which are the basis of the research problem proposed in this study, are presented. The review in this chapter focuses on the discussion on competition and collaboration between supplier and manufacturer in supply chains.

Chapter three frames the existing literature of ABM in supply chain competition and collaboration. This chapter identifies the opportunity for the use of ABM as well as the potential contribution in this study on the agent-based modelling approach.

Chapter four details the research methodology of this study. The hypotheses of objective 2 (to explore the effect of firm competitive and collaborative behaviour on supply chains, in terms of demand fulfilment and survivability of supply chains over the long-term) and objective 3 (to explore the generic effect of competition on supply chains, with regards to the long-term demand fulfilment and survivability of supply chains) are detailed. The research design to achieve all objectives of this research is also described in this chapter.

Chapter five explains the model building process. The logic of the agent's rules is detailed, and the several examples of the verification process of each agent's rule or experimental factor are presented.

Chapter six presents the results and analysis of the competition and collaboration effect on supply chains in the market. The analysis mainly addresses objective 2 and objective 3 of this study.

Chapter seven discusses the findings of the experiments. The findings are associated with achievement of each objective of this study. It also explains the limitations of the findings that are the basis for suggesting the further research, which is presented in the next chapter.

The thesis is concluded in *chapter eight*. Summarising the main findings, this chapter addresses conclusions of each hypothesis and objective achievements of this study. It also provides discussions of the reflection for the contribution of the research to the related research domains, which are SCM, strategic management, and ABM. This includes how the SCM and simulation community views an issue from a different perspective by making use simulation approach and a theoretical or analogical model to understand a phenomenon which is hard to explain empirically. This reflection defines the potential opportunity to create an impact on knowledge and business practice. This Thesis ends with a detailed agenda for further work, followed by a summary and the author's final comments.

CHAPTER 2 COMPETITION AND COLLABORATION STUDIES IN SUPPLY CHAINS: WHAT IS MISSING?

2.1 Introduction

This chapter presents a review of competition and collaboration in supply chains. It starts with an overview of supply chain management (SCM), which is the main domain that triggers the question of this study. Then, the scope and issues of each of competition and collaboration are described. According to perspectives found in the literature, conflicting opinions exist on this topic. The gap between the views seems to be more noticeable when a strategic management perspective is taken into account. Thus, identification of the missing gap in the literature is formalised and concluded, which is provided in the last section of this chapter.

2.2 Overview of supply chain management (SCM)

Supply chain management (SCM) is a field that is concerned with a set of techniques and practices for managing business networks. Meanwhile, supply chain is a term to describe a network of firms, including suppliers of raw materials, manufacturers, warehouses, retailers, and logistics service providers, who work together in replenishing demand of end consumers (Lambert and Cooper 2000; Simchi-Levi et al. 2000; Chopra and Meindl 2007). The term of SCM has been known since 1982 (Gibson et al. 2005), and the approach has been widely practised by many industries.

With regards to the relationships between firms, SCM views supply chains as a network of supply rather than a single chain of supply. Even though fragile, the network is a vital part of a supply chain; the network generates the critical competitiveness for the supply chain (Chopra and Meindl 2007; Simchi-Levi et al. 2000). Hence, a supply chain needs to be sustainable and robust. However, managing the relationships between companies in a supply chain is hard because most firms cooperate with more than one company at the same time. An illustration of the supply chain network complexity is illustrated in Figure 2.1.

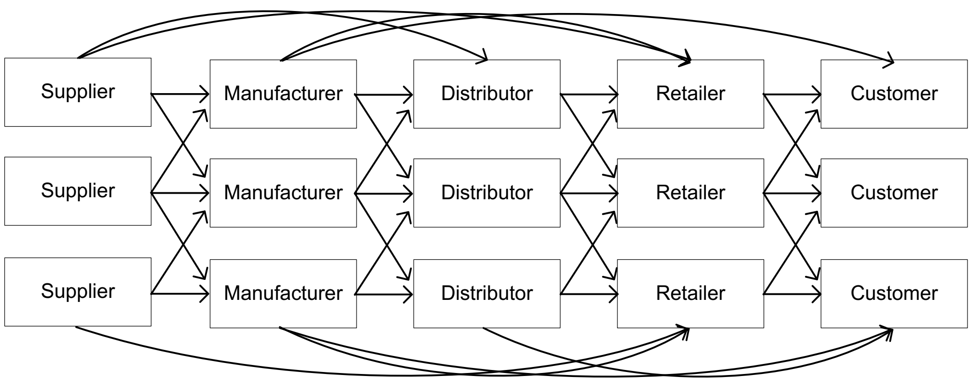


Figure 2.1 Supply chain complexity (Chopra and Meindl 2007)

The Supply Chain Council, an independent non-profit organisation, consisting of 70 world class industries (Stewart 1997), defines supply chain activities as operational processes. This organisation develops a Supply Chain Operations Reference (SCOR) model as a standard for benchmarking, business process reengineering, and measuring supply chain performance (Supply Chain Council 2010). The SCOR model divides supply chain operations into five elements: plan, source, make, deliver, and return. The decision for these elements is suggested to be integrated not only in the internal scope of a firm but also with the supplier and customer operations. This integration is intended to support strategic alignment through integrated operations along the supply chain. For instance, according to the SCOR model, a manufacturer's production plan should be determined together with its supplier and linked with the retailer's marketing plan. This suggests that ideal SCM practices have a wider scope with strategic implications rather than merely affect the firm's day-to-day operations.

In strategic management literature, supply chain activities are considered as the core business process of industries, such as modelled in the generic value chain model (Porter and Millar 1985), and in business process re-engineering of Computer integrated manufacturing open system architecture (Childe et al. 1994; Montreuil et al. 2000; Bititci et al. 2008; Bititci et al. 2011a; Bititci et al. 2011b). This means that supply chain decisions play a critical role in corporate decisions and performance, particularly in manufacturing industries.

SCM practices are a crucial determinant of business success. This has implications for its competitive advantage. It shifts the conventional view of competition, from individual companies to a supply chain perspective. SCM suggests that the real business competition should deal with the end consumers although firms in the supply market, such as suppliers of raw materials and components, have no direct interaction with them. Thus, coordinating activities along a supply chain through collaboration becomes the main focus of SCM.

In short, SCM is a critical aspect to enhance competitive advantage for business competition that mainly focuses on material flows. It provides an essential contribution to reach sustainable competitive advantage through customer service level improvement and better business performance for the individual firm (Tracey et al. 2005; Li et al. 2006).

The remaining sections of this chapter focus on the discussions on competition and collaboration issues in SCM. Several related studies in strategic management are considered to enrich the review, which is presented in the next section.

2.3 Competition in supply chains

As SCM manages operations beyond a firm's boundaries, supply chain competitiveness is driven by the product or material that flows between organisations (Fisher 1997). The right decisions on supply chain strategy have been shown to support business success, such as Toyota and Zara (Lee 2004; Christopher 2005). A literature review that describes competition strategies in SCM and the literature gap in competition issue is presented in the following subsections.

2.3.1 Competition strategies in SCM

SCM defines supply chain products in two categories: functional and innovative products (Fisher 1997). Functional products refer to items required in daily necessities and consumed continuously in a relatively stable pattern, such as toiletries, food, and beverages; while innovative products represent items which compete on innovation, such as automotive and smartphones. Functional product supply chains compete in stock availability in the market as the product is highly substitutable and a part of the everyday needs of consumers. Meanwhile, innovative product supply chains contend in innovation to meet what customer wants for non-primary needs, such as automobile, smartphones, and branded fashion.

The type of products determines the required supply chain strategy, categorised as efficient or lean supply chain, and responsive or agile supply chain (Chopra and Meindl 2007). Efficient or lean supply chains fit with functional products which have a relatively low demand uncertainty. The supply chains compete on low cost and product availability since the product is easily rivalled and imitated by competitors. In contrast, the responsive or agile supply chain approach is best implemented when the product has an uncertain demand spectrum, which is a characteristic of innovative products. The supply chain competes on the innovation or product design and time to deliver the innovation to market. As the life cycle for innovative products is relatively short, involving the supplier to the process of product development is critical to support competitive product design as well as accelerating the time to market. Therefore, SCM emphasises collaboration between supplier and manufacturer for innovative product supply chains.

The selection of supply chain strategy would affect all operations strategies and decisions, such as product design, pricing, manufacturing process, and supplier selection (Chopra and Meindl 2007). In *efficient supply chains*, all operations strategies are driven by cost, price, and efficiency. Meanwhile, in *responsive supply chains*, most decisions in supply chains are based on speed and flexibility. Table 2.1 summarises the focus of each supply chain strategy, as defined by Chopra and Meindl (2007). The fitness of the supply chain strategy with demand uncertainty level is illustrated in Figure 2.2. The zone of strategic fit shows the ideal area in implementing each supply chain strategy. The responsive supply chain strategy becomes more appropriate when the implied demand uncertainty spectrum is higher.

Many large companies achieve success because they select the right strategy for their supply chain. An example of competition on functional products is that of Walmart and Kmart. Walmart has the larger market share because it tends to operate its supply chain more efficiently than Kmart (Chopra and Meindl 2007). Through an efficient logistics strategy and aggressive supplier management, Walmart is able to offer lower prices to customers (Leinwald and Mainardi 2010).

Table 2.1 Efficient and *responsive supply chains* (adapted from Chopra and Meindl, 2007)

	Efficient supply chains	Responsive supply chains
Main goal	Fulfil the demand at the lowest cost.	Respond the demand quickly.
Product design Strategy	Minimise the cost.	Generate modularity for the components to allow high product variation.
Pricing strategy	Lower profit margin as the price is the main driver of customer preference.	Higher profit margin as a customer can tolerate the price.
Manufacturing strategy	Operate efficiently with high utilisation of the production line.	Flexible manufacturing system with low utilisation on the shop floor.
Supplier selection strategy	Driven by cost and quality.	Driven by speed, flexibility, reliability, and quality.

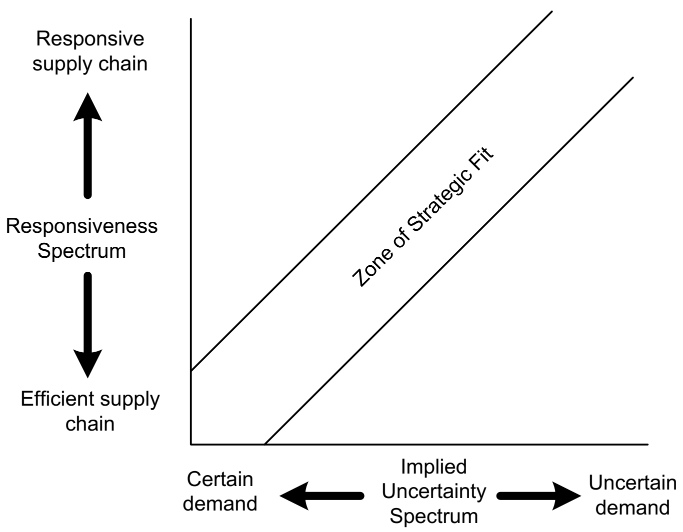


Figure 2.2 Strategic fit in supply chain (Chopra and Meindl 2007)

Meanwhile, competition among popular branded apparel companies is an example of the appropriate use of *responsive supply chains*, such as Benetton, Zara, H&M, Marks and Spencer, and Gap. These firms are popularly mentioned as SCM best practices by many authors, such as in Dapiran (1992), Christopher (2000), Rice and Hoppe (2001), Lee (2004), Chopra and Sodhi (2004), Thatte (2007), Squire et al. (2009), Turker and Altuntas (2014), and Stevens and Johnson (2015).

However, in reality, the implementation of supply chain strategy is not as linear as represented in Figure 2.2. Undertaking a survey study, Selldin and Olhager (2007) find that Fisher's theory on the link between supply chain strategy selection and product characteristics is not fully adopted in practice. Most of them apply both supply chain strategies at the same time to enhance their competitive advantages.

This practice is more often found in functional product supply chains. They are prone to apply a responsive strategy to improve their competitiveness instead of being highly efficient as successfully practised by Walmart. For example, 7-Eleven is a well-known retailer that adopts a responsive supply chain strategy in its convenience stores. It sells functional products but applies a responsive strategy by customising the type of products sold in each store at different times. This approach is supported by Lee (2004) and Christopher (2000) who recommend that the responsive strategy is more successful than the efficient approach to make a supply chain more competitive in general. This literature shows that product characteristics do not strictly drive the decisions on supply chain strategy.

However, Blackburn (2012) finds that being responsive is not always beneficial for supply chains, particularly in make-to-stock supply chains of functional products. His analytical model indicates that being more responsive in terms of time does not result in a substantial effect on the unit cost. The marginal value of time in a functional product supply chain only falls less than one per cent of product cost.

On the other hand, when a functional product is treated as an innovative product by introducing product customization by including additional features, it can make the operations more uncertain. Increasing product variety adds challenge to marketing and inventory management. It may also make it difficult for the company to understand what customers want. For instance, Starbucks and Ben & Jerry's are traditionally understood to use on efficient supply chain strategy, but they improve their product by offering a broad range of product selection. Even though the product innovation allows the firms to gain higher profit margins, it also increases their supply chain cost. This is because their individual products have a shorter lifecycle and the demand becomes more unpredictable and volatile (Fisher 1997).

These supply chain cases reflect that the relevance of supply chain strategy is not as simple as illustrated by Chopra and Meindl (2007) in Figure 2.2. A supply chain is not possible to be both extremely responsive and efficient at the same time. On the opposite, it is also impossible for it to be highly inefficient and irresponsive. However, a supply chain can be exceptionally responsive yet sufficiently efficient compared to other supply chains, and vice versa. Most supply chains are likely to perform either in high responsiveness but less efficient or eminently efficient but less responsive. This applicability range of supply chain strategy is illustrated in Figure 2.3. The grey zones illustrate the "not possible" areas of supply chain strategy implementation, while the white zone in the middle describes the applicability areas of supply chain strategy.

In practice, the level of responsiveness affects the level of efficiency. Nevertheless, the relationship between these factors is not linear. A higher level of responsiveness can either improve or lower the operations efficiency of a supply chain. On the contrary, when a supply chain is adjusted to have a higher efficiency level, the supply chain will likely need to decrease the responsiveness level. In other words, better operations responsiveness level could result in a wider range of efficiency level (zone *a* in Figure 2.3), while higher efficiency level would limit the supply chain responsiveness (zone *b* in Figure 2.3).

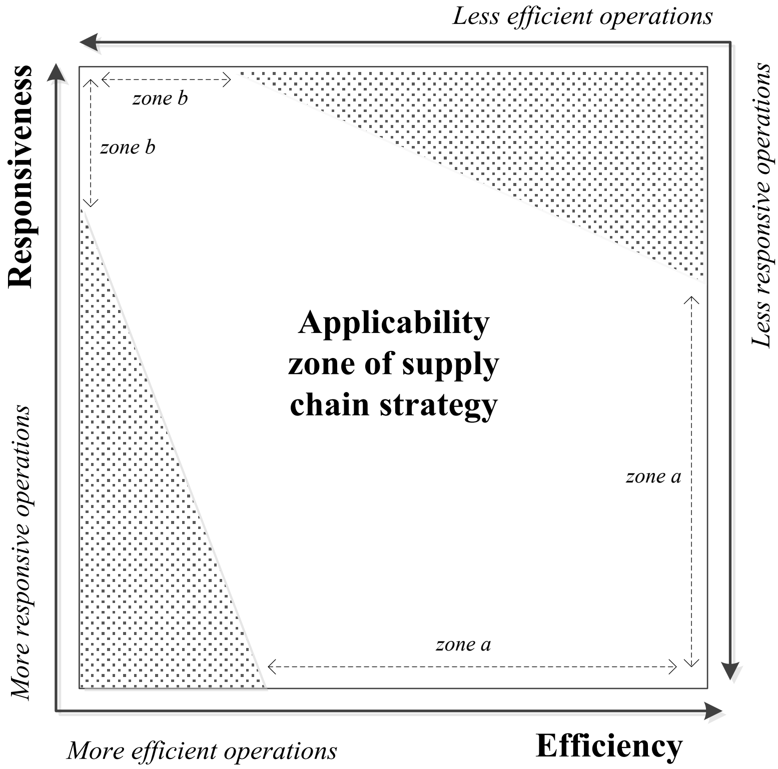


Figure 2.3 Illustration of the applicability of supply chain strategy: efficiency and responsiveness

2.3.2 Literature gap in competition

Competition is also studied in other research domains, particularly in strategic management. However, conclusions of the effect of competition tend to be inconsistent with the findings found in SCM literature on competition. The detail of this conflicting discussion is provided in section 2.3.2.1. Also, little mention is made of supply chain strategy in strategic management makes a gap between SCM and strategic management analysis. The following sections explain the knowledge gap on competition in SCM and strategic management.

2.3.2.1 Conflicting opinions on impact of competition

In strategic management, competition is considered to be an important factor in enhancing innovation (Porter 1997; Rathi 2014; Porter 1990). It is also beneficial for maintaining low prices, particularly for short-term contracts between suppliers and buyers (Humphreys et al. 2001). The absence of competition can worsen firms' profitability in the market. An illustration of this situation is that of the competition of Italian construction industries in between the late 1980s and the early 1990s (Anderson and Jap 2005). During this period, the contractors in Italy practised a cartel-type environment where there was no competition between firms. This type of environment deteriorated the firms' profitability as it made the firms were less willing to innovate and to operate more efficiently.

In contrast, in SCM, competition takes place among supply chains, not between companies, to gain better profit and market share. For instance, Benetton's and Zara's supply chain compete with each other by accelerating their time to market, in terms of delivering the product design innovation to end consumer (Christopher 2000; 2005). However, shifting a firm's goal into the supply chain's goal is still a significant challenge for most firms. Moreover, in reality, firm relationships are not as simple as a single chain of supply, as mostly assumed in SCM; in fact, the real supply chains are a complex network as illustrated in Figure 2.1.

Even though SCM has been well known by industry practitioners, competition among individual firms within the same supply chain still exists in the market. Each firm has conflicting interactions which create a restriction in achieving the goal of each firm. This interaction is unavoidable as each firm has limited resources while it wants to maximise its profit. In short, this competitive behaviour is mostly driven by the egocentric notion of the competing company (Meng and Layton 2011).

Several SCM researchers believe that competition can also be a cause of collaboration failures in supply chains. It makes good collaborations between organisations more difficult to establish (Rice and Hoppe 2001). Supplier competition, for example, can lead to quality distortion from the supply side (Altug and van Ryzin 2013). This drawback is supported by results of literature that examine this issue by using theoretical models. Moreover, researchers who work on total quality management, such as Walley (1998), demonstrate that competition provides fewer opportunities to reduce variation in lead time and quality.

Most arguments for examining the effect of competition in SCM focus on competition among suppliers. Through a game theory model, Xiao et al. (2014) show that competition generates longer supply chain lead time. Competition among suppliers is also seen as the cause of increases in the operational costs (Altug and van Ryzin 2013).

On the contrary, some findings suggest that competition among suppliers leads to a better understanding between firms (Forker and Stannack 2000), supports the achievement of an equilibrium price (Li et al. 2010), improves supplier performance (Babich 2006), and results in a better supply chain performance (Wang and Shin 2015). Meanwhile, Parker and Hartley (1997) find analytically that sourcing under competition on the supply side is no worse than having an intense long-term partnership with a single supplier. It means that competition can be advantageous to the manufacturer as it enhances the quality of coordination between buyer and supplier.

In social science, particularly in the field of strategic management, competition has been regarded as beneficial in improving business competitiveness (Axelrod 1997a). Competition supports corporate success (Porter 1990; 1997; 1998) and enhances innovation that leads to a better company profitability (Anderson and Jap 2005). From economists' perspective, competition can provide better value to the customer (Stucke 2013; Rathi 2014). It can also reduce total production costs for the manufacturer (Walker and Weber 1987). However, Huo et al. (2014) suggest that not all competition provides benefit to industries. They suggest only international scale competition has significant effects on business performance, especially in supply chains.

Table 2.2 provides a summary list of SCM studies that primarily examines the effect of competition. The list also includes papers which address competition as a supporting discussion topic, such as Christopher (2000) and Lee (2004). The table identifies the research domain of the papers, considering operational research (OR) and operations management (OM). Studies with mathematical modelling and statistical analysis are classified into OR, while OM refers to studies that focus more on a broader scope of the management aspect. Lastly, the research method used in each paper is detailed, regarding review paper, analytical paper, and empirical approach. Meanwhile, the list of strategic management studies that support the benefit of competition is provided in Table 2.3. To the author's knowledge, there is no conflicting opinion on the effect of competition in strategic management literature. Similar to Table 2.2, the list provided in Table 2.3 also includes the research method employed in each research.

From both Table 2.2 and Table 2.3, it can be seen that previous research comes to contradicting conclusions on competition. Most studies promote competition in business, while the rest do not advocate the existence of competition as beneficial to the industries. It indicates that this is a topic that requires further exploration in order to understand the causes of these opposing conclusions.

Table 2.2 Different recommendations on competition in SCM literature

Finding/suggestion	Author(s)	Method*
Competition is beneficial for the manufacturer when supplier competition exists.	***Operational research***	
	Parker and Hartley (1997)	A/C
	Babich (2006)	A
	Li et al. (2010)	A
	Wang and Shin (2015)	A
	Operation management	
	Forker and Stannack (2000)	E
	Humphreys et al. (2001)	E
Competition is not advantageous.	***Operational research***	
- Competition between suppliers increases the operational costs in a supply chain.	Altug and van Ryzin (2013)	A/N
- It leads to a longer supply chain lead time.	Xiao et al. (2014)	A

Finding/suggestion	Author(s)	Method*
	Operation management	
- It adds uncertainties in supply chains.	Christopher (2000)	R
	Lee (2004)	R
- It makes supply chain collaboration harder to achieve.	Rice and Hoppe (2001)	R
- Competition between suppliers increases supply chain costs.	Walker and Weber (1987)	E
- It increases lead time variations in supply chains.	Walley (1998)	R

*Note:
R : Review
A : Analytical approach (theoretical study)
A/N : Analytical approach with numerical analysis (theoretical study)
A/C : Analytical approach with a case study
E : Qualitative approach (empirical study)

Table 2.3 Recommendation on competition in strategic management literature

Finding/suggestion	Author(s)	Method*
Competition provides benefits to the enterprises.	Walker and Weber (1987)	E
	Axelrod (1997)	R
	Porter (1990; 1997; 1998)	R
	Anderson and Jap (2005)	R
	Meng and Layton (2011)	E
	Stucke (2013)	R
	Rathi (2014)	R

*Note:
R : Review
E : Qualitative approach (empirical study)

2.3.2.2 Differences in perspectives between SCM and strategic management

Following the conflicting opinions discussed in section 2.3.2.1, SCM and strategic management have a different perspective in examining business competition even though SCM activities are explicitly studied in many strategic management models. The noticeable distinction between these two sciences is that SCM views the problem from an operations point of view, whilst strategic management draws the conclusions from a market-level perspective.

For instance, SCM considers business failures as supply chain failures. The failures mostly arise as a result of mistakes in choice of supply chain strategy, and/or as failures on establishing a good collaboration. It does not consider the behavioural pattern of the market. An illustrative example of this case is the competition between Xbox and Play Station 2. From an SCM perspective, the defeat of Microsoft (the Xbox's producer) by Sony (the manufacturer of Play Station 2) in 2001 was because of mistakes in the choice of supply chain strategy. At that time, Microsoft used responsive strategy to enable the firm to launch the product earlier than Sony. Nevertheless, Sony implemented a lower price strategy for Play Station 2 and won market share. Realising that *responsive supply chains* is not the right approach, Microsoft changed its manufacturing and procurement approach to efficient strategy. This supply chain strategy led the company to gain a better share in the game console market (Lee 2004).

On the other hand, strategic management tends to view business failures as a consequence of mistakes in making a strategic movement, decisions in market segment selections, and/or as changing customer preference in the market. The operations and relationships between firms inside the supply chains are only considered as the supporting elements of the firm strategic movement. For example, Nintendo Wii lost is considered as a result of Nintendo's failures in making a suitable strategic movement (Hollensen 2013). Nintendo decided to make a big strategic *leap* and create a blue ocean - a term to describe an uncontested market space (Kim and Mauborgne 2005), but the company could not produce a product to protect its market share from the competitors - Play Station and Xbox. Nintendo experienced shortages of key components from its key suppliers when the demand of Wii was growing.

Another example of initial supply chain success is that of Nokia. From strategic management perspective, Nokia was an early mover in the smartphone market (Reeves and Deimler 2011), while SCM views that the success was highly driven by its robust supply chain rather than the appropriate selection of strategic movement (Collin and Lorenzin 2006). Nokia's collaboration with its supplier is considered as a best practice of SCM (Fourtane 2015; Johnson and Lauritzen 2015; Collin and Lorenzin 2006) and won the Supply Chain Management Award 2015 for Excellence in Supply Chain Operations at the EXCHAiNGE conference. However, Nokia is considered being defeated by its competitors, such as Apple. From strategic management point of view, Apple has a better strategic position than Nokia (McCray et al. 2011; Reeves and Deimler 2011), while this perspective has not been explained yet in an SCM-based review.

Based on these examples, it can be concluded that in strategic management, the strategic movement is critical for a company's competitiveness. Strategic movement is defined as "the set of managerial actions and decisions involved in making a major market-creating business offering", and has been regarded as a critical factor to support profitable growth (Kim and Mauborgne 2005). One of the recommended innovative approaches of strategic move is strategic *leap*, or blue ocean strategy (Kim and Mauborgne 1997; Mauborgne and Kim 1999; Kim and Mauborgne 2005; Kim and Mauborgne 2008). However, this approach has not been incorporated in SCM discussions yet since SCM never considers market-level perspective in its analysis.

Moreover, strategic management applies market-level perspective on research. The perspective enables the researchers to investigate the emergent pattern in a market, such as *shakeouts* (Bonaccorsi and Giuri 2000). This situation affects all firms in a market (Day 1997) and it is often interpreted as declining industries due to decreasing demand, or declining interest of customers in buying the product (Lieberman 1990). This kind of emergent phenomenon has not been considered in SCM literature. Instead, SCM analyses any business failures from operations-level perspective. If SCM perspective is incorporated into strategic management analysis, it will provide more comprehensive explanations. As a result, the market analysis could encompass not only one layer of competition but also several competition layers, as the scope of SCM is beyond a single company.

2.3.2.3 Competition strategies in SCM and strategic management: a missing link

As SCM and strategic management have a different perspective in studying competition in business, there is still a lack of SCM studies that links supply chain competitive strategy with the competition approach defined in strategic management. Each research domain has a different approach although both SCM and strategic management focus on long-term profitability. This gap may also be the reason of a conflicting perspective in understanding the effect of competition for supply chains.

A popular competition issues in strategic management is related to strategic change or movement. This issue is considered critical to have a better performance under a competitive environment (Kim and Mauborgne 2005). Strategic flexibility is one type of strategic change approach (Margolis et al. 2003; Stuart 1991), and a popular strategy on this approach is the *big leap* or blue ocean strategy. The *big leap* strategy is described as an innovative approach to strengthening a company's strategic position in the "blue ocean" of the market, where the competition is irrelevant. This strategy has been studied and suggested by many researchers, particularly by Rivkin (2000), Hart and Christensen (2002) Kim and Mauborgne (2005), Varga (2009), and Hollensen (2013). The closest SCM literature gets to this is supply chain flexibility as a part of supply chain competitive strategy (Duclos et al. 2003; Vereecke and Muylle 2006; Swafford et al. 2008; Squire et al. 2009). However, SCM defines the flexibility as a supply chain capability to response operational changes or dynamics rather than as *strategic mutation* or *big leap* strategy.

The different definition of competitive strategy in SCM and strategic management shows that a different perspective between SCM and strategic management affects the resulting analysis in these research fields. Hence, linking the competition approaches defined in strategic management to supply chain strategy would provide a better understanding of some arguable issues in SCM, such as the impact of supplier competition to supply chains. Moreover, looking at competition from a market-level perspective could provide a new insight in understanding the relationships between competition and supply chain failures in the market.

2.4 Supply chain collaboration between supplier and manufacturer

Business collaboration along the supply chain is considered to be the main driver to achieve SCM success. In theory, it integrates all operations from the upstream (supplier of raw materials) and downstream (end consumer) supply chain. An ideal collaboration should also be practised by firms in strategic, tactical, and operational level decisions. However, many businesses find that ideal collaboration is difficult to achieve. Most companies face challenges in integrating their planning and operations even only for aligning supply chain operations inside a single organisation (Fawcett and Magnan 2002). This challenge becomes greater when it involves other organisations in the operations alignment. The following sections discuss the collaboration features and the popular issues in supply chain collaboration, with respect to the *duration of collaboration*, *number of partnerships*, *trust*, supply chain *robustness* in terms of survivability, and the conflicting opinions about the benefit of collaboration.

2.4.1 Collaboration features in supply chain

Some basic features of relationships with suppliers are discussed within the issue of supply management, including in the purchasing portfolio model proposed by Kraljic (1983). The model suggests that supplier-buyer relationships are driven by the type of material exchanged. Even though several firms may not fully follow the suggested approach, this purchasing portfolio has helped researchers and business practitioners in SCM to understand and model the partnerships between buyer and supplier.

The Kraljic's portfolio model is described by two dimensions: *the strategic importance of the items*, and *the complexity of the sourcing market*. *The strategic importance of the items* represents "the value added by product line, the percentage of raw materials in total costs and their impact on profitability", whilst *the complexity of the supply market* gauged by "supply scarcity, pace of technology and/or materials substitution, entry barriers, logistics cost or complexity, and monopoly or oligopoly conditions". Based on these dimensions, it is found that the most complex procurement activities occur when the level of both the item *strategic importance* and *sourcing market complexity* are relatively high. The number of firms which can supply the items is limited, and it can cause a significant impact on manufacturers' profitability as well as their survivability. As the items in this category are considered strategic to the manufacturers, Kraljic (1983) recommends long-term partnerships with suppliers to minimise the risk in supply chains.

The model has assisted many SCM researchers to gain a basic understanding of the supply market features (Caniëls and Gelderman 2005). It helps the identification of the partnership approach with the supplier by determining the appropriate sourcing approach based on the characteristics of the supplied materials. However, this portfolio does not view the dynamic aspect of supply market, such as competition among the supply firms. The dynamics of the market can lead the portfolio model to be less accurate for some industries.

Similar to the competition strategy in SCM, supply chain collaboration strategies are categorised into responsive supply chain and efficient supply chain. This classification of strategies is the key driver of the sourcing decision or supplier selection, which is essential in establishing a successful collaboration (Matopoulos et al. 2007). Functional product supply chains are suggested to apply the efficient or lean supply chain strategy. Because the main materials of this product category are not difficult to obtain from the supply market, the collaboration issue with the supplier does not often become the main topic. The collaboration focus of these supply chains is mostly to improve the accuracy of the forecast of finished products so that collaborations with downstream trading partners, such as between manufacturers and distributors or retailers, are often raised. The collaboration approaches employed in this supply chain are designed to boost the product marketability (Alvarado and Kotzab 2001). The most popular collaboration strategies proposed are vendor managed inventory (VMI) and collaborative planning, forecasting, and replenishment (CPFR).

Meanwhile, supply chains for innovative products are considered to be best suited to adopting a responsive or agile supply chain strategy. This approach requires not only competitive product innovations but also competitive cycle time, which is defined as the time required from design to market. It means that the materials supplied by the suppliers have a significant influence on the manufacturing process and the value of the finished/end product. Hence, involving suppliers to the product design is important in order to achieve these goals, particularly the vendors of critical or strategic items.

The feature of partnerships in supply chains is detailed by considering the manufacturer or assembly plant of a finished product as the middle point of supply chains. Two categories of relationships are classified into the upstream level of the supply chain, and the downstream level of the supply chain. The interaction between a manufacturer and its supplier, including inbound logistics services, is considered as the upstream level of supply chains. Meanwhile, the relationships between the manufacturer and its customers, such as warehouses, retailers, end consumers, and outbound logistics services, are regarded as cooperation in the downstream level of supply chains.

The characteristics of supply chain collaboration, as well as the competition features, do not only depend on the supply chain strategy adopted (efficient and *responsive supply chains*) but also the stage of the supply chain. For the supply chain strategy, it has been clear that supply chain decisions, including the collaboration approach, are driven by the supply chain competitive strategy: efficient and *responsive supply chains*. Each supply chain strategy has different focus regarding the stage of the supply chain. These collaboration characteristics are summarised in Table 2.4. This study focuses on the relationship between manufacturer and supplier which is critical for innovative product supply chains; hence, discussions in the remaining sections of this chapter focus on purchasing activities between manufacturer and supplier.

Table 2.4 Supply chain elements that influence supply chain collaboration and competition

Type of finished products	Appropriate supply chain strategy	Critical supply chain stage	Critical item to manage
Functional	Efficient/lean	Downstream supply chain	Finished product
Innovative*	Responsive/agile	Upstream supply chain	Strategic or bottleneck items

**this study focuses on upstream supply chains of innovative products*

As an essential part of collaboration with suppliers, procurement activities provide a significant contribution to the manufacturer competitiveness. It has been found that product performance in the market is related to the performance of sourcing strategy (Kotabe and Omura 1989). Kraljic (1983) points out that working with the right supplier affects the supply chain performance significantly because it influences all the purchasing activities, which cost 40-70% of the cost of goods sold. Chopra and Meindl (2007) also find that 50-70% of total manufacturer's expenses are from procurement. The reason for this is that procurement requires many processes, such as defining the criteria for materials and suppliers required, organising meetings for bidding and negotiations, preparing contracts and even aligning the information system to improve the communication between manufacturer and supplier. Managing the relationships with suppliers has led several firms to achieve business success and made them be referred as the SCM best practices, such as Zara and Toyota (Gelderman and van Weele 2005). However, this literature does not consider the dynamic aspect in the supply market, with regards to competition among suppliers.

2.4.2 Collaboration studies in SCM

Many studies discuss supply chain collaboration and competition under the issue of supply chain contract. For example, Cachon and Lariviere (2005) study revenue sharing contracts by incorporating the newsvendor model for the collaboration approach and game theory and Cournot model for modelling the competition. Dimitriou et al. (2009) investigate the performance of newsvendor model under the bounded rational decision. Altug and van Ryzin (2013) model product selection with revenue sharing under supplier competition in an assemble-to-order system. Wu and Chen, (2013) perform a laboratory experiment to investigate rationally bounded behaviour in newsvendor settings under several theoretical supply chain contracts.

However, these studies only focus on inventory and logistics policy. Most of them apply analytical studies to evaluate and model supply chain contract, which is more appropriate to implement in the downstream level of the supply chain. Thus, the situation presented in these studies can hardly be adopted in studying the collaboration approach between manufacturer and supplier, particularly for critical or strategic items in innovative product supply chains.

On the other hand, several studies view that supply chain collaboration is taking a wider and more comprehensive scope. For instance, Simatupang et al. (2002) describe four supply chain coordination modes, which are logistics synchronisation, information sharing, incentive alignment, and collective learning. Holweg et al. (2005) define the key factors that drive supply chain collaboration; they are the geographical dispersion of customers and supplier plants, demand pattern of products, and product characteristics. Barratt (2004) proposes supply chain segmentation through literature study in defining the appropriate collaboration approach. Cao and Zhang (2011) explore the nature of supply chain collaboration and its impact on company's performance through empirical study in U.S. manufacturing enterprises. Purwaningrum and Evers (2012) study knowledge sharing in manufacturing industries in Indonesia and find that culture significantly affects the mechanism of supply chain collaboration. Ramanathan and Gunasekaran (2014) investigate the effect of collaborative planning, decision making and execution on all supply chain processes; they suggest that the successful short-term collaboration leads to a long-term relationship. However, none of these work attempts to address competition and collaboration in innovative product supply chains, particularly to analyse supply chain failure from market perspective.

Compared to proposed approaches for downstream collaboration, the available strategies for upstream supply chain collaboration are relatively more limited in SCM literature. The popular strategies suggested in this topic are about the establishment of a long-term partnership with suppliers and *single-sourcing*, as advised by Boddy et al. (1998), Kraljic (1983), and Lee (2004). Nevertheless, the studies which address this issue are relatively fewer than research in downstream collaboration and competition.

Few studies have attempted to review literature on supply chain collaboration, but they do not consider competition to the review. For instance, Soosay & Hyland (2015) consider publications on collaboration written from 2005 to 2014, but none of the reviewed articles studies the issue from a market perspective, particularly in measuring the effect through the degree of demand fulfilment and survivability of the supply chain. Moreover, they do not review supply chain collaboration by considering the type of products and the stage of supply chain which are fundamental to specify the feature and main problems of collaboration in supply chains.

2.4.3 Main topics in supplier-manufacturer collaboration

A brief review of the supplier-manufacturer collaboration issues in SCM literature is next presented in the following subsections. Five issues are identified: the *duration of collaboration*, the *number of partnerships*, *trust*, *robustness* for survivability, and the contradicting opinions of collaboration benefits.

2.4.3.1 The *duration of collaboration*: long-term partnerships

Long-term collaboration is considered the most effective approach to achieve a sustainable performance improvement for supply chains (Boddy et al. 1998; Christopher 2000; Lee 2004). This strategy is beneficial particularly for the firms which supply the critical or strategic items of the product to secure the supply flow (Kraljic 1983). It reduces the lead time to market (Christopher 2000) which is the critical driving force in innovative product supply chain. This approach is also credited as a critical enabler to achieve a long-term competitive advantage and performance for all firms along the supply chain (Li et al. 2006). These views are illustrated by the best practices adopted in the supply chain of large companies, such as Toyota and Benetton, which support that these strategies lead them to higher profits.

Before this approach was introduced, buyers or manufacturers were considered as ‘antagonist players’ towards their suppliers in the mid of 1980’s. They tended to be demanding and avoiding a long-term partnership with suppliers. They preferred to cooperate with a large number of different suppliers to obtain a lower price from their suppliers (Matthyssens and Van den Bulte 1994). Then, between 1996 and 2001, the partnerships trend drastically changed; establishing close relationships became popular in business strategy, including in SCM (Anderson and Jap, 2005).

Establishing close relationships with suppliers is one of the SCM goals to improve supply chain performance over the long-term. This strategy allows suppliers to get involved earlier in the process of product development, so both supplier and manufacturer can obtain a long-term joint competitiveness, as practised by Benetton with its supplier (Dapiran 1992). Moreover, it promotes a better efficiency since this method reduces the number of suppliers that affects transaction costs (Matthyssens and Van den Bulte 1994). Kraljic (1983) also documented that a Japanese steel industry has decreased their total spending up to 18% by applying this partnership style. Using a game theory model, Ren et al. (2010) also support this strategy as it facilitates *trust* improvement between collaborating firms. Nonetheless, the finding of the study is limited to information sharing on the sales forecast.

The most effective close relationship suggested are the ones where the manufacturers in the supply chain establish a long-term relationship with either one (*single-sourcing*) or two suppliers (*dual-sourcing*). This strategy has been considered as a fundamental approach in SCM to improve and optimise supply chain competitiveness over the long term (Matthyssens and Van den Bulte 1994; Li et al. 2006). It secures the supply, particularly in settling the long-term availability of critical goods or materials (Kraljic 1983). The lead time to market for introducing new products can also be lowered (Christopher 2000) because it enables information and operations integration that improves supply chain performance (Prajogo and Olhager 2012).

However, close partnerships do not always have positive impacts on the firms. Partnership failures have been found at a relatively high rate, which is between 30% and 50% (Anderson and Jap, 2005). Also, Parker and Hartley (1997) find that long-term partnerships tend to cause suppliers to be more vulnerable in controlling the price of their materials compared to short-term partnerships. Kraljic (1983) also suggests that long-term partnerships can provide a significant benefit if the suppliers are operating beyond their capacity, and when the uncertainty level of the relationship is high and complicated. Furthermore, Porter (1997) does not recommend long-term partnerships as it can reduce suppliers' willingness to innovate.

Several findings also identify that closer relationships lead the partners to be more likely dissatisfied with the cooperation. Marketing researchers have empirically proven that long term relationships can lower *trust* and service performance (Grayson and Ambler 1999). Strategic management research posits that close partnerships encourage partners to be too dependent on each other (Inkpen and Beamish 1997). It suggests that close relationships can dampen innovations. In addition, when a firm has a better understanding of what the other knows through a high degree of information sharing between parties, the partnerships become unstable and fragile. Other findings also suggest that this method does not always provide a better supply chain performance, such as Anderson and Jap (2005), Burke et al. (2007), Leeuw and Fransoo (2009), Squire et al. (2009), and Sun and Debo (2014). This approach has been found to be more risky to implement when the demand uncertainty is very high or very low (Sun and Debo 2014).

Different findings in analysing the relation between long-term partnerships with close relationships are also found in the previous work. Comparing U.S. car manufacturers with Japanese firms, Dyer and Ouchi (1993) conclude that a long-term collaboration does not necessarily need a very high involvement of collaborating firms. This view contradicts the findings of a study by Prajogo and Olhager (2012) who suggest that high involvement, or a closer relationship, is required as it significantly affects the improvement of supply chain performance. However, Prajogo and Olhager do not particularly discuss the long-term collaboration in their study, but close relationships in general.

This long-term relationship strategy is also often doubted by SCM practitioners. This strategy is viewed to be risky as developing and maintaining *trust* between firms are difficult in business relationships. This negative opinions often come from suppliers with larger scale buyers who aggressively established strategic and long-term cooperation with them (Bensaou 1999).

An empirical study conducted by Wagner (2011) finds that the length of partnership has no relationship with performance improvement, as illustrated in Figure 2.4. Instead, according to Wagner (2011), supply chain performance is influenced by the level of supplier development - a set efforts of a manufacturer spends to enhance supplier performance and/or capabilities. However, the effectiveness of supplier development tends to follow a curvilinear pattern against the length of partnership. It implies that excessive duration of relationship would not provide a significant benefit to the success of supplier development.

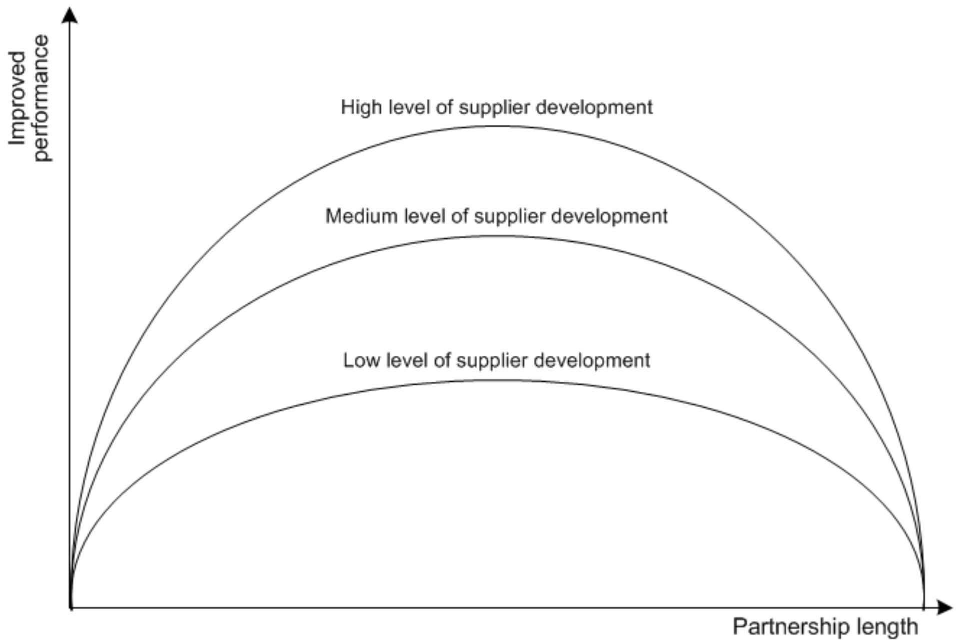


Figure 2.4 The pattern of performance improvement, considering the level of supplier development and the length of partnership (Wagner 2011)

This finding is consistent with the study conducted by Squire et al. (2009) who also conclude that collaboration has a curvilinear relationship. It improves manufacturer's responsiveness, but when manufacturer becomes dependent on the supplier, it may have an adverse impact on suppliers' performance. It implies that the more stable the relationship between firms, the more vulnerable it is to destruction. This is because it requires high investments in order to establish the long-term partnership which then turns into a barrier dissolving an ineffective relationship (Anderson and Jap 2005). However, both Wagner (2011) and Squire et al. (2009) do not explain the length of relationships duration for a specific unit of time. A summary of the conflicting views found in the literature is presented in Table 2.5.

Table 2.5 Summary of various perspectives on long-term partnerships

Finding/suggestion	Author(s)	Research domain	Method
Long-term partnerships provide more advantages to the supply chain than a short-term partnership.	Kraljic (1983)	SCM	Review
	Dapiran (1992)	SCM	Review
	Matthyssens and Van den Bulte (1994)	SCM	Review
	Boddy et al. (1998)	SCM	Empirical study
	Christopher (2000)	SCM	Review
	Lee (2004)	SCM	Review
	Ren et al. (2010)	SCM	Analytical approach*
Long-term collaboration <u>does not</u> consistently benefit the firms.	Porter (1997)	Strategic management	Review
	Parker and Hartley (1997)	SCM	Analytical approach with a case study
	Grayson and Ambler (1999)	Strategic management	Empirical study
	Anderson and Jap (2005)	Strategic management	Review
	Li et al. (2006)	SCM	Empirical study
	Leeuw and Fransoo (2009)	SCM	Analytical approach*
	Squire et al. (2009)	SCM	Empirical study
	Wagner (2011)	SCM	Empirical study
	Sun and Debo (2014)	SCM	Analytical approach*

**Note: theoretical study*

2.4.3.2 *Number of partnerships*

The second collaboration topic that attracts SCM researchers is the *number of partnerships* (or number of sourcing). It refers to manufacturers' decision in selecting and limiting the *number of partnerships* with suppliers. The decision of number partnerships is related to supply chain strategy to secure the supply flow.

The issue raised on this topic is around the value of having one supplier (*single-sourcing*), two suppliers (*dual-sourcing*), and many suppliers (*multi-sourcing*).

Many SCM experts recommend *single-sourcing* strategy to achieve a sustainable improvement in supply chain performance. This approach is generally adopted as a part of a long-term *duration of collaboration* and considered extreme because the manufacturer is only allowed to interact with and obtain supplies from one supplier only.

The *single-sourcing* approach is mostly supported by studies which consider variation reduction on product quality and lead time, such as Christopher (2000), Chopra and Meindl (2007) and Vereecke and Muylle (2006). This strategy would be more beneficial when the supplier has a large capacity (Kraljic 1983; Burke et al. 2007).

However, in reality, several Japanese firms that have claimed to adopt this strategy successfully are found to be no longer reliant on *single-sourcing* (Fisher 2011). Furthermore, according to the findings in Richardson (1993), *single-sourcing* is never perfectly practised in Japanese automotive companies, who applied this collaboration approach. Some apply dual or *multi-sourcing*. Dyer and Ouchi (1993) also find that even though the Japanese collaboration are characterised by long-term mutual partnerships, they cooperate with a relatively small number of suppliers.

Many experts have also doubted the effectiveness of the *single-sourcing* approach. Porter (1990; 1997) does not recommend this strategy because it does not provide incentives to the suppliers to improve their overall performance. A finding from Squire et al. (2009) support this perspective by showing that supply chain performance would be worse when the manufacturer becomes dependent on the supplier, although collaboration with suppliers is proven to enhance manufacturer responsiveness. Parker and Hartley (1997) also suggest that having more than one supplier allows for a more competitive supply chains.

Another alternative sourcing strategy is that of *dual-sourcing*. The strategy establishes close relationships with two suppliers. This strategy is generally understood to result in lower risks compared to *single-sourcing* while maintaining cost effectiveness in partnerships. Through an analytical analysis on inventory decisions, Ramasesh et al. (1991) recommend that *dual-sourcing* is more efficient than *single-sourcing*. This finding is consistent with the conclusion of Lyon (2006) that suggest *dual-sourcing* over *single-sourcing* in order to achieve better efficiency in U.S defence procurement strategy. Chiang and Benton (1994) also suggest *dual-sourcing* provides a better service level than *single-sourcing*. They also find that splitting the order to two suppliers does not mean that the buyer misses out on having quantity discounts on purchasing.

However, several studies indicate that *dual-sourcing* is not better than *single-sourcing*. Tyworth and Ruiz-Torres (2000) prove analytically that *dual-sourcing* in logistics practice results in lower efficiency than *single-sourcing*. Through an analytical approach, Yu et al. (2009) also show that *dual-sourcing* provides more benefit than *single-sourcing* when the material price is sensitive to the partnerships and supply disruption can be predicted.

Instead of having a single or two suppliers, recommendation on establishing relationships with many suppliers, known as *multi-sourcing*, are also provided in the literature. Multi-sourcing is commonly considered as the opposite of a close relationship. It is considered as an effective strategy to secure a steady supply by avoiding dependency on a particular supplier. Several studies suggest that *multi-sourcing* provides more advantages than other sourcing strategies. Burke et al. (2007) find that *multi-sourcing* is an optimal sourcing approach, although *single-sourcing* performs better when supplier capacity is relatively larger than demand. However, *multi-sourcing* has its own drawbacks for the supply chain. Even though *multi-sourcing* can lower risk of sourcing, having the risks of lead time discrepancy among suppliers tends to increase (Babich 2006). Moreover, having many suppliers can increase hidden costs, such as handling costs and transaction costs (Gadde and Snehota 2000).

On the other hand, maintaining relationships with a small number of suppliers, but not with a single supplier, is also considered beneficial compared to *single-*

sourcing and *multi-sourcing* for long-term partnerships. This is due to the fact that long-term relationships are risky and costly to establish and maintain (Bensaou 1999). This conclusion is supported by the findings of Kotabe and Omura (1989) who found that *multi-sourcing* with a limited number of suppliers results in a better supply chain performance. This situation is experienced by car manufacturer companies in Japan and Europe.

In relation to the SCM literature, a number of contradicting views have been expressed. In the early development of SCM, *single-sourcing* was the very popular approach for supply chain collaboration. However, this strategy could be too risky to implement. Hence several options are proposed, such as *multi-sourcing* and *dual-sourcing*. A summary of the different views found in the literature is presented in Table 2.6.

Table 2.6 Various suggestions on number of sourcing

Finding/suggestion	Author(s)	Research domain	Method
Single-sourcing is the best approach for supply chains.	Christopher (2000)	SCM	Review
	Vereecke and Muylle (2006)	SCM	Empirical study
	Tyworth and Ruiz-Torrez (2000)	SCM	Analytical approach*
	Chopra and Meindl (2007)	SCM	Review
Single-sourcing <u>does not</u> always provide benefit:	Parker and Hartley (1997)	SCM	Analytical approach with a case study
	Porter (1990; 1997)	Strategic management	Review
	Lee (2004)	SCM	Review
- Dual-sourcing is better than *single-sourcing*.	Ramasesh et al. (1991)	SCM	Analytical approach*
	Chiang and Benton (1994)	SCM	Analytical approach*
	Lyon (2006)	SCM	Empirical study
	Yu et al. (2009)	SCM	Analytical approach*
- Multi-sourcing strategies provide better advantages to the supply chain.	Gadde and Snehota (2000)	SCM	Review
	Burke et al. (2007)	SCM	Analytical approach*

Finding/suggestion	Author(s)	Research domain	Method
- **Multi-sourcing with a limited number of suppliers results in a better performance.**	Kotabe and Omura (1989)	SCM	Analytical approach*
	Bensaou (1999)	SCM	Review

**Note: theoretical study*

2.4.3.3 *Trust* and *loyalty*

Trust and *loyalty* are behaviour-related factors of an organisation or individual that deals with maintaining its relationship with a particular company. In many business studies, *trust* and *loyalty* are frequently considered simultaneously in a single study even though these terms do not have an identical interpretation. In SCM, *trust* is discussed as a core part of collaboration between enterprises, while *loyalty* is used to describe customer's characteristics in buying a product from a similar company in other business fields. Both *trust* and *loyalty* are required to establish business relationships (Singh and Sirdeshmukh 2000). Most studies consider *loyalty* as a consequence of *trust* and satisfaction (Singh and Sirdeshmukh 2000; Alhabeeb 2007; Horppu et al. 2008), while others suggest *trust* and *loyalty* have no cause and effect relationship, such as O'Cass and Carlson (2012). Therefore, with respect to these studies, *trust* and *loyalty* can be considered to provide concurrent effects on business partnerships. Henceforth, these terms are categorised into *trust/loyalty* in this Thesis.

In SCM, *trust* between collaborating firms is suggested crucial in achieving collaboration success (Dapiran 1992, Dyer and Ouchi 1993, Ganesan 1994, and Nyaga et al. 2010). Meanwhile, Kannan and Tan (2003) recommend that supplier *trust* is the key success of supply chain collaboration. Many studies have addressed the issue of *trust* in supply chain collaboration, but most of them focus on *trust* improvement, such as a study conducted by Mohamed et al. (2015). None studies focus on examining the significant influence of *trust* from one of the collaborating companies, such as comparing the effect of manufacturer *trust* and supplier *trust*.

Moreover, in reality, it is difficult to establish a perfect *trust* along the supply chain. *Trust* building is challenging and difficult to perform during the partnerships. It often requires higher involvement to build the *trust* which can result in higher costs to support and maintain the relationship. When the collaborating firms trusted each other and established a close partnership, it may increase the vulnerability of the relationships as discussed by Anderson and Jap (2005). Furthermore, *trust* in intermediate level represents the reality of business partnerships, which means a firm may not extremely trust the collaborating partner forever. In this case, an imperfect (or non extreme) trust may not be significant in supporting collaboration success. This factor is difficult to measure, and it may not be possible to investigate in the real world. Therefore, exploring the effect of particular degree of trust in supply chain collaboration requires an advance approach, such as simulation.

2.4.3.4 Supply chain robustness for long-term survivability

SCM believes that successful collaboration with suppliers can enhance supply chain robustness. When a supply chain is resilient, it has an ability to minimise any risk from its supply market. This capability is able to be achieved by establishing strong relationships with one or more than one key suppliers (Yu et al. 2009).

One of best practices of robust supply chains is Nokia. The firm has strong relationships with its suppliers that support its supply chain robustness from supply disruption (Rice and Galvin 2006). However, in fact, its strong supply chain does not guarantee the company from its recent declining market share.

Japanese firms' supply chains are also considered as best practices in maintaining supply chain robustness, such as Toyota, Sony, and Panasonic. A factor that assists their resilient supply chain is the government supports by protecting Japanese firms financially, particularly for companies which stay in the upstream supply chain (Dyer and Ouchi 1993). The subsidy has been proven effective in promoting their supply chains survivability although natural disasters frequently occur in Japan. It aids Japanese firms to survive and maintain stable business partnerships in their supply chain.

However, Japanese electronics firms are now experiencing declining profitability. Suggested reasons for profit loss in Japanese firms are: inappropriate marketing approach (Fingleton 2012; Morris 2012; Wingfield-Hayes 2013), mistakes on strategic movement (Hall 2009), high manufacturing costs due to the deteriorating Japanese economy (Ihlwan 2009; Wakabayashi 2012), and the culture of Japanese firms (Ihlwan 2009; Hall 2009). None considers the loss caused by the supply chain. Indeed, their supply chain practices are still regarded as a success story. Again, this case indicates that supply chain robustness achieved from good collaboration practices could not secure long-term supply chain profitability.

In other words, the effect of individual firm's survivability on supply chains long term robustness needs a further exploration. However, empirical observation is hard to adopt to the exploratory study. Simulation approach can be the appropriate alternative to research this issue.

2.4.3.5 Benefits of collaboration

Collaboration in SCM is intended to lower the operational uncertainties between collaborating firms. It is expected to allow the firms within the supply chain to have a similar perspective on winning the competition and working as a team. Most research in SCM considers collaboration is the most effective approach to improve supply chain performance, with regards to flexibility and speed. This perspective is suggested by, such as, Dapiran (1992), Matthyssens and Van den Bulte (1994), Christopher (2000), Simchi-Levi et al. (2000), and Chopra and Meindl (2007). Collaboration is also believed to be a strategy to align roles and responsibility between cooperating firms (Boddy et al. 1998). Therefore, close and intense relationships have become a basis for supply chain collaboration.

However, having close partnerships through collaborations do not suit all supply chains. Several studies, such as Anderson and Jap (2005), Burke et al. (2007), Leeuw and Fransoo (2009), Squire et al. (2009), and Sun and Debo (2014), suggest that the strategies do not consistently help a supply chain to have a better performance. This approach can also hinder the benefit of competition from a strategic management perspective (Porter 1990; 1997). Moreover, empirical evidence in U.S. manufacturing companies shows that the benefit of this approach is more significant to small firms compared to medium and large enterprises. This is because small firms relish the collaboration as a medium for learning and distributing knowledge while medium and large enterprises already have proficient capabilities (Cao and Zhang 2011).

In addition, some studies suggest that the advanced collaboration practice does not necessarily improve supply chain performance. Parker and Hartley (1997) find that partnership sourcing (with a close and intense interaction) does not lead to a better performance than adversarial competition relationships, with regards to transaction costs during the partnerships. Vereecke and Muylle (2006) also empirically conclude that collaboration partially supports supply chain performance improvement, in terms of cost, flexibility, and procurement. Stank et al. (2001) also find that collaboration, either with customers or suppliers, would not enhance firm performance, particularly in logistical service performance. Even though collaboration and information sharing with external allows risk reduction and having more informed decisions, these benefits do not result in performance improvement.

A summary list of these conflicting findings is presented in Table 2.7. However, these findings relatively have a minor position compares to other business research which endorses collaboration between firms. Also, these studies do not concentrate on supply-side collaborations, which is the main focus of this study.

Table 2.7 Summary of conflicting perspectives on supply chain collaboration

Finding/suggestion	Author(s)	Method
Collaboration enhances supply chain performance.	Most studies in SCM, such as:	
	Dapiran (1992)	Review
	Matthyssens and Van den Bulte (1994)	Review
		Empirical study
	Boddy et al. (1998)	Review
	Christopher (2000)	Review
	Simchi-Levi et al. (2000)	Review
	Lee (2004)	Review
	Chopra and Meindl (2007)	
Collaboration does not support performance improvement.	Parker and Hartley (1997)	Analytical approach with a case study
	Stank et al. (2001)	Empirical study
	Vereecke and Muylle (2006)	Empirical study

2.5 Summary of the literature gap

Based on the literature reviewed in this chapter, it can be concluded that although there is a healthy body of works on collaboration and competition in SCM and strategic management, contradicting views are still expressed. These concern the following: the *duration of collaboration*, the *number of partnerships*, *trust*, survivability of individual firm, and strategic movement. Some issues also remain unexplained, such as assessing the issue for long-term impact. With respect to this, several possible reasons are analysed to understand why they stay unaddressed, presented as follows.

Reason 1: Difference in perspective

Most conflicting opinions come from different perspectives used in the analysis. The gap is more apparent when both SCM and strategic management studies investigate the effect of competition, so the resulting analyses and perspective of each discipline can be compared. Strategic management views the problem from market-level perspective and pays less attention to the operational aspects. In this research field, operational effectiveness is considered not a strategy to achieve a sustainable competitive advantage (Porter 2006). Meanwhile, SCM observes the issue from an operational perspective – without taking into account the emergent behaviour of the market.

However, according to the literature reviewed, social studies seem to have limited interest in investigating collaboration in supply chains, particularly in associating it with the strategic movement. Conversely, in SCM limited efforts have been made to link the competition approach in strategic management, such as *big leap* or *strategic mutation* approach, with popular collaboration strategies in SCM. This could explain cases, such as Nokia and Sony, which experience declining profit even though their collaboration practised are still endorsed in SCM. Hence, considering market-level perspective used in strategic management in analysing collaboration issues in supply chains would provide an opportunity to understand the problem in a more comprehensive approach.

Reason 2: Unintegrated investigations

Each critical factor in supply chain collaboration issues is mostly investigated separately from the competitive environment. Strategic movement of other competitors in the market has not been considered in current studies. Incorporating both aspects of competition and collaboration would be useful to understand the gap between the conflicting opinions found in the literature.

Moreover, the competition observed in both SCM and social studies only covers one layer of competition. For instance, SCM tends to focus only on addressing competition among suppliers, while strategic management focuses more on competition between firms in downstream supply chains. However, in reality, competition exists both in upstream and downstream level of supply chains, which means it occurs in each stage of supply chain. This different focus of analysis would result in different conclusions; SCM prefers to investigate the effect of competition from manufacturer's perspective, whilst strategic management tends to observe it without considering competition in the supply market of an industry.

Reason 3: Limited scope of existing work

SCM research rarely observes the impact of competition and collaboration approach from supplier's perspective. Most previous studies analyse the issues from the perspective of a manufacturer in the downstream market. This perspective is inconsistent with the aim of SCM in improving competitiveness along the supply chains. Instead, most SCM studies only assessed the issue from manufacturer's point of view, and the impact for the supplier is often ignored.

Moreover, supply chain performance is not only affected by the operations of a supply chain. It is also affected by other firms in the market. The current SCM perspective does not consider the firm behaviour in the markets to assess the effectiveness of supply chain collaboration approach, such as strategic movement. This limitation may be the reason why an appropriate collaboration practice with key supplier/s does not prevent the supply chain from profit loss and long-term survivability in the market.

Another factor that is considered essential in competition issue but still not regarded in supply chain collaboration literature is customer behaviour. It has been widely accepted that customers play a significant role in business competition, and the main issues are about understanding their preference and *loyalty*. Many studies have examined customer behaviour by considering preference and *loyalty* in order to analyse business competition, such as Irmen and Thisse (1998), Turnbull et al. (2000), and Reeves and Deimler (2011). However, most these studies undertake a strategic management lens to the issue. In SCM, demand market is often expressed as a simplified uncertainty by assuming it into a form of statistical distribution of probability. Despite adopting this assumption, formalising the uncertainty as a result of decision-making behaviour, such as *loyalty*, allows more information to explore in studying competition and collaboration study.

Reason 4: Limited study that measures long-term impact of a strategy on supply chain

The benefit of business relationships is difficult to measure in reality, particularly in terms of its impact on the market. It is more complicated than measuring the costs for establishing and maintaining the relationships. This is because most benefits of partnerships are intangible and are not explicit in the firm's financial report (Gadde and Snehota 2000).

Even though SCM has a wide scope and multiple activities, supply chain success is often measured by its operations performance only. For example, the SCOR model employs the following metrics to measure the supply chain activities (Supply Chain Council 2010):

a. perfect order fulfilment
b. order fulfilment cycle time
c. upside supply chain flexibility
d. upside supply chain adaptability
e. downside supply chain adaptability
f. overall value at risk
g. total cost to serve
h. cash-to-cash cycle time
i. return on supply chain fixed assets
j. return on working capital

Existing research has attempted to assess the supply chain collaboration performance, but it still views the performance from operational perspective. Although supply chain collaboration aims to enhance the operations performance, the perspective could not indicate the long-term effect of the collaboration, particularly to the market. Moreover, even though SCM has been known for 34 years since it was first introduced in literature ─ 1982 by Oliver and Weber (Gibson et al. 2005), many firms still have not yet implemented successful collaboration. When a close and robust relationship is successfully developed between organisations within a supply chain, it does not guarantee the sustainability of business success. For instance, Nokia has been widely known to be successful because of its supply chain. It still has a strong supply network, but its market share is now declining significantly compared to Samsung and Apple.

It implies that the existing performance measures in SCM literature cannot be adopted to assess demand fulfilment and survivability of supply chains over the long-term, particularly in investigating the effect of competition and collaboration on the supply chains in the market. The analysis of the supply chain should consider other perspectives and/or other approaches to measuring supply chain success, such as market-level perspective used in strategic management.

2.6 Conclusions: The missing points from existing literature

SCM and strategic management have both investigated competition and collaboration in business. Both disciplines have addressed the important elements of competition and collaboration, but there are still several gap and limitations found in the literature.

To minimise the gap in the literature, linking the separate perspectives between related disciplines (SCM and strategic management) as well as relaxing the scope and limitations of the previous studies are required. The viewpoint of strategic management should be incorporated to supply chain analysis to allow a more comprehensive understanding of the impact of the factors. A market-level perspective used in strategic management enables SCM researchers to measure the performance of supply chains, regarding the level of demand satisfaction and supply chain survivability in the market. In addition, competition in both supplier and manufacturer stage should be combined in the analysis. The competition approaches discussed in strategic management, regarding strategic move and *big leap* (or *strategic mutation*), are also required to be taken into account to obtain a better understanding of the impact of this strategy on supply chain collaboration. A reason for this is that the *big leap* strategy still has a limited doubt in strategic management literature so far, but many business practitioners are sceptical towards this strategy. In addition, *supply chain robustness* should be analysed by considering individual firm survivability. It could provide insights whether intervention in supporting individual firm *robustness* or survivability significantly improves the long-term supply chain performance and survivability. Finally, uncertainty in demand market should also be considered as a result of customers' decision making, instead of assuming it into a demand rate with particular statistical distribution, which is performed by most SCM modelling with analytical approaches.

With respect to market-level perspective adopted in this study, the important factors of competition and collaboration can be generalised as companies' behaviour in the market. As in reality and most literature assumes that collaborative initiatives come from the manufacturers of finished products, the collaboration strategies are regarded as a part of manufacturer behaviour.

The critical issues in competition and collaboration and the conclusions for each of these factors are summarised in Table 2.8. The conclusions are based on previous studies that do not fully support the benefit of these collaborative and competitive factors.

Table 2.8 Important behavioural factors of competition and collaboration and the hypotheses

	Essential issues	Conclusions
A	Competitive and collaborative behaviour	
	1. *Duration of collaboration*	The recommended *duration of collaboration*, which is long-term collaboration, does not guarantee a better long-term supply chain performance and survivability.
	2. *Number of partnerships*.	The *number of partnerships* may not significantly affect supply chains for the long-term.
	3. *Trust*	*Trust* among firms and customer may not be beneficial significantly to supply chains.
	4. Individual firm's survivability	Long-term supply chain profitability and survivability may not be related to individual firm's *robustness* or survivability.
	5. Manufacturer strategic movement (the *strategic mutation*)	The *big leap* or *strategic mutation* may not be beneficial to supply chains.
B	Effect of competition on supply chains	Competition may be not detrimental to supply chains.

The final point of this literature gap is that the high-level complexity of competition and collaboration in supply chains. Each issue addressed in this chapter have relationships with each other in reality. The interdependencies are difficult to model by using an analytical approach as performed by the previous research. It is also hard to explain empirically since it requires transparency in formalising firm's behaviour in making decisions and long-term period investigation. An empirical approach would consume a great amount of cost and time, as well as causing potential problems related to research ethics. It indicates that an innovative approach is required to observe and investigate this issue.

2.7 Summary

The description provided in this chapter focuses on identifying the important issues in supply chain competition and collaboration that have inconsistent conclusions in the previous studies and business articles. The findings in the literature are also linked to the current situations of several big companies based on news from reliable sources. The gap identified is used as the basis for defining the behavioural factors of competition and collaboration that are modelled in this research. The literature-based conclusions of each factor are also presented. Regarding the complexity that is incorporated into this study, it is indicated that simulation is the appropriate approach to bridge the gap from the literature.

The following chapter (Chapter 3) discusses the research opportunity of agent-based modelling (ABM) approach, which is employed to provide a novel and innovative approach for SCM analysis in this Thesis. The methodology of the implementation of ABM approach in modelling competition and collaboration in supply chains is presented in Chapter 4.

CHAPTER 3 RESEARCH OPPORTUNITY OF AGENT-BASED MODELLING FOR STUDYING COMPETITION AND COLLABORATION IN SUPPLY CHAINS

3.1 Introduction

The previous chapter describes the literature gap addressed in this Thesis. The chapter also identifies the important issues in competition and collaboration. Meanwhile, the research opportunity of agent-based modelling (ABM) for studying supply chain competition and collaboration is outlined in this chapter. The description is pointed out based on reviews of existing ABM applications on competition and collaboration issues, particularly in supply chain management (SCM) and strategic management context. The review starts with an overview of ABM approach and follows with a synopsis of available ABM models of collaboration and competition. The ABM challenge, as well as the opportunity to use ABM in supply chains competition and collaboration, is identified in the next section. Finally, the conclusions and summary of this chapter confirm the position of this Thesis relative to the entire research domains involved, with regards to SCM, strategic management, and ABM.

3.2 Overview of agent-based modelling (ABM) approach

ABM is a simulation approach that is increasingly employed to explain phenomena emerged from complex and non-linear systems in our world (Heath and Hill 2010). The agent represents individual entities, which are independent but interact with others. This modelling approach has become popular since it can be applied in a wide variety of problem situations, such as cultural diffusion studies (Axelrod 1997b), political party competition (Laver 2005; Axelrod 1997a), sociology (Gilbert 2004), transportation (Dugundji and Gulyás 2008), finance and economics (Schelling 1969; LeBaron 2000; LeBaron 2001; Leombruni and Richiardi 2005; Axtell 2007; LeBaron 2011), biology (Hilscher 2005), and strategic management (Robertson 2003; Robertson 2004; Robertson and Caldart 2008; Robertson and Caldart 2009). Moreover, supported by the advancement of computational capability, its application is becoming more widespread (North and Macal 2007).

As opposed to other simulation approaches, such as discrete-event simulation (DES) and system dynamics (SD), ABM employs a bottom-up modelling. The modelling approach starts with defining the individual agent, making them interact with each other, and ends with an observation on the resulting emergent behaviour. It is a non-aggregated method that allows system perspective analysis to the emergent results. Meanwhile, DES and SD use a top-down approach, starting by defining the system as an aggregate of entities.

However, the implementation of ABM is still less popular than DES and SD, particularly in operational research. A reason for this is that ABM is still relatively newly added to operational research, compared to DES and SD (Taylor 2014; Onggo and Karatas 2015). The lack of use of graphical notation or visualisation in ABM is also pointed out as a cause of the limited application of ABM in operational research and management science area (Siebers and Onggo 2014). DES and SD have a better approach in visualisation; DES employs process flow diagram to represent the simulated system and SD utilises stock and flow diagram to draw the logic of simulation. Furthermore, compared to DES and SD, also, ABM programming language is generally more complicated (Siebers et al. 2010).

Its applications to SCM context are also still limited. As reviewed by Tako and Robinson (2012), 127 SCM journal articles applied DES or SD to the modelling, which indicates that DES and SD have been widely practised in SCM. Nevertheless, few ABM approach in SCM research can still be found. According to a literature survey of conducted by Jahangirian, Eldabi, Naseer, Stergioulas, and Young (2010), few studies published in between 1997 and 2006 have applied ABM to manufacturing and business analysis, including SCM. The detail discussion of this issue would be provided in section 3.3.1.

Regarding the visualisation of the modelling approach, most DES and SD software and SD have visualisation embedded in their platform. For instance, Arena and Simul8, as examples of DES software, has a graphical view of entities' flow and sequential boxes of processes or activities. Similarly, SD software has integrated stock and flow diagram is also a compulsory part of SD simulation programme, which is already incorporated in the SD software. This embedded graphical notation of investigated system into the simulation software has been found to assist the operational research modellers in developing the model; while ABM software does not have this feature (Siebers and Onggo 2014). However, when the problem complexity is high, DES and SD are less difficult to apply compared to ABM (Siebers et al. 2010).

In social science, the application of ABM approach is wider compared to the field of operational research and management science. It is proven by the number of publications of ABM in social science that is higher than in operational research and management science. Nonetheless, Pavón et al. (2008) find that the application of ABM in social science is still limited when it is contrasted with other approaches such as mathematical models and qualitative reasoning approaches. As strategic management is considered as a part of social science, this finding also applies to the ABM implementations in strategic management.

The main features of ABM simulation are composed of a set of agents acting in an environment. The environment is the virtual world where the agents act. The agents take actions based on particular interaction rules and autonomy. The actions are executed based on timescales, or schedules, which is prosecuted discretely as in discrete event simulation (Collier 2003; Gilbert 2008; Robertson and Caldart 2009). The following sections detail the main features of ABM, which are the agent, the environment, the interactions and autonomy, the schedule, and the emergent behaviour.

3.2.1 The agent

The agent is the individual entity, which represents the intelligence object that we want to simulate. It can make a decision without an explicit guidance of humans or other agents. The agent is also sociable since it cooperates with the other agents to achieve its objectives or help the other agents. During its interactions with other agents, it can be responsive; it has an ability to plan and execute tasks. Finally, it has pro-active features which allow an agent to perform and learn how to improve its action and decisions (Wooldridge and Jennings 1995; Fu and Fu 2012).

The agents are modelled individually to create the system. Using a bottom-up approach, their individual autonomous actions generate the global patterns of the system. The agents are sociable and interdependent, so they can influence the others in response to the effect that they obtain. Even though the agents can have a learning ability, they are bounded rational as their main characteristic is continuously seeking improvement to achieve their individual satisfaction (Watts and Gilbert 2014).

3.2.2 The environment

The environment is the abstract space where the agents are populated. It can be a two-dimensional world in the simplest representation (Robertson and Caldart 2009). It is defined based on the focus of the interaction, whether the link between the agents is necessary or the spatial space is more significant than the links. The agent's position in the environment influences its state towards the other agents and its decision during their interaction with the others (Gilbert and Terna 2000).

3.2.3 The interactions and autonomy (the rules)

The rules of agent refer to the detail interaction, the autonomy of behaviour of an individual agent. This feature leads the individual actions or decisions of agents. A simple rule of the agent can lead to complexity represented as the emergent pattern in the system. The rules can be classified into two categories. The first one is the base rules, and the other is those that adjust or modify the base rules (*meta-rules*). The latter leads the agents to be proactive and adaptive (Macy and Willer 2002). These rules describe how the agents interact with others and the level of agent's autonomy in the model.

3.2.4 The schedule

The schedule represents a list of events that are executed in a discrete quantum unit of time, which is known as a *tick* in the ABM platform (Collier 2003; Robertson and Caldart 2009). It regulates the sequence of agents' actions and triggers the time unit of the simulation. It controls whether all agents act at the same time or in a particular order. When one or several events, or the actions, are prosecuted, the schedule allows the time unit of the simulation to advance by a *tick*.

3.2.5 Emergent behaviour

Regarding the computer modelling, the code is started by defining the agent's characteristics. However, the modelling approach requires a description of the emergent phenomena of interest before developing the computer model. Gilbert and Terna (2000) define the emergent phenomenon in ABM is as follows:

"A phenomenon is emergent if it requires new categories to describe it which are not required to describe the behaviour of the underlying components (in this case, the agents)."

This emergent phenomenon can occur from simple features of an agent that creates complexity in the system. The complexity is represented by the interdependencies among factors in the real world, with stochastic variability for each factor, which creates emergent order. It also represents the decisions created by each agent are a result of the agent's adaptation process. However, these interdependencies should be structured to help the analysis of the emergent pattern.

In other words, the ABM approach is not a purely bottom up approach. In practice, ABM combines top-down and bottom-up approaches to the modelling process. This is because ABM approach is commonly started by describing the whole system by defining the emergent phenomenon. Then, it is followed by defining the individual agent. The final step is comparing the resulting behaviour with the expected emergent pattern. These stages are considered appropriate when ABM is used to model problems in the social science domain (Gilbert and Terna 2000).

3.3 Existing ABM work

As discussed in Chapter 2, the discussion of collaboration and competition arises not only in SCM but also in other contexts, particularly in strategic management. Here brief review on the application of ABM in modelling this issue is presented with regards to the type of contexts.

3.3.1 Supply chain management context

ABM is a growing body of research with many applications in supply chain operations, such as manufacturing, telecommunications, transportation systems, information management, interactive entertainments, and healthcare (Jennings et al. 1998). The agents are commonly described as companies with decision-making intelligence to manage sourcing, stocking, and shipping (Macal and North 2011). However, its application is still limited.

The earliest and most popular ABM simulation in SCM is the beer game (North and Macal 2007) although it is more popular to be modelled in system dynamics approach, such as Forrester (1962) and Sterman (2000). The beer game simulates the increase of demand volatility as it moves further up a supply chain, which is known as the bullwhip or whiplash effect. This effect emerges because each company inside the supply chain is a rationally bounded entity and does not coordinate with each other in their decision-making process. The pattern of the increases in demand volatility is considered as the emergent outcome resulting from the interaction of individual firm. The earliest version of the beer game, which was introduced before the computer modelling software was developed, is the first agent-based model in business competition and collaboration.

In addition to the beer game, a vast body of ABM literature in SCM context has been established. However, not all these studies focus on supply chain analysis.

Most of them are developed under computer science domain, so the research focuses on software development instead of analysing the supply chain problem.

SCM research that employs ABM in analysing the collaboration issue is still relatively limited. Several studies consider supply chain collaboration as firms integration, such as Xue et al. (2005) and Zhang et al. (2006). Xue et al. (2005) employ ABM to address collaboration issue in construction supply chain, but they concentrate on the information flow and negotiation. Zhang et al. (2006) present an ABM as an approach for e-manufacturing to provide flexibility, robustness, and adaptability to the rapid changes. Zhu (2008) also models supply chain collaboration, but it does not consider the collaboration as integration between firms; the study focuses on investigating the impact of information sharing in a single *two-echelon* supply chain. Chen et al. (2013) conduct a literature review on the use of ABM in supply chain risk management (SCRM). They consider that SCRM as a result of collaboration success in a supply chain. They define the goal of SCRM is establishing a robust supply chain, which is determined by supply chain ability to response changes and supply disruption. Other studies consider supply chain collaboration only in the scope of inventory decision, such as Dimitriou et al. (2009), Dimitriou (2010), and Robinson et al. (2016). The study examines the effect of bounded rational decisions in a classical inventory model for perishable products (the Newsvendor inventory model) by combining ABM and multiple linear regressions. Nevertheless, all these research are limited to a single supply chain. Trust between collaborating firms has also modelled and investigated by using ABM, but not many studies can be found in this topic. Only Mohamed et al. (2015) examine this issue in SCM context through an empirical approach in Malaysian industries.

Meanwhile, other works focus on modelling and analysing collaboration issue in the downstream level of supply chain, such as Caridi et al. (2005). They review the literature on ABM applications in managing supply chain processes, particularly in collaborative planning, forecasting, and replenishment (CPFR). In SCM, CPFR involves procedures and guidelines for sharing sales and forecast information between buyer and seller. The study finds that compared to traditional CPFR (without the support of intelligent agents), agent-based CPFR can reduce costs, inventory, sales, and shortages.

With regards to all ABM studies in supply chain collaboration, they concentrate mostly on software architecture than investigating the problem. These studies tend to employ ABM as a part of intelligent system in decision making rather than solely use it for simulation. The following are several examples of these studies described in brief. Swaminathan et al. (1998) utilise ABM as a multi-agent approach to develop a supply chain modelling framework. It addresses supply chain configuration, coordination, and contracts issues, which deal with inventory decisions. Julka et al. (2002) propose an ABM framework for developing a decision support system prototype to integrate supply chain processes in a refinery supply chain. However, the goal of the system is optimising a firm's performance, not the supply chain. Jiao et al. (2006) apply an ABM system to develop a framework of collaborative negotiation in a supply chain. The framework incorporates supply chain network and inventory decisions. Kwon et al. (2007) develop an integrated framework of supply chain collaboration based on ABM and case-based reasoning. The ABM architecture emphasises on information sharing among supplier, manufacturer, and customer. Cheng (2011) proposes an agent-based supply chain collaboration model that studies production and logistics processes at enterprise-level. The model comprises a single two-stage supply chain, which involves a manufacturer and a supplier. It considers competition to the model, but the competition is only represented by achieving on-time delivery target. Kwon et al. (2011) propose an agent-based web approach to support supply chain collaboration in e-business. It models a three-stage supply chain that consists of suppliers, manufacturers, and retailers. The framework focuses on inventory decisions and allows flexibility in coping with partnerships changes. Santos et al. (2013) develop a prototype of an agent-based framework for negotiation. The system is intended to support a supply chain collaboration network by improving the interoperability in the single supply chain. Hsieh and Lin (2014) proposes ABM model with multi-agent system (a distributed agent-based modelling) to manage collaborative workflows. However, it only focuses on scheduling activities within a firm.

Besides supply chain collaboration, ABM has been widely applied in many SCM issues. To obtain a general view of ABM applications in SCM which is outside the collaboration issue, several of the studies are briefly reviewed. Parunak et al. (1998) compare ABM and equation based modelling for modelling inventory problems. They find the use of ABM is still relatively new compared to equation-based modelling which is more mature in supply chain cases, particularly in inventory decisions. Gjerdrum et al. (2001) combine ABM with optimisation techniques to model a simple supply chain network which focuses on scheduling and inventory control. Kaihara (2003) formulates a supply chain model for resources allocation problem using ABM. Ahn et al. (2003) perform ABM to model adaptation processes in the financial transaction of a supply chain. It considers the dynamic of new products development, customers, and suppliers. D'Amours and Guinet (2003) compile literature on agent-based research in operational research area, which also represents SCM issues. Several research topics are related to ABM application in product development, scheduling, production management system, layout configuration problem, and real-time distributed control system. Akanle and Zhang (2008) introduce a methodology using ABM to optimise supply chain networks configuration of an original equipment manufacturer (OEM). Zarandi et al. (2008) employ ABM to reduce the bullwhip effect by coordinating all entities along the supply chain to minimise the total costs. Fu and Fu (2012) apply ABM to manage collaborative costs in supply chain. Li and Chan (2013) utilise ABM as a tool for studying the dynamic of supply chain in several manufacturing systems. He et al. (2013) examine pricing and inventory policies in a retailer supply chain through a laboratory experiment.

Other studies more focus on simulation software development rather than adopting ABM to analyse the problem. This is because they are conducted under the research area of computer science, not operational research and management science or SCM. For example, Barbuceanu et al. (1997) model a supply chain system that focuses on the information architectures; Shen and Norrie (1999) survey the application of agent distributed computing in supporting the mechanism of manufacturing systems; García-Flores et al. (2000) introduce the use of ABM to manage information flow of a manufacturing industries' supply chain.

For ABM competition models, there are only two ABM studies which model competition by incorporating SCM perspective to the modelling and analysis; they were conducted by Arunachalam and Sadeh (2005) and He et al. (2013). Arunachalam and Sadeh (2005) simulate competition between manufacturers of electronics industries by using an online participatory simulation approach. To assess the performance, the study compares inventory level, price, market share, and revenue between the competing teams. He et al. (2013) develop an agent-based competition model for multi-product supply chains, and only focuses on competition among retailers. Both these studies examine the competition issue in a particular single supply chain. Although Cheng (2011) claims his study covers competition, the model does not consider other companies in the competition.

Based on the literature that has been reviewed, there is still limited ABM research which incorporates competition and collaboration in SCM. Most previous studies investigate supply chain collaboration and competition in separate studies. When collaboration issue is addressed, they also do not regard collaboration strategy to the problem. All of these studies only observe a particular single supply chain; none of them views supply chain problems from a market-level perspective. In short, research that analyses firms' behaviour in competition and collaboration by using an ABM approach has not yet been carried out in SCM.

Furthermore, compared to DES and SD, the use of ABM in supply chain analysis is still limited to date. This comparison is distinct when no paper has reviewed the applications of ABM in SCM. Where ABM has been applied to the SCM context, it is mostly conducted through computer science research. The works tend to focus on software architecture rather than analysing a problem of the proposed topic.

A summary of previous research on competition and collaboration in SCM is presented in Table 3.1. The table also outlines the scope of application for each research, which are classified into 12 issues: supply chain planning, bullwhip effect, network/supply chain configuration, scheduling, trust, inventory, product development, logistics, supply chain risks, information sharing, supply chain financial aspect, and product pricing. This categorisation represents the scope of supply chain problems that is popularly discussed in SCM literature. According to the area of applications, it can be seen that all of these research measures collaboration performance based on the performance of supply chain operations. These measurement approaches could not assess the long-term survivability and performance of the supply chain in the market.

3.3.2 Strategic management context

ABM has been increasingly used to model business interactions issue. Many of them simulate or adopting a well-proven theory to the agent-based model, such as the Prisoner's dilemma or game theory (Axelrod 1997a) in business and politics, NK model (Robertson and Caldart 2009) in strategic management, and Hotelling's competition model (Wilensky 2013) in economics.

Simulation in social science, including ABM in strategic management, is employed as a methodology rather than as a tool to solve a problem (Gilbert and Terna 2000). It helps social scientists to develop a theory, which is more complex than predicting the future of a system. This perspective of the use of simulation is opposite to engineering and operational research field, which more focuses more on prediction than theory development. ABM has also been considered as a sensible approach to model a market (Onggo 2016). This is because a market is formed by interactions among individual - whether it is customers or individual firms. The result of individual behaviour creates market behaviour that emerges at system level.

Table 3.1 Previous work of supply chain competition and collaboration that employ ABM

Author(s)	Topic		Scope													
	Coll	**Comp**	**Plan**	**Bull**	**Netw**	**Sche**	**Trus**	**Inve**	**Pro**	**Log**	**Risk**	**Info**	**Fina**	**Pric**
Forrester (1962)	✓			✓				✓						
Swaminathan et al. (1998)	✓				✓			✓						
Ahn et al. (2003)	✓												✓	
Xue et al. (2005)	✓													
Arunachalam and Sadeh (2005)		✓						✓						✓
Caridi et al. (2005)	✓		✓	✓				✓						
Zhang et al. (2006)	✓												✓	
Jiao et al. (2006)	✓				✓			✓						
Kwon and Lee (2007)	✓													
Zarandi et al. (2008)	✓			✓										
Zhu (2008)	✓											✓		
Dimitriou et al. (2009) and Dimitriou (2010)	✓							✓						
Cheng (2011)	✓	✓							✓	✓				
Kwon et al. (2011)	✓							✓						
Fu and Fu (2012)	✓												✓	
Chen et al. (2013)	✓										✓	✓		
He et al. (2013)		✓						✓						✓
Santos et al. (2013)	✓				✓									
Hsieh and Lin (2014)	✓					✓								
Mohamed et al. (2015)	✓						✓							

Note:

Coll	:	Collaboration/coordination	Sche	:	Scheduling	Risk	:	Supply chain risks
Comp	:	Competition	Trus	:	Trust	Info	:	Information sharing
Plan	:	Supply chain planning	Inve	:	Inventory	Fina	:	Supply chain financial aspect
Bull	:	Bullwhip effect	Pro	:	Product development	Pric	:	Pricing
Netw	:	Network/supply chain configuration	Log	:	Logistics			

As ABM is used to understand the real world rather than to solve a problem, the studies are mostly theory-driven works (Siebers and Onggo 2014). Also, the model is used for learning and understanding the problem rather than implementing the findings in the real world. It means no empirical data is required to the modelling approach so that dynamic hypotheses play a major role in the model development.

Moreover, ABM allows social researchers, including strategic management researchers, to undertake inductive and deductive analysis. Inductive finds patterns from empirical data and deductive derives conclusions from particular axioms, ABM enables both approaches in order to undertake *what-if* analysis (Axelrod 1997a). If these approaches are applied for ethnography observation, it may need 30-40 years to complete (Watts and Gilbert 2014).

Compared to mathematical modelling, ABM has many benefits in social science modelling (Axtell 2007; Zenobia et al. 2009); it does not need assumption of equilibrium and is able to incorporate the process dynamics and feedback, which are essential in analysing an emergent behaviour (Pavón et al. 2008; Robertson and Caldart 2009; Farmer and Foley 2009). Thus, simulation has been considered as a promising contribution to social science (Louie and Carley 2008).

Nonetheless, little mention is made of business competition and collaboration in ABM literature. When the issues are considered, most previous work separates it into two different research topics. Only a few studies incorporate these problems in a single research, such as Axelrod (1997a) who models competition and cooperation interaction by adopting game theory. Nevertheless, when competition and cooperation are taken into account, the study focuses on the emergence of coopetition - a term to define cooperative competition. In reality, this pattern typically occurs in horizontal supply chains, such as coopetition among Toyota's suppliers (Wilhelm 2011).

For ABM competition models, most previous research combines a traditional competition model with other natural models, such as the NK model in Lenox et al. (2006) and Caldart and Ricart (2007), and the forest fire model in Robertson and

Caldart (2008). The NK model is a biological model introduced by Kauffman (1993) to describe adaptive evolution as opposed to Darwinian 'selectionist' theory, while the forest fire model is a theoretical physics model. In Lenox et al. (2006), the NK model is employed to investigate the coordination of interdependence activities among enterprises under competition situation. It is incorporated with a classical economic model of competition to generate the competitive behaviour. Even though the study model activities coordination beyond a single firm, it does not represent particular operations that can be related to SCM. Meanwhile, Caldart and Ricart (2007) adopt the NK model to mainly investigate competition issue, particularly in studying exploitation and exploration in corporate strategy. Robertson and Caldart (2008) introduce the adoption of the forest fire model to simulate firms' behaviour in business strategy implementation. The forest fire logic is employed to represent the effect of advertising or diffusion of innovation as a result of a competition strategy implementation. However, these studies tend to produce a complex model as it adopts a complicated behavioural rule from the logic of natural models. To some extent, it may not be possible to generalise the emergent pattern from a simple behaviour in the real problem situation.

In ABM platforms, several classical economic models of competition have also been developed as a part of the software's library, such as Hotelling's competition model (Hotelling 1929) developed by Wilensky (2013) in NetLogo. Hotelling's model is often illustrated as a competition between two ice cream stalls located in along the street on a beach (i.e. one-dimensional competition). As both stalls always attempt to optimise their market share, they keep changing their location until they come with the right to each other at the same halfway point (Robertson and Caldart 2009). However, Wilensky (2013) allows more than two firms to compete, and the competition space can be set into two dimensions.

There are still many other ABM studies in competition, but they are limited in one layer of competition. None of them considers multiple layers of competition, such as competition among firms that emerges in each stage of supply chains. However, compared to ABM studies in collaboration or cooperation issue, ABM model in business competition is more numerous. ABM research that is related to collaboration topic mostly corresponds to SCM context, and cooperation is typically attributed to game theory to model coopetition problems.

3.4 ABM validation

ABM still has a challenge, particularly in terms of validation. This is because the resulting emergent result of the agent-based simulation model is sometimes difficult to compare with the real world. Several ABM models that are developed based on theories, such as the Hotelling's competition models (Wilensky 2013), are easier to validate compared to the non-theory-based models. Nevertheless, no theory is precise and complete even though it has been well proven (Gross and Strand 2000; Zenobia et al. 2009).

Some researchers argue that ABM is not a better approach than mathematical models, such as Casti (1997), Louie and Carley (2008), Gross and Strand (2000), and Casti (1997). The reason for this is that all variables are still under control in simulation, whereas system should not be isolated once developing theory, particularly in social science (Louie and Carley 2008). These debates mostly emerged in social science domain, including strategic management, where theory generation is the main outcome of research.

On the other hand, ABM tends to produce theoretical models. With respect to this, Heath and Hill (2010) suggest the system dynamics validation approaches to determine the plausibility of ABM results. They propose the use of system thinking to understand and model the problem situation in ABM. It allows modellers to structure the interdependencies, understand the properties and the limitations, and analyse the emergent behaviour. The beer game simulation is an example of a model that can be validated by this approach. The time delays in receiving and responding information, which reflects the human bounded rationality, is considered as the main cause of the 'misperceptions of feedback' that causes the bullwhip effect (Diehl and Sterman 1995).

Gilbert (2008) also proposed two validation methods in ABM: fitting it with the theory and with the real-world phenomenon. The first comparison is called as a theory-based explanation, and the latter is a case-based explanation. For the case-based explanation, it corresponds to the comparison of the resulting behaviour with the empirical behaviour of the real-world, known as a phenomenon. This test does not necessarily need a quantitative match of the model results with the real world; the qualitative similarity between model outputs and the real world is sufficient to be the basis of model validity.

There are still many validation approaches that have been employed in validating theoretical or hypothetical models in ABM studies. They includes biological behaviour explanation as conducted by Levinthal (1997), empirical validation through, for example, case studies (Zenobia et al. 2009), parameter calibration with the real world (LeBaron 2001; Zenobia et al. 2009), model docking by developing two models and comparing the results (Burton 2003), and empirical validation for the micro level behaviour (Zenobia et al. 2009). However, these validation approaches are difficult to perform when the model is hypothetical and not developed to explain a theory or phenomenon. The approaches would also be impossible to apply if the ABM study aims to understand and explore several behavioural rules as the empirical data is hard to obtain.

Validation process in any research should be related to the purpose of the model (Robinson 1997; Robinson 2014). The validity of a model should represent plausibility related to the related problem domain (Sargent 2013). If the problem is hypothetical and does not have a strong relevance with any previous theories, the models can be validated only according to its plausibility, such as the Schelling's segregation model, the Hotelling's competition model, and the beer game.

Despite these contradictory opinions, ABM still offers some advantages compared to other approaches. It can incorporate the concept of complexity to produce and understand an emergent behaviour (Robertson and Caldart 2008). Moreover, ABM is known as an effective approach to study simple individual rules that lead to an emergent behaviour at the macro level system. Several studies that employ this approach have been used as the main reference for other studies, such as Schelling's segregation model and the beer game. It means that the benefit of ABM outweighs the challenge in validation.

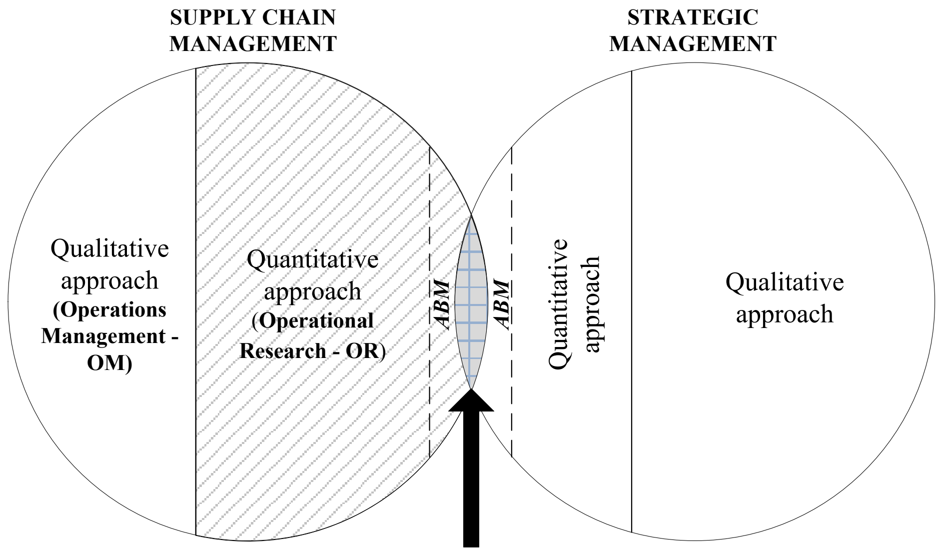
3.5 Conclusions and summary

This chapter shows that ABM approach has been well implemented in both SCM and strategic management, particularly in modelling competition and collaboration in business issues. Although the application of ABM has significantly increased in recent years, the ABM studies in SCM are still limited, particularly in modelling competition and collaboration issue. No study attempts to benefit the system perspective analysis in ABM for analysing the long-term demand fulfilment and survivability of supply chains in the market. In other words, there is an opportunity to apply ABM in modelling the issue in SCM.

Furthermore, compared to other simulation approaches, ABM has a unique feature to model and observe a problem. While DES and SD have a top-down approach, ABM employs a bottom-up approach. It enables researchers to understand an emergent behaviour at macro level by investigating the behaviour at the micro level of individual agent. This approach is appropriate to model a phenomenon that is difficult to explain empirically and analytically. It is also suitable to explore the emergent outcome of *what-if* experiments on the individual agents. In short, ABM is the best approach where the problem situation requires analysis from two level of point of views: from the agent-level and the system-level. Although ABM still has an issue to validate theoretical models, the advantages of the use of ABM still outweigh the drawback, particularly when the problem is not possible to study by using an empirical approach.

This research benefits the unique features of ABM to bridge the literature gap in the SCM and strategic management. SCM has operations-level perspective, which is close to the agent-level view. Meanwhile, strategic management tends to employ market-level perspective that can be similar as a system-level standpoint. Moreover, according to the literature that is reviewed in this study, ABM has been implemented both in SCM and strategic management to model competition and collaboration even though the problem is still examined separately. It means that ABM is the most appropriate approach to bridge the literature gap in supply chain competition and collaboration, as defined in Chapter 2.

The use of ABM in this research is essential to provide new insight about competition and collaboration in SCM. It also offers a contemporary approach to strategic management in modelling and understanding the emergent outcome of multi-layer competition driven by decision makings at operations level. The ABM role in bridging the gap that is identified in this study is illustrated in Figure 3.1. A rough estimation of the application of quantitative and qualitative approach to each research domain (SCM and strategic management) is presented, and the shaded area represents the main domain of the problem proposed in this study. The use of ABM also allows operational research (OR) feature to the modelling approach and operations management (OM) approach to the analysis. The methodology of the ABM application in this Thesis is presented in the next chapter, which is Chapter 4.



The use of ABM in this research (OR & OM):

"Competition and collaboration in supply chains"

SCM perspective:
applying competitive and collaborative behaviour at individual firm- level

Strategic management perspective:
analysing the supply chains long-term performance and survivability from market-level perspective

Figure 3.1 ABM role in this research: to merge the gap between the related research domains.

CHAPTER 4 METHODOLOGY

4.1 Introduction

This chapter describes the methodology of this study. It involves the details of the research objectives, a description of the modelling approach, and the design of the study. The specific objectives of this study are expressed by retrieving the overall research aim defined in Chapter 1. The hypotheses, which are constructed based on literature gap identified in Chapter 2, are structured according to the related research objective. Finally, the methods appropriate to the research and the design of research that is relevant to the objectives are also explained.

4.2 Overview of the research aims and objectives

The main motivation of this Thesis is that the conflicting findings and opinions on competition and collaboration in supply chains. In SCM, competition is viewed as a source of uncertainty and inefficiency, but it can provide contributions to the improvement of supply chain performance. Meanwhile, strategic management considers competition as an important key to the business and economics. On the other hand, collaboration has been regarded as the core element of supply chain success, while not all experts in strategic management support the benefit of collaboration. However, the effectiveness of collaboration strategies suggested in SCM literature is still arguably, such as having long-term partnerships, adopting *single sourcing* approach, and establishing *trust* during collaboration. Therefore, as mentioned in Chapter 1, this study aims to:

> "Explore the impact of competition and collaboration strategies on supply chains from a market perspective".

The research aim of this study is the key driver of the modelling process. It is the basis for the development of the modelling objectives and must be maintained during the modelling process.

This aim is specified to study the interaction between manufacturer and supplier, particularly with respect to the suppliers who supply the key components of the finished products. Hence, this study focuses on modelling the competitive and collaborative behaviour in two-stage supply chains, involving the manufacturer and the supplier. This partnership is critical in supply chains that operate in a market of innovative products, such as automobile and high technology devices. The scope of the behaviour observed is determined based on the gap that is identified in Chapter 2.

In order to transform the aim into a more measurable context, several objectives were developed. The objectives controlled the modelling process, but they were also influenced and improved by the process. This reciprocal approach came about because the model development was iterative. It started with the simplest representation and then detail was added until the key facets of the problem domain had been characterised. Moreover, the literature analysis was carried out continually during the modelling process. The updated knowledge of this affected the definition of the problem situation. This approach made the research to be narrowed into a more specific project scope. Thus, the objectives of this research are:

Objective 1: To develop an agent-based model that explores the effect of competition and collaboration on supply chains.

> A theory-driven approach is used as the basis for developing the model to explore the impact of competition and collaboration on supply chains. The model is described based on the problem situation defined in this study. The use of the ABM approach allows a *what-if* analysis through a bottom-up approach in investigating the resulting emergent behaviour. It also enables a deduction and induction approach to examine the behaviour generated as a result of the intrinsic behaviour of the agents. Instead of observing a single supply chain, the model is constructed to enable market-level analysis, taking a system perspective.

Objective 2: To explore the effect of competition on supply chains and market structure, with regards to the demand fulfilment and survivability of supply chains for the long-term.

> This objective is constructed to investigate the generic effect of competition on the supply chain as a market. Obtaining the explanations from the overall model run, the impact of competition can be generalised, in terms of how competition can and/or could not benefit the supply chain.

Objective 3: To explore the effect of competition and collaboration strategy on the market, in terms of demand fulfilment and survivability of supply chains over the long-term. The following factors are considered to describe the competition and collaboration strategies:

1) *Duration of collaboration*
2) *Number of partnerships*
3) *Trust*

4) Individual firm's survivability
5) Strategic movement, considering the *strategic mutation*

Most of these factors are observed in isolation. However, several factors are investigated in two different situations of the *duration of collaboration*, with respect to the *number of partnerships* and *trust*. This is because the issue of *number of partnerships* and *trust* are often discussed in conjunction with *duration of collaboration* in SCM literature. For instance, it is suggested that either *single-sourcing* or *dual-sourcing* strategy will be more effective in achieving collaboration success when it is applied under the long-term collaboration. Similarly, a higher degree of *trust* will be advantageous when *long-term collaboration* is adopted. The impact of all these competitive and collaborative behaviour on the supply chain is investigated at a market-level, or from a system perspective.

The demand fulfilment is adopted to represent the aggregate measure of supply chain performance or ability in satisfying demand in the market, and it is assessed by calculating the percentage of demand fulfilled relative to all demand that exists. Meanwhile, the supply chain survivability reflects the ability to survive in competition for overall supply chains in the market. This response is measured by counting the number of supply chains which survive at the end of the experiment.

4.3 Research hypotheses

Objective 1 is achieved through the development of the agent-based model into a computer model to allow experimentation, whilst objectives 2 and 3 are fulfilled by performing the experiments. The experimentation is designed according to the hypotheses that are proposed based on the gap found in the previous research, reviewed in Chapter 2. The hypotheses are used to specify the scope as well as the features required for the simulation model. As with the objectives, the detailed hypotheses defined in this study are also enhanced during the development of the model and the process of conducting the literature review. The detailed hypotheses of this research are presented in the following subsections.

4.3.1 *Hypothesis A* aimed to objective number 2: To explore the effect of competition on supply chains and market structure, with regards to the demand fulfilment and survivability of supply chains for the long-term

With regards to the literature discussed in Chapter 2, it is indicated that competition may not have an adverse impact on supply chains. Several studies find that competition can enhance business performance, particularly in supply chains, although others have come to the opposite conclusion. However, these studies have different perspectives and do not examine the impact of a long-term analysis. Therefore, *Hypothesis A* is proposed for this issue, which is:

> "Competition can be beneficial to supply chains, with respect to long-term competition".

4.3.2 *Hypotheses B* aimed to objective number 3: To explore the effect of firm competitive and collaborative behaviour on supply chains, in terms of demand fulfilment and survivability of supply chains over the long-term

Most existing studies regarding SCM assess the collaboration performance based on the manufacturer's standpoint. This is related to the real world situation where manufacturers tend to initiate and lead the collaboration practice. However, in reality, competition and collaboration involve behaviour in the supply and demand market, by considering supplier and customer behaviour. To define and formalise the experimental design, the following hypotheses were constructed. They are related to the important behavioural factors of the manufacturers in both competition and collaboration that are identified in Chapter 2.

Hypothesis B.1: Duration of collaboration

The hypothesis for the issue of the *duration of collaboration* is that

"Adopting longer *duration of collaboration* does not lead to a better long-term demand fulfilment and survivability of supply chains".

This hypothesis is proposed according to the previous studies that suggest long-term collaboration does not consistently benefit the firms (section 2.4.3.1), such as Porter (1997), Parker and Hartley (1997), Grayson and Ambler (1999), Anderson and Jap (2005), Li et al. (2006), and Sun and Debo (2014). As the issue of the *duration of collaboration* is often discussed concurrently with the *number of partnerships*, this hypothesis is applied and tested under two different number of supplier's partnerships. These are:

a) *single-link* supplier, to represent a situation when both the manufacturer and the supplier are only allowed to collaborate with one firm (one-to-one partnerships).

b) *dual-link* supplier, to reflect situations when the manufacturer can only collaborate with one supplier, but the supplier can cooperate with up to two manufacturers (one-to-many partnerships).

Hypothesis B.2: Number of partnerships

The hypothesis of the *number of partnerships* is:

"Having a lower *number of partnerships* does not improve long-term demand fulfilment and survivability of supply chains".

As for *Hypothesis B.1*, this hypothesis is constructed based on SCM literature that presents inconsistent suggestions on the *number of partnerships* (section 2.4.3.2). With respect to the close association between the issue of the *duration of collaboration* and the *number of partnerships* in the literature, this hypothesis is enacted under two situations: when the *duration of collaboration* between the manufacturer and the supplier is short and long.

Hypothesis B.3: Trust

This study intends to observe whether the *trust* which applies at only one side of the supply chains affects the supply chains for a long-term period of competition. Thus, Hypothesis B.3 is arranged into three hypotheses.

Hypothesis B.3.1: The manufacturer trust of the supplier

"Higher *manufacturer trust of the supplier* does not enhance long-term demand fulfilment and survivability of supply chains".

Hypothesis B.3.2: The supplier trust of the manufacturer

"Higher *supplier trust of the manufacturer* does not enhance long-term demand fulfilment and survivability of supply chains".

Hypothesis B.3.3: The customer loyalty towards manufacturer

"Higher *customer loyalty* towards manufacturer does not improve long-term demand fulfilment and survivability of supply chains".

These hypotheses refer to the conclusions of the literature review, which find that *trust* among firms and customer may not be advantageous significantly to supply chains (section 2.4.3.3). As the behaviour of the manufacturer and the supplier are the main interest of this study, *Hypothesis B.3.1* and *Hypothesis B.3.2* are thus examined with respect to two situations: when the *duration of collaboration* between the manufacturer and the supplier is short and long. These situations are considered because *trust* is popularly considered as the enabler of long-term collaboration and *single-sourcing* success in previous research. Therefore, both in *Hypothesis B.3.1* and *Hypothesis B.3.2*, the length of the collaboration is highlighted.

Hypothesis B.4: Individual firm survivability

As this research investigates the effect of the individual survivability of the manufacturer and the supplier to the supply chains, *Hypothesis B.4* is arranged into two following hypotheses.

Hypothesis B.4.1: Manufacturer survivability

"Higher *manufacturer survivability* does not enhance long-term demand fulfilment and survivability of supply".

Hypothesis B.4.2: Supplier survivability

“Higher *supplier survivability* does not improve long-term demand fulfilment and survivability of supply chains".

These hypotheses are based on the gap in the literature that indicates that enhancing the firm survivability for supply chain robustness may not improve supply chain performance and survivability for the long term (section 2.5).

Hypothesis B.5: Manufacturer strategic movement (the strategic mutation)

In section 2.5, it is discussed that strategic move should be taken into account to understand the impact of competition strategy on supply chains, with respect to *strategic mutations*. Although no empirical study discusses the disadvantage of *strategic mutation*, the mistake in strategic movement has been found to be a cause of business failure, such as the case of Nintendo Wii in its early competitive movement (Kim and Mauborgne 2005; Hollensen 2013). Therefore, the hypothesis of the *manufacturer strategic movement (the strategic mutation)* is:

"The competition approach suggested in strategic management, regarding the *strategic mutation*, does not improve demand fulfilment and survivability of supply chains for the long-term".

All of these hypotheses proposed in this study can be summarised by an illustration shown in Figure 4.1.

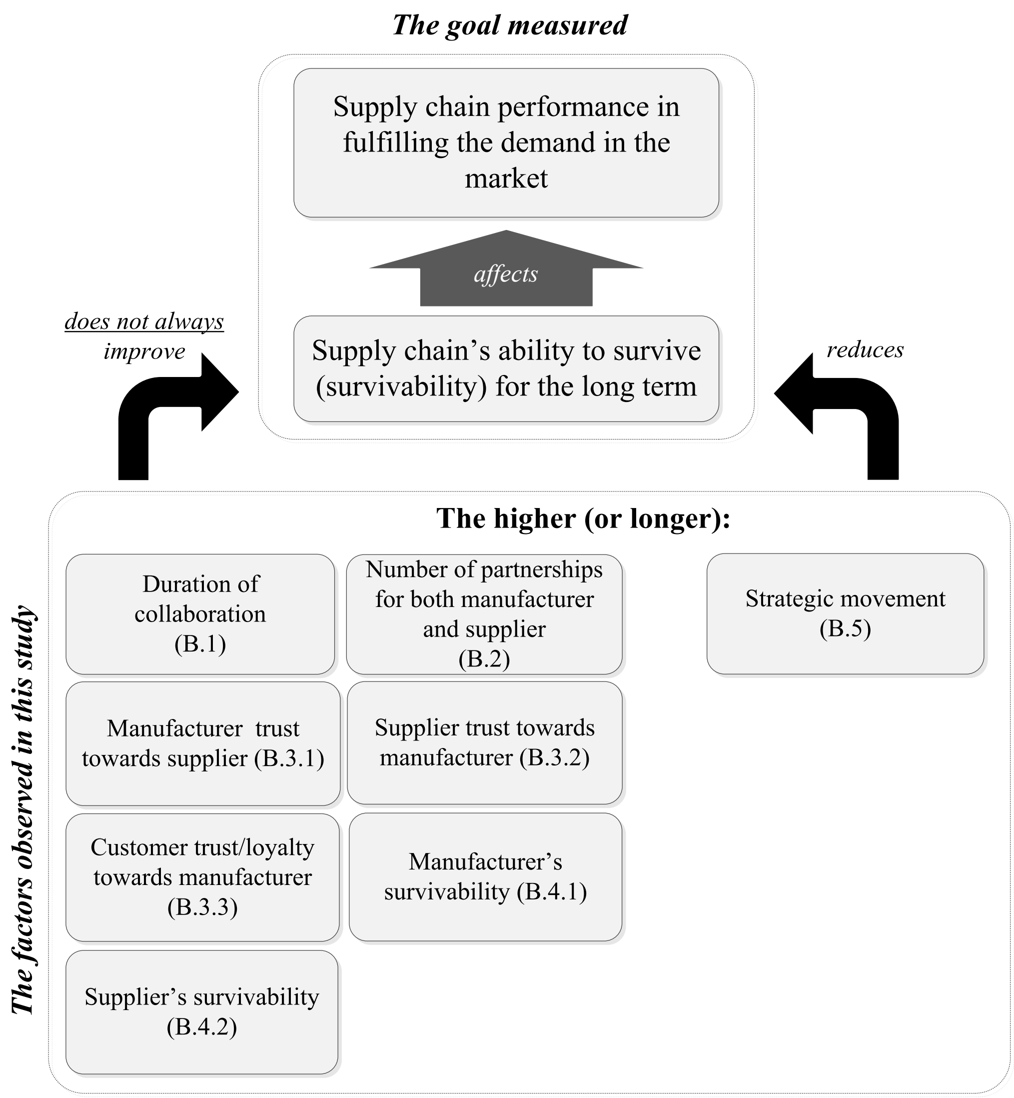


Figure 4.1 The structure of *Hypotheses* B

Two main performance measures are used in the hypotheses: demand fulfilment and survivability of supply chains. The first measure is to assess the supply chain's ability to meet the demand, and the latter represents the supply chain's robustness towards competition. Both measures are observed for a long duration of the competition. Even though the long-term supply chain profitability or demand fulfilment rate in the market is presumed to be influenced by the long-term supply chain's survivability, this relationship does not act as a modelling assumption.

4.4 The modelling approach

This study adopts a theory-driven approach to the modelling instead of empirical observations. This is because the complexity level of the problem situation is high and difficult to observe using empirical data. Therefore, the problem situation of this research was described based on the related literature, which are SCM, social science, and ABM. Although three research domains were involved in this research, the dominant domains used in this study are SCM and ABM.

In general, the modelling process in this study involved the four steps of simulation model development suggested by Robinson (2008). The steps are conceptual modelling, model coding or computer modelling, experimentation and analysis. The output of each stage in this research is, consecutively, a conceptual model, a computer model, and a better understanding of the problem in the real world. The processes were performed in an iterative and repetitive approach as the model was developed incrementally; it started with the simplest representation and then detail was added until the key facets of the problem domain had been characterised.

The conceptual modelling was started from abstracting the problem situation and research aim into the modelling objectives. Each objective is detailed through the hypotheses to make it measurable. The hypotheses led to the description of the model, which includes the experimental factors (or inputs), the model contents, and the responses (or outputs). The experimental design was also constructed in this phase in order to test the hypotheses. These conceptual modelling processes were performed in an iterative and repetitive approach.

The outcome of this conceptual modelling process was a conceptual model. The documentation provides the details required for the computer model development.

The computer model was verified by comparing the individual agent's behaviour with the conceptual model and then debugging the model. The validation was conducted in two approaches: employing a face validation with a simulation expert, and explaining the results using several case studies that were obtained from the existing literature.

When the computer model had been verified and validated, the experimentations were run. Analyses of the results were then conducted to obtain an understanding of the problem situation. The knowledge gained from the model was then reflected back into the problem situation defined in this study, to understand whether the research aim had been achieved.

Figure 4.2 illustrates the modelling approaches applied in this study. The figure is adapted from Robinson (2008) with several modifications to represent the real modelling processes performed in this research. The first modifications focused on the implementation of the theory-driven approach, which was the essential element in defining the problem situation as well as analysing the experimental results. The second component added is the part of the hypotheses development, which was constructed after describing the modelling objectives. The verification and validation of the computer model are also expressed in the diagram; this shows the elements that were compared for each test. The double arrows represent the iterative process, and the circular diagram reflects the repetition process in the model's development. A brief overview of each modelling step is described in the succeeding subsections.

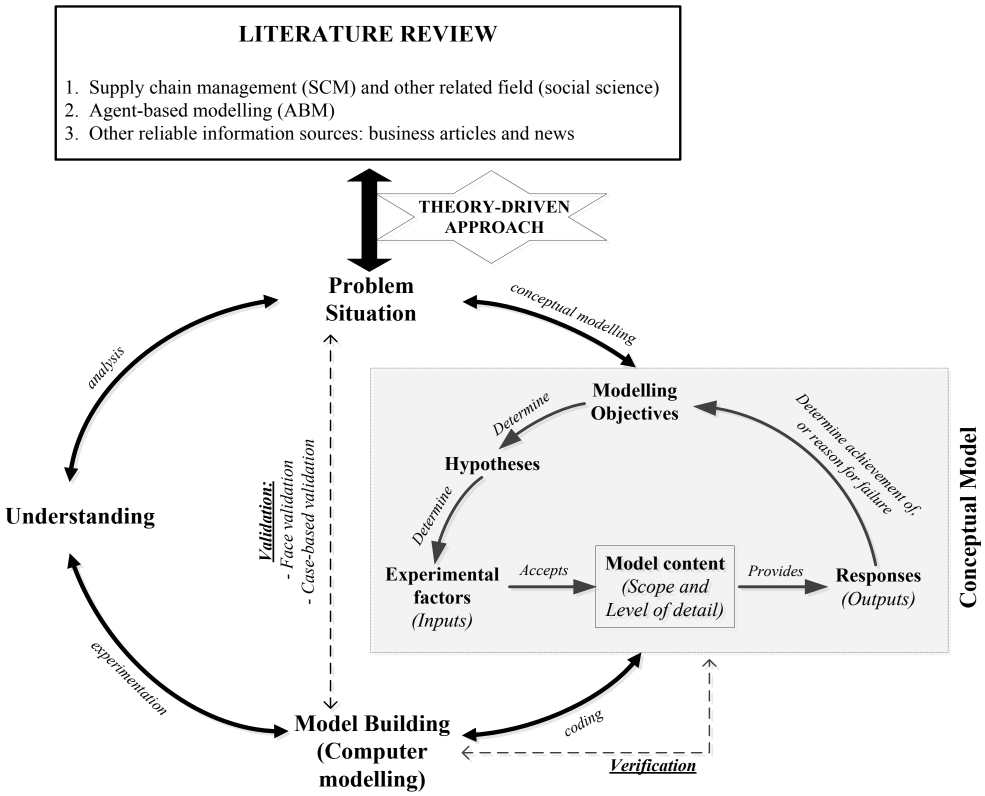


Figure 4.2 The modelling approach of this study (adapted from Robinson 2008)

4.4.1 Conceptual modelling

Robinson (2014) defines conceptual modelling as the process of abstracting a problem in the real world into a model. It bridges the problem description of the real world and the simulation model. It helps the simulation modeller to communicate the research in a simplified way without requiring any technical skill, so it is a part of method models, such as agent-based modelling, system dynamics, and discrete-event simulation. Conceptual modelling also reflects how the simulation model should work (Wang and Brooks 2007). To the author's knowledge, no previous study has made use of the conceptual modelling approach for structuring the agent-based modelling process, so the implementation of this approach in this study can be considered innovative in conducting ABM research.

Meanwhile, a conceptual model is the documentation of the conceptual modelling process. It is apart from the programming language and not related to reproducible issues. The elements of the conceptual model consist of the definition of the modelling objectives, the inputs or experimental factors, the outputs or responses, the content, the assumptions and the simplifications of the model. The experimental factors represent the variables varied in the experimental design or the behaviour space. The outputs or responses reflect the measures employed in the simulation model. The model content consists of the scope and level of detail. The scope is related to 'what to model' and determines the component of the real system that is considered in the model. Meanwhile, the level of detail, which deals with how to model, explains the details for each element defined in the scope (Robinson 2014).

In this study, conceptual modelling was performed by structuring the hypotheses into ABM features, which affect the elements of the conceptual model. The scope of the model content is defined by the agent, the environment, the interaction, the autonomy, and the schedule. The hypotheses are converted by the inputs or experimental factors. The outputs or responses were determined based on the supply chain perspective on demand fulfilment and survivability, but adjusted to enable system perspective analysis.

4.4.2 Computer modelling (coding)

Building a computer model requires three essential elements: coding, testing, and documenting. The coding deals with translating the conceptual model into the computer model, the testing is related to verification and validation tests, and documenting is the process of preparing and providing the evidence of the model building process. The computer code was produced from small or simple behaviour, and each phase of additional complexity was tested and documented. This approach is employed to ensure that the model is verified thoroughly and avoids unsolved errors.

The programming language used in this study is NetLogo. This platform is selected because it has several advantages. Firstly, it is relatively simple to use whilst still providing sufficient features for observing complex problems (Railsback, Lytinen, and Jackson 2006; Wilensky 2013). It also has a simplified programming language and a graphical interface, which enable the modeller to develop an ABM without needing to learn a complex programming language. In addition, much publishable research has been carried out with NetLogo. Finally, NetLogo is a *freeware* and can be run on most operating systems.

4.4.2.1 Verification

Model verification was conducted using several approaches. The first attempt was by writing the logic interpretation of each code in NetLogo. Each code was tested by inspecting the movement and states of the agent as well as the model output. Secondly, the code logic was converted into a simplified representation using flow diagrams. The diagrams guided the modeller in following the model logic for each event or action of the agent. Finally, the model was confirmed to be free from error by running it under several combinations of parameters. The modeller (or the present researcher) also joined the official NetLogo mailing list during the computer model's development. The mailing list is useful for confirming the logical flow of the code by sharing some parts of the code.

4.4.2.2 Validation

Two validation approaches were applied to assess the plausibility of the model. The first approach was the plausibility test through face validation. This assessment was conducted by an expert in simulation. This validity check was performed by comparing the simulation result to an available theoretical competition model. In this stage, the model was concluded to have a similar resulting pattern to a classical competition model developed by Hotelling (1929). The second validity test was attempted by explaining the simulation result with respect to the competition cases found in the literature. This attempt is called case-based explanation.

4.4.3 Experimentation

The experiments were conducted when the model had been verified and validated. The experimental design, from now on referred to as the behaviour space, was constructed based on the hypotheses of this research. As the basis for the behaviour space development, a base run was defined. Each scenario in the behaviour space was defined by varying the level of the variable associated with the hypothesis. Several experiments in the behaviour space were performed under several supply chain strategies, in order to understand the extent of the impact of the competitive and collaborative behaviour that was implemented.

4.5 Analysis method

After the results of the experiments have been obtained, a structured analysis is conducted. A different analysis approach was performed to achieve the objectives described in section 4.2, particularly in objective 2 (exploring the generic influence of competition on the supply chains and market structure) and objective 3 (exploring the effect of the firm competition and collaboration strategy on the supply chains).

For objective 3, *Hypothesis A* is achieved by analysing the overall emergent behaviour from the experiments. If the output contained extreme values, visual investigations are performed by rerunning the simulation and inspecting the agents' movements during the simulation run on the NetLogo space. The visual investigations are conducted by capturing the agents' movement in several ticks. This assisted the modeller in providing an explanation of how the extreme values came about, and this was done by inspecting the changing agent's distribution on the strategic space over time, particularly with respect to the manufacturer and supplier positions. The next subsections discuss the detail of method analysis for each hypothesis.

Meanwhile, objective 3 (*Hypotheses B*) are answered by comparing and interpreting the effect of each behavioural factor. In general, the analysis approach is composed of two stages. The first stage describes the outcomes of each scenario in the behaviour space. The boxplots analysis is employed to visualise and examine the pattern of the data characteristics for each of the demand fulfilment in the market and the supply chain's ability to survive in the market. The demand fulfilment is measured by the *supply chain fill rate,* and the supply chain's ability to survive is assessed by the *number of supply chains in the market*. The second stage is inferential analysis. This approach is used to draw a conclusion about the significant difference between the scenarios in each experiment. Having compared several inferential methods, the nonparametric Mann-Whitney U test with Bonferroni corrections is selected for concluding the multiple comparisons.

4.5.1Analysis method for *Hypothesis A*

Objective 2 is related to the exploration of the generic influence of competition on supply chains. It aims to find an explanation for the contradicting views found in the literature, which is associated with the benefit of competition on supply chains. In this study, the generic effect of competition is examined by considering the generic emergent behaviour of all the experiments. The investigation is conducted with two approaches.

4.5.1.1 Approach 1: Visual investigation

The visual investigations were conducted by observing the agents' movement in each tick. The interactions between the agents, which are represented as links that connect two agents, were also inspected in each tick. In this case, observations on the collaboration link created between the manufacturer and the supplier are more highly emphasised than the relationship between the manufacturer and the customer. If a behavioural pattern emerges consistently in each run of all the experiments, it can be suggested that the emergent pattern is a result of competition.

To measure the agent's movement as well as its collaboration links, a time series graph of the average position of the manufacturer and the supplier in their supply chains was defined in the model. This enabled the author to record and quantifies the emergent behaviour concluded from the visual investigations.

4.5.1.2 Approach 2: Model outputs investigation

The model outputs used in this study (the *supply chain fill rate* and the *number of supply chains* which can survive in the market) were also employed to analyse and conclude the generic emergent results of competition. These measures were used to identify and describe the repeated pattern found in all the experiments. Moreover, they were useful to explain the extreme outputs that occurred several times in the different experimental factors. They can also be the basis of explaining whether the demand fulfilment (*supply chain fill rate*) depends on the supply chain's ability to survive (the *number of supply chains in the market*), which is expected in Figure 4.1.

4.5.2 Method of analysis for *Hypotheses B*

As explained in the previous section, two analytical approaches were conducted with respect to the simulation results: the boxplots analysis and the Mann-Whitney U test. Each analysis method is detailed in the following subsections.

4.5.2.1 Stage 1: The boxplots analysis

The boxplots analysis was performed to visualise the data characteristics of the outputs, with respect to the *supply chain fill rate* and the *number of supply chains in the market* which can survive in long-term competition. The boxplot approach is useful for describing the data characteristics of the simulation results. It provides visual comparisons between scenarios, particularly when trying to visualise the mean, median, range, quartiles, and data distribution. The resulting analyses in this stage would support the conclusion obtained in the inferential approach conducted in the next stage.

If the boxplots show an extreme pattern, particularly when the results are extremely narrow, a data proportion is presented to comprehend the detail data pattern of the output. Extreme boxplots are likely to occur in the results of the *number of supply chains in the market*. In several experiments, it can lead to only two values as the result of the emergent outcomes at the end of several runs. This is because the value range of the *number of supply chains in the market* is far more limited than the *supply chain fill rate*; the maximum value is ten, and the lowest scale is zero. When the outputs only consist of two values, the boxplot analysis would not be sufficient to visualise and explain the data characteristics. Hence, providing a tabulation of the proportion of occurrences of each value provides more information in this extreme case.

4.5.2.2 Stage 2: Inferential statistics

Prior to determining the use of Mann-Whitney analysis, the use of t-confidence intervals with the Bonferroni correction (also known as the Bonferroni inequality) was considered. This approach is commonly used to compare multiple scenarios in a simulation study (Robinson 2014). Moreover, the t-confidence interval is appropriate when the population standard deviations are not known (Groebner et al. 2011). This condition is fitting to analyse the results of a simulation study.

In addition, an effort to lower the output variation was also performed. Adopting the use of common random numbers, as suggested by Robinson (2014), the experiments were replicated by controlling the seed numbers for the simulation run. Nonetheless, these attempts have been found inappropriate to infer the results. Hence, the one-tailed Mann-Whitney U test was selected as the appropriate method for drawing the comparisons. The details of the approach selection process are given in the following sections.

The use of the parametric approach: the confidence intervals

Confidence intervals are considered to be a better approach than hypothesis testing in comparing multiple scenarios, particularly when the sample size is not large, and the variability degree of the observed factor is relatively not small. It provides more information than hypothesis testing through the size of the interval. The data size of the experiment could be relatively not large and may be statistically insignificant, but it has important implications (Gardner and Altman 1986). Furthermore, this method was conducted because the number of data points in the results is considered to be sufficient for performing a parametric analysis. The number of data for each scenario is 50 data points, which can meet the assumption of normality for the population.

However, the resulting data patterns for both the *supply chain fill rate* and the *number of supply chains in the market* are not normal. This non-normal pattern was concluded based on normality analysis, which involves an investigation of central tendency (mode, median, and mean), data shape (*skewness* and *kurtosis*), and outliers detection. The normality feature of the population was also inferred in this investigation.

The shape of the data distribution was inspected by measuring *skewness* and *kurtosis*. *Skewness* provides information for the direction of skew, and kurtosis indicates the sharpness or peakness (pointiness) relative to a standard bell curve. These measures have been used to test data normality and study the robustness of normal theory procedures (Joanes and Gill 1998), as adopted by parametric confidence intervals. Most of the outcomes of these analyses lead to the conclusion that not all outputs of each scenario had normal features for the population.

Even though checking the normality assumption of the output is rarely conducted in a simulation study, the conclusion obtained from the parametric statistics is highly affected by this assumption. Moreover, most boxplots of the experimental results indicate that the outputs are likely to be skewed. Significant numbers of experiments also have multi-modals, which suggest that the data shape is likely not to be normal.

The outliers were also investigated in detail. It was assured that they are part of true observations. They are caused by the agents' behaviour and not by error measurement, or by unverified or invalid codes in the computer model. They are legitimate outputs which require consideration and should be treated similarly to other data. Moreover, the outliers are the modes of the experimental variable. They help in the explanation of the resulting behaviour, as performed in analysing the emergence effect of the manufacturer behaviour when making strategic movements. Thus, removing the outliers would potentially lead to a less robust analysis. Furthermore, when the outliers were removed, this did not always turn the data into a normal shape.

Regarding the nature of the outliers, this indicates that the normality assumption probably does not correspond to the situation that is simulated. The population distribution of the emergent outcome is still not confidently known even though the agents are homogeneous. Moreover, the sample size is not relatively large, so removing the outliers would not necessarily improve the analysis and render it to be more scientifically robust. Thus, it can be concluded that the use of the parametric approach is not appropriate for comparing the scenarios in this study. A detailed description and an example of this normality analysis are provided in Appendix A.

Common random numbers for variance reduction

In addition to normality analysis, the attempt to reduce the output variance by applying similar streams of random numbers was found to be ineffective. Variance reduction was performed by applying a certain range of seed numbers for the replication of each scenario. For instance, the number of replication for each scenario is fifty, so seeds 1 to 50 were employed to control the random number generation of the model. This method is known as the common random approach suggested by Robinson (2014).

According to the NetLogo guidelines, the process of generating the random numbers in NetLogo is based on a deterministic procedure, which is pseudo-random (Wilensky 2013). In software engineering, the pseudo-random procedure has been developed into many approaches. They have a different mechanism to generate the same sequence of random events. This means that the effective use of common random numbers is highly dependent on the mechanism of the platform.

The use of common random numbers affects the construction of the confidence intervals. If the variance is reduced, the data produced by each seed would be considered as paired data, so the confidence intervals are constructed by using a paired t approach. Otherwise, the data of each scenario should be treated as independent samples. Robinson (2014) suggested that the common random numbers are considered to be working properly when:

$$S_D^2 < S_1^2 + S_2^2 \qquad \text{(eq. 4.1)}$$

where S_D is the standard deviations of the mean differences between scenario 1 and 2, S_1 is the standard deviations of the mean of scenario 1, and S_2 is the standard deviations of the mean of scenario 2.

However, the application of common random numbers does not always result in a lower output variance. Moreover, controlling the random seed generation does not result in a similar sequence for each scenario. NetLogo provides different random seed sequences in every different parameter settings. This means that the samples of each scenario run with similar seed numbers are generated from different populations. In other words, controlling the seed number in NetLogo only allows the observer to reproduce the run, but it does not generate a similar sequence for the agent's movement. This issue has never been discussed yet in the previous work as no ABM studies has considered the use of common random number in NetLogo. Therefore, this work does not apply common random number to compare the results of multiple scenarios run in NetLogo. The example of the investigation of the use of common random numbers is presented in Appendix A.

The Mann-Whitney U test: the selected approach

Because the outputs are not normal and the approach of common random number cannot be adopted in NetLogo, nonparametric analysis was chosen to infer the comparisons. Although nonparametric statistics are known to be less sensitive than the parametric approach, they are not biased by outliers as well as the shape of the data.

The Mann-Whitney U test was selected as the samples are from different populations. The one-tailed approach is used to infer which scenario has a better performance. The alternative hypothesis of this test is that the scenario with a higher median (which has a smaller U-value) is significantly different from the other.

A normal approximation is applied to the test because the sample size is considered to be large, where 50 replications have exceeded 20 (Groebner et al. 2011). The Bonferroni correction is applied to reduce the likelihood of incorrectly concluding the insignificant difference in multiple comparisons (Ludbrook 1998; Bender and Lange 2001; Robinson 2014). In other words, the Bonferroni correction reduces the risk of rejecting a true null hypothesis. This probability of error in normal approximation is known as alpha, or Type 1 error, or level of significance. The Bonferroni correction is suggested when at least two statistical tests are constructed. Once the Bonferroni correction is used, it is assumed that the correlation between the tests is low and this condition conforms to the results of the experiments.

The overall level of significance implemented in the inferential analysis is 10%. This means that the likelihood that at least one of the ten comparisons which falsely infers the true mean is less than or equal to ten per cent. In order to compare the five scenarios in each scenario in the behaviour space, ten comparisons of the Mann-Whitney U test are required. With the Bonferroni correction, the level of significance for each comparison is adjusted to 1% (the overall level of significance /number of comparisons = 10%/10) with a critical value -2.33.

The U-statistics are obtained by using the following formulae (see Groebner et al. 2011):

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - \sum R_1 \qquad \text{(eq. 4.2)}$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - \sum R_2 \qquad \text{(eq. 4.3)}$$

where n_1 and n_2 are the sample sizes from populations 1 and 2, and $\sum R_1$ and $\sum R_2$ are the sum of ranks from samples 1 and 2.

The normal approximation is given by:

$$Z = \frac{U - \frac{n_1 n_2}{2}}{\sqrt{\frac{(n_1 n_2 (n_1 + n_2 + 1))}{12}}} \quad \text{(eq. 4.4)}$$

where U is a minimum value between U_1 and U_2. If Z is less than the critical value (-2.33), the null hypothesis can be rejected. This means that the claim that the scenario with the higher median (with a smaller U value) has a significant higher output than the other scenarios. Compared to the parametric approach, the Mann-Whitney U test provides identical conclusions. However, this nonparametric analysis results in more reliable conclusions for the non-normal data. Thus, the Mann-Whitney U test is applied to compare the *supply chain fill rate* for all the experiments in this study.

4.6 Commentary on the results

Prior to concluding the overall results of the experiments, a model structure investigation was performed to relate the results to the model characteristics. This was conducted by recalling the model setup, assumptions, and simplifications. The logical flow of each experimental factor was also analysed to understand how the emergent outcomes had resulted. The logic flow or mechanism of the experimental factor structured the complexity of the model. It framed the interdependencies among the experimental factors, outputs, attributes and behaviour of all the agents. These relationships could not be explained in the process of model building and the conceptual modelling process. An illustration of the factors that are considered in commenting on the experiment results is presented in Figure 4.3.

Discussions relating the results of the present research to existing literature and reality (case studies) were also incorporated to achieve the main aim of this study, which is "to understand the effect of competition and collaboration on supply chains". Following the summary of the analysis, further comments were provided to interpret the results in conjunction with business practice, particularly with respect to competition and collaboration in upstream supply chains.

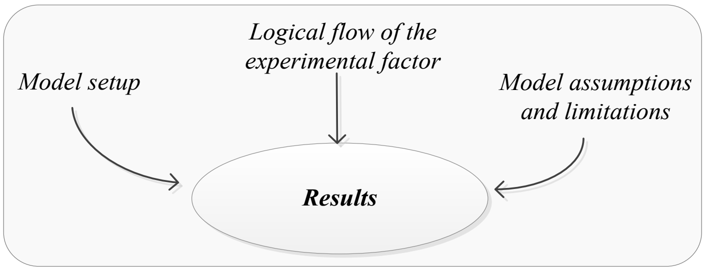


Figure 4.3 The basis for commentary on the results of this study

4.7 Summary

According to the literature gap and research opportunity identified in the literature review, the current chapter has outlined the research aim of this study, which is to understand and explore the effect of competition and collaboration on supply chains. Three objectives were set out, and each of them was supported by several hypotheses formulated based on the review of previous research given in Chapter 2. Furthermore, the modelling approach was described, which followed the steps of simulation modelling suggested by Robinson (2008). This consists of conceptual modelling, computer modelling, experimentation, and analysis. The methods of analysis were designed with respect to achieving each of the objectives. Lastly, a brief description of how the discussion was performed in this Thesis has been expressed.

CHAPTER 5 THE AGENT-BASED MODEL OF SUPPLY CHAIN COMPETITION AND COLLABORATION

5.1 Introduction

This chapter explains the agent-based model of supply chain competition and collaboration. It presents the conceptual model, followed by the computer model. The conceptual model details the inputs, outputs, model contents, simplifications and assumptions of the model. Meanwhile, the computer model describes the model interface in NetLogo briefly, as well as the verification, validation, and parameter setup for the behaviour space.

5.2 Conceptual model

The conceptual model describes the modelling objectives, the inputs or experimental factors, the outputs or responses, the content, the assumptions and simplifications of the model. The structure is adapted from Robinson (2008), and the ABM features are incorporated into the model content. The fundamental ABM properties described in the conceptual model are the agent, environment, interaction, autonomy, and schedule. These elements are based on the ABM main features defined by Macal and North (2013), and Robertson (2003).

The objectives of this study have been presented in Chapter 4. They are detailed in several hypotheses described in section 4.3. In general, the modelling objectives are to explore the extent to which certain competitive and collaborative behavioural factors influence long-term demand fulfilment and survivability of supply chains. Due to the problem's complexity, each factor is isolated during the experiment; the interaction or interdependencies among behavioural factors are not considered in this study. An overview of the conceptual model is presented in Table 5.1, and the details of each element are described in the following subsections.

5.2.1 Model contents: Scope and level of detail

As previously mentioned, the extent of this research encompasses modelling competition and collaboration in supply chains that involve a manufacturer and supplier. In doing so, two-stage supply chains are modelled, and a market for innovative products is considered, such as for automobile and high technology devices. The detail of each scope is presented in the following subsections.

Table 5.1 The conceptual model

Model content (Scope and Level of Detail)
The agent: Customers, manufacturers, and suppliers. **The environment:** Two-dimensional strategic space defined as the degree of efficiency and responsiveness. **The interaction:** Each customer creates a link with a manufacturer, and each manufacturer makes connection/s (collaborations) with one or several suppliers. **The autonomy:** *CUSTOMERS* Each customer selects a manufacturer in accordance with its preference presented by its position, and its degree of *willingness to compromise* towards its preference, represented as a circular radius from its position. *MANUFACTURERS* Each manufacturer selects one or several suppliers based on its preference presented by its position, and its degree of *willingness to compromise* towards its preference, represented as a rectangle distance from its position. It also always moves to the closest new customer. *SUPPLIERS* Supplier competition movement depends on manufacturers' position and its *trust* to the manufacturer. **The schedule:** The agent's movement, link creation, life (for manufacturer and supplier to allow them to die), and output measurement
Inputs/Experimental Factors
Manufacturer behaviour: 1. *Duration of collaboration* between supplier and manufacturer, 2. *Number of partnerships*, 3. *Trust* to supplier (as a representation of *manufacturer trust of the supplier*), 4. *Survivability*, and 5. *Strategic movement*. **Supplier behaviour:** 1. *Number of partnerships*, 2.*Trust* to manufacturer (as a representation of *supplier trust of the manufacturer*), and 3. *Survivability*. **Customer behaviour:** *customer loyalty*.
Outputs/Responses
1. The *supply chain fill rate*, and 2. The *number of supply chains in the market*.
Main Assumptions and Simplifications
All agents are homogeneous and have no learning ability.

5.2.1.1 The agent

The agents are defined as the customers, manufacturers, and suppliers. The customer agent can be interpreted as a group of customers, retailers, or a warehouse (i.e. a large distributor) in an innovative product market. Each customer has a fixed preference in buying the product. Meanwhile, suppliers compete to attract manufacturers to cooperate with them, and manufacturers try to optimise their market share by attracting customers.

Each agent has attributes and behavioural features. The attributes characterise what the agent is, and the behavioural features describe how the agent acts (North and Macal 2007). In this study, the agents are described based on two types of attributes, namely fixed and variable. The fixed attributes represent the agent's features which remain the same or constant during the simulation runs. Meanwhile, the variable attributes are the agent's characteristics, which change as the *time unit* ticks. Both attributes affect the agent's behaviour in making decisions.

For customers, the fixed attributes are specified by the agent's type (customer), its buying preference towards a product, and the compromise limit to its preference. The buying or product preference is represented by the agent's position in the environment, which in the model is fixed (the customers do not move). The compromise limit reflects the maximum degree of the customer's willingness to compromise toward their product preference, referred to as the *customer's willingness to compromise* hereafter.

Meanwhile, the variable attributes represent the agent's state, which changes during simulation runs. This is explained by the link existence with a manufacturer to denote its state of buying a product from that manufacturer. The link is created when a customer finds a manufacturer which meets its *willingness to compromise* and is close to its buying preference. However, the customer will not create a link if the closest manufacturer has no link with any supplier, or the customer decides to maintain its link with another manufacturer.

The customer's behavioural features are characterised by the customers' action in choosing a manufacturer. It selects the closest manufacturer which stays within the limit of the *customer's willingness to compromise*. This behavioural decision is also affected by the *customer loyalty* towards the manufacturer. When the customer decides to be loyal to the company, it will continue buying the product from the manufacturer. This can be represented as a situation when a customer keeps buying other innovative products that are produced by the similar manufacturer. A summary of the customer's attributes and behaviour is presented in Figure 5.1.

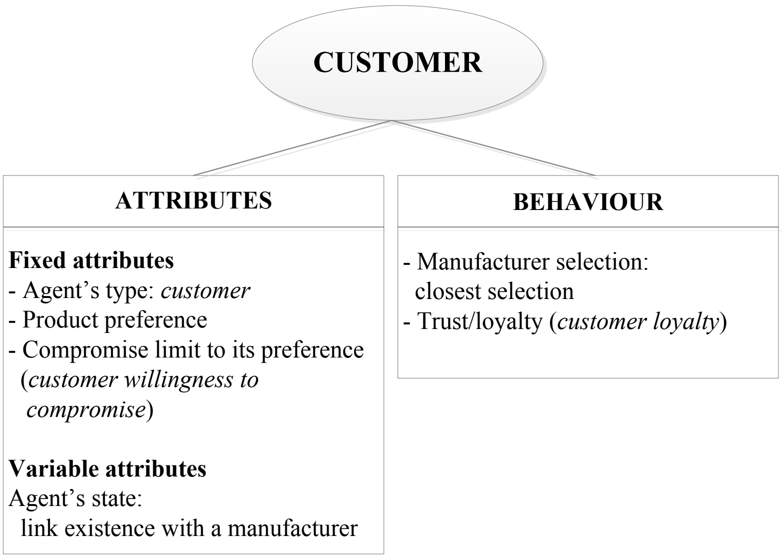


Figure 5.1 The attributes and behaviour of the customer agents

For the manufacturers, the fixed attributes are characterised by five features: the agent's type (manufacturer), the fixed limit of compromise towards its supplier preference (*manufacturer's willingness to compromise*), the *lifetime* or *survivability* limit, the *duration of collaboration* with the selected supplier, and the maximum *number of partnerships* with the suppliers. The *manufacturer's willingness to compromise* represents the tolerable capability gap between the manufacturer and the supplier when the manufacturer has to link with less efficient and/or responsive supplier/s. This factor also represents the degree of supplier/s' impact on the manufacturers or supply chain capability. This effect can limit the manufacturers' competition movement because the supply chain capability is the aggregate capability of the manufacturer and its suppliers.

The effect of the *manufacturer's willingness to compromise* to the manufacturer position adjustment reflects an old saying in SCM that 'a chain is only as strong as its weakest link' (Simchi-Levi et al. 2000; Chopra and Meindl 2007). In SCM, the capabilities of the suppliers are considered to be of the utmost importance to the performance of entire supply chain. If a manufacturer, or a company, has suppliers with capabilities that are not in accordance with the manufacturer's requirement, the entire chain could collapse, and the customers would immediately feel its effects. Reflecting on this situation, in this study, the manufacturer's capability or strategic position was regarded as the representation of the supply chain's strategic position, since it interacts with downstream customers directly.

The limit of *manufacturer life* (*survivability*) is described in two separate conditions:

1. When it does not manage to find a supplier nor customer to link with.
2. When it is working with less efficient and/or responsive (or undesired) supplier(s) to represent losses. This situation represents manufacturers with less efficient and/or responsive suppliers can survive longer than the other manufacturers with no supplier at all. Thus, the minimum value that can be set for *manufacturer survivability* with the undesired supplier is equal to the survivability without the supplier.

Both are defined by a time length in which a manufacturer can exist under each of these conditions.

The variable attributes of the manufacturer agents are described as the manufacturer's state during the simulation and are specified as follows.

1. Manufacturer's strategic position which changes as it competes with other manufacturers,
2. The existence of the manufacturer's link with one or several suppliers, depending on the design of the experiment,
3. The existence of the manufacturer's link with the customers, and
4. Manufacturer's life, determined by its connection with the supplier and customers. It is limited by its survivability limit as defined in the fixed attributes.

Meanwhile, the manufacturer behaviour in competition and collaboration is characterised as follows.

1. Acquisitive, represented by manufacturer movement which is continuously searching and changing the supply chain strategy to attract customers as many as possible. In other words, the manufacturers move dynamically in the simulation space while customers do not move.
2. Supplier selection behaviour, by choosing one or several suppliers who are more efficient and responsive than the manufacturer. Otherwise, when the desired supplier is not available, it would pick one or several suppliers who are less efficient and/or responsive than the agent and stay within the *manufacturer's willingness to compromise*,
3. *Trust*, by keeping the link with the previous supplier when the agent decides to be loyal, and
4. Strategic movement, to represent competitive movement by changing its strategic position gradually to attract more customers. However, the manufacturer can choose to make a *big leap* or create an extreme strategic change or *mutation*.

A summary of these attributes and behaviour is presented in Figure 5.2.

Compared to manufacturers, the attributes of supplier agents are relatively simple. The fixed attribute is defined as the agent's type (supplier), lifetime or survivability limit, and a maximum *number of partnerships* with the manufacturer. The limit of the supplier's life is determined by the time length in which a supplier can exist in the system when it does not have a link with any manufacturer. The variable attributes represent the agent's state described by the strategic position, link existence with one or several manufacturers (depending on the experimental setting), and the supplier's life. The supplier would die when it reaches the limit of its survivability.

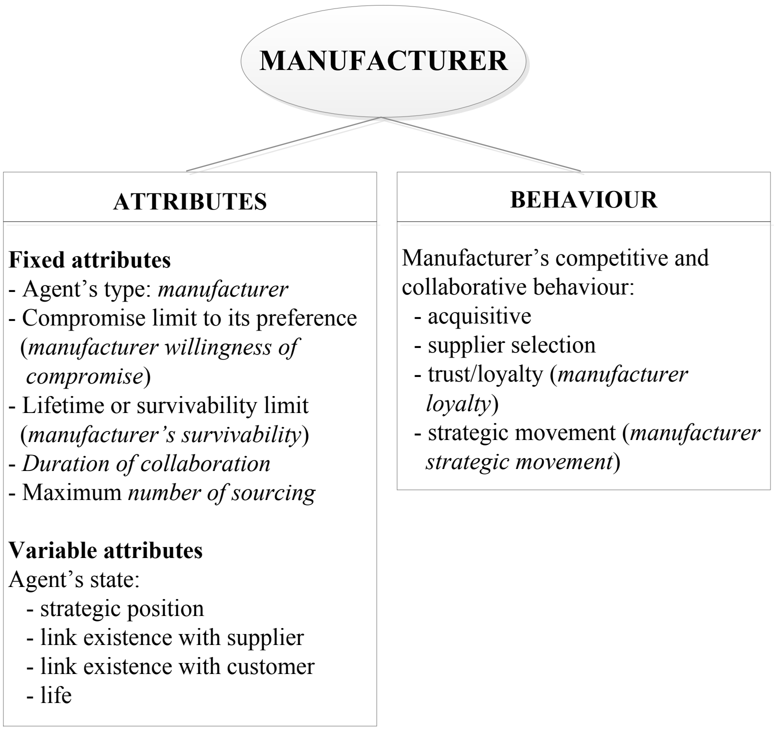


Figure 5.2 The attributes and behaviour of the manufacturer agents

Meanwhile, the supplier's competitive and collaborative behaviour is represented by its acquisitiveness in having a new manufacturer and its strategic movement affected by its *trust* towards the manufacturer. When a supplier decides to be loyal to the manufacturer, it will follow the manufacturer's strategic change; otherwise, it would approach another manufacturer to work with the agent. These supplier features are illustrated in Figure 5.3.

5.2.1.2 The environment

The agents act in a two-dimensional environment, which represents their strategic position from an SCM perspective. The dimensions are referred to supply chain competitive strategy as described by Chopra and Meindl (2007), namely efficiency and responsiveness.

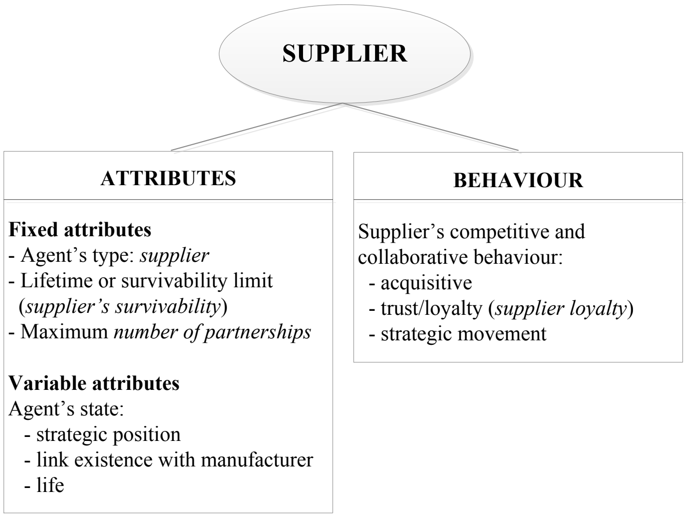


Figure 5.3 The attributes and behaviour of the supplier agents

These dimensions are interpreted differently by each agent. From the customers' viewpoint, it reflects the customer preference. Manufacturers also interpret the dimension as manufacturer preference aside from their strategic position relatives to the others. From the supplier's perspective, the dimensions only represent their relative strategic position.

For the customers, the *x*-axis represents the product's price as sold by the manufacturer. A manufacturer that is further to the right would offer more expensive products, but would also provide more value to the customer. Within a limit, customers can choose to purchase products that are cheaper or more expensive than their preferred price and value. Meanwhile, the *y*-axis reflects the customers' perception of the product innovation level. The perception of innovation level increases when moving down the axis. Again, customers can choose to purchase products that are more or less innovative than their preference, but within a limit.

From the firms' standpoint, the *x*-axis delineates the operational efficiency (further to the left is more efficient), and the *y*-axis represents operational responsiveness (closer to the bottom is more responsive). The efficiency level is assumed to be proportional to the material price and value while responsiveness is inferred as the innovation level.

Within the environment, two infeasible areas reflect the limits to the competitive landscape. So, for a product with a relatively high level of customisation, variety or innovation, it is impossible to have a very low price (or cost) and product value, and vice versa.

Besides this, the feasible area for being a highly efficient and more responsive firm, or being a highly responsive and more efficient company (zone *b*), is narrower than the area for having a high responsiveness but a less efficient capability, or eminently efficient but less responsive competitiveness (zone *a*). This uneven size represents a situation where it is hard to have highly efficient and more responsive operations. A widely held view is that supply chains are likely to perform either in high responsiveness but be less efficient, or be very efficient but less responsive. Moreover, the feasible area reflects the non-linear relationship between responsiveness and efficiency in supply chain practice. As explained in section 2.3.1 and Figure 2.3, a higher responsiveness level of supply chain operations can either enhance or decrease the supply chain efficiency. In contrast, if a supply chain decides to be highly efficient, this decision will make the supply chain to be very likely less responsive. In short, higher responsiveness levels can lead to a wider range of efficiency degree (zone *a* in Figure 5.4), and higher efficiency levels would limit the responsiveness (zone *b* in Figure 5.4). An illustration of the agents and their environment is presented in Figure 5.4. The agents are scattered on the space to depict their positions corresponding to the others.

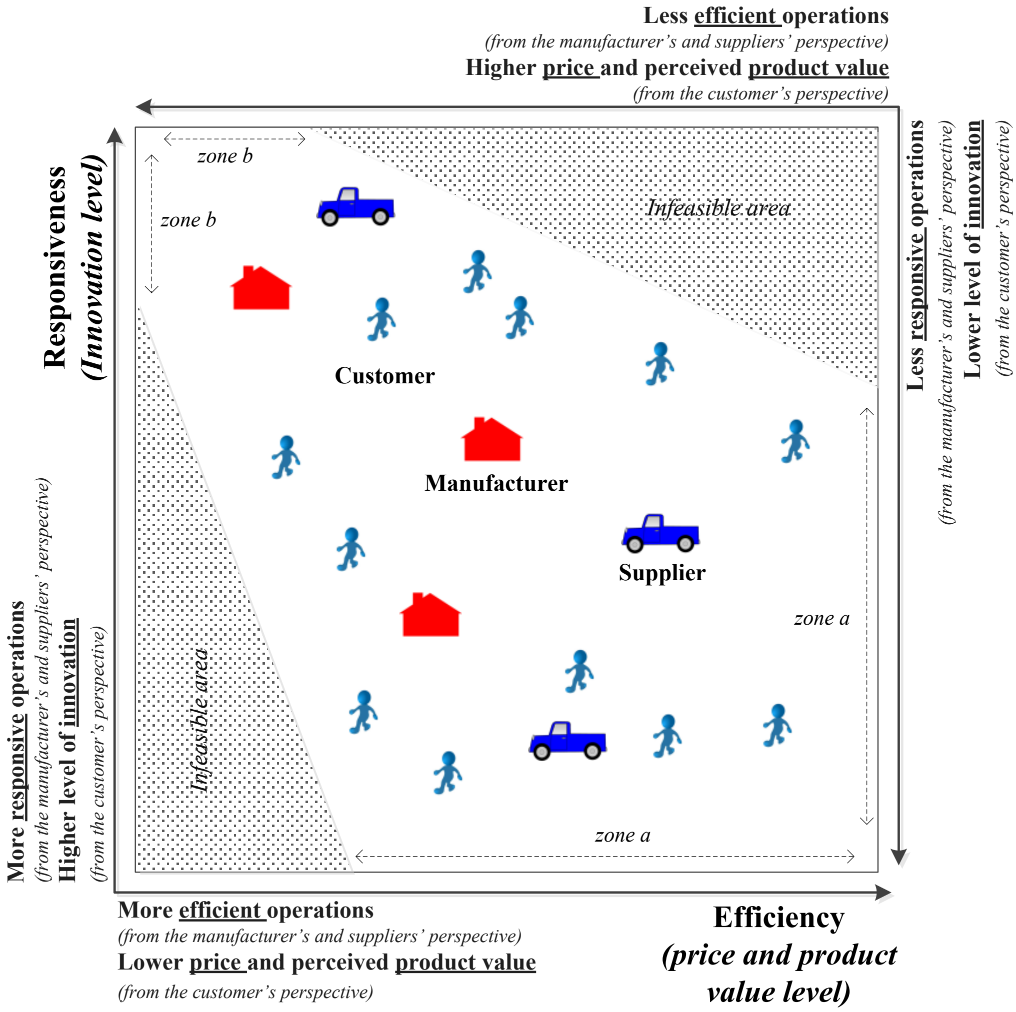


Figure 5.4 An abstraction of the agents within their environment

5.2.1.3 The interactions

The interaction between the agents is characterised by the link created between different types of agents. Each manufacturer agent creates a connection with one or several suppliers, while the customer agent generates a link with a manufacturer agent. The customers create links with a manufacturer which represents the decision to purchase the manufacturer's product. However, the customers will only buy a product from a manufacturer which has at least one link with supplier agents. Meanwhile, manufacturers create links with suppliers which represent the decision to collaborate with one or several suppliers. The creation of these links is ruled by each agent's autonomy.

5.2.1.4 Autonomy

The autonomy of a customer is indicated by its preference and behaviour in selecting a manufacturer within its *willingness to compromise*. The preference is represented by the agent's position and its degree of *willingness to compromise*. The customers decide which manufacturer is most appropriate for supplying to their preference with a particular degree of *willingness to compromise* (Figure 5.6). The circular shape of *willingness to compromise* reflects a simplification of customer's characteristics in general, where customers will to either reduce or increase their standard on buying preference, for both innovation level *(y-axis)* and price *(x-axis)*.. This representation is adopted from the agent-based model of customer-firm interaction introduced by Robertson and Caldart (2009). The customers also have *trust/loyalty*, which represents the probability of choosing the same manufacturer as previously selected.

The manufacturer's autonomy is characterised by its behaviour in choosing supplier/s and in changing the strategic position for the competition. Each manufacturer selects one or several suppliers based on its preference presented by its position and its degree of *willingness to compromise*. They collaborate with suppliers while they compete to attract the closest new customer. This behaviour represents firm's acquisitiveness in gaining more revenue continuously as most companies are hard to feel satisfied with their current achievements.

The manufacturers' preference is to select suppliers who are more responsive and efficient than their capability. This enables the manufacturers to supply the customers according to their strategy for efficiency and responsiveness. However, if they could not collaborate with the desired suppliers, the *manufacturer willingness to compromise* feature allows the manufacturers to work with the suppliers who are less responsive and efficient than their capability (Figure 5.5). The manufacturers who could not manage to find suitable suppliers would die after they have exceeded their lifetime or survivability limit, defined as a number of *time units* in which the manufacturer can survive without a supplier.

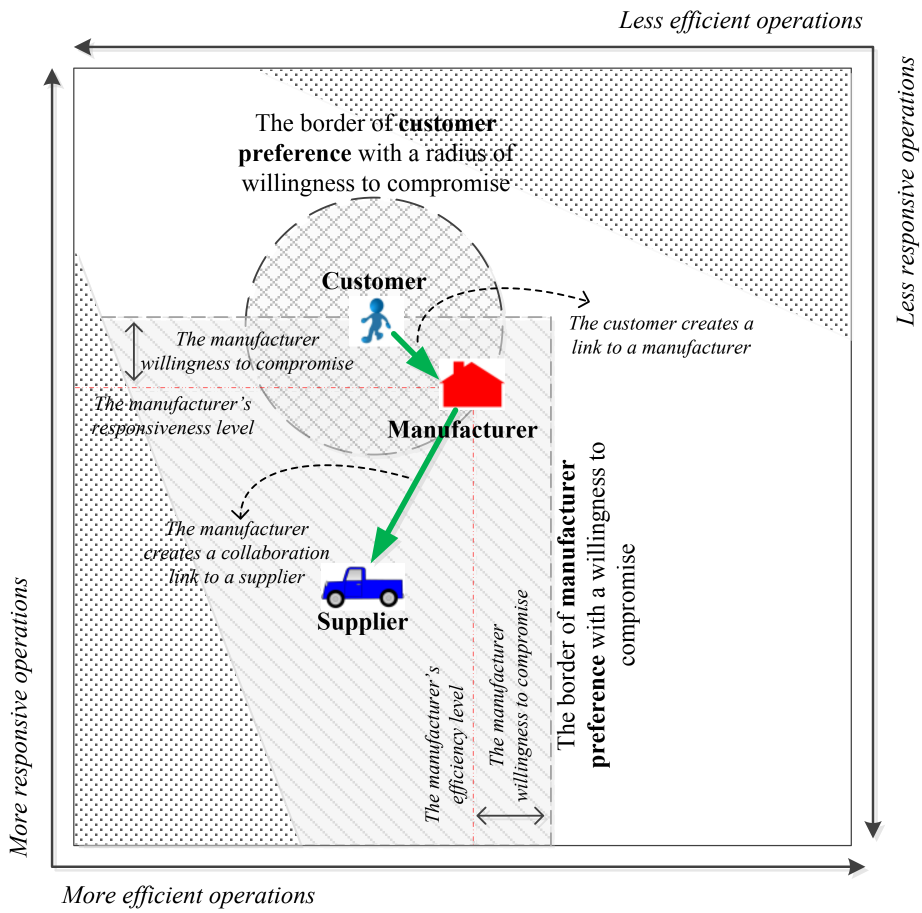


Figure 5.5 The abstraction of link direction and border of customer and manufacturer preference, with a degree of *willingness to compromise*

The mechanism of the *manufacturer willingness to compromise* is illustrated as follows. The manufacturer's position in the model represents its preference in selecting supplier/s. For instance, if the manufacturer stays at coordinate (50, 40), it will firstly choose a supplier/s which stay in the coordinates between 0 and 50 for the *x*-axis, and between 0 and 40 for the *y*-axis. It represents the manufacturer's rule in choosing suppliers which are more efficient and responsive than the manufacturer, which are reflected by the *x*-axis and *y*-axis respectively. However, if the manufacturer cannot manage to find any available supplier inside its preference range, it will consider to working with the suppliers which are less efficient and/or less responsive than the agent. The less efficient suppliers stay in the higher coordinate of *x*-axis than the manufacturer's *x*-axis coordinate, and the less responsive suppliers have larger *y*-axis coordinate than the manufacturer's position. If the degree of *manufacturer willingness to compromise* is 5%, it reflects that the maximum distance of compromise range is:

$$5\%\ x\ the\ maximum\ diagonal\ distance\ of\ the\ simulation\ space$$

If the maximum coordinate of both *x*-axis and *y*-axis are 67, the *maximum diagonal distance of the simulation space* will be $\sqrt{67^2 + 67^2} = 94.75$. Then, the distance of the *manufacturer willingness to compromise* will be 5% x 94.75 = 4.74, calculated from the manufacturer's position. Thus, the area of *manufacturer willingness to compromise* is between 50 and 54.74 for the *x*-axis (efficiency level), and between 40 and 44.74 for the *y*-axis (responsiveness level).

The manufacturer determines the relationship between supplier and manufacturer. They set the length of the relationships (*duration of collaboration*). When the manufacturer trusts the current supplier, it will continue the partnership with the same supplier when the previous *duration of collaboration* ends. The probability of the manufacturers working with the same supplier for the next collaboration is represented by the *manufacturer trust*.

Lastly, supplier autonomy is represented by its movement during the competition. The movement direction is affected by the manufacturers' position and the supplier's *trust* towards the current manufacturer. An illustration of agent's interactions and movement is presented Figure 5.6.

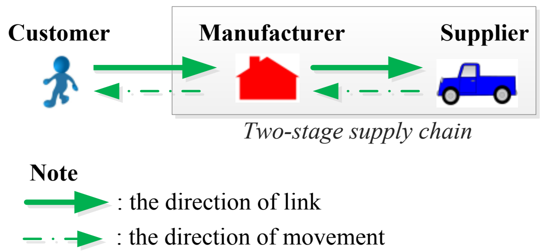


Figure 5.6 Agent's interactions and movements

5.2.1.5 The schedule

The schedule is characterised by the agent's movement for the competition, link creation for the relationship between the agents, life (for the manufacturer and supplier), and output measurement. These features of the schedule are the events executed in sequence at the same time; so when all of these events have been performed, the simulation time or time step (known as a *tick* in ABM) is executed in a discrete *time unit*.

The *tick*, hereinafter referred to as *time unit*, represents a period, which is considered sensible to allow a firm to make a slight adjustment to their strategic position. Regarding the operations in supply chains, the duration of making a slight strategic change can be related to the time bucket used in the sales and operations plan (SOP). This plan (SOP) affects other plans and company strategies, such as the marketing strategy, the workforce or resources plan, the procurement strategy, product development, and the plant expansion plan.

The time bucket commonly used in the SOP is between 3 and 18 months. The duration is mostly affected by the total production lead time. In the computer model, we assume that one *time unit* represents at least 3 months for making a gradual strategic change. A period of 3 months is also considered as the common *time unit* representation for the seasonal demand and supply pattern that is likely to be related to the operations along the supply chain of innovative products.

5.2.2 Inputs or experimental factors

The key issues examined in this study are competitive and collaborative behaviour. Collaborative behaviour includes the collaboration strategy, which involves the *duration of collaboration* between a supplier and a manufacturer, and the *number of partnerships* for both the manufacturer and supplier. Collaborative behaviour also represents the characteristics of the agents, considering *trust* and survivability. Meanwhile, competitive behaviour as represented in this study is the acquisitiveness and the distance of the strategic movement. Acquisitive behaviour reflects the desire to earn more revenue on an ongoing basis, as a representation of competition motives. For instance, manufacturers change their strategy by incrementally moving towards nearby customers that are currently not buying from them. The manufacturers have no way of assessing the effect of moving towards a new customer, but due to acquisitiveness, they would always attempt to gain new customers. In doing so, they may lose some of their current customers to another manufacturer.

In a similar way, suppliers move to try and gain collaborative relationships with new manufacturers by moving towards the closest manufacturer with whom they do not currently collaborate. However, this study does not explore the supplier's strategic movement as observed for the manufacturers.

Taking the type of agents, the inputs or experimental factors considered in this research can be classified into three categories. The first group is the classification of the manufacturer's behaviour in competition and collaboration, the second represents the behaviour of the suppliers, and the last category reflects the customer's behaviour. The inputs regarded in the first group are manufacturers' strategic movement, the *duration of collaboration*, the *number of partnerships*, *trust*, and survivability to work with undesired supplier/s. The second group consists of the supplier *number of partnerships*, *trust*, and survivability. Meanwhile, the third category only consists of the *customer loyalty*. A categorisation of the inputs is summarised in Table 5.2 and also described in the following subsections.

Table 5.2 The inputs or experimental factors

Manufacturer behaviour	Supplier behaviour	Customer behaviour
✓ ***Duration of collaboration*** ✓ ***Number of partnerships*** ✓ ***Manufacturer trust*** ✓ ***Manufacturer survivability* to work with undesired supplier/s** ✓ **Probability of making extreme strategic changes (*manufacturer strategic movements*)**	✓ *Number of partnerships* ✓ *Supplier trust* ✓ *Supplier survivability*	✓ *Customer loyalty*

5.2.2.1 Manufacturer behaviour

The experimental factors concerning manufacturer behaviour are described in the following way:

1. *Duration of collaboration*

   The *duration of collaboration* represents the manufacturers' agreement to maintain the partnerships. In this study, it is defined as the length of the relationships between manufacturer and supplier.

2. *Number of partnerships*

   The *number of partnerships* is another debatable supply chain collaboration approach on the supply side. In the model, this factor is defined as the maximum number of suppliers that each manufacturer can have.

3. *Manufacturer trust*

The *manufacturer trust* reflects the degree of *manufacturer*'*s trust* towards the supplier. In the model, it is assumed that when a manufacturer trusts a supplier, which is currently linked to the firm, it will be loyal to the supplier by continuing to collaborate with the previous supplier. A high level of *trust* is likely to lead to a similar effect as extreme long term collaboration. The probability of *manufacturer trust* follows random uniform distribution. For example, if the *manufacturer trust* is 75%, and the random number generated is 0.6 (below 75%), the manufacturer will maintain its collaboration link with the supplier.

4. Survivability to work with undesired supplier/s (*manufacturer survivability*)

   Manufacturer survivability represents the manufacturer's ability to cope with loss when it collaborates with a less efficient and less responsive supplier. It can be related to the firms' adaptability that is supported by the company's tolerance to failure. When a company has a better ability to survive, by having a higher tolerance to loss, it would have more opportunities to adjust its strategy as well as grow its business (Reeves and Deimler 2011). The variable can also be interpreted as a government support or subsidy for helping the companies to survive, as practised by the Japanese government in protecting their local manufacturers (Dyer and Ouchi 1993).

5. Probability of making extreme strategic changes (*manufacturer strategic movement*)

   This factor represents the likelihood that all manufacturers in the market have an extreme strategic change in each *time unit*. It examines whether the *big leap* or *strategic mutation* strategy applied by the manufacturer affects the supply chains in the market.

5.2.2.2 Supplier behaviour

The inputs of this group simulate an environment that is subject to complexity and uncertainty in the upstream market. It is characterised by the characteristics and bounded-rationality of the suppliers. The inputs of the supplier behaviour are explained as follows.

1. Supplier's *number of partnerships*

   This factor reflects a situation where suppliers can supply more than one manufacturer. It is defined as the maximum number of manufacturers with whom each supplier can work. This factor is addressed because most SCM studies consider the *number of partnerships* from the manufacturer's perspective only. The reason for this is that collaboration initiators commonly come from the manufacturer, not the supplier. However, since SCM considers the supplier and the manufacturer as a supply chain rather than individual firms, the issue of the *number of partnerships* for the supplier should be addressed from both firms' perspective.

2. *Supplier trust*

   Trust represents the probability that the suppliers would follow the manufacturer strategic movement so they can maintain their current relationships. Once a supplier links with several manufacturers, it has to choose the manufacturers to which it would remain loyal. The *supplier trust* is represented by the supplier's movement, which follows the manufacturer's strategic position. This supplier's movement represents the supplier's effort to minimise the capability gap between the supplier and the manufacturer in the supply chain.

3. *Supplier survivability*

   Supplier survivability reflects a supplier's robustness or ability to survive when it has no collaboration with a manufacturer. Regarding one of the findings of Dyer and Ouchi (1993), the suppliers of Japanese car manufacturers supported by the government are regarded as one of the success factors in Japanese car supply chains. However, with regards to *manufacturer survivability*, the individual *firm survivability* does not guarantee long-term supply chain success, as proven by the decreasing market share of Japanese electronics firms recently.

Unlike with the manufacturer, it is assumed that there is no negative consequence for the supplier who links with a manufacturer who is less efficient or responsive than the firm. Thus, *supplier survivability* only depends on the link existing with the manufacturer/s without regards to the manufacturer's position.

5.2.2.3 Customer behaviour: *customer trust/loyalty*

The customer behaviour represents the downstream market uncertainty, and one popular issue in business competition is customer *trust* towards the manufacturer. This factor is generally addressed as customer *loyalty* in the literature and found to be significant to the business performance through long-term relationships with customers. As the increase of *trust* is found to be linear to the improvement of *loyalty* (O'Cass and Carlson 2012), this Thesis considers *customer trust* and *customer loyalty* as a single variable, namely *customer trust/loyalty*.

This variable is described as the probability of the customer having cooperation with the same manufacturer. The lowest value of *customer trust/loyalty* (0%) represents the likelihood of customers shifting their selection to another manufacturer that stays within their *willingness to compromise* is 100%. It means that when the customers have no *trust/loyalty* towards manufacturer, the customers will always select a different manufacturer which is closest to them and stays within the *customer willingness to compromise*. Meanwhile, the highest percentage of trust (100%) reflects the fact that once the customer selects a manufacturer, it will keep buying the product from that manufacturer even though the firm has moved away from the customer's *willingness to compromise*.

The probability follows random uniform distribution and it affects the links between the customer and the manufacturer. For example, if the *customer loyalty* is 75%, and the random number generated by NetLogo falls to 0.7 (below 75%), the customer will remain connect to the previous manufacturer although the firm's position has shifted to be outside the customer's *willingness to compromise*.

5.2.3 Outputs

Two are the main outputs obtained from this model are the *supply chain fill rate* and the *number of supply chains in the market*. The *supply chain fill rate* represents the aggregate performance of the supply chains in the market, measured by the proportion of demand fulfilled with respect to the total available demand. Meanwhile, the *number of supply chains in the market* indicates the number of supply chains which can survive in long term competition.

The *supply chain fill rate* employed in this study is a simplification of the supply chains *service level* as a measure of supply chain performance. Rather than measuring the order fulfilment in probability as the real definition of *service level*, the *supply chain fill rate* is calculated as the percentage demand satisfied relative to all the available demand.

The definition of the *supply chain fill rate* has also been simplified from the actual definition. In SCM, the metric is described as the fraction of demand satisfied from the available inventory, or as the proportion of demand that comes to be sales (Chopra and Meindl 2007). However, this study does not regard inventory in measuring the *supply chain fill rate*. Instead, the metric measures the fraction of customer demand that is satisfied from the available supply chains in the market. This simplification assists the modeller or observer in assessing the supply chains performance as a market.

In model building, this measure is calculated as the number of customers served divided by the total number of customers in the system. For instance, if the available demand in the market is 1000 customers and the available supply chains serve only 100 customers, the *supply chain fill rate* is equal to (100 / 1000) x 100% = 10%.

Meanwhile, the *number of supply chains in the market* is measured by counting the number of manufacturers which have at least one link with suppliers. It does not include the manufacturers and suppliers which have no collaboration link, so the *number of supply chains in the market* can be fewer than the number of available manufacturers and suppliers.

The *supply chain fill rate* and the *number of supply chains in the market* are expected to have a positive relationship, where a higher *number of supply chains in the market* provides a higher *supply chain fill rate*. The logic is that when more supply chains can survive for a long term, more demand or customers can be served. This is indicated by a higher *supply chain fill rate*. In other words, a higher *supply chain fill rate* is an indicator of the better performance of the supply chains in the market. This goal is supposed to be achieved when more supply chains can survive the competition.

In addition to these two principal measures, the strategic position of the supplier and manufacturer within their supply chain is presented in the graphical outputs of the computer model, as presented in the computer model representation in Appendix B. These outputs are just additional measures and were employed in understanding the generic effect of competition.

5.2.4 Assumptions and simplifications

The model developed in a simulation study is intended to be a basis for arguing the predicted or *what-if* situation compared to the existing condition. In this sense, models might not clearly need to picture the real world (Pidd 1999). In other words, all simulation models have limitations which are driven by its assumptions and simplifications. Simulation models are developed by employing several assumptions and are simplified from the real system. Model assumptions represent uncertainties or beliefs which exist in the actual system. Meanwhile, simplifications are made to pace the model development and use, such as removing elements and interactions which have no significant influence on model accuracy (Robinson 2014). There are several ways of simplifying the model: aggregating the model elements, deleting elements and interactions, displacing elements with random variables, ignoring infrequent events, simplifying the rule, splitting the large model into smaller simulation models**.** Compared to the real world, the model advanced in this study holds several assumptions and simplifications. It affects the model content proposed in the conceptual model, which consists of the agent, the environment, the interaction, the autonomy, and the schedule.

For the agent, the model considers all agents to be homogeneous. This assumption has been widely applied in most strategic competition models (Robertson 2004). Also, all agents have no learning ability, so they could not update their behavioural rules. The manufacturers have a similar bargaining position to the suppliers, so one of them could not pressure another. As for the suppliers, they provide critical material to the manufacturer; hence, manufacturers who cannot find a supplier with whom they can collaborate with will die.

Several assumptions and simplifications also compose the model environment. First, the dimensions of efficiency and responsiveness are assumed to be independent of each other. From the customer's perspective, product value is considered to be linearly proportional to the product cost, whilst the operation efficiency is linearly proportional to the product price.

Most of the assumptions and simplifications prevail over the agent's interaction and autonomy. They affect the agent's state, link creation, and movement. For the customer, they have a consistent preference for all time (i.e. they do not move). It is also assumed that the *customer's willingness to compromise* is not affected by manufacturer behaviour. This assumption may not represent reality as customer preference and *willingness to compromise* can be influenced by the company's competitive strategy. The customer also has a simplified *trust/loyalty*. When it decides to *trust* a manufacturer, it will continue buying a product from the manufacturer although the company has moved outside its *willingness to compromise*. This situation also applies to *manufacturer trust of the supplier*s.

For the manufacturer, the agent is assumed to offer only one type of product to the customers. It does not allow for having product differentiation or more than one market segment to serve. It is also assumed that the manufacturer is the leader for the collaboration. It decides the *duration of collaboration* and the number of suppliers that can work with them. The agent also has *trust* towards their supplier by continuing to choose the same supplier as previously selected. When a manufacturer link with more than one supplier, it would treat the suppliers equally (i.e. not loyal) unless it decides to be loyal to one of them. In this case, the *manufacturer trust* and the *supplier trust* is independent of each other. Hence, the manufacturer behaviour does not influence supplier behaviour towards the supplier and vice versa. In addition, once a manufacturer links with a supplier, the supplier is regarded as being capable of providing a continuous supply without disruption. Thus, the supplier would not die when it has a collaboration link with at least one manufacturer.

For the schedule, the decisions of all the agents are assumed to be made at the same *tick* or *time unit*. Even though in the computer model they are generated based on a particular sequence, there is no delay in the decisions, which occurs in reality. This is due to the homogeneous agents who act similarly, and they make the decision at the same time. Furthermore, as the model does not explain a case study of a particular market, the *tick* could not be defined in an exact period. Instead, the *ticks* in the computer model henceforward will be called as *time unit* to represent a generic representation of a period. As stated in Section 4.3.1.2, the *time unit* is considered to lie between 3 and 18 months, allowing for the firms to make a gradual strategic change. A summary of the assumptions and simplifications employed in this study is given in Table 5.3.

5.3 Computer model

The model is developed in NetLogo and consists of three parts: setup, outputs, and execution buttons. An illustration of the computer interface can be seen in Appendix B. This section explains the technical process of model building. It is structured into three subsections: the setup, the model testing (verification and validation), and the generic emergent outcome.

Table 5.3 Assumptions and simplifications applied in the model scope

Model scope		Assumptions and simplifications
The agent	1	All agents are homogeneous and have no learning ability.
	2	The manufacturers and suppliers have an equal bargaining position, so the manufacturers cannot pressure the suppliers and vice versa.
	3	The suppliers supply a critical component to the manufacturer. Thus, when a manufacturer could not manage to find a supplier for several periods, it would die.
The environment	1	Efficiency and responsiveness are independent of each other.
	2	Product value is linearly proportional to product cost.
	3	More efficient supply chain operations provide a lower price for customers.
The interactions and autonomy	1	Customer preference, *willingness to compromise* and *trust/loyalty* are not influenced by the behaviour of the manufacturers.
	2	Customers have a consistent preference for all time (i.e. they do not move).
	3	Once a customer decides to be loyal to a manufacturer, it would continue buying a product from the manufacturer although the firm has moved outside its *willingness to compromise*. This situation also applies to the *manufacturer trust towards the supplier*s.
	4	Manufacturer behaviour does not affect customer behaviour, and supplier behaviour does not influence manufacturer behaviour.
	5	Each manufacturer is only able to offer one type of product to the market so that it has only one market segment
	6	Manufacturers lead the supply chain collaboration.
	7	*Trust* (for the manufacturers and the suppliers), and *duration of collaboration* are independent of each other.
	8	When a manufacturer links with more than one supplier, it selects a supplier to be loyal to randomly without considering *supplier trust*.
	9	No supply disruption is applied.
The schedule	1	All agents' decisions are made at the same *time unit*.
	2	One *tick* represents a *time unit*, which may lie between 3 and 18 months.

5.3.1 The model setup

The variables for the setup are characterised into two types; they are non-input (fixed/constant) and input (experimental factor). Both types of variables are fundamental in defining the problem situation that is simulated in this study. The detailed description on each type of variables is provided in the following subsections.

5.3.1.1 Fixed setup (non-input variables)

The non-input parameters (including the variable name in the computer model) are the:

1. number of customers *(#customer*)
2. number of manufacturers (*#manuf*)
3. switch for turning on the supplier agent (*SupplierOn?*)
4. switch for turning on the control of the seed number (*ControlSeed?*)
5. seed number (*SeedNumber*)
6. customer's willingness to compromise (*willingness_to_compromise*)
7. switch for allowing the suppliers to move (*SuppMove?*)
8. switch for allowing the suppliers to die (*SuppDie?*)
9. switch for manufacturer movement (*ManufMove?*)
10. switch for allowing the manufacturer to die (*die?*)
11. limit of the *manufacturer survivability* with no supplier (*SurvivabilityWithoutSupplier*)
12. manufacturer's willingness to compromise (*manuf_willingness_to_compromise*)
13. manufacturer's position adjustment (*AdjustPosition?*)

The description of each parameter included in the interface is detailed in Appendix C.

The non-inputs variables characterise the base situation of the problem, particularly in representing innovative product markets. In general, it situates a market with a limited number of manufacturers which compete. The number of suppliers which have the capability to supply the key components of the finished products is also highly limited. Hence, the supplier's operational capability, in terms of efficiency and responsiveness, has a significant influence on the manufacturer's strategic position. If a manufacturer is linked with a less efficient and/or responsive supplier, its strategic movement would be limited by the supplier's strategic position; in the model, this situation is defined by the procedure of manufacturer's position adjustment.

In the model setup, the number of customers is set to 1000 customers. It represents an unlimited demand that is available in the market. This setup also represents a real situation where the size of actual demand in the market is never exactly known. Meanwhile, both the number of manufacturers and suppliers are adjusted to 10 agents, which is far lower compared to the available demand in the market (i.e. the number of customers). It reflects a very limited number of firms which can compete in the market of a type of innovative product. These adjustments of the number of agents (customer, manufacturer, and supplier) have no significant impact (insensitive) on the conclusion of the multiple comparisons analysis, with respect to the *supply chain fill rate* and the *number of supply chains in the market*.

The market is considered to have a relatively low *willingness to compromise* for both customers' product preference and manufacturers' preference in selecting supplier/s. This is due to the characteristics of the product which could not be substitutable easily by competitors' products. From the customer's perspective, the *willingness to compromise* represents the product characteristics. If the product deals with daily consumption or primary needs, such as consumer goods, the *willingness to compromise* would be very high since customers must have the product. In contrast, if the product is highly innovative, the *willingness to compromise* would be very low. As this study focuses on collaboration between supplier and manufacturer in innovative products market, the *customer willingness to compromise* is set to be very low. As a consequence, not all customers interact with a manufacturer. This situation represents the main feature of innovative product where not all customers have to buy an innovative product. For instance, not everyone has a tablet PC. In other words, not all customers' preference can be fulfilled by the available firms in the market.

The degree of *willingness to compromise* is presented as a percentage, which is converted to a radius of compromised preference relatives to the diagonal length of the square space. The radius is calculated from the customer's fixed position. The lowest degree of *willingness to compromise* (0%) represents the customers who would only buy a product that has the same supply chain features, in terms of efficiency and responsiveness, as they wanted. If there is no manufacturer that precisely meets their wants, they will not buy any product from the available manufacturers. In contrast, if the value of the *willingness to compromise* is 100%, the customer will always purchase a product from any manufacturer although the available manufacturer provides a product that is far from their actual preference.

With respect to representing innovative product markets, the *willingness to compromise* was set to a constant 10% for the customers and 5% for the manufacturers. The constant of *customer's willingness to compromise* is an approximation of the demand market feature such that the customers only buy an innovative product when the product price and value are close enough to its preference. This factor is sensitive to *the supply chain fill rate*, but it is not sensitive (i.e. it has no significant impact) to the *number of supply chains in the market*.

Unlike the *customer's willingness to compromise*, the *manufacturer's willingness to compromise* provides more complex interactions and autonomy than the *customer's willingness to compromise*. In the model, this parameter affects manufacturers in two ways. The first is related to the manufacturers' decision in selecting suppliers. Once a manufacturer could not find a supplier who is more responsive and efficient than the firm, it would choose a supplier who is less efficient and/or responsive than the manufacturer. The tolerable capability gap between the manufacturer and the less efficient and/or responsive supplier is represented by the value of the *manufacturer's willingness to compromise*. Secondly, the parameter affects the manufacturer's strategic movement. Once a manufacturer has collaborated with a supplier/s, its strategic position would be influenced by its supplier capability, particularly when the supplier/s is less efficient and/or responsive. In this situation, the *manufacturer's willingness to compromise* adjusts the manufacturer's strategic position once the gap between the suppliers and the manufacturer is more than the tolerable capability gap.

The constant of the *manufacturer's willingness to compromise* illustrates the importance of the supplier. As this study focuses on modelling partnerships with suppliers who provide *strategic* or *bottleneck items*, the 5% *willingness to compromise* is considered as a sensible small compromise level with regards to the manufacturer's strategic position. This factor is insensitive to the result of inferential analysis, which employs the Mann-Whitney U multiple comparisons, unless the constant is set to an extremely small value (less than 1%). A summary of constants and descriptions for each of the non-inputs values is presented in Table 5.4.

Table 5.4 The non-input variables and the constants for the simulation setup

Non-input variable	Constant	Descriptions
Global setup		
#customer	1000	Many customers in the market.
#manuf	10	A limited number of manufacturers are available.
SupplierOn?	On	Supplier agents are simulated.
ControlSeed?	On	The seed number is controlled.
SeedNumber	1-50	The range of seed number used is from 1 to 50; it means the number of replications is 50 for each experiment.
Demand setup		

Non-input variable	Constant	Descriptions
willingness_to_compromise	10%	Customers have a relatively limited compromised level to their preference.
Supply setup		
SuppMove?	On	Suppliers are competitive and acquisitive.
SuppDie?	On	Suppliers can die.
Manufacturer behavioural rules in competition		
ManufMove?	On	Manufacturers are competitive and acquisitive.
die?	On	Manufacturers can die.
SurvivabilityWithoutSupplier	4 *time units*	Manufacturers have a relatively short duration to survive when they could not manage to find a supplier to link with.
Manufacturer behavioural rules in collaboration		
manuf_willingness_to_compromise	5%	Manufacturers have a very limited compromise level to select the appropriate supplier/s.
AdjustPosition?	On	Manufacturers' position is affected or adjusted by their suppliers' position, when they link with less efficient and/or responsive suppliers.

The mechanism of *willingness to compromise* (a non-input variable) is sometimes interchangeable with *trust/loyalty* (an input variable). For the customer agent, a customer would not automatically switch to another manufacturer when it decides to be loyal to a manufacturer, even if the manufacturer moves away from the customer. The customer would stay with the manufacturer until the next time they decide to be disloyal and look for another manufacturer. This mechanism also applies to manufacturer agents with respect to supplier agents. As such, *willingness to compromise* is set only to come into play when an agent (a customer or a manufacturer) decides to be disloyal and choose a new manufacturer. The details of the logic flow of the computer model are provided in Appendix E. The NetLogo code can also be found in Appendix H.

5.3.1.2 Input variables: the experimental design or the behaviour space

The input variables play important roles in the behaviour space, particularly in achieving objective 3 – exploring the effect of firm competition and collaboration strategy on supply chains. They include the:

1. *customer loyalty,*
2. *manufacturer survivability to work with undesired supplier/s*
3. *duration of collaboration*
4. *maximum number of partnerships*
5. *manufacturer trust*
6. *manufacturer strategic movement*
7. *supplier survivability*
8. *supplier trust*

The idea of behaviour space construction is by varying the agent's attributes and behaviour. However, the agent's attributes and behaviour are not only characterised by the input parameters, but also by the non-input variables in the model setup. The non-input defines the agent's attributes and behaviour that have a fixed or constant value in all experiments, while the input refers to the experimental factor. A list of the variables in the simulation setup which affect the agent's attributes and behaviour is provided in Table 5.5.

The experimental design is set into two parts: the base run and the behaviour space. The base run represents the default behaviour when most of the experimental factors are adjusted to their lowest value to represent the conventional business relationships, except the *manufacturer survivability* to work with undesired supplier/s. In the base run, the *manufacturer survivability* is set at medium value or level because this factor is sensitive to the outputs, so the medium level of this experimental factor is considered to be the realistic point to represent the average manufacturer's ability to survive when it works with the undesired suppliers. Meanwhile, the behaviour space characterises the *what-if* analysis to test the hypotheses proposed in this study. Each experiment in the behaviour space consists of 5 scenarios to represent 5 levels of expected influence of each experimental factor on the model outputs.

Table 5.5 Variables' feature in the simulation setup

Agent's attributes or behaviour	Setup type: Non-input (fixed/ constant)	Setup type: Input (experimental factor)
Customer		
1. *Customer's willingness to compromise*	✓	
2. *Customer loyalty*		✓
Manufacturer		
1. *Manufacturer's willingness to compromise*	✓	
2. *Manufacturer survivability:*		
- without supplier	✓	
- to work with undesired supplier/s		✓
3. *Duration of collaboration*		✓
4. *Maximum number of sourcing*		✓
5. *Manufacturer trust*		✓
6. *Manufacturer strategic movement*		✓
Supplier		
1. *Supplier's maximum number of partnerships*		✓
2. *Supplier survivability*		✓
3. *Supplier strategic movement*	✓	
4. *Supplier trust*		✓

Each scenario of the experiment is described as the following:

- the lowest extreme level of the experimental factor (scenario 1)
- the low level of the experimental factor (scenario 2)
- the medium level of the experimental factor (scenario 3)
- the high level of the experimental factor (scenario 4)
- the highest extreme level of the experimental factor (scenario 5)

The values of each experimental factor are determined hypothetically according to the practical experience towards the implementation of the experimental factor.

In other words, empirical judgement is adopted to set the experiments in the behaviour space. These experiments are run after the computer model had been verified and validated.

Driven by the main hypothesis in each research objective, the exploration process for each experimental factor was conducted dynamically. It means that the behaviour space was also defined in a dynamic approach. For example, for the *duration of collaboration*, it was presumed that the results would be different when the suppliers could link with more than one manufacturer, so the *duration of collaboration* was run under two levels of the supplier *number of partnerships*: *single-link* supplier and *dual-link*-supplier. A discussion of behavioural space is presented in the next chapter. Each scenario in the behaviour space was run for 1000 *time units* with 50 replications. A description of the experimental factor setup for the base run and the behaviour space is provided in Table 5.6. A detail of experimental design or behaviour space is presented in Table 5.7.

Table 5.6 The base run and the behaviour space

	Experimental factor	Base run	Behaviour space
1	*Duration of collaboration*	The shortest duration, to represent the no collaboration approach.	5 scenarios, including the base run, with 2 levels of supplier *number of partnerships*: - single-link suppliers, and - dual-link suppliers.
2	*Number of partnerships*	The fewest *number of partnerships* (one-to-one relationships).	5 scenarios, including the base run. The level of each scenario is varied proportionally and combined with the behaviour space of the supplier *number of partnerships*. Each scenario was run under 2 levels of *duration of collaboration*: - extremely short duration, and - extremely long duration.
3	*Trust*		

Experimental factor	Base run	Behaviour space
3.1 *Manufacturer trust*	No *trust*.	5 scenarios, including the base run. The scenarios were run under 3 levels of *duration of collaboration*: - extremely short duration, - extremely long duration.
3.2 *Supplier trust*	No *trust*.	5 scenarios, including the base run, with 2 levels of *duration of collaboration* - extremely short duration, and - extremely long duration.
3.3 *Customer trust/loyalty*	No *trust/loyalty*.	5 scenarios, including the base run.
4 Individual *firm survivability*		
4.1 *Manufacturer survivability* to work with undesired supplier/s	The medium level of survivability.	5 scenarios, including the base run, with several low levels of manufacturer strategic movements.
4.2 *Supplier survivability*	The medium level of survivability.	5 scenarios, including the base run.
5 Probability of making extreme strategic changes (manufacturer strategic movements)	No extreme strategic change.	5 scenarios, including the base run.

Table 5.7 The scenarios for the *manufacturer collaborative and competitive behaviour*

Experimental factor	Scenario	Computer setup	Scale representation
Duration of collaboration (D)	D-1	4 *time units*	*Extremely short duration*
	D-2	20 *time units*	*Short-medium duration*
	D-3	40 *time units*	*Medium-long duration*
	D-4	60 *time units*	*Long duration*
	D-5	80 *time units*	*Extremely long duration*
Number of partnerships (P)	P-1	1 link	*Single sourcing with a single-link supplier*
	P-2	2 links	*Dual sourcing with dual-link suppliers*
	P-3	3 links	*Multi sourcing with 3-link suppliers*

Experimental factor	Scenario	Computer setup	Scale representation
	P-4	4 links	*Multi sourcing with 4-link suppliers*
	P-5	5 links	*Multi sourcing with 5-link suppliers*
Manufacturer trust (T_M)	T_M-1	0%	*Extremely disloyal*
	T_M -2	25%	*Disloyal*
	T_M -3	50%	*Moderately loyal*
	T_M -4	75%	*Loyal*
	T_M -5	100%	*Extremely loyal*
Supplier trust (T_S)	T_S -1	0%	*Extremely disloyal*
	T_S -2	25%	*Disloyal*
	T_S -3	50%	*Moderately loyal*
	T_S -4	75%	*Loyal*
	T_S -5	100%	*Extremely loyal*
Customer loyalty (T_C)	T_C-1	0%	*Extremely disloyal*
	T_C -2	25%	*Disloyal*
	T_C -3	50%	*Moderately loyal*
	T_C -4	75%	*Loyal*
	T_C -5	100%	*Extremely loyal*
Manufacturer survivability (S_M)	S_M-1	12 *time units*	*Extremely low survivability*
	S_M -2	16 *time units*	*Low survivability*
	S_M -3	20 *time units*	*Average survivability*
	S_M -4	24 *time units*	*High survivability*
	S_M -5	28 *time units*	*Extremely high survivability*
Supplier survivability (S_S)	S_S -1	1 *time unit*	*Extremely low survivability*
	S_S -2	2 *time units*	*Low survivability*
	S_S -3	4 *time units*	*Average survivability*
	S_S -4	6 *time units*	*High survivability*
	S_S -5	8 *time units*	*Extremely high survivability*
Probability of manufacturer *strategic mutation*	M-1	0%	*No mutation*
	M-2	2%	*Very less likely to mutate*
	M-3	5%	*Less likely to mutate*
	M-4	7%	*Likely to mutate*
	M-5	10%	*Very likely to mutate*

The main goal of the experimental design is to analyse the level of experimental factors (the scenario) that result in a better market performance than the base run. Despite the complexity caused by the agents' interactions, a higher level of most of the experimental factors is expected to improve the supply chains performance, as observed from the market-level perspective. In particular, higher levels of the *duration of collaboration,* the *maximum number of manufacturer*'*s partnerships,* the *manufacturer trust,* the *manufacturer survivability to work with undesired supplier/s,* the *supplier number of partnerships,* the *supplier trust,* the *supplier survivability*, and the *customer loyalty* are expected to improve the agent's existence in the long-term; whereas a higher likelihood of the manufacturers making *big leap*s (represented by higher *manufacturer strategic movement*) would lead to a shorter agent's life. When each firm can exist longer – regarding the manufacturer and supplier agents, the *number of supply chains in the market* which can survive would be higher for a long run competition. As a result, the more customers able to be served by the available supply chains and the market performance (indicated by the *supply chain fill rate*) would be higher. Nonetheless, as previously discussed in Chapter 2, this expectation is difficult to realise due to the complexity in the real world. Hence, most of the hypotheses of this study are constructed against this static expectation. An illustration of the expected static effect is presented in Figure 5.7.

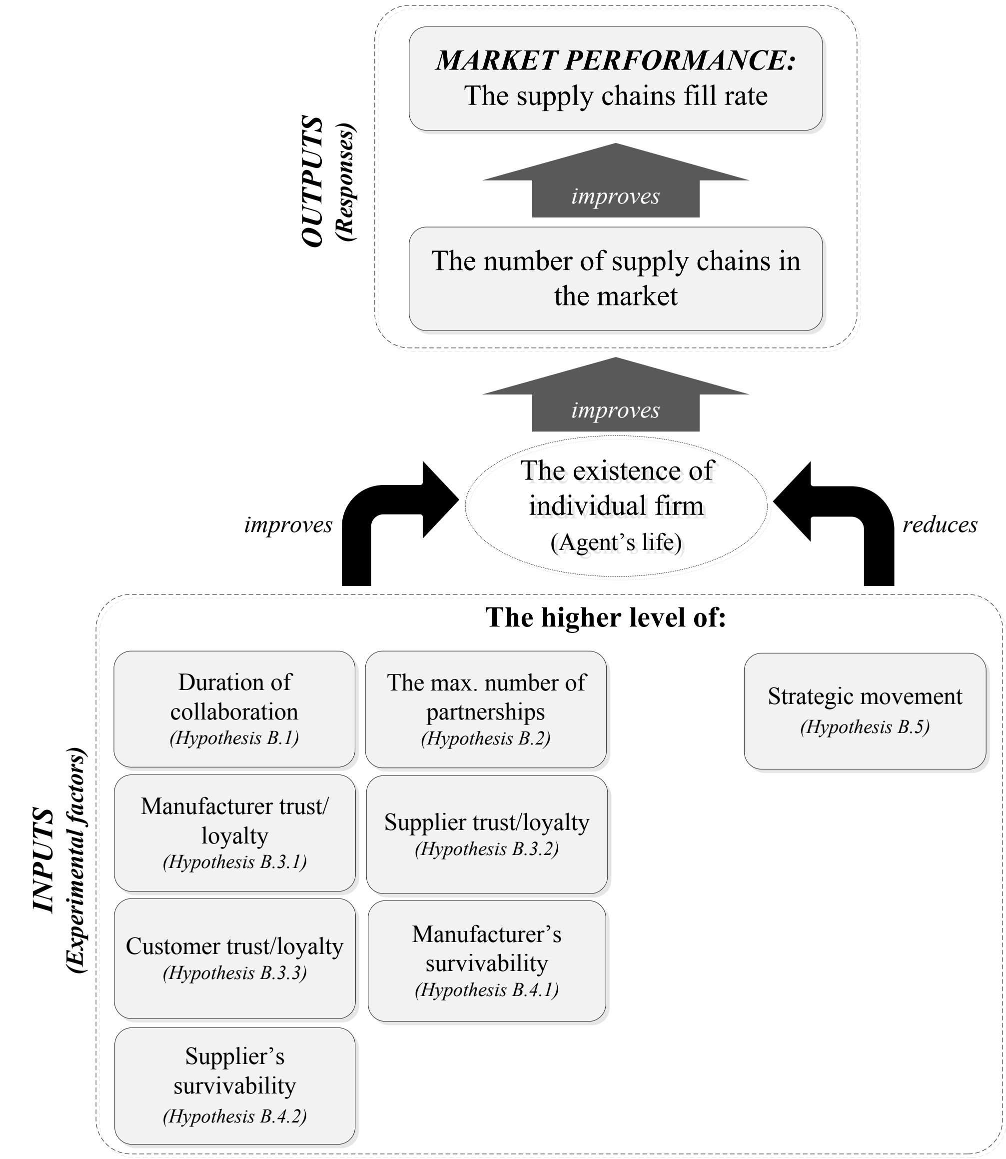


Figure 5.7 The expected effect of the individual experimental factor to the outputs

5.3.2 Model testing

In the early stage of model building, one layer of the competition (manufacturer competition) was modelled. Once the interaction and the autonomy of the customers and the manufacturers had been verified, the supplier agent was then added. This section explains the process of verification and validation for the finished or completed model. The verification was attempted first; followed by the validation. Two validation approaches were employed to the base run of the model:

face validation and case-based explanation. The following sections provide details of the mechanism of verification and validation.

5.3.2.1 Verification

Verification is performed not only to ensure that the model is free from error, but also to demonstrate that the logic has been coded properly. This is the basis for concluding that the computer model has represented the conceptual model correctly. To inspect the code, the modeller's logic is expressed in a single flow chart, and each process has to be explained by related parameters, for both the fixed setup (non-input) variables and the experimental factors (input). Several examples of the verification process are provided in Appendix G.

Figure 5.8 gives an overview of the logic flow of the computer model. This is expressed by relating it to the input variables for each process. The simulation starts from moving the manufacturer, which is influenced by the *manufacturer strategic movement*. This experimental factor determines the probability of the manufacturer creating a *big leap*. Then, the suppliers' move depends on the degree of their *trust* to the manufacturers; they would follow the manufacturers' competitive movement when they decide to be loyal to the company. After that, the manufacturers have to select a number of suppliers that suit their preference. The collaboration link between the manufacturer and the supplier is affected by the *duration of collaboration*, the maximum number of manufacturer's partnerships, the *manufacturer trust*, and the maximum number of supplier's partnerships. The customers can create a link to a manufacturer which has at least one link with a supplier. If the customer is loyal to the manufacturer, it will not switch its link to another manufacturer. As manufacturers and suppliers have a survivability limit, the life of each agent is evaluated, and the agents that have exceeded their survivability limit are removed. At the end of the simulation iteration, the model performance is measured.

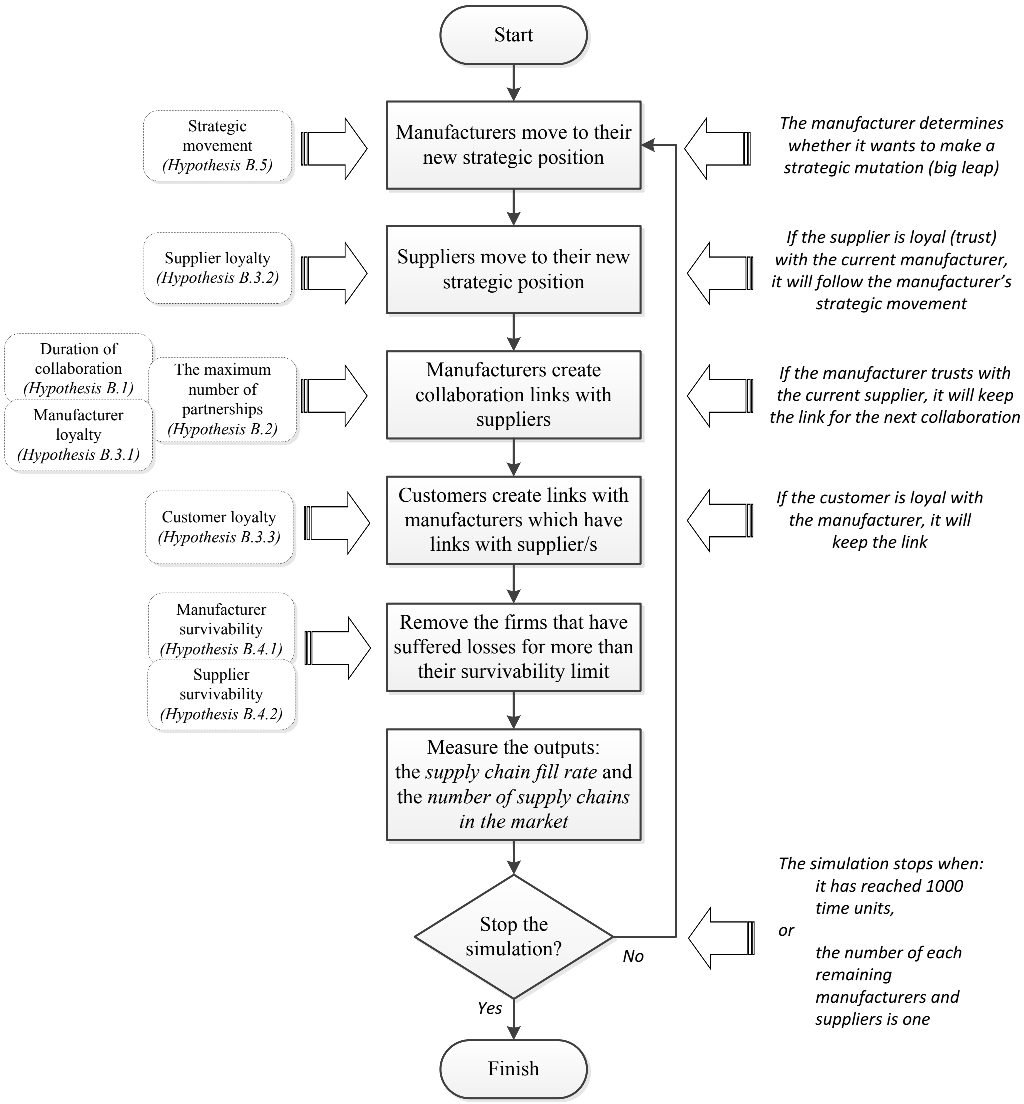


Figure 5.8 The simulation procedure with the related experimental factors in each step

Besides being influenced by the experimental factors, these steps in the model's logic are also affected by the fixed setup. The process followed by the customers in creating links is controlled by the *customer's willingness to compromise*. It also applies to the manufacturers when they have to select relevant suppliers with whom to collaborate; their criteria for supplier selection are ruled by the *manufacturer's willingness to compromise*. Lastly, the *supplier strategic movement* affects the supplier competitive movements and the manufacturer's life is influenced by *manufacturer survivability without a supplier*.

5.3.2.2 Face validation: Hotelling's competition model

The first validation approach conducted was face validation. By observing the emergent behaviour of the base run with different seed numbers, it was concluded that the result is plausible. The outcome resembles the result of the classical competition model developed by Hotelling (1929). As a consequence of competition, the competing agents (manufacturer and supplier) moved closer to each other and finished with an almost identical strategic position or almost overlap with the others.

In Hotelling's competition model, also known as Hotelling's law, the competition is presented in spatially-based terms. The model is often illustrated as a competition between two ice cream stalls which are located along the street. As both stalls continually attempt to optimise their market share, they keep changing their location until they come closer to the halfway point of the street (Robertson and Caldart 2009). In this model, the customers are assumed to have uniform preferences and always buy a product from one of the shops. The Hotelling's competition model can be illustrated by the picture presented in Figure 5.9.

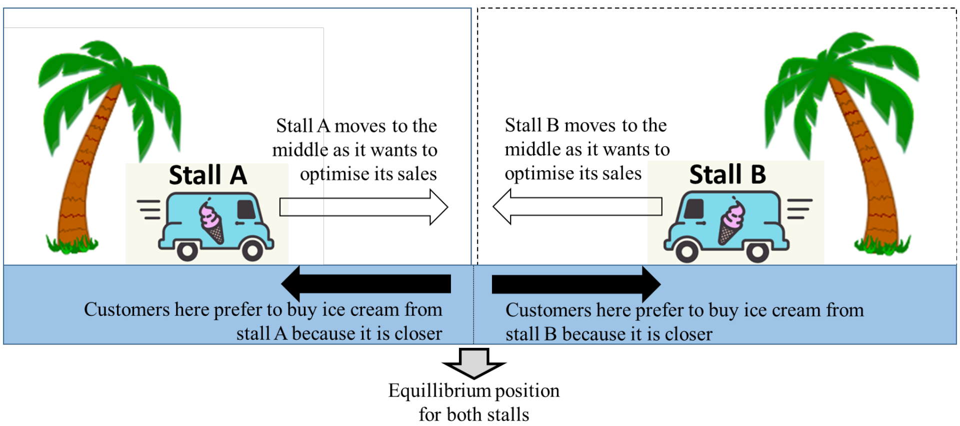


Figure 5.9 An illustration of Hotelling's competition model

Compared to Hotelling’s model, the model developed in this study involves a higher complexity level. This is for the reasons outlined below. The model includes two layers of competition: competition among the manufacturers and among the suppliers. The supply chain perspective is applied to the model, such as the position adjustment for the manufacturer when it is linked with a less efficient and/or responsive supplier; thus, the manufacturer competition movement is limited by the supplier’s strategic position in the model. Moreover, the model allows the manufacturer and supplier to die, while in Hotelling's model, the firms continue to compete. Also, the customers in this study do not buy a product when none of the manufacturer stays within their *willingness to compromise*, whilst Hotelling’s model considers that the customers are always buying and select a firm to satisfy their demand. Lastly, this study assumes that the agents are bounded-rational, while Hotelling’s model assumes rational firms and customers. The only assumption in this study which similarly applies to Hotelling’s model is the fixed customer’s preference.

The emergent behaviour that corresponds to Hotelling’s model is illustrated in Figure 5.10. This simulation result is obtained from the base run with a random number seed 10. At the initial condition (*time unit* 1, Figure 5.10.a), 10 manufacturers, which represent 10 supply chains, are dispersed on the space and form eight clusters. Next, they converge to several particular locations and create fewer clusters while they are moving to explore new customers. This situation can be seen in Figure 5.10.b (*time unit* 1000), where the 5 remaining supply chains concentrate on two strategic locations. This convergence pattern applies to both manufacturers and supplier.

Given the similarity of outcomes to Hotelling’s law, it can be concluded that the behaviour presented can be considered accurate in modelling competition behaviour. This also indicates that the model in this study produces a similar outcome to Hotelling's prediction even though the modelling assumptions are different.

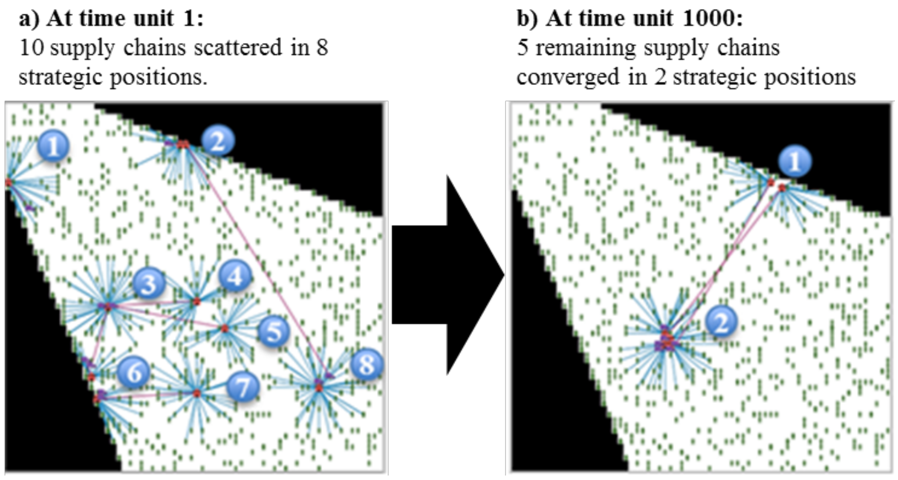


Figure 5.10 The convergence of the firms' positions, which is similar to Hotelling's prediction

5.3.2.3 Case-based validation: the *shakeout* phenomenon

The second validation approach performed in this study is case-based validation. This validity test explains the emergent pattern of the model by using a real case study found in the literature. The case that was confirmed by this approach is the decreasing *number of supply chains in the market*, which can reflect the supply chain failures. This outcome emerged consistently from the simulation run, not only in the base run but also in the behaviour space. Hence, it can be interpreted as the general effect of long-term competition - without considering new entrants to the market.

The model shows that competition reduces the number of firms both in extreme and non-extreme ways, and the extreme way is known as a *shakeout*. *Shakeout* is a term popularly used in business and management analysis to describe a phenomenon whereby there are massive exits of a number of companies in a market due to competition (Bonaccorsi and Giuri 2000). The failures of firms can be an effect of profit loss, declining demand, or acquisition by a competitor. This situation is very likely to intimidate all the firms in a market (Day 1997). It is also often interpreted as the decline of industries due to decreasing demand, or the decline of interest of the customers in buying the product (Lieberman 1990).

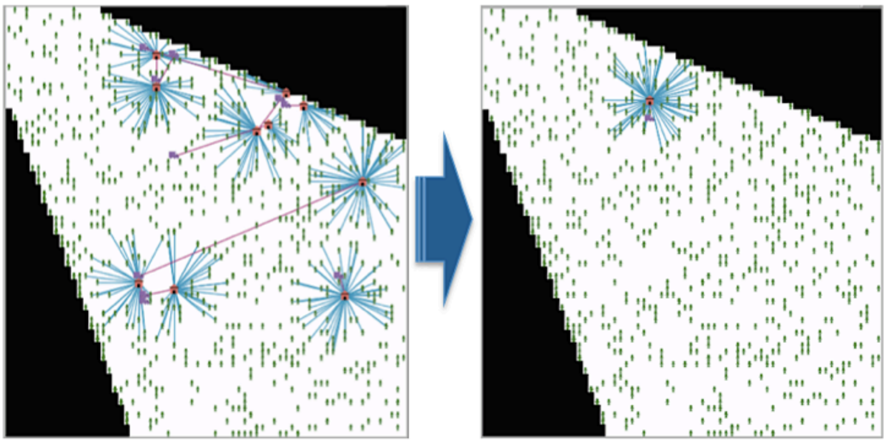
However, the results of the simulation indicate that a decrease in the *number of supply chains* and the *supply chain fill rate* in the market are solely caused by the competition, not by the customer. Assuming that the customer's preference is fixed, the demand seems to decrease because the firms (the manufacturers) converge in particular strategic locations. When the strategic position of the manufacturers is similar to that of each other, the manufacturers serve a similar market segment; so the manufacturers share the market with each other. Moreover, as explained in section 6.2, the number of market clusters or market concentrations is very likely to decline during the competition. This leads to a lower *supply chain fill rate* as the firms become more similar to each other. In reality, this behaviour may often be interpreted as declining demand, as explained by Lieberman (1990).

In this model, the firms who exit from the market are represented by the *dead* agents. A manufacturer agent will die if it has one of these following states:

- it does not have any link with the customer until it overs a particular time limit, which is assumed to be similar as *manufacturer survivability without supplier.* it does not have a supplier until it reaches the end of the length of the *manufacturer survivability without supplier*.
- it links with less efficient and/or responsive supplier for several ticks until it spans the limit of the *manufacturer survivability to work with an undesired supplier*.

The first condition is much less likely to occur in the base run as the customer is set to be not loyal to the manufacturers; so the customers always choose the closest manufacturer to them as long as the manufacturer has a supplier. In other words, the manufacturers in the base run always have customers as long as they have links with a supplier. Meanwhile, a supplier agent would die if it cannot manage to find a manufacturer to collaborate with before it reaches the limit of the *supplier survivability* period.

An example of an extreme *shakeout* resulted by the model is illustrated in Figure 5.11. The figure shows the emergence of a monopoly obtained from the base run. The monopoly occurs in just 88 *time units* of the simulation. As 1 *time unit* can be interpreted as between 3 and 18 months (see section 5.2.1.5), the 88 *time units* can be implied to be between 22 and 132 years. Hence, it can be considered as a very short duration of the competition period.



a) *b)*

Figure 5.11 Competition can lead to one supply chain moving to domination:
a) 10 supply chains exist at the initial condition (*time unit* 1);
b) monopoly emerges at the end (*time unit* 88).

The monopoly occurs when most manufacturers, who stay in less efficient and responsive positions, select suppliers who are far more efficient and responsive than them; whereas, these suppliers approach manufacturers who stay in more efficient and responsive locations. This means that these manufacturers (who are in more efficient and responsive positions) could not manage to find an appropriate supplier with whom they can collaborate. On the other hand, the other suppliers, who are in less efficient and responsive positions, move closer to the manufacturers. However, they fail to attract the target manufacturers as the firms have been linked with other suppliers who are far more efficient and responsive than them. These less efficient and responsive suppliers also stay too far beyond the *willingness to compromise* of the manufacturers who stay in in more efficient and responsive region and still have no supplier to work with them. If this situation occurs continuously for a long time, it would potentially lead to a monopoly. Moreover, this situation would be likely to emerge when most of the suppliers are far more efficient and/or responsive than the manufacturers.

In the base run, the occurrence of a monopoly is in 6 out of 50 cases (12%) of the results. The dominant result of the *number of supply chains in the market* at the end of the simulation is two supply chains (13 out of 50 replications), followed by three supply chains (12 out of 50 replications). The other results for the *number of supply chains in the market* are 5 and 6 supply chains, which for each of them occurs 5 times out of 50 replications. These numbers resulting from the base run are presented in Figure 5.12.

However, most simulation outcomes in this study very likely result in a high reduction in the *number of supply chains in the market*, which can be interpreted as the potential occurrence of a *shakeout*. This *shakeout* phenomenon reflects several case studies in business competition. This is likely to occur in an innovation-based competition strategy (Bonaccorsi and Giuri, 2000; Klepper and Simons, 2005).

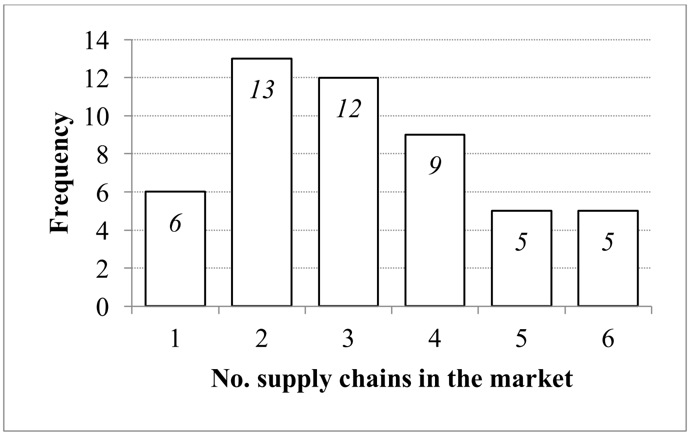


Figure 5.12 The *number of supply chains in the market* of the base run ($\bar{x}$ = 3.18, s = 3.01)

Several *shakeout* cases have been documented in the academic literature. In the PC industries, the number of PC manufacturers decreases from 832 to 435 firms in the late 1950s. This figure is estimated to be as few as five firms for the long-term winners. For the television picture-tube industries, 40 television manufacturers existed and 74 picture-tube manufacturers operated in 1955. In 1959, 52 picture-tube manufacturers remained, and this decreased to 7 picture-tube manufacturers in 1997. In Magnetic Resonance Imaging (MRI) equipment, 28 MRI manufacturers operated in 1982 and 20 MRI manufacturers remained in 1993. It is predicted that only two manufacturers would survive in the future (Day 1997). The UK steel casting industry also experienced the *shakeout* phenomenon; about 60 firms operated with about 90 plants in 1975, but 70,100 tonnes of capacity had been closed by the end of 1983 (Baden-Fuller 1989).

Shakeout also emerged to an extreme degree in innovation or technology-based competition. As reviewed by Klepper and Simons (2005), the manufacturers of automobile, tyres, televisions, and penicillin have experienced extreme *shakeouts*. The number of manufacturers of each product fell by 70% to 97% over three decades or more after it reached the peak. For automobile industries, the highest number of producers was in 1909 with about 270 automobile manufacturers. Then, it dramatically decreased to about ten manufacturers in 1967. For the tyre industries, the number of manufacturers peaked at about 275 firms in 1922 and then fell sharply to about 30 manufacturers in 1980. Meanwhile, for the television and penicillin industries, the highest number of manufacturers occurred in 1951 with about 90 manufacturers and in 1952 with about 30 firms respectively. Both industries then fell dramatically, with 20 manufacturers in 1989 for the television industries and 10 manufacturers in 1992 for the penicillin producers. Regarding the conformity of the results with real case studies, it can be suggested that the model developed in this study is valid to represent the real world. The declining number of firms in the market in the model can be seen in the actual cases.

Nevertheless, these *shakeout* cases can hardly be explained from the supply chain perspective. This is because the existence of the SCM paradigm is still relatively new compared to the period required for understanding the *shakeout* phenomenon. It has only been known for 34 years since it first appeared in the academic literature in 1982 (Gibson et al. 2005). Moreover, most studies and analysis in SCM are conducted for analysing a particular supply chain, not for market analysis. Most of them only address the issue of the supply chain failures that occur in particular companies.

On the other hand, the recent phenomenon of declining companies, such as Japanese electronics firms (Sony, Sharp, and Panasonic), is generally considered not to be related to supply chain failures. A widely held view is that this phenomenon regards marketing failure as the main causes rather than viewing the problem from the SCM perspective. For example, many business news stories point out that the reasons for the profit loss in Japanese electronics companies are the uncompetitive marketing approach (Fingleton 2012; Morris 2012; Wingfield-Hayes 2013), which is considered the result of a mistake in taking a strategic movement (Hall 2009), and the rigidity of Japanese corporate culture which hinders the response speed of the firm (Ihlwan 2009; Hall 2009). The weakening Japanese economy is also regarded as a cause of rising costs in innovation and the manufacturing processes (Ihlwan 2009; Wakabayashi 2012). Even though their market share is decreasing, their supply chain practices are still regarded as successful. They even also have an excellent supply chain risk management which prevents them from suffering from supply disruptions, as caused by disasters or earthquakes.

In addition to this, Nokia was also seen to experience lower market shares. It is widely understood that the factor that led Nokia to its past successes was its supply chain (McCray et al. 2011). Nokia was referred to as having the best supply chain practices by Reeves and Deimler (2011). It even won the Supply Chain Management Award for Excellence in Supply Chain Operations at the EXCHAiNGE conference in 2015 (Fourtane 2015). Nevertheless, Nokia was overtaken by its competitors, e.g. Apple and Samsung.

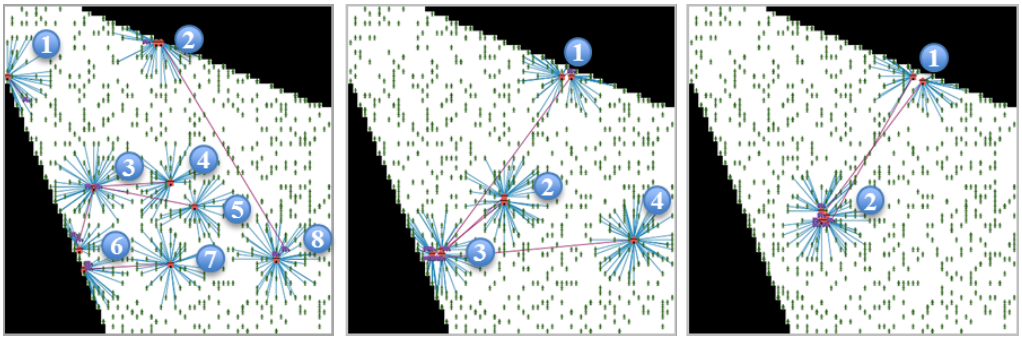
Regarding its competition with Apple, Nokia was deemed to be in crisis by 2011 (McCray et al. 2011). While Nokia claimed that their supply chain was strong, by contrast, Satariano and Burrows (2011) found that Apple's relationships with its supplier were not really congenial; the suppliers experienced high pressure in supporting Apple's success.

These findings imply that collaboration success may not guarantee the long-term survivability of a supply chain. It also indicates that supply chain failures may not be solely caused by the inappropriate implementation of supply chain collaboration strategies. Because there is still no literature which incorporates the supply chain perspective in analysing industry *shakeouts*, this study initiates a new insight into understanding the issue, which considering SCM and strategic management perspective.

5.3.3 The generic emergent outcomes: formation of the market structure

In general, the simulation results indicate that competition can drive the formation of the market structure. The convergence pattern of the firms' strategic positions, which appears like market clusters, tends to change during the competition. The changes apply not only to the number of market clusters created but also for the location of the clusters. The clusters are created because manufacturers and suppliers move dynamically whereas the customer preference or position remains fixed in the strategic space. This outcome emerges consistently in both the base run and the behaviour space. Thus, it indicates that the market structure is solely driven by the competition, not by customers.

An example of this situation is illustrated in Figure 5.13. The structure is illustrated as clusters formed by the competing firms. The cluster of the market is simply defined based on the visual interpretation of the simulation run. If two or several firms appear to share similar customers which can be served by these companies, these firms are considered to stay in a same market segment/clusters. In other words, if several customer links towards manufacturers create a circular shape, this circular configuration is considered to be one market cluster.



a) *b)* *c)*

Figure 5.13 The market structure driven by the competition:
a) Eight market concentrations at *time unit* 1;
b) Four market concentrations at *time unit* 100;
c) Two market concentrations at *time unit* 1000.

As can be seen in Figure 5.13, the market structure changed during the competition. At the initial condition (*time unit* 1, Figure 5.13.a), the supply chains are located randomly and create approximately seven to eight clusters. Then, both the manufacturers and the suppliers converge and create fewer clusters while they move continuously to explore new customers. In Figure 5.13.b, it is shown that the market clusters are reduced from eight clusters to four clusters at *time unit* 100. At the end of the simulation run presented (Figure 5.13.c, *time unit* 1000), the number of clusters reduces to two clusters or concentrations.

From this illustration, it is shown that a longer duration of competition tends to lead to a lower number of market clusters. The number of clusters decreases when the *number of supply chains in the market* which can survive in the long-term competition is fewer. As the firms are becoming more concentrated in a lower number of market clusters, as a consequence, the supply chain performance in fulfilling the demand, represented as *supply chain fill rate*, decreases over the simulation run. However, when the researcher tried not to allow the agents (manufacturer and supplier) to die during simulation, this pattern is still produced; both the number of clusters and *supply chain fill rate* decrease over the competition period. This means that the pattern is solely driven by the competition, not by the customers.

In economic studies, the formation of the market structure is often related to innovation and firm size, as in the work of Scherer (1965), Loury (1979), and Acs and Audretsch (1987). The firms' innovation level can be explained by the firms' strategic position, particularly in those relating to the *y*-axis. Nevertheless, this study assumes a homogeneous size for both manufacturers and suppliers; this suggests that the firm's size may not be an essential driver for the formation of the market structure. Instead, the strategic positions of manufacturers and suppliers in the market determine this emergent pattern. This issue has not been discussed in the literature, particularly when it is addressed by regarding the supply chain context.

5.4 Summary

The agent-based model of supply chain competition and collaboration is shown in two forms of representation: a conceptual model and a computer model. The technical description of the problem situation is represented in the conceptual model, and the computer or simulation model was coded in NetLogo. The code was verified, and the emergent results were validated by employing two validity tests: face validation and case-based validation. The generic emergent output of the model is also presented, which is the formation of the market structure, which is followed by the decreasing demand fulfilment rate (the *supply chain fill rate*) over the competition period. This outcome has not been addressed in previous research, so the model provides a new perspective for understanding the effect of competition on the market structure. A further investigation of the model results is provided in the next chapter.

CHAPTER 6 MODEL RESULTS AND ANALYSIS

6.1 Introduction

This chapter provides the results of the experiments. The experiments are designed based on the hypotheses proposed in this study, which is constructed in section 5.3.1.2 (Chapter 5). The results are presented in two main sections: effect of competition on supply chains, and effect of firm strategy on supply chains. Both effects are examined at market-level.

6.2 Effect of competition on supply chains and market structure (*Hypothesis A*)

Hypothesis A is constructed to explore whether competition is beneficial to supply chains from market perspective. This hypothesis aims to obtain insights on the effect of competition on supply chains, which has conflicting opinions in the literature (section 2.3.2). This hypothesis is not tested using a statistical approach.

Instead, this hypothesis is concluded by investigating the generic results of all experiments. Two emergent effects are found to consistently appear in the overall experiments. One pattern shows the positive impact of the competition, while the other one reflects the negative effect. The detailed discussion of the positive and negative effect of competition is provided in the following subsections.

6.2.1 Positive effect: Strategic alignment within supply chain

The model shows that competition can narrow the strategic gap between the manufacturer and the supplier in a supply chain. The gap is measured by taking the average distance between the manufacturer and the supplier within their supply chain for all supply chains at the end of the simulation run. The distance is measured by the level of efficiency (*x-axis*) and responsiveness (*y-axis*). This gap is not related to the face validation (with Hotelling's model) discussed in section 5.3.2.2. In the face validation, the gap discussed is focused on the distance between similar types of agents, while this section concentrates on the distance between different types of agents, with regards to the supplier and the manufacturer.

To understand the emergence of this outcome, observation to the relationship between the strategic gap in the simulated supply chains and the *number of supply chains in the market* is performed. Figure 6.1 shows an example of the time series relationship pattern of the base run. The gap is presented in averaged Euclidean distance between the linked manufacturer and supplier for all supply chains. An illustration of how the gap between firms in supply chains measured in the Euclidean distance is shown in Figure 6.2.

From Figure 6.1, it can be seen that the average gap between the manufacturer and the supplier in their supply chains tends to be smaller as the number of firms in the market decreases, although the pattern is not linear. The gap is relatively large in the first *time unit* of simulation, where the *number of supply chains in the market* is still ten; the average distance between the manufacturer and the supplier is between 8.39 and 7.22 grids. As the competition "kills" the firms, the *number of supply chains in the market* drops gradually as well as the *number of supply chains in the market*. Even though the gap tends to fluctuate each time the *number of supply chains in the market* decreased (as can be seen in between *time unit* 57 and 72, 141 and 155, 169 and 183, 197 and 211, and 239 and 253), these fluctuations occur only briefly before the gap is reduced again to smaller values than the previous *time unit*. It suggests that a higher rate of supply chains failures can assist better strategic alignment for supply chains during competition.

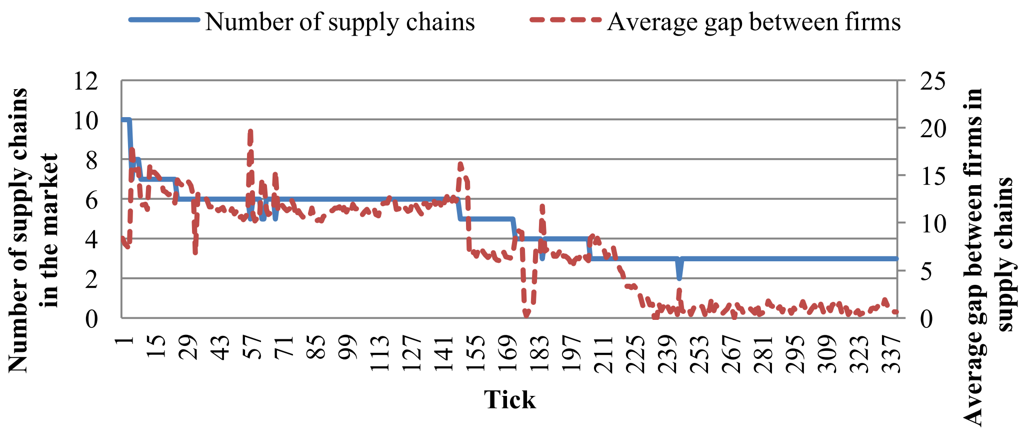


Figure 6.1 The relationship between the *gap between firms in supply chains* and *the number of supply chains in the market*

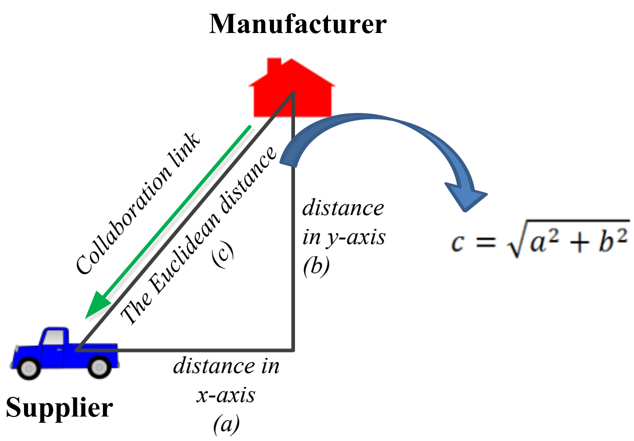


Figure 6.2 An illustration of measuring the gap between firms in a supply chain in Euclidean distance

Nevertheless, the strategic alignment does not apply to all supply chains in the simulation. Although the gap decreases at market-level, several supply chains still have a significant capability gap between the manufacturer and supplier until the simulation ends, as shown in Figure 6.3. Moreover, the strategic alignment at market-level does not consistently occur in each experiment. This pattern is caused by the distribution of manufacturers and suppliers in the system during the simulation. When the suppliers highly concentrate on the strategic area which is far more efficient and responsive than most of the manufacturers, competition would very likely not be able to assist the strategic alignment of the supply chains in the market.

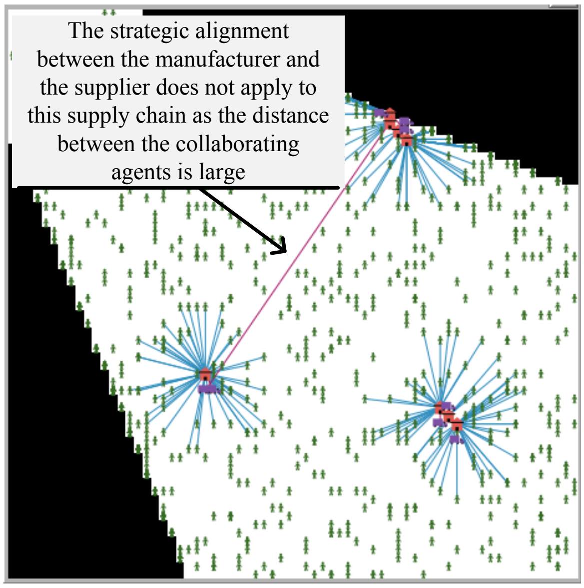


Figure 6.3 Competition does not assist strategic alignment for all supply chains

Regarding these outcomes, it can be suggested that competition can be useful for supply chains. It can benefit supply chains in the market regardless the collaboration strategy which is implemented. It minimises the strategic gap between the manufacturer and the supplier within their supply chain. The gap reduction presented in the simulation result can be represented as a strategic compromise improvement in aligning supply chain capability between firms in a supply chain. However, this benefit would not apply when most suppliers in the market are highly more efficient and responsive than the manufacturers.

In addition, an effective strategic alignment occurs when the *number of supply chains in the market* is lower than the initial state, it reflects that competition with a fewer number of firms does not always indicate an unfavourable situation for the market. This issue has not been studied in detail both empirically and theoretically, so this discussion has led to a new insight on the effect of competition on supply chains.

6.2.2 Negative effect: Extreme *shakeouts*

The extreme is represented by the extreme *number of supply chains in the market*, which can survive in the competitive market. The results can be classified into two categories; they are monopoly (one supply chain) and zero supply chain. These outcomes as well as the effect on the *supply chain fill rate* are discussed in the following subsections.

6.2.2.1 Monopoly or one supply chain

The first resulting extreme pattern of the simulation is the emergence of monopoly. It reflects a situation where only one supply chain remains in the system. Compared to zero supply chain, the occurrence of this outcome is slightly more frequent. Almost all scenarios of each experimental factor have the possibility to end with a monopoly.

The high occurrence of monopoly emerges in the highlighted values. They emerge in the extremely low level of individual *manufacturer survivability*, most probabilities of manufacturer's strategic *leap*, and high degrees of *customer loyalty*. All of these factors result in more than 70% event of monopoly – which is considered as an extreme occurrence rate of monopoly. The extremely low level of individual *manufacturer survivability* (scenario 1) results in 76% of total occurrence or 38 out of 50 results. The strategic *leap* movements (represented by scenario 2, scenario 3, scenario 4, and scenario 5) also provide a high frequency of occurrence, which is between 56% (28 of 50 results) and 90% (45 of 50 results). Lastly, the high levels of *customer loyalty* provide 72% (36 of 50 results) and 96% occurrences for the high and extremely high level of *loyalty* respectively.

The emergence of monopoly is also addressed as a part of model validation, which is case-based validation (section 5.3.2.3). This situation is considered as an extreme *shakeout*, and it is likely to occur when most of the suppliers are far more efficient and responsive than the manufacturers.

6.2.2.2 Zero supply chain

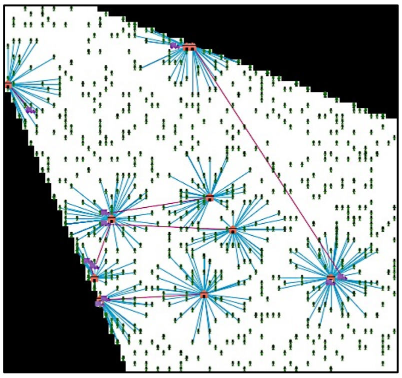
The zero supply chain represents a situation where one manufacturer and one supplier remain in the market. However, they could not collaborate with each other as their strategic position does not allow the manufacturer to create a link with the supplier. Even though the occurrence of this event is far less frequent than the other emergent outputs, this resulting situation may occur in reality if no new firms enter the market during the competition.

This state emerges in several scenarios of several experimental factors. The factors that have high percentages of zero supply chain on the simulation results are the *number of partnerships* in long-term collaboration, and *manufacturer strategic movement* (*strategic mutation*, or *big leap*). For the *number of partnerships*, the zero supply chain occurs when the *number of partnerships* of both the manufacturers and the suppliers is more than one link. The proportion of this event is considerably significant: 52% (26 out of 50) in scenario 2 and scenario 5, and 48% (24 out of 50) in scenario 3 and scenario 4. Meanwhile, the strategic *leap* leads the zero supply chain emerges as much as 10%. This proportion increases significantly to 44% as the probability of manufacturer *strategic mutation* rises.

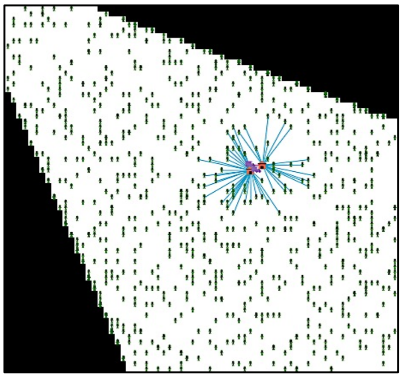
An example of the emergence of zero supply chain is illustrated in Figure 6.4. It is obtained when the manufacturers allow making strategic *leap*s, with a probability of *mutation* 2%. At the initial condition (Figure 6.4.a), ten supply chains are located in random positions on the strategic space. At *time unit* 115 (Figure 6.4.b), two supply chains left in the market and their strategic positions are close to each other. This situation makes them share their market. Then, at *time unit* 116 (Figure 6.4.c), a manufacturer *mutates* to a new strategic space. However, as the mutated manufacturer has no *loyalty* to its supplier and its partnership with the previous supplier ends at *time unit* 117 (Figure 6.4.d). No supplier is suitable with the manufacturer's preference and all suppliers stay outside its radius of *willingness to compromise*. The manufacturer could not be back to the previous strategic position, so it remains to have no supplier.

At *time unit* 119 (Figure 6.4.e), the other manufacturer also *mutates* and being away from its current supplier. It *mutates* to a location that is close to the other manufacturer. Finally, at *time unit* 120 (Figure 6.4.f), the first *mutated* manufacturer and one supplier are died, since they have reached their survivability limit. At the same time, the other manufacturer has reached the end its collaboration with the remaining supplier. They could not create a collaboration link because the distance of all suppliers exceeds the *manufacturer's willingness to compromise*.

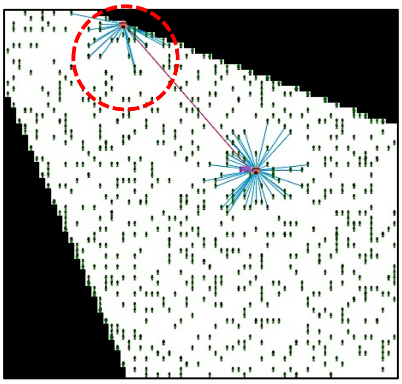
This resulting behaviour shows that if firms who remain in the market mutate at a relatively close period, it can threaten their existence in the market. This risk becomes apparent when the manufacturers decide to be far more efficient or responsive than their supplier, while they are not loyal to their supplier and the supplier has no ability to follow their *strategic mutation*.



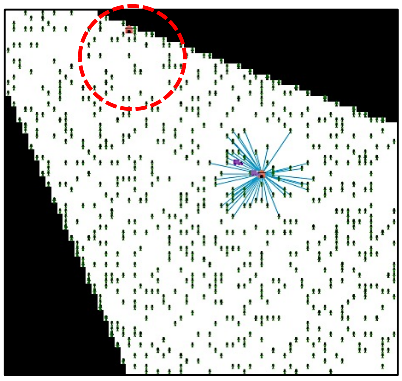
a) Time unit: 1
The initial condition.



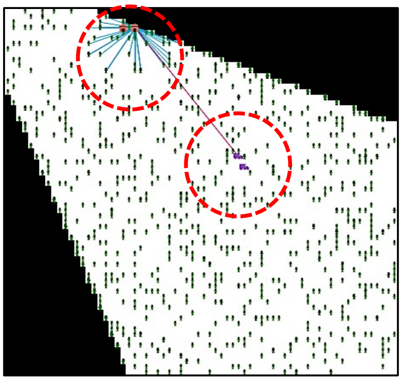
b) Time unit: 115
Two supply chains remain, and they stay in the same market concentration.



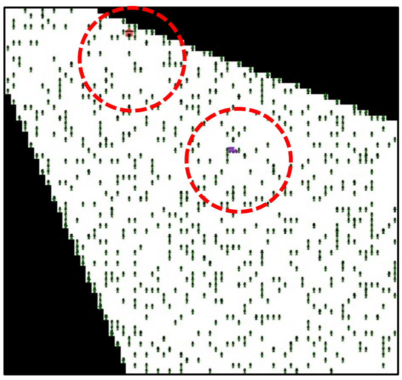
c) Time unit: 116
A manufacturer mutates to a new strategic position, while the other stays at the same market segment.



d) Time unit: 117
The manufacturer who mutated has lost its supplier. However, it still survives as it has survivability for a year.



e) Time unit: 119
The other manufacturer also mutates.



f) Time unit 120
One manufacturer and one supplier remain in the market. However, the supplier position is too far from the manufacturer, so no collaboration link is created.

Figure 6.4 Illustration of the occurrence of zero supply chain in the manufacturer *strategic mutation* – with 2% *manufacturer probability of mutation*.

6.2.2.3 Effect of extreme *shakeouts* on demand fulfilment rate

As the number of supply chains which can survive during long-term competition decreases, the demand fulfilment rate in serving customer demand also reduces. This pattern can be measured from the deterioration of *supply chain fill rate* during simulation.

However, the model does not measure the deterioration rate of *supply chain fill rate*. As an approximation, the average of the initial value of *supply chain fill rate* in the base run, which is 45.4%, is used as a basis for measuring the decay rate of demand fulfilment for all experiments in the behaviour space. This initial value is compared to the median value of final *supply chain fill rate* to estimate the decay rate of demand fulfilment of each experimental factor. The median value of demand fulfilment is adapted because the measure is more reliable to use when the data distribution is potentially skewed and contains outliers. The decay rate of demand fulfilment for each behavioural factor is presented in Appendix I.

The most extreme decay rate occurs because the emergence of zero supply chain in these scenarios is extremely high, which is 53%. On the other hand, the highest occurrence rate of more than one supply chains, which occurs when the *manufacturer trust of the supplier* is extremely high (scenario 5 of the *manufacturer trust*), provides the lowest decay rate of demand fulfilment, which is 67.8%. However, this relationship does not consistently emerge to all experimental factors.

With regards to all of these results, it can be suggested that *Hypothesis A* is supported, which is:

> "Competition can be beneficial to supply chains, with respect to long-term competition".

6.3 Effect of competition and collaboration strategy on supply chains (*Hypotheses B*)

The competitive and collaborative behaviour that are examined in this study are the *duration of collaboration,* the *number of partnerships,* the *trust,* the *individual firm's robustness (survivability)*, and the *manufacturer strategic mutation*. The hypothesis of each factor, along with information of the related section, is listed in Table 6.1. The detailed setup of each scenario of each experimental factor in the behaviour space is provided in Appendix D. As described in section 5.3.1.2 (Chapter 5), the scenarios for each experimental factor are determined based on empirical judgement to represent the practical experience towards the implementation of the experimental factor. A summary and analysis of sensitive experimental factors are presented in the last part of this section.

Table 6.1 The experimental design and the hypothesis

Experimental factor	Hypothesis	Section
1. *Duration of collaboration*	*Hypothesis B.1:* Adopting longer *duration of collaboration* does not lead to a better long-term demand fulfilment and survivability of supply chains.	6.3.1
2. *Number of partnerships*	*Hypothesis B.2:* Having a lower number of partnerships does not improve long-term demand fulfilment and survivability of supply chains.	6.3.2
3. *Trust*		
3.1 Manufacturer trust of the supplier	*Hypothesis B.3.1:* Higher *manufacturer trust* of the supplier does not enhance long-term demand fulfilment and survivability of supply chains.	6.3.3.1
3.2 Supplier trust of the manufacturer	*Hypothesis B.3.2:* Higher *supplier trust* towards manufacturer does not improve long-term demand fulfilment and survivability of supply chains.	6.3.3.2
3.3 Customer trust/loyalty towards manufacturer	*Hypothesis B.3.3:* Higher *customer loyalty* towards manufacturer does not improve long-term demand fulfilment and survivability of supply chains.	6.3.3.3

Experimental factor	Hypothesis	Section
4. *Individual firm survivability*		
4.1 Manufacturer survivability	*Hypothesis B.4.1:* Higher *manufacturer survivability* does not enhance long-term demand fulfilment and survivability of supply chains.	6.3.4.1
4.2 Supplier survivability	*Hypothesis B.4.2:* Higher *supplier survivability* does not improve long-term demand fulfilment and survivability of supply chains.	6.3.4.2
5. Manufacturer *strategic mutation*	*Hypothesis B.5:* The competition approach suggested in strategic management, regarding the *strategic mutation*, does not improve demand fulfilment and survivability of supply chains for the long-term.	6.3.5

6.3.1 *Hypothesis B.1*: *Duration of collaboration*

The *duration of collaboration* represents the length of the relationship between the supplier and the manufacturer. This factor is observed in five scenarios: extremely short duration, short-medium duration, medium-long duration, long duration, and extremely long duration. In the computer model, these duration levels are represented in 4 *time units*, 20 *time units*, 40 *time units*, 60 *time units*, and 80 *time units*. If the *time unit* is interpreted in the shortest possible period, which is 3 months (see Section 5.2.1.5); each scenario can be explicated as 1 year, 5 years, 10 years, 15 years, and 20 years. A summary of the scenarios is presented in Table 6.2.

Table 6.2 The scenarios for the *duration of collaboration*

	Duration of collaboration	Scale representation
Scenario D-1	4-time *units*	*Extremely short duration*
Scenario D-2	20 *time units*	*Short-medium duration*
Scenario D-3	40 *time units*	*Medium-long duration*
Scenario D-4	60 *time units*	*Long duration*
Scenario D-5	80 *time units*	*Extremely long duration*

These experimental levels are selected empirically since the definition of the length of collaboration depends on the detail characteristics of the innovative products, particularly in relation to supply and demand markets. For instance, ten-year collaboration for a supply chain (40 *time units*, in scenario D-3) can be considered as a medium duration, while other supply chain may regard it as a long duration. The analysis of the results for each situation of collaboration (with *single-link* and *dual-link* suppliers) is presented in the following subsections.

6.3.1.1 Collaboration with *single-link* suppliers

In this section, the *duration of collaboration* is simulated under a situation where both manufacturers and suppliers only allow having one collaboration link (*one-to-one* relationship). The boxplots of the *supply chain fill rate* in this situation is presented in Figure 6.5. A prominent feature is a longer *duration of collaboration* that does not improve the *supply chain fill rate* when the suppliers are linked with only one manufacturer. Only the medium-*long-term collaboration* (40 *time units*, scenario 3) has a slightly better *supply chain fill rate* than other scenarios, but it does not seem significant compared to the other scenarios.

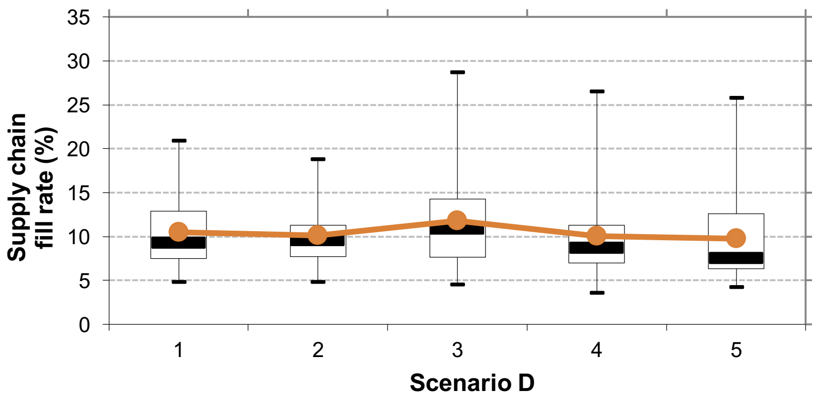


Figure 6.5 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of *duration of collaboration* with *single-link firms*

To assess the significant difference among these scenarios, a Mann-Whitney U test is performed and presented in Table 6.3. Ten comparisons with normal approximation are constructed, and Bonferroni correction is applied with 10% overall level of significance (the critical value is -2.33). Based on the comparison, it is suggested that the *supply chain fill rate* resulted in scenario D-3 is significantly higher than scenario D-5, but it is insignificant when it is compared with the remaining scenarios. Meanwhile, the results of other comparisons are suggested to be similar. In other words, only one comparison results in a significant difference from 10 comparisons created.

A similar pattern is resulted for the *number of supply chains in the market*. The *duration of collaboration* does not affect the *number of supply chains in the market*, which can be seen in Figure 6.6. The result of the Mann-Whitney U test (Appendix J, Table J.2) also suggests that all comparisons have no significant difference.

Table 6.3 The Mann-Whitney U test of *supply chain fill rate* between all scenarios of the *duration of collaboration* with *single-link firms* (with critical value -2.33 for Z_{stat})

Scenario	**2** (**20 *time units***)	**3** (**40 *time units***)	**4** (**60 *time units***)	**5** (**80 *time units***)
1 (**4 *time units***)	Z stat = -0.25 Do not reject H_0 *No significant difference*	Z stat = -1.05 Do not reject H_0 *No significant difference*	Z stat = -0.89 Do not reject H_0 *No significant difference*	Z stat = -1.5 Do not reject H_0 *No significant difference*
2 (**20 *time units***)		Z stat = -1.59 Do not reject H_0 *No significant difference*	Z stat = -0.75 Do not reject H_0 *No significant difference*	Z stat = -1.39 Do not reject H_0 *No significant difference*
3 (**40 *time units***)			Z stat = -1.93 Do not reject H_0 *No significant difference*	Z stat = -2.38 Reject H_0 *Scen.3 > Scen.5*
4 (**60 *time units***)				Z stat = -0.67 Do not reject H_0 *No significant difference*

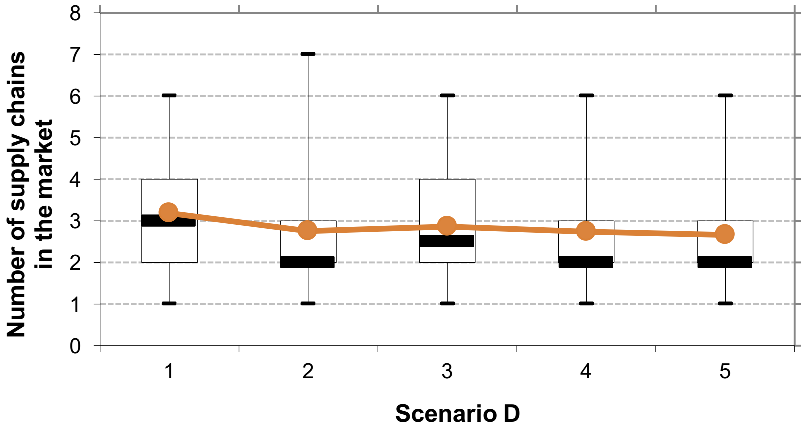


Figure 6.6 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of *duration of collaboration* with *single-link firms*

6.3.1.2 Collaboration with *dual-link* suppliers

In this experiment, the *duration of collaboration* is simulated under the similar levels defined in Table 6.2. However, the scenarios are run under a setting in which the suppliers can link with up to two manufacturers at the same time. As the manufacturers are assumed to collaborate with one supplier only, the number of suppliers is set to be half of the number of manufacturers. The hypothesis of this experiment is that a longer *duration of collaboration* is not required to enhance the performance of all supply chains in the market when the suppliers link with more than one manufacturer.

Figure 6.7 illustrates the boxplots of the *supply chain fill rate* for the *duration of collaboration* with *dual-link* suppliers. The collaboration with *dual-link* suppliers can result in zero percent for the *supply chain fill rate* in most scenarios, which does not apply when the suppliers are only able to have a *single-link*. This situation occurs in the scenario D-1, scenario D-2, and scenario D-3.

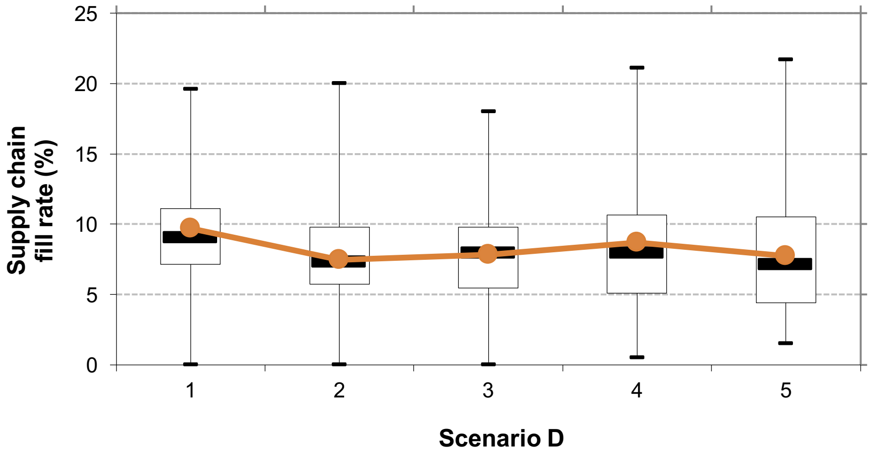


Figure 6.7 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of *duration of collaboration* with *dual-link suppliers*

For the mean and the median, the boxplots indicate that the longer *duration of collaboration* does not lead to a better *supply chain fill rate*. Surprisingly, the extremely short duration (scenario D-1) provides the highest *supply chain fill rate*, with 9.68% and 9.05% for the mean and the median respectively. Meanwhile, the extremely long duration results in the lowest *supply chain fill rate*, with 7.73% for the mean and 7.15% for the median.

When these results are assessed by using the Mann-Whitney U test, it is concluded that only scenario D-1 has a significantly higher *supply chain fill rate* than scenario D-2 and scenario D-5 (Appendix J Table J.3). The difference is insignificant when it is compared to scenario D-3 and scenario D-4. Meanwhile, scenario D-2, scenario D-3, scenario D-4 and scenario D-5 are considered to be not different significantly, in terms of *supply chain fill rate*. In other words, only 2 out of 10 comparisons have a significant difference for *supply chain fill rate*.

Figure 6.8 illustrates the feature of the *number of supply chains in the market* for this experiment. It can be seen that scenario D-1 results in the highest *number of supply chains in the market*. The mean of this scenario is 3.2 supply chains, and the median is 3 supply chains. Thus, it can be interpreted that a longer *duration of* *collaboration* tends to reduce the *number of supply chains in the market* for the long run.

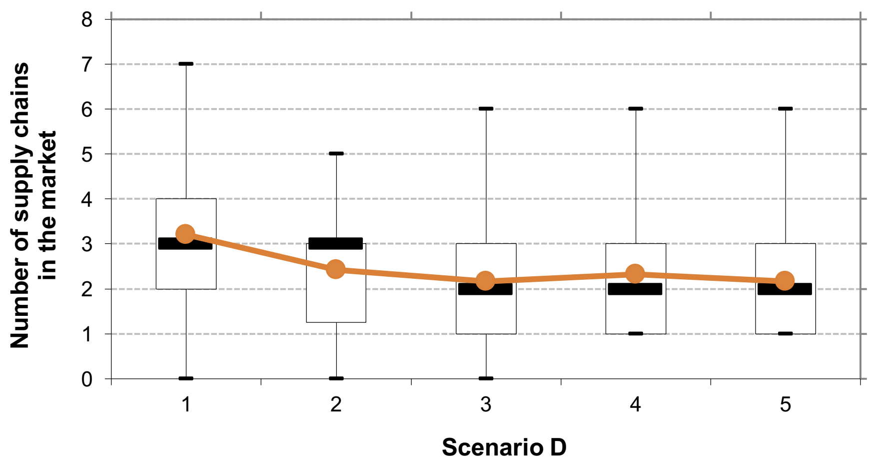


Figure 6.8 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of *duration of collaboration* with *dual-link firms*

Meanwhile, the Mann-Whitney U test shows that scenario D-1 provides the most significant difference compared to other scenarios, but it is not different significantly from scenario D-2 (Appendix J, Table J.4). Scenario D-1 has a higher *number of supply chains in the market* compared to scenario D-3, scenario D-4, and scenario D-5. It means that only 3 of 10 comparisons have a significant difference for the *number of supply chains in the market*. Moreover, in the boxplots, the longer *duration of collaboration* represented by scenario D-4 and scenario D-5 is shown to prevent the market from ending with zero supply chains. Nonetheless, it is statistically considered insignificant when these scenarios are compared with scenario D-2 and scenario D-3. The logical explanation of these results is discussed further in section 7.4.1.

6.3.1.3 Comparison of results between the *single-link* suppliers and *dual-link* suppliers

Figure 6.9 shows the comparison of *supply chain fill rate* between the output of collaboration with *single-link* suppliers and *dual-link* suppliers, for The scenarios for the *duration of collaboration*. The median is employed because the measure is more reliable than mean when the data does not follow a normal distribution. As can be seen in Figure 6.9, it indicates that collaboration with *single-link* suppliers (one-to-one relationships) seems to provide a higher *supply chain fill rate* than collaboration with *dual-link* suppliers. This feature increases as the *duration of collaboration* rises to medium-long duration (scenario D-3). Then, the difference declines when the *duration of collaboration* is set to be longer than scenario D-3.

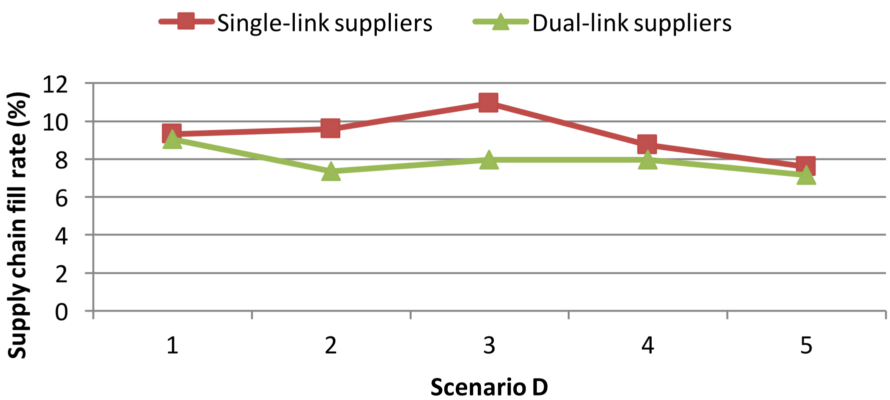


Figure 6.9 The *supply chain fill rate* comparison between *single-link* suppliers and *dual-link* suppliers with various *duration of collaboration*

The comparison of the *number of supply chains in the market* of these experiments is shown in Figure 6.10. In scenario D-2, the collaboration with dual-link suppliers has a higher median of the *number of supply chains in the market* than the result of collaboration with the *single-link* supplier. The difference between these medians is one supply chain. By contrast, the output of collaboration with single-link suppliers is higher than the output of collaboration with dual-link suppliers in scenario 3, and the difference between these values is 0.5 supply chain.

The remaining scenarios (scenario D-1, scenario D-4, and scenario D-5) have no difference median between these two situations.

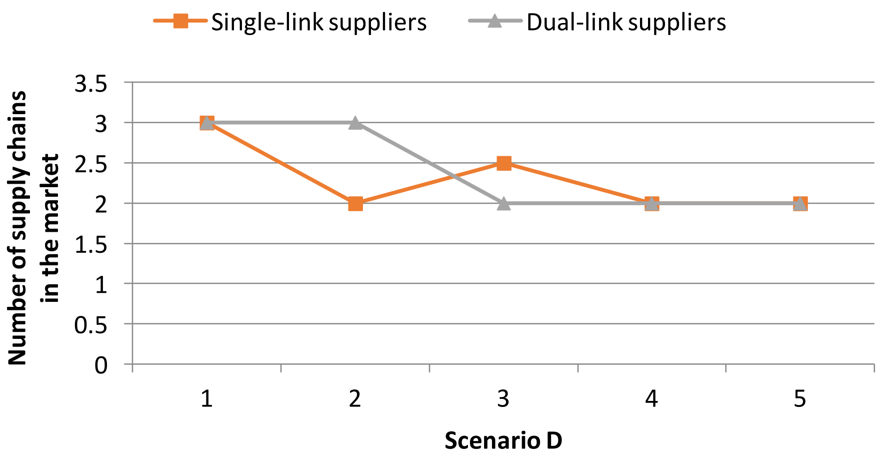


Figure 6.10 The comparison of the *number of supply chains in the market* between *single-link* suppliers and *dual-link* suppliers with different *duration of collaboration*

With respect to this outcome, in general, it can be suggested that the results confirm the hypothesis proposed (*Hypothesis B.1*), which is:

> "Adopting longer *duration of collaboration* does not lead to a better long-term demand fulfilment and survivability of supply chains".

When both the manufacturer and the supplier have one collaboration link (the *one-to-one* relationships in the *single-link* supplier scenarios), the duration of collaboration has no significant impact on both demand fulfilment rate (the *supply chain fill rate*) and survivability (the *number of supply chain in the market*) for the long-term. Meanwhile, when the suppliers are allowed to collaborate with up to two manufacturers (the *dual-link* supplier scenarios), the extremely short-term collaboration provides a significant better demand fulfilment rate as well as the supply chain survivability. When these outcomes of *single-link* and *dual-link* supplier experiment are compared, the collaborations with the *single-link* supplier (or the *one-to-one* relationships) tend to provide better demand fulfilment rate in all scenarios, although this does not apply to the supply chain survivability.

6.3.2 *Hypothesis B.2*: *Number of partnerships*

The *number of partnerships* is described as the maximum number of collaboration links for both manufacturers and suppliers. In the experiment, the *number of supplier's partnerships* is defined as proportional to the manufacturer's number of sourcing. For instance, when the *number of partnerships* is defined as *2 links*, both the manufacturers and the suppliers are allowed to collaborate with up to two agents.

This experimental factor is observed in five scenarios: *single-sourcing* with a *single-link* supplier (1-link collaboration), *dual-sourcing* with *dual-link* suppliers (2-link collaboration), *multi-sourcing* with 3-link suppliers (3-link collaboration), *multi-sourcing* with 4-link suppliers (4-link collaboration), and *multi-sourcing* with 5-link suppliers (5-link collaboration). The first scenario (1-link collaboration) is the most suggested collaboration approach in SCM, which also refers to *one-to-one* relationships, despite it can be regarded as an extreme approach for several firms in the real world. Scenario P-2 (*dual-sourcing* strategy) is also regarded as a recommended strategy in SCM as it minimises the risk of *single-sourcing* approach while taking advantage of having *multi-sourcing*. Meanwhile, when the *number of partnerships* is more than 2 agents, the scenarios are considered as *multi-sourcing* approach for the manufacturers, under a situation of *many-to-many* partnerships. Lastly. scenario P-5 (5-link collaboration) is considered as another extreme strategy of *multi-sourcing* because the number of suppliers and manufacturers are set to be highly limited in the market. These scenarios are summarised in Table 6.4, and the results of the simulation are presented in the next subsections. The logical explanation of these following results is presented in Chapter 7.

Table 6.4 The scenarios for the *number of partnerships*

	Number of partnerships	**Scale representation**
Scenario P-1	1 link	*Single sourcing with a single-link supplier*
Scenario P-2	2 links	*Dual sourcing with dual-link suppliers*
Scenario P-3	3 links	*Multi-sourcing with 3-link suppliers*
Scenario P-4	4 links	*Multi-sourcing with 4-link suppliers*
Scenario P-5	5 links	*Multi-sourcing with 5-link suppliers*

6.3.2.1 In *short-term* collaboration

Figure 6.11 presents the boxplots of the *supply chain fill rate* for all The scenarios for the *number of partnerships*. The results are generated under a situation of *short-term collaboration*, set by 4 *time units*. The figure shows that the *dual-sourcing* with dual-link suppliers (scenario P-2) provides the lowest mean and median of the *supply chain fill rate*, which is 8.31% and 8.15% respectively. The highest mean (11.33%) and median (9.75%) are resulted in the scenario of *multi-sourcing* with 4-link suppliers (scenario P-4). Another prominent feature of this boxplots is only *single-sourcing* with a single-link supplier (scenario P-1) does not result in the lowest extreme *supply chain fill rate*, which is 0%, while the others have the possibility to end with this undesirable output. However, the conclusions in the Mann-Whitney U test suggest that all scenarios have no significant different results (Appendix J, Table J.5).

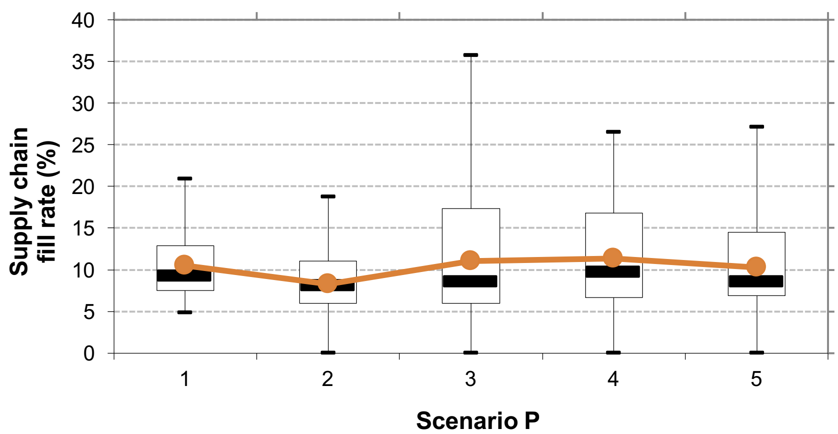


Figure 6.11 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *number of partnerships* in *short-term* partnerships

A similar pattern is also shown for the *number of supply chains in the market* of these scenarios, as presented in Figure 6.12. It can be seen that *dual-sourcing with dual-link suppliers* (scenario P-2) provides the fewest *number of supply chains in the market*, which is 2.58 supply chains for the mean and 3 supply chains for the median. Meanwhile, the *multi-sourcing* strategies (scenario P3, scenario P-4, and scenario P-5) have the highest *number of supply chains in the market*, which are 4 supply chains for its median. Lastly, the *single-sourcing with a single-link supplier* (scenario P-1) is the only scenario that does not result in zero supply chain at the end of the simulation. However, the Mann-Whitney U test concludes that only scenario P-2 has a significant difference with other scenarios (Appendix J, Table J.6). Scenario P-2 has the significant lowest *number of supply chains in the market,* even though it is insignificant when it is compared to scenario 1. The significant difference, nevertheless, only applies to 30% of the total number of comparisons. It indicates that the level of significant difference is low.

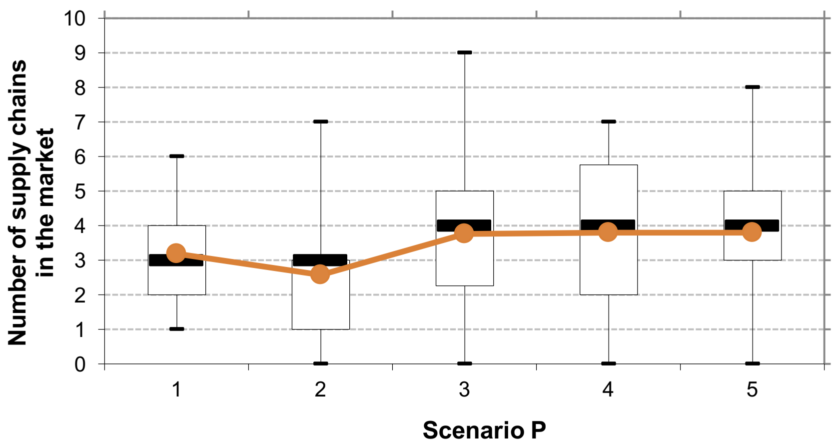


Figure 6.12 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of *number of partnerships* in *short-term* partnerships

These results suggest that collaborations with *dual-link* firms (scenario P-2) seem to provide less benefit to supply chains in the market than other cooperation approach, particularly in terms of supply chain survivability represented by the *number of supply chains in the market*. Surprisingly, the *single-sourcing with a single-link supplier* (scenario P-1) seem not to have significant differences in outcome compared to *multi-sourcing* strategies or *many-to-many* partnerships. These results are counterintuitive with the common belief in SCM that suggests *single-sourcing* with a single-link supplier (*one-to-one* relationship) and *dual-sourcing* as the best strategies to achieve supply chain success.

6.3.2.2 In *long-term* collaboration

Figure 6.13 illustrates the boxplots of the *supply chain fill rate* for all The scenarios for the *number of partnerships* in *long-term collaboration* (adjusted by 80 *time units*). It is clearly shown that *single-sourcing* with a *single-link* supplier (scenario P-1) results in higher *supply chain fill rate*. The mean of this scenario is 9.45%, and the median is 7.6%. Meanwhile, the *dual-sourcing with dual-link suppliers* (scenario P-2) and *multi-sourcing with 5-link suppliers* (scenario P-5) provide the lowest median of *supply chain fill rate*; both of them results in 0% for the median of *supply chain fill rate*. However, the lowest mean of *supply chain fill rate* is not resulted in these scenarios; it is generated by *multi-sourcing with 3-link suppliers* (scenario P-3), which is 3.83% for the mean.

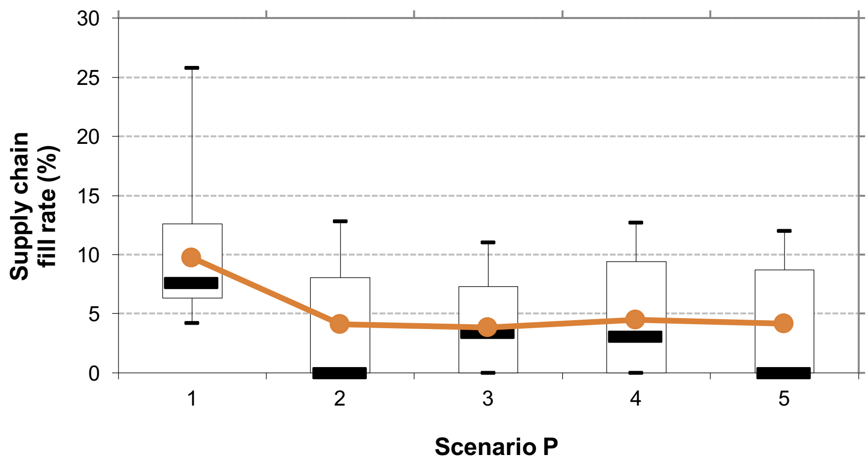


Figure 6.13 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of *number of partnerships* in *long-term* partnerships

Nevertheless, the Mann-Whitney U test concludes that only scenario P-1 is significantly different from the other scenarios (Appendix J, Table J.7). It provides the significant highest *supply chain fill rate* compared to the other scenarios. The remaining scenarios are not considered significantly different with each other, with respect to the *supply chain fill rate*.

Meanwhile, Figure 6.14 illustrates the boxplots of the *number of supply chains in the market* for the *number of partnerships,* under the long *duration of collaboration*. The pattern of the output shown in this figure is similar to the *supply chain fill rate* presented in Figure 6.9. The highest number of supply chains is resulted in scenario P-1 with 2.66 supply chains as the mean and 2 supply chains as the median. The mean tends to decline as the *number of partnerships* increases, while the median tends to be slightly more dynamic at between zero and one supply chain. Based on the assessment results of the Mann-Whitney U test, it is suggested that the highest *number of supply chains in the market* is resulted in scenario P-1 (Appendix J, Table J.8). Meanwhile, the results in scenario P-2, scenario P-3, scenario P-4 and scenario P-5 are considered to be not different significantly from each other.

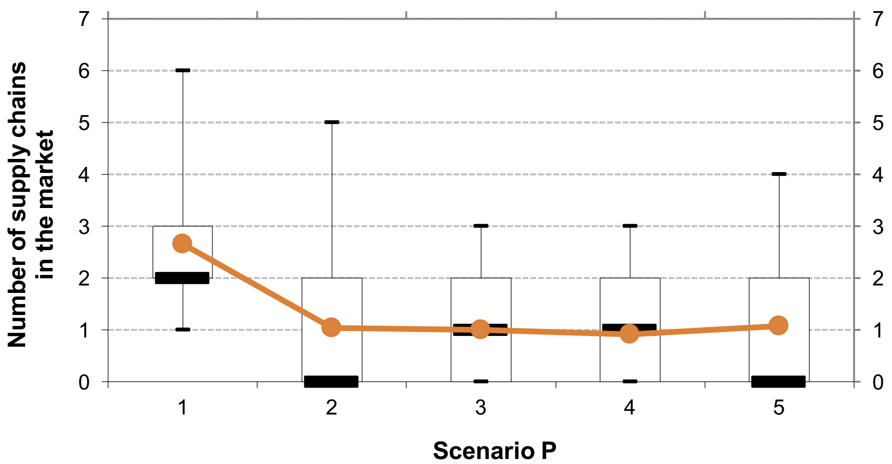


Figure 6.14 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of *number of partnerships* in *long-term* partnerships

6.3.2.3 Output comparison of the *number of partnerships* between *short-term* and *long-term* collaboration

Figure 6.15 presents the comparisons of the median of the *number of partnerships*, between *short-term collaboration* and *long-term collaboration*. Surprisingly, it is shown that *short-term collaboration* result in the higher median of *supply chain fill rate* for all scenarios of *number of partnerships* compared to the results in *long-term collaboration* (section 6.2.2.2). In *short-term collaboration*, the median of *supply chain fill rate* is between 8% to 10% percent, while the range of this value is much wider in the *long-term collaboration*, which is between 5% and 7.8%. Moreover, the *dual-sourcing* strategy with *dual-link* suppliers (scenario P-2) under *long-term* collaboration provides an unexpected outcome. This scenario is considered as an alternative collaboration approach that is suggested in SCM instead of *single-sourcing* strategy.

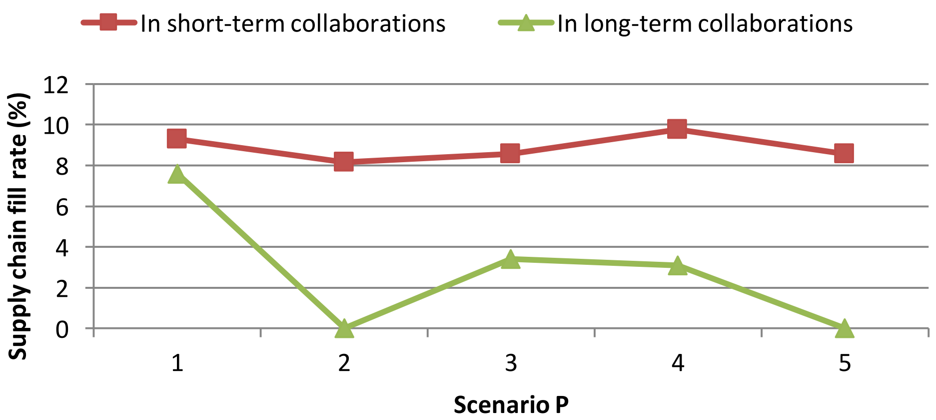


Figure 6.15 The comparison of *supply chain fill rate* between *short-term* and *long-term collaboration*, with different levels of *duration of collaboration*

A similar pattern is also resulted in the comparisons of the *number of supply chains in the market* (Figure 6.16). All scenarios with *short-term collaboration* provide a higher *number of supply chains in the market* than when they are run under *long-term*. The higher values occur consistently in *multi-sourcing* scenarios (scenario P-3, scenario P-4, and scenario P-5) with *short-term collaboration*. Nonetheless, as explained in section 6.2.2.1, these *multi-sourcing* scenarios are not different significantly from *single-sourcing* approach (scenario P-1) when *short-term* collaboration is applied to all firms.

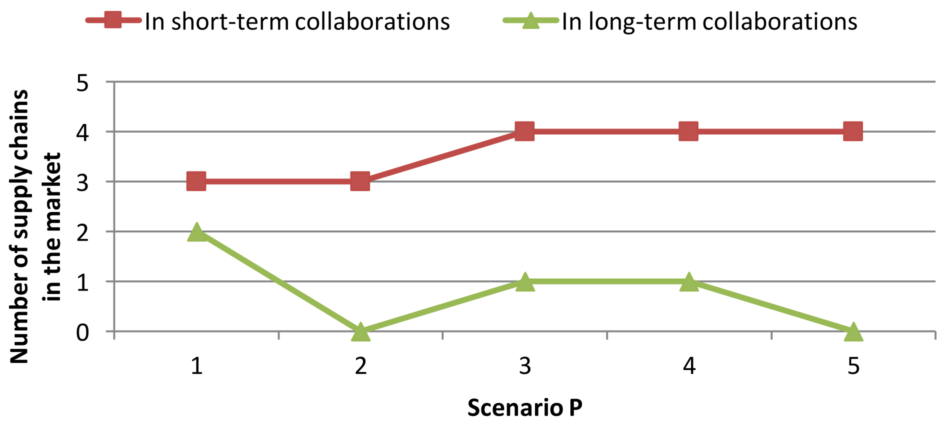


Figure 6.16 The comparison of the *number of supply chains in the market* between *short-term* and *long-term collaboration*, with different levels of *duration of collaboration*

Based on these results, it can be suggested that the *Hypothesis B.2* is supported, which is:

> "Having a lower number of partnerships does not improve long-term demand fulfilment and survivability of supply chains".

In general, the issue of the *number of partnerships* can be considered insignificant to the demand fulfilment rate, particularly when all firms implement short-term collaboration. However, it becomes significant when both manufacturer and supplier only collaborate with one firm (*one-to-one* relationship) in long-term partnerships. In other words, only one-to-one relationships with long-term collaboration provide significant benefit to both demand fulfilment and survivability of supply chains. Nevertheless, the degree of the significant difference of this result is low. It suggests that this finding could turn to be insignificant when different model setup is applied, with respect to the initial number of manufacturers and suppliers.

6.3.3 *Hypothesis B.3*: *Trust*

The model represents *trust* as a degree of *loyalty* that applies to the manufacturer and supplier agents. It is examined by regarding the manufacturer *trust* of the supplier (the *manufacturer trust*), supplier *trust* of the manufacturer (the *supplier trust*), and *customer loyalty* towards manufacturer (the *customer trust/loyalty*). Each of these factors is examined under two collaboration situations: *short-term* and *long-term* collaboration. The simulation results of *trust* for each manufacturer, supplier, and customer are analysed in the following subsections.

6.3.3.1 *Hypothesis B.3.1*: The *manufacturer trust* of the supplier

The *manufacturer trust* is simplified as a probability of *loyalty* that the manufacturer agents would choose the same supplier agent as selected previously. The *trust* value is determined at five levels (or scenarios) of probability: 0%, 25%, 50%, 75%, and 100%. These values are selected to represent these following degrees of *manufacturer trust*: extremely disloyal (extremely distrustful - 0%), disloyal (distrustful - 25%), moderately loyal (moderately trustful - 50%), loyal (trustful - 75%), and extremely loyal (extremely trustful - 100 %). These scales are chosen empirically to observe the effect of different levels of *manufacturer trust* on the model outputs. The variation of the variables for the scenarios is summarised in Table 6.5.

The expected outcome of this experiment is defined based on the *duration of collaboration* applied, with respect to *short-term* collaboration (4-*time unit* partnership) and *long-term* collaboration (80-*time unit* partnership). In *short-term* collaboration, it is expected that a higher *manufacturer trust* does not enhance the demand fulfilment rate when the firm prefers to have a *short-term* collaboration. In contrast, a higher *manufacturer trust* is expected to improve the performance of a single supply chain when the firm prefers to collaborate in long duration. Nevertheless, with regards to the gap of the existing work, these expectations should turn to be opposite at market-level when all firms apply a similar *trust* strategy. The simulation results are provided in the next sections.

Table 6.5 The scenarios for the *manufacturer trust*

	Probability of the *manufacturer trust*	Scale representation
Scenario T_M-1	0%	*Extremely disloyal/distrustful*
Scenario T_M-2	25%	*Disloyal/distrustful*
Scenario T_M-3	50%	*Moderately loyal/trustful*
Scenario T_M-4	75%	*Loyal/trustful*
Scenario T_M-5	100%	*Extremely loyal/trustful*

In *short-term collaboration*

Figure 6.17 shows the boxplots of the *supply chain fill rate* of *manufacturer trust* that is simulated under *short-term* collaboration (4-*time unit* partnership). As shown in the figure, both median and mean of *supply chain fill rate* have a slight U pattern as the probability of the *manufacturer trust* increases. Furthermore, the boxplots indicate that the 100% *manufacturer trust* (scenario 5) generates the highest *supply chain fill rate* and *number of supply chains in the market*, and the 0% *manufacturer trust* (scenario T_M -1) provides the second highest outputs. Meanwhile, scenario T_M-2 (25%), scenario T_M-(50%), and scenario T_M-4 (75%) provide no significant difference effect, particularly on the *supply chain fill rate*.

The inferential analysis of the results also concludes that scenario T_M-5 (100%) is significantly different from other scenarios. It provides the highest value of *supply chain fill rate* (Appendix J, Table J.9). Scenario T_M-1 (0%) also has a significant difference from the others, but it is not different significantly with scenario T_M -2 (25%). It has higher *supply chain fill rate* comparing to scenario T_M-3 (50%) and T_M-4 (75%), but it is lower than scenario T_M-5. Scenario T_M-2 (25%) is significantly different from scenario T_M-4 and scenario T_M-5, but it is insignificant with scenario T_M-1 and scenario T_M-3. It provides higher *supply chain fill rate* than scenario 4, but it is lower than scenario T_M-5. Scenario T_M-3 (50%) is only significantly different from scenario T_M-1 and scenario T_M-5. It has lower *supply chain fill rate* than scenario T_M-1 and scenario T_M-5. Lastly, the *supply chain fill rate* in scenario T_M-4 (75%) is significantly lower comparing to scenario T_M-1, scenario T_M-2, and scenario T_M-5.

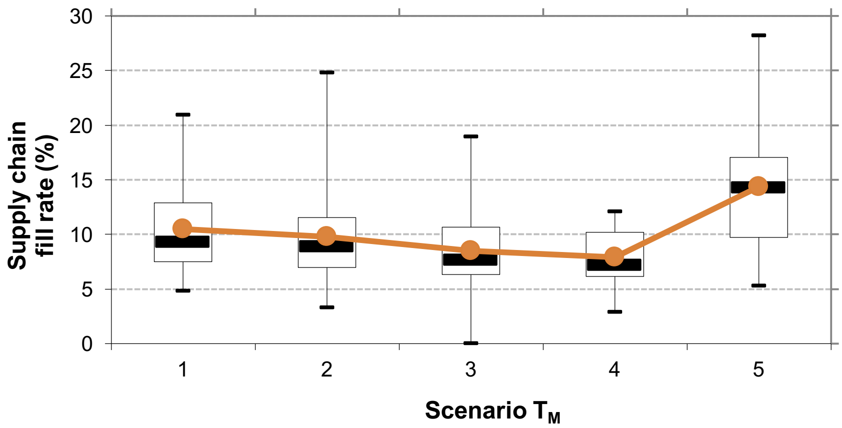


Figure 6.17 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *manufacturer trust*

Meanwhile, the median and the mean of the *number of supply chains in the market* also depict a slight U shape, as shown in Figure 6.18. Both the median and the mean of the output decrease from 3 supply chains to 2 supply chains, from scenario T_M-1 to scenario T_M-2 (the *manufacturer trust* is 25%). The values do not change until the *manufacturer trust* is 75% in scenario T_M-4. In the last scenario, both values increase to 4 supply chains.

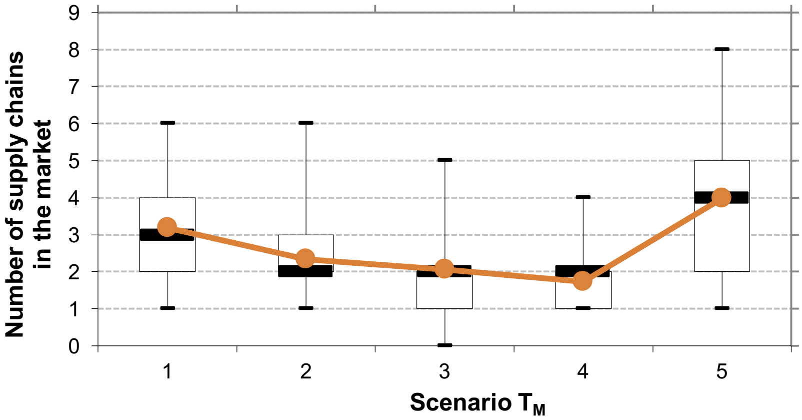


Figure 6.18 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of the *manufacturer trust* with *short-term* collaboration

The Mann-Whitney U test concludes that scenario 5 (100%) provides a significantly higher *number of supply chains in the market* compared to other scenarios, particularly when it is contrasted to scenario T_M-2, scenario T_M-3, and scenario T_M-4 (Appendix J, Table J.10). It is considered to be not different significantly when it is compared to scenario T_M-1. Scenario T_M-1 (0%) is only significantly different from scenario T_M-3. It generates *number of supply chains in the market* than scenario T_M-3. Finally, an insignificant difference between scenarios is concluded for the remaining comparisons.

In *long-term collaboration*

The data characteristics of the *supply chain fill rate* for this experiment is presented in Figure 6.19. In the *long-term* collaboration, which is set to 80 *time units*, the pattern of the mean and the median of *supply chain fill rate* for all scenarios of the *manufacturer trust* are no longer similar to a U-shaped. In this situation, the 0% *manufacturer trust* (scenario T_M-1) results in the lowest *supply chain fill rate*, with a mean of 9.75% and median of 7.6%. Meanwhile, scenario T_M-5 is consistent resulting in the highest outcome; its mean is 14.52%, and the median is 14.6%. The

Mann-Whitney U test also concludes that only scenario T_M-5 is significantly different from other scenarios (Appendix J, Table J.11). It has a significantly higher *supply chain fill rate*, while the remaining scenarios are concluded to be not different significantly with each other.

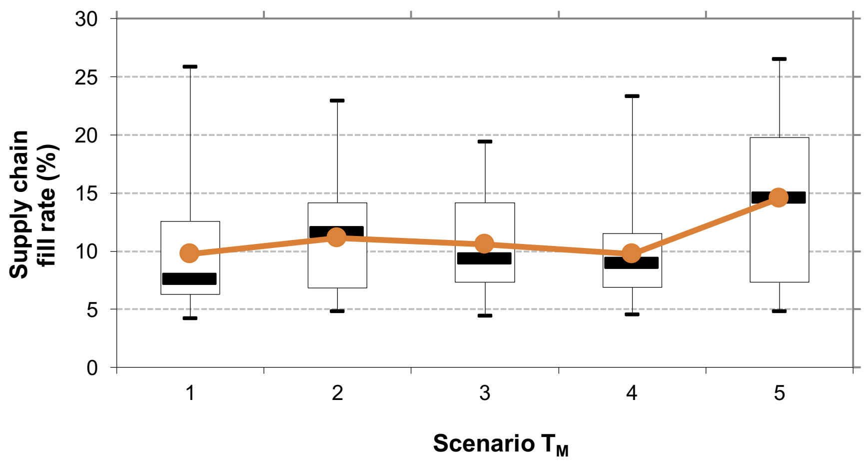


Figure 6.19 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *manufacturer trust* with *long-term* collaboration

As for the *supply chain fill rate*, the *number of supply chains in the market* of this experiment also shows an almost similar pattern. The highest output is obtained in scenario T_M-5, where the mean and median are 4.1 supply chains and 4 supply chains respectively. The lowest mean and median are generated by scenario T_M-1 and scenario T_M-4; both scenarios have a mean of 2.66 supply chains and median of 2 supply chains. However, the analysis resulted from the Mann-Whitney U test concludes that only scenario T_M-5 is significantly different from other scenarios (Appendix J, Table J.12). It significantly provides the highest *number of supply chains in the market* compared to other scenarios. The boxplots of this output is presented in Figure 6.20.

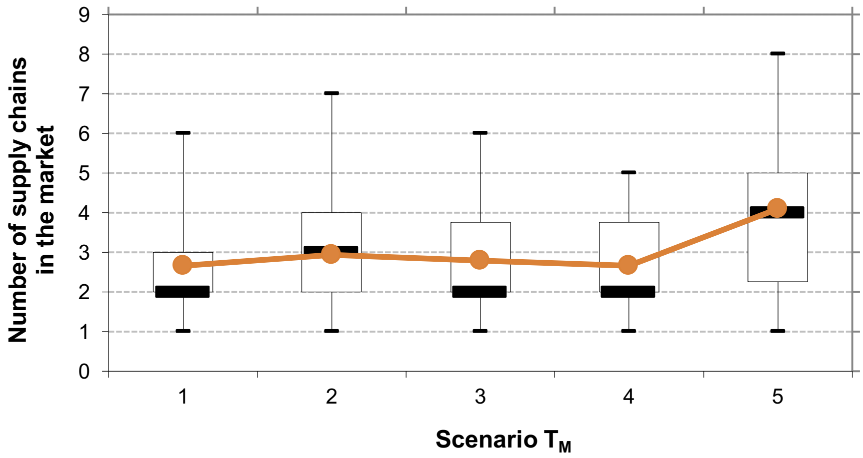


Figure 6.20 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of the *manufacturer trust* with *long-term* collaboration

Output comparison of the *manufacturer trust* between *short-term* and *long-term* collaboration

Figure 6.21 presents the comparison of the *manufacturer trust* in different levels of *duration of collaboration,* with respect to *short-term* and *long-term* partnership. Overall, the extremely loyal manufacturers (scenario T_M-5 - the 100% *trust*) provide the highest *supply chain fill rate*. Surprisingly, the extremely disloyal manufacturers (scenario T_M-1 - the 0% *trust*) results in the second highest *supply chain fill rate* in *short-term*. However, when the *long-term* collaboration is applied, scenario T_M-1 provides the lowest *supply chain fill rate*, while scenario T_M-5 still results in the highest outcome for this measure.

The intermediate levels of *manufacturer trust* (the 25%, 50%, and 75% *trust*) are not significantly different from the other scenarios, in terms of *supply chain fill rate* in *short-term*. Only when the manufacturers are disloyal (scenario T_M-2 - the 25% *loyalty*) in *long-term collaboration* can result in a better *supply chain fill rate* than the zero *manufacturer trust*. However, this result is insignificant when it is assessed by using the Mann-Whitney U test.

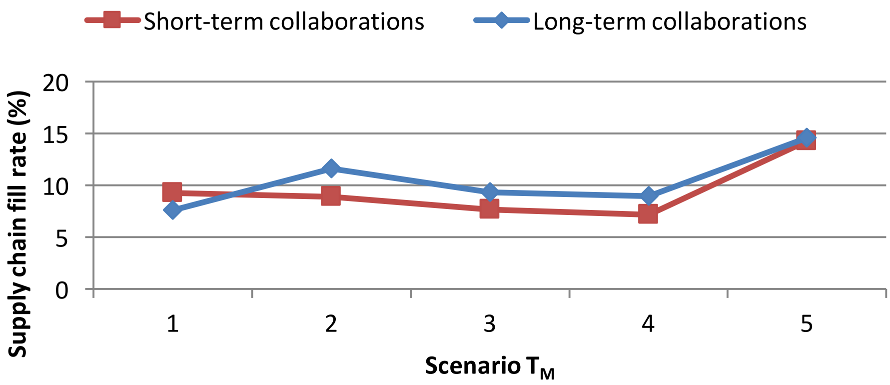


Figure 6.21 The comparison of *supply chain fill rate* between *short-term collaboration* and *long-term collaboration*, with different levels of *duration of collaboration*

Meanwhile, the comparison of the *number of supply chains in the market* in different levels of *duration of collaboration* is illustrated in Figure 6.22. As can be seen from the figure, the extreme manufacturer *trust* (scenario T_M-5) consistently results in the highest *number of supply chain in the market*, while the extremely disloyal manufacturers (scenario T_M-1) provides the second highest output for this measure. However, the value decreases when the *long-term* collaboration is applied. As for the *supply chain fill rate*, the intermediate levels of *manufacturer trust* do not provide a different *number of supply chains in the market* compared to extreme scenarios (scenario 1 and 5). Only the scenario of disloyal manufacturers (scenario T_M-2 - the 25% *loyalty*) in *long-term collaboration* has a higher median than scenario T_M-1, scenario T_M-3, and scenario T_M-4. However, this pattern is not significant when it is assessed by the Mann-Whitney U test.

Based on these output comparisons, it can be suggested that the *manufacturer trust* can only leverage the supply chains performance and survivability as a market when it is applied to the extreme high level of *trust*. The in-between levels of *manufacturer trust* do not seem to be beneficial to the supply chain over the long-term, particularly when they are compared to the situation where all manufacturers have no *trust* towards the supplier. Thus, the hypothesis of this experimental factor is supported by the simulation results, which is:

"Higher *manufacturer trust* of the supplier does not enhance long-term demand fulfilment and survivability of supply chains ".

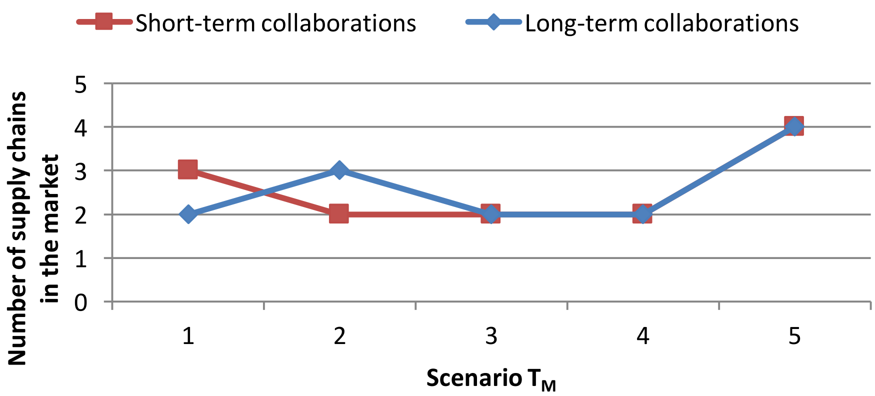


Figure 6.22 The comparison of the *number of supply chains in the market* between the *short-term collaboration* and the *long-term collaboration*, with different levels of *duration of collaboration*

6.3.3.2 *Hypothesis B.3.2*: The *supplier trust* towards supplier (*supplier trust*)

Similar to the *manufacturer trust,* the *supplier trust* is a simplified representation of supplier trust to the manufacturer. In the computer model, this factor is defined as a probability of the suppliers to follow the manufacturer's movement. When a supplier decides to be loyal to the manufacturer whom it links with, it will move closer to the manufacturer strategic position. This factor is also simulated under two levels of the *duration of collaboration*: *short-term collaboration* (4 *time units*) and *long-term collaboration* (80 *time units)*.

Five scenarios are defined in this experiment. The first is the 0% *supplier trust* to reflect extremely disloyal (distrustful) suppliers. The second scenario is 25% *trust* to represent low trust or disloyal suppliers. The third scenario is defined as 50% *trust* to present moderately loyal suppliers with a medium level of *trust*. Lastly, scenario T_S-4 and scenario T_S-5 are defined as, respectively, the 75% *trust* to represent loyal suppliers and the 100% *trust* to reflect extremely trustful/loyal suppliers. These scenarios are summarised in Table 6.6, and the results are provided in the following subsections.

Table 6.6 The scenarios for the *supplier trust*

	Probability of the *supplier trust*	**Scale representation**
Scenario T_S-1	0%	*Extremely disloyal/distrustful*
Scenario T_S-2	25%	*Disloyal/distrustful*
Scenario T_S-3	50%	*Moderately loyal/trustful*
Scenario T_S-4	75%	*Loyal/trustful*
Scenario T_S-5	100%	*Extremely loyal/trustful*

In *short-term collaboration*

From Figure 6.23, it can be seen that there is no different outcome between the scenarios for the supplier *trust*, in terms of *supply chain fill rate*. The mean is relatively consistent at between 9.4% and 10.8%, and the median is at between 9.15% and 9.85%. A similar conclusion is also drawn by the result of the Mann-Whitney U test, summarised in Appendix J, Table J.13. The test shows that all scenarios are not different significantly with each other. It means that the *supplier trust* has no significant influence on the *supply chain fill rate* in the market.

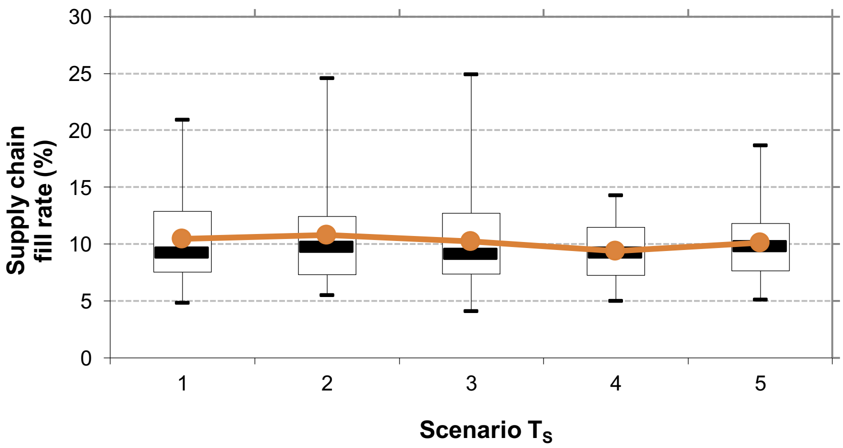


Figure 6.23 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *supplier trust*, with *short-term collaboration*

The *number of supply chains in the market* also has an identical interpretation. As shown in Figure 6.24, the boxplots indicate that there is no different between the scenarios. This is confirmed by the conclusion of the Mann-Whitney U test, which results in no significant difference for all scenarios (Appendix J, Table J.14). It suggests that when *short-term collaboration* is preferred in the market, having loyal suppliers would provide no benefit to the supply chains when this is observed from a market-level perspective.

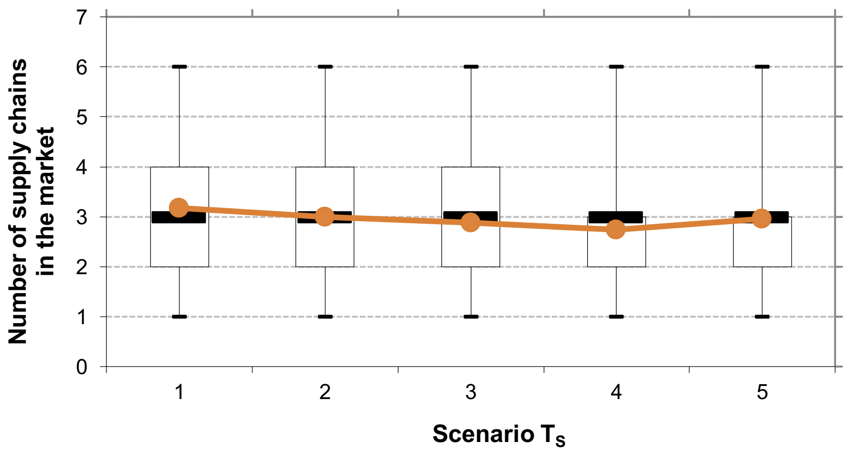


Figure 6.24 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of the supplier *trust*, with *short-term collaboration*

In *long-term collaboration*

Figure 6.25 illustrates the boxplots of the *supply chain fill rate* of *supplier trust* in a *long-term collaboration*. In the *short-term* collaboration, there is no prominent feature which shows any significant effect of *supplier trust* on the *supply chain fill rate*. The Mann-Whitney U test also suggests that the resulting *supply chain fill rates* are not different significantly among the scenarios (Appendix J, Table J.15).

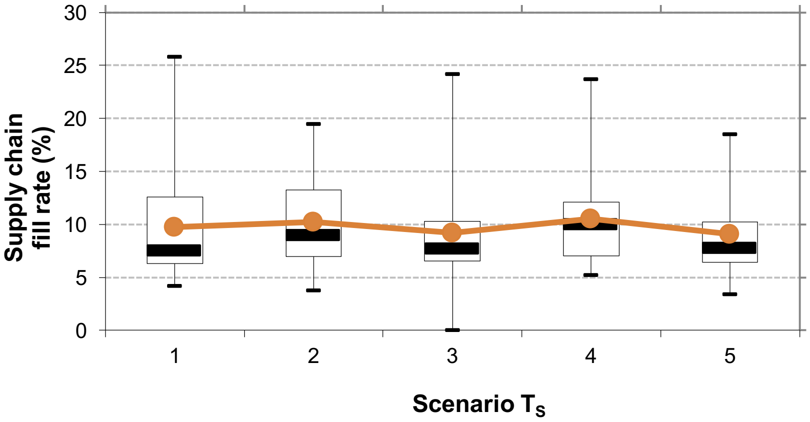


Figure 6.25 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *supplier trust* with *long-term* collaboration

Meanwhile, the boxplots of the *number of supply chains in the market* is presented in Figure 6.26. It is shown that the 25% *supplier trust* (scenario T_S-2) provides the highest mean of the *number of supply chains in the market,* but its median (2 supply chains) is relatively not different from the other scenarios. This interpretation is then inferred using the Mann-Whitney U test, which confirms that scenario T_S-2 generates a higher *number of supply chains in the market* at the end of the simulation (Appendix J, Table J.16). Nonetheless, it is only different significantly from scenario T_S-3 (the 50% *supplier trust*) and scenario T_S-5 (the 100% *supplier trust*), whereas scenario T_S-3 and scenario T_S-5 are considered to be not different significantly from scenario T_S-1 (the 0% *supplier trust*) and scenario T_S-4 (the 75% *supplier trust*). It means that the *supplier trust* has a very low significant impact on supply chains.

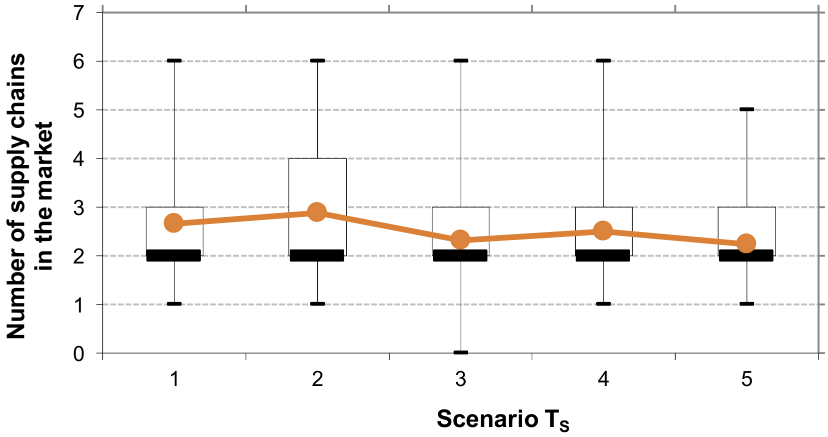


Figure 6.26 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of the *supplier trust* with *long-term* collaboration

Comparison of the *supplier trust* results in *short-term* and *long-term* collaboration

Figure 6.27 compares the median of the *supply chain fill rate* of the *supplier trust* resulted in *short-term* and *long-term* collaboration. It can be seen that *short-term* collaboration provides higher *supply chain fill rate* than *long-term collaboration* for most scenarios of the *supplier trust*, particularly with respect to scenario T_S-1, scenario T_S-2, scenario T_S-3, and scenario T_S-5. This feature also emerges in the comparison of the *number of supply chains in the market* shown in Figure 6.28.

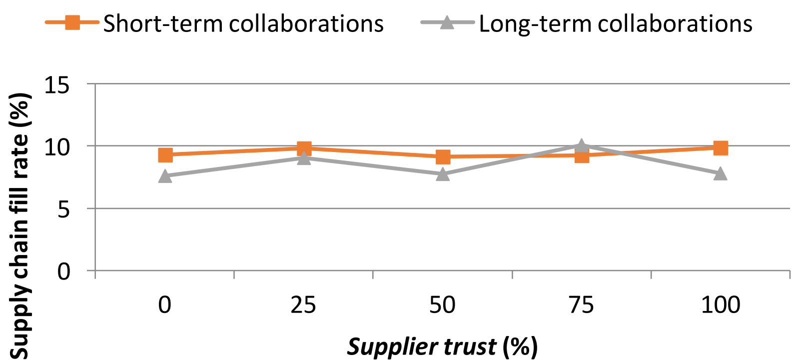


Figure 6.27 The comparison of *supply chain fill rate* between *short-term collaboration* and *long-term collaboration*, with different levels of *duration of collaboration*

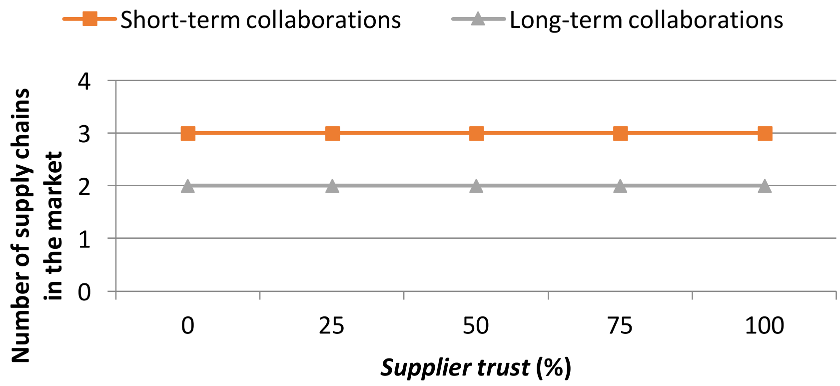


Figure 6.28 The comparison of *supply chain fill rate* between *short-term collaboration* and *long-term collaboration*, with different levels of *duration of collaboration*

Based on these results, it can be interpreted that there is no significant interaction between the *supplier trust* and the *duration of collaboration*. This is shown by the limited intersections between the resulting outcomes. This is unexpected as a higher *supplier trust* is supposed to be more beneficial to supply chains when a longer *duration of collaboration* is applied.

With respect to this result, it can be suggested that *Hypothesis B.3.2* is supported, which is:

> "Higher *supplier trust* towards manufacturer does not improve long-term demand fulfilment and survivability of supply chains".

Even though in the *long-term* collaboration, the non-extreme level of low *supplier trust* (scenario T_S-2) has a better result in the *number of supply chains in the market* than the other scenarios, this conclusion does not apply to all the comparison results. This is because all simulation results indicate that the *supplier trust* has insignificant influence on both *supply chain fill rate* and *number of supply chains in the market.*

6.3.3.3 *Hypothesis B.3.3*: The *customer loyalty* towards manufacturer (the *customer trust/loyalty*)

The *customer trust/loyalty* is employed to represent demand market behaviour that provides uncertainties to supply chains. In the computer model, it is defined as the probability that a customer will select the same manufacturer as previously chosen. The experiment considers five levels of *customer loyalty*. It represents extremely disloyal customers (0%), disloyal customers (25%), moderately loyal customers (50%), loyal customers (75%), and extremely loyal customers (100%). The scenarios are provided in Table 6.7.

Table 6.7 The scenarios for the *customer loyalty*

	Probability of the *customer loyalty*	**Scale representation**
Scenario T_C-1	0%	*Extremely disloyal*
Scenario T_C-2	25%	*Disloyal*
Scenario T_C-3	50%	*Moderately loyal*
Scenario T_C-4	75%	*Loyal*
Scenario T_C-5	100%	*Extremely loyal*

The boxplot shown in Figure 6.29 compares the *supply chain fill rate* for all scenarios of the *customer trust/loyalty*. Overall, scenario T_C-5 (the 100% *customer loyalty*) has the highest mean and median of *supply chain fill rate*, and scenario T_C-4 (the 75% *customer loyalty* results in the lowest mean and median. In scenario 5, the mean is 15.4%, and the median is 13.9% while scenario T_C-4 provides 7.7% and 7.5% for the mean and the media consecutively.

As it can be seen in Figure 6.29, the mean and the median of the scenarios follow a flat u-shaped pattern. From scenario 1 (the 0% *customer loyalty*) to scenario T_C-4 (the 75% *customer loyalty*), there is a slight downward trend for both the mean and the median of *supply chain fill rate* as the degree of *customer loyalty* rises. Then, the trend is reversed when *customer trust/loyalty* is extremely high (scenario T_C-5 - 100%). Even though scenario T_C-5 has a higher outcome than other scenarios, 96% results end with monopoly (one supply chain). Scenario T_C-5 also has an extreme value of *supply chain fill rate* (43.4%) that is obtained from monopoly outcome. It suggests that when the monopoly comes when the customers are extremely loyal to the firm, it can enhance the *supply chain fill rate* in the market.

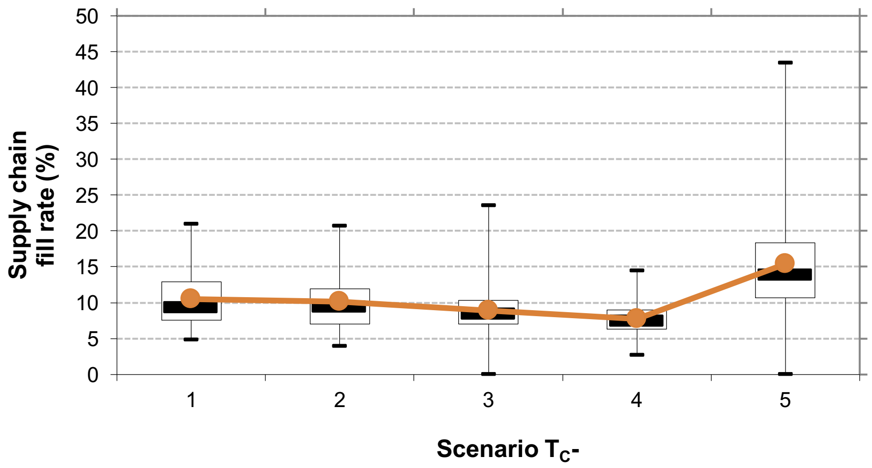


Figure 6.29 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *customer trust/loyalty*

The results of the Mann-Whitney U test point that scenario T_C-5 has the most significant difference compared to the other scenarios (Appendix J, Table J.17). It provides the highest *supply chain fill rate,* and the result is significant compared to the other scenarios. Meanwhile, the lowest *supply chain fill rate* results by scenario T_C-4, but it is not different significantly from scenario T_C-3.

Meanwhile, the *number of supply chains in the market* has a downward trend as *loyalty* increases. The highest mean and median of the *number of supply chains in the market* is 3.14 and three supply chains respectively obtained in scenario T_C-1 (the 0% *customer loyalty*). The mean decreases to 2.44 supply chains and the median is three supply chains in scenario T_C-2 (the 25% *customer loyalty*). In scenario T_C-3 (the 50% *customer loyalty*), the mean is 1.94 supply chains, and the median is two supply chains. It drops again to 1.32 supply chains and one supply chain for the mean and the median in scenario T_C-4 (the 75% *customer loyalty*). Lastly, the mean decreases to 0.96 supply chains and the median remains the same in scenario 5 (the 100% *customer loyalty*). The figure also indicates that the data distribution of the output, shown by the size of the boxplot, also tends to be smaller as the degree of *customer loyalty* increases. It is shown in the boxplots presented in Figure 6.30.

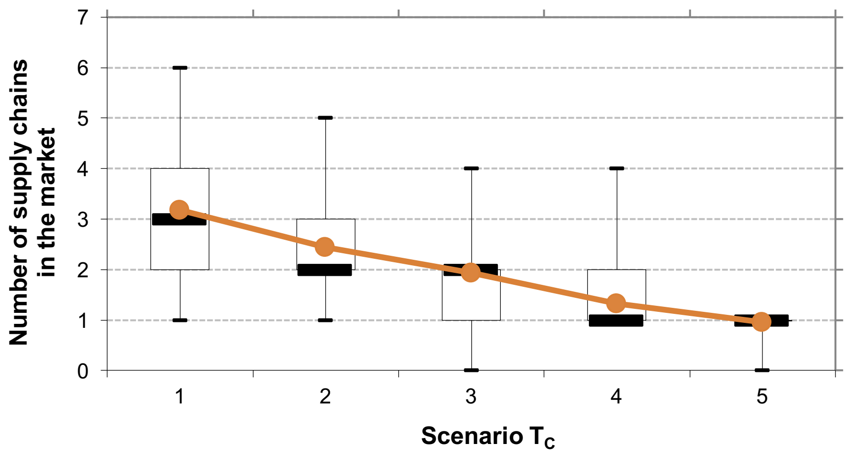


Figure 6.30 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of the *customer loyalty*

This decreasing pattern for the *supply chain fill rate* and the *number of supply chains in the market* indicates that the occurrence of monopoly tends to be more frequent as customer *trust/loyalty* increases. Moreover, scenario T_C-5 results in only two values: zero and one supply chains. Therefore, a proportion presentation is required to obtain more detail information for comparing the scenarios.

The analysis of the Mann-Whitney U test of this experiment concludes that no loyal customers (scenario T_C-1 – 0%) provide a significantly higher *number of supply chains in the market* for a *long-term* than customers with any degree of *loyalty* (Appendix J, Table J.18). It has a consistent conclusion of significant difference between the outputs of the *number of supply chains in the market* with all other levels of *customer loyalty*. The Mann-Whitney test also indicates that all scenarios of the *customer trust/loyalty* are different significantly with each other, but scenario T_C-2 and scenario T_C-3 are considered to have no significant difference.

Based on the results of *supply chain fill rate* and the *number of supply chains in the market*, it indicates that no loyal customers can lower the number of supply chain failures in the market than customers with any degree of *loyalty*. However, it does not provide the highest *supply chain fill rate* and is considered to be not different significantly from several intermediate levels of *customer loyalty* (scenario T_C-2 and scenario T_C-3).

Considering the hypothesis stated about *customer loyalty* (*Hypothesis B.3.3*), it can be suggested that the result confirms the hypothesis that

> "Higher *customer loyalty* towards manufacturer does not improve long-term demand fulfilment and survivability of supply chains".

In fact, the results show that the higher *customer loyalty* strongly affects the supply chain survivability (represented by the *number of supply chains in the market*) in a negative way unless the *loyalty* does not exist at all.

6.3.4 *Hypothesis B.4*: Individual *firm survivability*

This factor aims to investigate the effect of the *manufacturer survivability* and the *supplier survivability* during long-term competition. Each observation refers to *Hypothesis B.4.1* and *Hypothesis B.4.2* respectively.

6.3.4.1 *Hypothesis B.4.1*: *Manufacturer survivability*

The *manufacturer survivability* described in the experiments is the manufacturer's ability to cope with losses when it collaborates with less efficient and/or responsive supplier/s. In the computer model, the variable is denoted as *SurvivabilityWithUndesiredSupplier* and defined as the number of *time units* that the manufacturer can survive to work with undesired supplier/s.

The factor is simulated under five conditions: extremely low survivability (12 *time units*), low survivability (16 *time units*), average survivability (20 *time units*), high survivability (24 *time units*), and extremely high survivability (28 *time units*). The interpretation of these scenarios is described by considering *time unit* as the possible shortest time in allowing the firms to create a slight strategic change. Hence, each scenario can be implied at least 3 years, 4 years, 5 years, 6 years, and 7 years consecutively. A summary of these scenarios is presented in Table 6.8. Scenario S_M-3 is empirically considered as the base run of the experiment as 5 years is assumed to be a moderate degree of survivability.

Table 6.8 The scenarios for the *manufacturer survivability*

	Level of the *manufacturer survivability*	**Scale representation**
Scenario S_M-1	12 *time units*	*Extremely low survivability*
Scenario S_M-2	16 *time units*	*Low survivability*
Scenario S_M-3	20 *time units*	*Average survivability*
Scenario S_M-4	24 *time units*	*High survivability*
Scenario S_M-5	28 *time units*	*Extremely high survivability*

The results of this experiment indicate that scenario S_M-1 (12 *time units*) provides most significant difference against other scenarios, except with scenario S_M-2 (16 *time units*). It has the significant lowest *supply chain fill rate* in this experimental set, particularly when it is compared with scenario S_M-2 (16 time unit), scenario S_M-3 (20 *time units*), scenario S_M-4 (24 *time units*), and scenario S_M-

5 (28 *time units*). These scenarios (S_M-2, S_M-3, S_M-4 and S_M-5) are also considered not significantly different.

Figure 6.31 shows the boxplots presentation of the simulation results for *supply chain fill rate*. It can be seen that scenario S_M-1 (12 *time units*) provides the lowest *supply chain fill rate* both for the mean and median. The mean of this scenario is 8.03% and the median is 7.2%. It also has the densest output distribution compared to the other scenarios. Meanwhile, scenario S_M-2 (16 *time units*), scenario S_M-3 (20 *time units*), scenario S_M-4 (24 *time unit*), and scenario S_M-5 (28 *time units*) seem to be similar. The distribution of the output is also relatively not different in these scenarios.

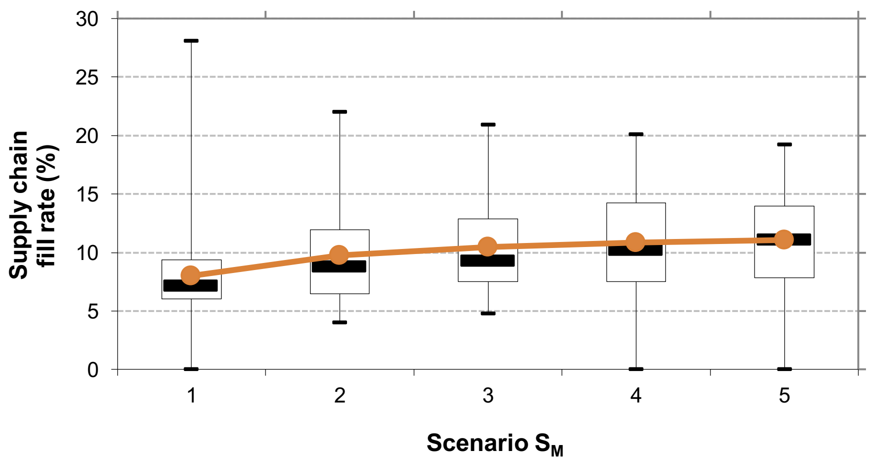


Figure 6.31 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *manufacturer survivability*

However, compared to the others, scenario S_M-2 and scenario S_M-3 are considered to be different because there is no 0% in *supply chain fill rate*, while others are possible to end with zero *supply chain fill rate*. The occurrence of zero supply chain in scenario S_M-1 is 4% (2 out of 50 results), while in both scenario S_M-4 and scenario S_M-5 is 2% (1 out of 50 results). Meanwhile, the results of the Mann-Whitney U test suggest that the manufacturers with an extremely low survivability to work with a less efficient and/or responsive supplier will lead to a lower the *supply chain fill rate* in the system (Appendix J, Table J.19). Meanwhile, the higher *manufacturer survivability* (scenario S_M-2 to scenario S_M-5) does not seem to affect *supply chain fill rate*.

Similarly, as shown in Figure 6.32, the lowest mean and median of the *number of supply chains in the market* are given by scenario S_M-1, while the highest outcome is in scenario S_M-5. The values have an upward trend as the *manufacturer survivability* increases, although the result of the Mann-Whitney U test for the *number of supply chains in the market* of *manufacturer survivability* suggests that only scenario S_M-1 and scenario S_M-2 are significantly different from other scenarios (Appendix J, Table J.20). Scenario 1 provides the lowest result, followed by scenario S_M-2 as resulting in the second lowest value for the *number of supply chains in the market*. Scenario S_M-3, scenario S_M-4, and scenario S_M-5 are considered provides no difference output with each other. It suggests that a higher manufacturer's individual survivability does not consistently result in higher supply chain's survivability; a medium to high level of manufacturer's individual survivability would provide a not different effect to the supply chain' survivability.

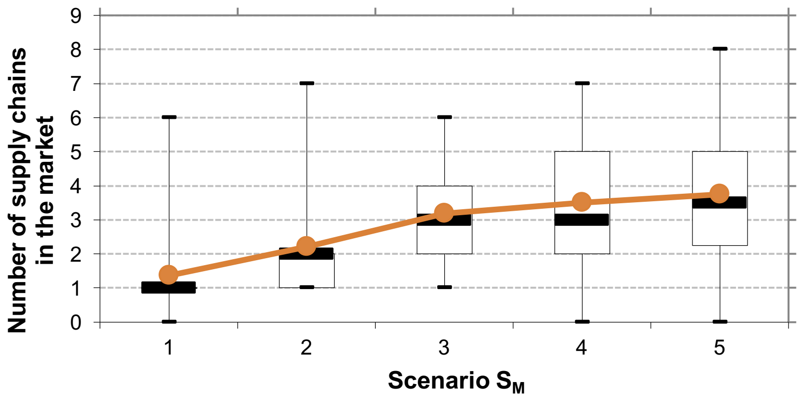


Figure 6.32 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of the *manufacturer survivability*

With respect to this outcome, the hypothesis of this study is supported by the results, which is:

> "Higher *manufacturer survivability* does not enhance long-term demand fulfilment and survivability of supply chains".

The *manufacturer survivability* is not significant to the supply chains when it is evaluated at medium to high level, whereas the extremely low survivability has a significant impact on both *supply chain fill rate* and the *number of supply chains in the market*.

6.3.4.2 *Hypothesis B.4.2*: Supplier survivability

The *supplier survivability* is defined as the supplier's ability to cope with uncertainties in supply chains. One source of uncertainties for suppliers comes from the demand side, including failure to maintain the manufacturer as their customer. Thus, the *supplier survivability* examined in this study focuses on the supplier's ability to survive with the loss when it does not establish a partnership with the manufacturer. In the computer model, it is defined as the length of the supplier to survive in *time unit* when it does not have a link with the manufacturer agent at all. In the base run, the *supplier survivability* is set to 4 *time units* or one year. Five levels of *supplier survivability* are considered, which form the scenarios presented in Table 6.9.

Table 6.9 The scenarios for the *supplier survivability*

	The level of *supplier survivability*	**Scale representation**
Scenario S_S-1	1 *time unit*	*Extremely low survivability*
Scenario S_S-2	2 *time units*	*Low survivability*
Scenario S_S-3	4 *time units*	*Average survivability*
Scenario S_S-4	6 *time units*	*High survivability*
Scenario S_S-5	8 *time units*	*Extremely high survivability*

The boxplots presented in Figure 6.33 shows that no particular pattern emerges for the mean and the median of *supply chain fill rate* of these scenarios. Even though the mean has a slight increase as the *supplier survivability* rises, the difference between the results is not significant. The conclusions in the Mann-Whitney U test also indicate that there is no significant difference between the scenarios, unless between scenario S_S-1 and scenario S_S-5 (Appendix J, Table J.21). The *supply chain fill rate* in scenario S_S-1 is only significantly lower than scenario S_S-5, but it is not different significantly from other scenarios. Meanwhile, as shown in Figure 6.34 the mean of the *number of supply chains in the market* increases as the *supplier survivability* rises, while the median only increases from scenario S_S-1 to scenario S_S-3. The mean and median of scenario S_S-1 are the lowest values compared to other scenarios. It suggests that the extreme low survivability can lead to more supply chain failures in the market. However, the maximum value for this scenario is 7 supply chains, which is higher than the maximum value in scenario S_S-2 and scenario S_S-3.

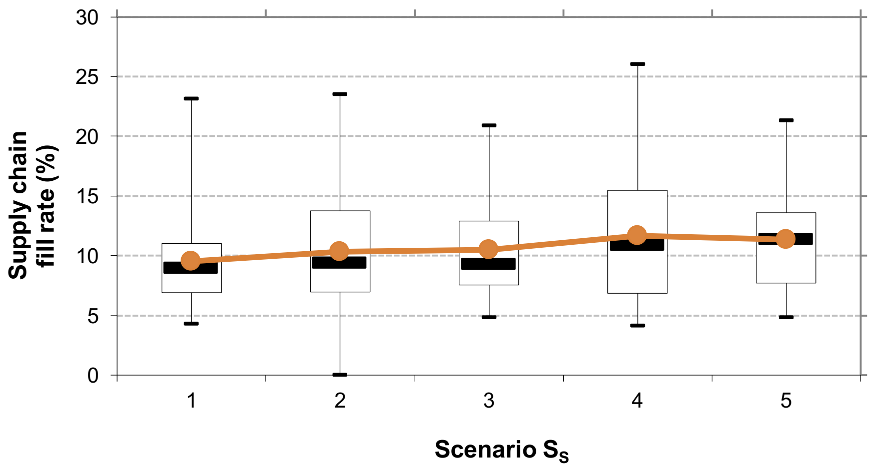


Figure 6.33 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of the *supplier survivability*

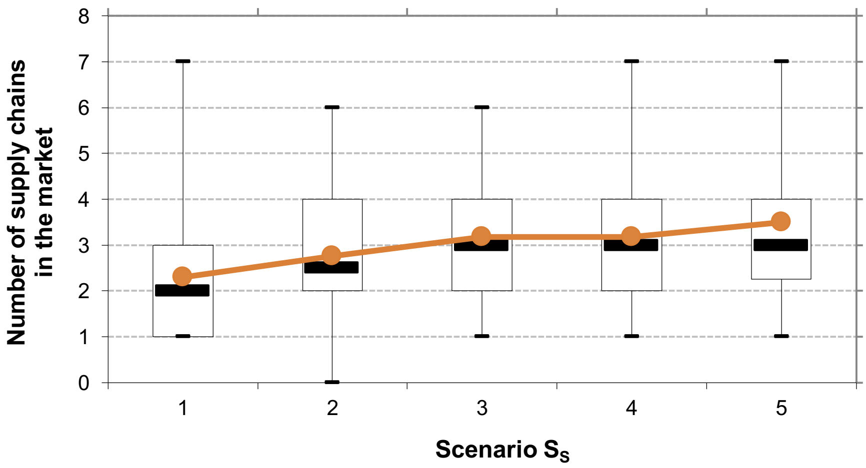


Figure 6.34 Boxplots of the *number of supply chains in the market* and a line representing mean values for each scenario of the *supplier survivability*

The Mann-Whitney U test of the *supplier survivability* for the *number of supply chains in the market* confirms the conclusion, which is only scenario S_S-1 has the most significant difference compared to other scenarios, although it is not different significantly from scenario S_S-2 (Appendix J, Table J.22). Scenario S_S-1 is concluded to be significantly lower than scenario S_S-3, scenario S_S-4, and scenario S_S-5 the *number of supply chains in the market*. Regarding these results, *Hypothesis B.4.2* is considered supported, which is:

> "Higher *supplier survivability* does not improve long-term demand fulfilment and survivability of supply chains".

6.3.5 *Hypothesis B.5*: Manufacturer *strategic mutation*

The competition approach suggested in strategic management, regarding the *big leap* or *strategic mutation*, does not consistently enhance demand fulfilment rate and *survivability* for a long term; it can lead the supply chains to be more vulnerable in the market.

The manufacturer *strategic mutation* reflects a manufacturer competitive behaviour in changing its strategic position. This factor is presented as the probability of the manufacturer agents in making a *big leap* when they move on the NetLogo space*,* and defined as *MutationProbability* in the computer model. This variable can also be represented as the risk attitudes of manufacturers in the market in changing their strategy.

The hypothesis of this experimental factor is that the performance of all supply chains in the market is lower when all manufacturers are more likely to create a *big leap* in their strategic change. This expectation is intuitively judged based on many doubts from supply chain practitioners on the benefits of this strategy to the supply chain stability and sustainability.

This variable is observed by varying the value into five levels or scenarios of probability: 0%, 2%, 5%, 7%, and 10%. These values are considered as a representation of these following manufacturer characteristics: no *mutation* (0%), very less likely to *mutate* (2%), less likely to *mutate* (5%), likely to *mutate* (7%), and very likely to *mutate* (10%). These scales are chosen empirically to obtain intuitions for testing *Hypothesis B.5*, which is

> "The competition approach suggested in strategic management, regarding the strategic mutation, does not improve demand fulfilment and survivability of supply chains for the long-term."

The detail of the scenarios is summarised in Table 6.10.

The interpretation of the scales used is illustrated as follows. The 2% manufacturer *strategic mutation* probability, for example, represents the likelihood of a manufacturer decides to *mutate*. As a simple illustration, a manufacturer is expected to mutate at least twice within 100 *time units*. As one *time unit* is assumed to represent at least 3 months, the *mutation* is supposed to be twice within (at least) 75 years.

Table 6.10 The scenarios for the manufacturer *strategic mutation*

	Probability of manufacturer *strategic mutation*	Scale representation
Scenario M-1	0%	*No mutation*
Scenario M-2	2%	*Very less likely to mutate*
Scenario M-3	5%	*Less likely to mutate*
Scenario M-4	7%	*Likely to mutate*
Scenario M-5	10%	*Very likely to mutate*

Meanwhile, the 10% manufacturer *strategic mutation* probability reflects the very high or extreme probability for a company to change its strategic position dramatically. By the probability, as a simple illustration, the manufacturer is expected to mutate ten times within 100 *time units*, or once within 10 *time units*. If one *time unit* is described as 3 months, a *mutation* is supposed to occur in a manufacturer within 7.5 years. The probabilities defined in between 0% and 10% are considered to represent the intermediate probability between the extreme situations (the 0% and 10% probability of manufacturer *strategic mutation*).

The boxplots presented in Figure 6.35 illustrate that both the mean and the median of the *supply chain fill rate* decreases as the probability of manufacturer *strategic mutation* increases. However, the comparison analysis obtained from the Mann-Whitney U test concludes that only scenario M-1 and scenario M-5 are significantly different from others (Appendix J, Table J.23). The *supply chain fill rate* of scenario M-1 is significantly higher than other scenarios, whilst scenario M-5 has the lowest *supply chain fill rate*. Scenario M-2, scenario M-3, and scenario M-4 are regarded to be no different significantly with each other.

As can be seen in Figure 6.36, the probability of manufacturer *strategic mutation* significantly affects *the number of supply chains in the market*. When the manufacturers do not mutate or change their strategic position in an extreme way (scenario M-1 – 0%), the behaviour provides the highest mean and median for the *number of supply chains in the market*, which are 3.18 and 3 respectively. The median of scenario M-2 (the 2% probability of manufacturer *strategic mutation*), scenario M-3 (the 5% probability of manufacturer *strategic mutation*), scenario M-

4 (the 7% probability of manufacturer *strategic mutation*), and scenario M-5 (the 10% probability of manufacturer *strategic mutation*) are consistent with one supply chain.

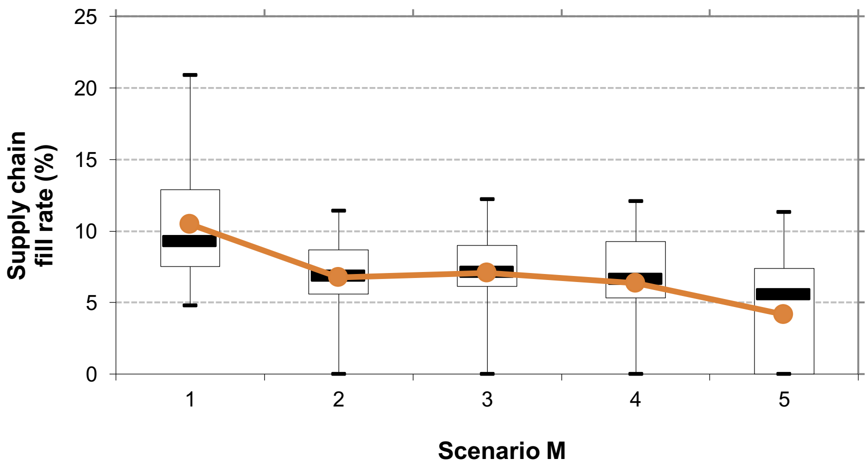


Figure 6.35 Boxplots of the *supply chain fill rate* with a line of mean values for all scenarios of manufacturer *strategic mutation*

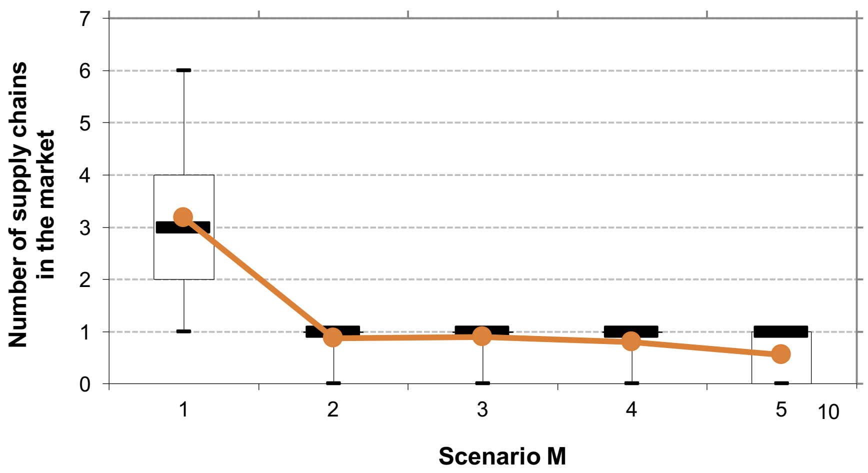


Figure 6.36 Boxplots of the *number of supply chains in the market* with a line of mean values for all scenarios of manufacturer *strategic mutation*

The data distribution, shown by the size of the box, also shrinks significantly from scenario M-1 to scenario M-2. Then, the data distribution remains the same until the box size extends in scenario M-5. Scenario M-2, scenario M-3, scenario M-4 and scenario M-5 only have two values that emerge in these scenarios for the *number of supply chains in the market;* they are zero and one. The one supply chain appears more often than zero supply chain. The extreme manufacturer *strategic mutation* (scenario M-5) has a taller box size than scenario M-2, scenario M-3 and scenario M-4. This is because the occurrence of zero supply chains in the market in scenario M-5 is more likely than the other scenarios.

The Mann-Whitney U test is performed to infer the conclusion of the *number of supply chains in the market* of The scenarios for *manufacturer strategic movement* (Appendix J, Table J.24). Scenario M-1 has the most significant difference with other scenarios. It provides the highest *number of supply chains in the market*. In contrast, scenario M-5 significantly has the lowest *number of supply chains in the market*, but it has no significant difference with scenario M-4. Lastly, the result of scenario M-2, scenario M-3, and scenario M-4 are considered not different significantly with each other.

Due to the limited values of the *number of supply chains in the market* resulted in scenario M-2, scenario M-3, scenario M-4, and scenario M-5, which only have two values (one and zero), a proportion graph (Table 6.11) is incorporated to add the confidence of the analysis. However, the conclusions of the Mann-Whitney U test are relatively consistent with the visual representation in both figures. All these analysis approaches conclude that scenario M-1 (no *mutation* - 0%) significantly results in higher *number of supply chains in the market*, scenario M-5 significantly has the lowest output of this measure, and the remaining scenarios are not different significantly with each other.

Table 6.11 The proportion of extreme numbers of supply chains in the experiment of the manufacturer *strategic mutation*

Scenario	Number of supply chains in the market		
	0	1	> 1
M-1	0 (0%)	6 (12%)	44 (88%)
M-2	6 (12%)	44 (88%)	0 (0%)
M-3	5 (10%)	45 (90%)	0 (0%)
M-4	10 (20%)	40 (80%)	0 (0%)
M-5	22 (44%)	28 (56%)	0 (0%)

With respect to these outcomes, it can be suggested that the competition approach suggested in strategic management, regarding the *big leap* or *strategic mutation*, does not consistently enhance supply chains ability to meet the demand and *robustness* for the long term; it can lead the supply chains to be more vulnerable in the market. Therefore, *Hypothesis B.5* is supported, which is that

> "The competition approach suggested in strategic management, regarding the strategic mutation, does not improve demand fulfilment and survivability of supply chains for the long-term ".

6.3.6 Results summary for *Hypotheses B*

A summary of scenarios that leads to better outcomes for each experimental factor is provided in Table 6.12. A degree or level of significance of each factor is presented to represent the overall conclusions of the Mann-Whitney analysis. The term 'significance' does not refer to the statistical level of significance, but to a general belief in the model results. If a factor has significant differences for more than equal to 50% of total number of comparisons (5 out of 10) for each demand fulfilment rate (*supply chain fill rate*) and supply chain survivability (the *number of supply chains in the market*), it will be considered to have a high degree of significance.

Table 6.12 Summary of the resulting experiments for *Hypotheses B*

Experimental factor	Degree of significance	Scenario with better results	Affected outputs: Demand fulfilment rate	Affected outputs: Supply chain survivability
1 *Duration of collaboration*				
when manufacturers work with one supplier at one time,				
1.1 as well as the suppliers.	Not significant	-		
1.2 and the supplier can link to more than one manufacturer.	Low	Short-term collaboration	✓	✓
2 *Number of partnerships*				
2.1 when short-term collaboration applies.	Low	***Not*** *dual-sourcing* for manufacturer when the suppliers can link with more than one manufacturer		✓
2.2 when long-term collaboration applies.	Low	Single-sourcing with one-to-one partnerships.	✓	✓
3 *Trust*				
3.1 Manufacturer trust of the suppliers				
3.1.1 when short-term collaboration applies.	**High**	Extremely high *loyalty* or no *loyalty* at all	✓	✓
3.1.2 when long-term collaboration applies.	Low	Extremely high *loyalty*	✓	✓
3.2 Supplier trust of the manufacturers				
3.2.1 when short-term collaboration applies.	Not significant	-		
3.2.2 when long-term collaboration applies.	Low	Somewhat disloyal, by not consistently following manufacturer strategic movement		✓
3.3 Customer trust/loyalty towards manufacturers	**High**	No *loyalty* at all		✓
4 Survivability				
4.1 Manufacturer survivability	**High**	***Not*** extremely low survivability	✓	✓
4.2 Supplier survivability	Low	***Not*** extremely low survivability		✓
5 Manufacturer strategic movement	**High**	No *big leap* at all	✓	✓

If the number of differences is between 20% (2 out of 10) and 40% (4 out of 10), the factor will be regarded to have low significance degree or low sensitivity, while the remaining proportion (≤ 10%) represents not significant (or not sensitive at all) factor to maintain supply chain long-term performance and survivability. If a factor is highly significant or sensitive only to one model output, the average number of significant differences of both model outputs (*supply chain fill rate* and the *number of supply chains in the market*) will be used.

The results indicate that not all popular issues in competition and collaboration are highly significant to the supply chains in terms of maintaining demand fulfilment rate (the *supply chain fill rate*) and survivability (the *number of supply chains in the market*) for a long-term competition. The factors that have significant impacts are *manufacturer trust* toward supplier (the *manufacturer trust*), manufacturer's individual survivability (the *manufacturer survivability*), the manufacturer strategic movement or *mutation*, and the *customer loyalty* towards the manufacturer. These factors result in high numbers of significant differences in the Mann-Whitney U test.

6.4 Summary

The results and analysis of this study have been presented in this chapter. Overall, all proposed hypotheses provided in Methodology (Chapter 4) are supported by the outcomes. The competitive and collaborative behaviour recommended in SCM and strategic management does not seem to guarantee a better demand fulfilment and survivability of supply chains. Also, competition can have both positive and negative impacts on supply chains. It can assist strategic alignment within the supply chain although no particular collaboration approach is implemented. Nevertheless, a long-term competition can lead to an extreme *shakeout*. A discussion of all of these findings is presented in Chapter 7.

CHAPTER 7 DISCUSSION OF THE FINDINGS

7.1 Introduction

Discussions of the resulting emergent outcomes presented in Chapter 6 are presented in this chapter. The discussions are structured based on the three objectives of this study. Then, limitations of the interpretations of the results are also addressed at the end of this chapter.

7.2 The agent-based model of competition and collaboration in supply chains (Objective 1).

An agent-based model of competition and collaboration in supply chain has been developed in this study. The model is designed to bridge the gap in the literature of supply chain competition and collaboration, which is related to the debate on the effect of competition and collaboration strategies to supply chains, as described in Chapter 2. The main issues examined by the model are the *duration of* *collaboration*, *number of partnerships*, *trust*, individual firm *survivability*, and manufacturer *strategic mutation*. All of these issues are the main attributes of the model and explored from market-level perspective.

The use of theory-driven approach has assisted the determination of the study objectives to achieve the aim of this study, which is:

> "To explore the impact of competition and collaboration strategies on supply chains from a market perspective".

The approach is also the foundation of the construction of research hypotheses defined in section 4.3. The hypotheses help the present researcher to explain the dynamic behaviour as 'endogenous consequences' of the model, which leads to the emergent behaviour of the agent's interactions.

Based on the existing theories and findings found in the literature, the research Hypotheses B are deployed into the experimental design to represent business situations with particular levels of market adoption towards competition and collaboration strategies recommended in SCM and strategic management. Some experiments are relevant to the reality, particularly to reflect the trend of the implementation of a strategy that has been successfully practised by large companies. Meanwhile, the other scenarios may not describe the current reality, but they are possible to occur in the real world, such as the extremely high probability of strategic *mutation*.

The model shows that a simple micro behaviour of an individual agent leads to the emergence of market-level behaviour. This emergent pattern is resulted from the agent interactions that create feedback to each agent, particularly for the manufacturer and supplier. This feedback mechanism generates complexity to the system that could not be interpreted explicitly from the code. In this sense, the "emergent properties" resulting from the model is generated as the macro or system implications of local agent's interactions, as described by Axelrod (1997). It also conforms to Onggo (2016) who explains that the market behaviour is created as a result of interaction between individuals, such as customers and companies. Hence, the model developed in this study is able to investigate the problem situation of competition and collaboration in supply chains, taking from market-level perspective.

This model capability also shows that the model has been able to elaborate a better understanding of competition and collaboration in supply chains. The exploration of the effect of competitive and collaborative behaviour has been performed as intended, as described in the conceptual model (section 5.2 - Chapter 5). The generic effect of competition can also be investigated by the model, which denotes that the developed agent-based model is capable to assist the present researcher to obtain intuitions, in terms of understanding the effect of competition and collaboration strategy in supply chains. This feature corresponds to North and Macal (2007) who suggested ABM as an appropriate method to acquire intuitions of a problem, instead of proving theorems. In addition, this study verifies the perspective of Zenobia et al. (2009) and LeBaron (2000), who find that an efficient model is a simple model that is useful to gain insights. In this study, the intuitions and insights are related to the interpretation of competition and collaboration impact on supply chains. Overall, this study indicates that a long-term competition has positive and negative emergent impacts on the market, and what is good for a single company is not always beneficial for others, even it could be detrimental for the market if it applies to all firms for the long-term.

An illustration to describe the complex relationships between the agents that lead to a market-level behaviour is presented in Figure 7.1. This illustration is not the agent-based model developed in this study, but it is a representation of the causal link of the resulting interactions between the agents in the model during the simulation. The elements presented in the figure are also useful to provide explanations on the model results in the next sections.

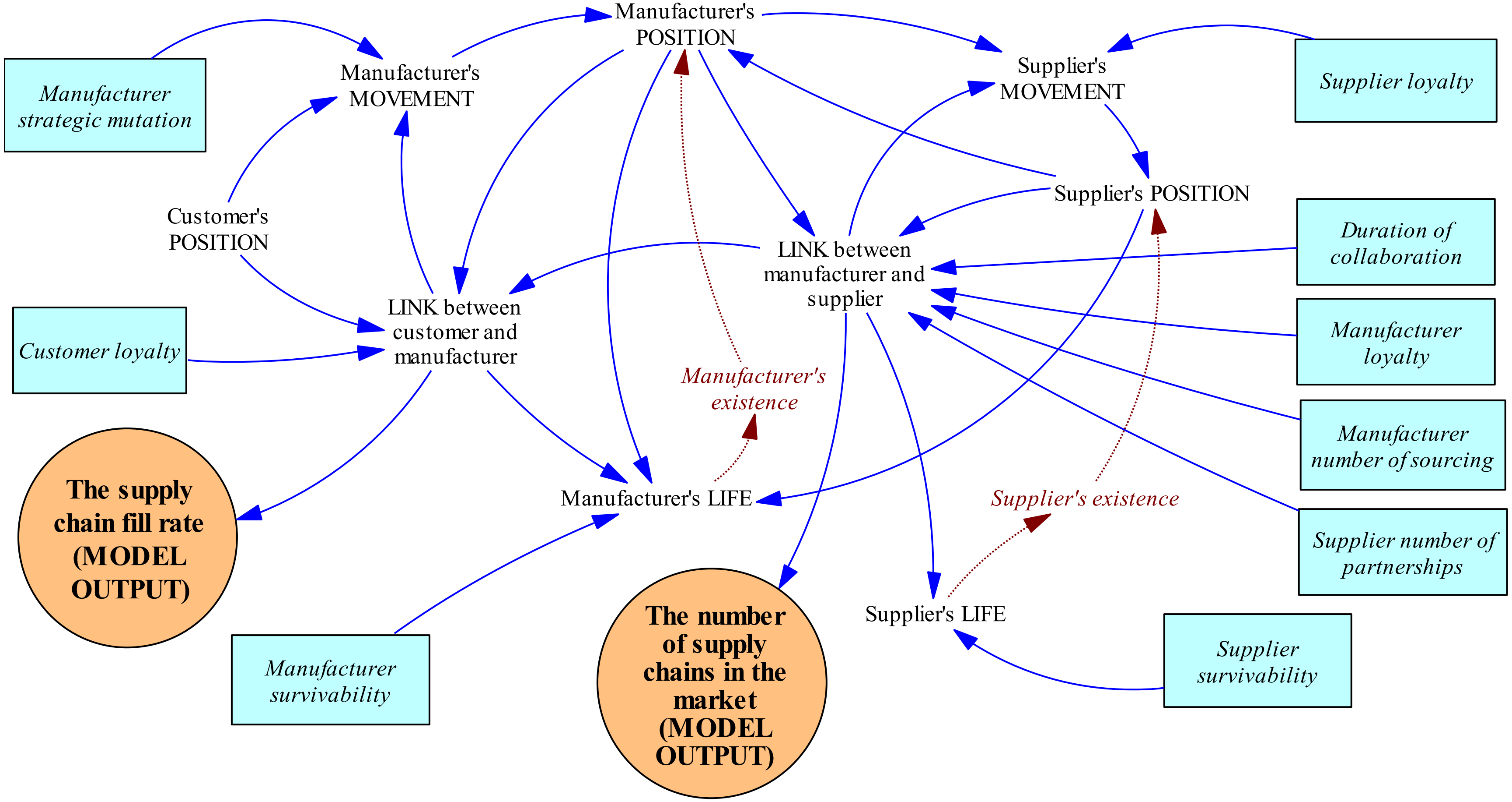


Figure 7.1 The model mechanism that makes micro behaviour emerge as system level behaviour

From Figure 7.1, it can be seen that the interaction is produced based on the feedbacks that are generated during the simulation run. Each feedback changes each agent's state, which is listed as variable attributes in section 5.2.1.1. The investigated competitive and collaborative strategies (the experimental factors) are illustrated as rectangular variables, and the model outputs are presented inside the circle shape. The solid lines represent the direct effect of the changes, and the dashed lines reflect indirect effect to a variable. For example, the arrow from *customer's position* to *manufacturer's movement* means that the position of the customer agents has a direct effect on the direction of the manufacturer's movement. If a customer links with a manufacturer, the manufacturer will move away from that customer to approach a new customer. Meanwhile, the indirect effect between the agent's attributes is illustrated by the following example. The *manufacturer's life* has an indirect effect on *manufacturer's position* by lengthening the *manufacturer's existence* in the system. Consequently, if the manufacturer is still "alive", it will stay in a particular strategic position; otherwise, the manufacturer agent disappears (*die*) from the model. This mechanism of indirect interaction also applies similarly to the supplier agents.

Figure 7.1 also demonstrates that each experimental factor has a different impact on the agent's attributes. The manufacturer *strategic mutation* affects the *manufacturer's movement*, which affects the *manufacturer's position*. The *customer trust/loyalty* influences the duration of customer's interaction with a manufacturer, which is represented as a *link between customer and manufacturer*. This link also has a direct impact on the direction of *manufacturer's movement* because the manufacturers are acquisitive to attract another customer who has not being linked with them. The *manufacturer's survivability* impacts on *manufacturer's life*, which is also influenced by the existence of the *link between customer and manufacturer* and the position of the collaborating agents (*manufacturer's position* and *supplier's position*). The *supplier's survivability* influences the *supplier's life*, which affects the *supplier's existence* in the system. The *link between manufacturer and supplier* is influenced by the *duration of* *collaboration*, the *manufacturer trust,* the *manufacturer number of sourcing*, and the *supplier number of partnerships*. Each factor has a different mechanism in changing the *link between the manufacturer and the supplier*, as explained in the conceptual model (Chapter 5). Lastly, the *supplier trust* influences the *supplier's movement*, which affects the *supplier's strategic position* in the system.

As for the model outputs, even though it is expected that a higher *number of supply chains in the market* results in a higher *supply chain fill rate* (as presented in Figure 5.6 - Chapter 5), these measures are assessed in a different approach. As shown in Figure 7.1, the *supply chain fill rate* is measured by counting the number of *links between customer and manufacturer*, while the *number of supply chains in the market* is quantified based on the number of *links between manufacturer and supplier*. These measures have been found effective in assessing the resulting emergent pattern of each competitive and collaborative factor addressed in this study.

7.3 The long-term impact of competition on supply chains and market structure (Objective 2 – *Hypothesis A*).

The model results indicate that competition has both positive and negative effects on supply chains for a long-term despite the collaboration approach implemented. For the benefit, competition seems to be able to assist the process of strategic alignment between firms in the supply chain, while the drawback of competition is the potential occurrence of *shakeouts*. These findings support a conclusion in Chapter 2 that suggests not all studies support the benefits of competition (section 2.3.2.1). However, previous studies that are reviewed in Chapter 2 do not consider the issue for a long term competition period. Thus, the strategic alignment and *shakeouts* are not addressed in association with competition impact. The following subsections detail these competition impacts, with respect to strategic alignment and extreme *shakeouts*.

7.3.1 Strategic alignment within supply chain

In general, the model shows that competition can assist strategic alignment in supply chains, despite competitive and collaborative behaviour. It indicates that competition can benefit supply chains in the market although no particular collaboration strategy is implemented. It minimises the strategic gap between manufacturer and supplier within their supply chain. The gap reduction presented in the simulation result can be represented as a strategic compromise improvement in aligning supply chain capability between firms in a supply chain.

This finding supports the belief of Parker and Hartley (1997), Forker and Stannack (2000)**,** Humphreys et al. (2001), Li et al. (2010), and Wang and Shin (2015), who suggest that supplier competition is beneficial to the supply chain. However, these previous studies address this issue in a particular type of supply chain; they do not view this issue from system or market-level perspective. Moreover, their suggestion is not based on the strategic alignment factor.

This emergent outcome of competition on gap reduction also confirms the extent view in strategic management, such as Porter (1990; 1998). In this research domain, competition has been considered as an effective mechanism to enhance the quality of cooperation. This is because competition encourages better mutual understanding between collaborated firms. Therefore, this perspective argues that having *long-term* partnerships with a single supplier can hinder the occurrence of competition in the market.

The strategic alignment is also regarded as a fundamental aspect of supply chain success in SCM. The alignment is represented by operations synchronisation along the supply chain that can maximise the overall value of the finished product. However, it is generally understood that this alignment or synchronisation can only be achieved well by applying a close relationship through collaboration (Rich and Hines 1997; Spekman et al. 1998; Simatupang and Sridharan 2004; Choudhary et al. 2006; Ha et al. 2011; Ramanathan and Gunasekaran 2014). In SCM, collaboration with suppliers has been regarded to be the crucial enabler to improve the understanding between firms by reducing the uncertainties in the supply side. In other words, the collaboration approach in SCM is proposed to reduce the emergence of competition, particularly on the supply side.

However, the simulation results presented in section 6.2.1 shows that strategic alignment can be achieved even if no collaboration approach is applied, such as presented in Figure 6.1. It means that even though there is no attempt in reducing the uncertainty in the supply side, supplier and manufacturer can align their strategic capability through competition. The result of this study conforms with Hamel (2013); he finds that collaboration does not consistently help the collaborating firms to reduce the gap in their capability. The gap emerges as each firm has different learning capability. Even though the relationship between firms is stable and has been developed for a long time, Hamel (2013) suggests that it could not be considered an indicator of collaboration success.

Nevertheless, the strategic alignment does not apply to all supply chains. Although the gap decreases at the market-level, several supply chains still have a significant capability gap between the manufacturer and supplier until the simulation ends. Moreover, the strategic alignment at a market-level does not consistently occur in each experiment. This pattern is significantly caused by the distribution of manufacturers and suppliers in the system during the simulation, as presented in Figure 6.3. When most suppliers in the market are highly more efficient and responsive than the manufacturers, competition would very likely not be able to assist the strategic alignment of the supply chains in the market. However, in reality, it is hard to manage the firms' strategic position in the market.

In addition, as a strategic alignment occurs when the number of supply chains which can survive in the market is fewer than the initial state, it reflects that competition with a fewer number of firms does not represent an undesirable situation for the market. This issue has not been studied in detail both empirically and theoretically, so this discussion has led to a new insight on the effect of competition on supply chains.

7.3.2 Extreme *shakeouts*

Besides strategic alignment, the model also shows that competition can lead to *shakeouts* (massive reductions in the number of firms in the market), which can happen in any competitive and collaborative approach. The *shakeouts* can result in extreme cases, such as monopoly (section 6.3.2.2) and zero supply chain which can survive in the market (section 6.3.2.1). Although the zero supply chain is difficult to explain based on the existing literature, this emergent output may occur if no new firms enter the market during the competition. It may also be relevant to represent a specific monopoly situation where one of the collaborating firms has to adjust its strategic position extremely in order to enable the company to collaborate with the available collaborating partner. Compared to the occurrence of other number of supply chains in long-term competition, these extreme outcomes (monopoly and zero supply chains) does not emerge frequently.

A *shakeout* emerges when most companies share similar target customers with competitors. Also, when most manufacturers select suppliers who are more efficient and/or responsive than the firms, it can also lead to a *shakeout*. This is because the selected suppliers could not collaborate with the other manufacturers who have a more urgent requirement to be supplied by the suppliers.

As a *shakeout* phenomenon is relevant to several cases in the real world, it has been used as a basis for validating the model (section 5.3.2.3). It confirms several case studies in business competition, such as in industries of television, Magnetic Resonance Imaging (MRI) equipment (Day 1997), the UK steel casting industry (Baden-Fuller 1989), automobile, tires, and penicillin (Klepper and Simons 2005). The detail discussions of *shakeouts* can be referred to the validation of the model presented in section 5.3.2.3.

In addition, the results show that the extreme *shakeouts* can occur when all manufacturers implement a strategy suggested in the literature, such as the *strategic mutation* or *big leap*. This indicates that a good strategy could be catastrophic when all enterprises adopt it. This situation confirms the opinion suggested by Mintzberg et al. (2005) who tend not to support the deliberate strategies recommended in the management literature. They suggest that emergent strategies, which are developed informally inside the organisation, are more appropriate to implement.

It should be noted that the model developed in this study does not allow new firms to enter the market during the competition, which is not possible in reality. This assumption may be the reason for the emergence of extreme *shakeouts* (monopoly and zero supply chain) in the model. Moreover, in the real world, the extreme *shakeouts* are often prevented in advance by the market or trading regulator or government. One of the prevention attempts is by enacting a policy to allow or encourage new firms to enter the competition. This attempt, for example, practised by FCC (Federal Communications Commission) in the U.S. when AT&T (an American multinational telecom company) dominated the telecom equipment market prior to 1960s (Melody 1999). This regulation, or intervention, has been found to be vital to prevent the market from the political interests of major players in the market.

Assessing demand fulfilment rate, surprisingly, the extreme *shakeouts* (particularly in monopoly) do not significantly affect the demand fulfilment rate. As analysed in section 6.2.3, the decay rate of demand fulfilment in extreme *shakeouts* is not different from the non-extreme *shakeout* situations. The number of enterprises which can survive in competition does not influence the form of the market structure, which reflects the market segment of supply chains in the market. Although more than one supply chain can survive during the competition, if they serve the same customers (i.e. similar market segments), the total demand fulfilment would be similar as a monopoly supply chain. A better demand fulfilment for non-extreme *shakeout* situations can only be achieved when most supply chains in the market serve completely different market segment during the competition. Nevertheless, this ideal situation is difficult to attain in reality as firms are acquisitive in increasing income or performance. This competitive behaviour could lead the market segment of each firm to overlap with the other companies that were previously not its competitor. Once a supply chain shares a similar customer, the supply chains would likely end with a relatively similar strategic position in the long-term. An illustration of non-extreme shakeout can be referred to Figure 6.3, where six supply chains can survive and each market cluster does not intersect with the other clusters during the competition.

7.4 The exploration of competition and collaboration strategy on supply chains (Objective 3)

As explained in the methodology chapter, particularly in section 4.3, the hypotheses of this study are constructed based on the literature gap reviewed in Chapter 2. The gap, which is formalised into detailed hypotheses, is tested through the experiments on the agent-based model, and statistically verified by using multiple comparison approach, with regards to the Mann-Whitney U test. Each hypothesis is observed by applying 5 levels of experiments or scenarios, which means that each hypothesis is tested and concluded based on the results of 10 paired-comparisons.

As presented in Chapter 6, all hypotheses proposed in this study are supported by the simulation results. It indicates that the suggested competition and collaboration strategies in SCM and strategic management do not always lead to business success, with respect to demand fulfilment and survivability of supply chains over the long term. Table 7.1 summarises the results of the experiments as well as the degree of significance of each result.

As explained in section 6.3.6, the term of “significance” in Table 7.1 is not related to statistical level of significance, but to overall confidence in the model results. The term represents the extent of the robustness of the statistical test conclusion. This robustness is related to the ability of the findings to remain effective under different situations, with respect to the simulation settings. The discussions of the model results provided in the following subsections.

Table 7.1 Summary of the results

		Competition and collaboration issue	Scenario with better outputs	Degree of significance
1		*Duration of collaboration*		
		with single-link suppliers (one-to-one relationship).	-	Not significant
		with dual-link suppliers.	*Short-term* collaboration	Low
2		*Number of partnerships*		
		when short-term collaboration applies.	***Not*** *dual-sourcing* for the manufacturer when the suppliers can link with more than one manufacturer	Low
		when long-term collaboration applies.	One-to-one partnerships for both the manufacturer and the supplier	Low
3		*Trust*		
	a	*Manufacturer trust of the suppliers*		
		when short-term collaboration applies.	Extremely high *trust* or no *trust* at all	High
		when long-term collaboration applies.	Extremely high *trust*	Low
	b	*Supplier trust of the manufacturers*		
		when short-term collaboration applies.	-	Not significant
		when long-term collaboration applies.	No *trust*, but not in an extreme way, by not consistently following the manufacturer strategic movement	Low
	c	*Customer trust/loyalty towards manufacturers*	No *trust/loyalty* at all	High
4		Survivability		
	a	*Manufacturer survivability*	***Not*** extremely low survivability	High
	b	*Supplier survivability*	***Not*** extremely low survivability	Low
5		Manufacturer strategic movement	No *big leap* at all	High

7.4.1 The effect of the *duration of collaboration* (*Hypothesis B.1*)

As explained in the conceptual model in Chapter 5 (section 5.3.1.2, Figure 5.6), a longer *duration of collaboration* is expected to improve the "life" of both the manufacturer and the supplier. However, the results indicate that when both the manufacturers and the suppliers are allowed to collaborate with one firm only at a time (or under *one-to-one* relationship), this factor does not provide significant changes to demand fulfilment and survivability of supply chains. On the other hand, when the supplier can work with up to two manufacturers (the *dual-link* supplier) while the manufacturers can only collaborate with one supplier, the extremely short *duration of collaboration* seems to provide better demand fulfilment and survivability of supply chains for a long-term. This indicates that adopting a longer *duration of collaboration* does not lead to a better long-term demand fulfilment and survivability of supply chains.

Although this conclusion is restricted to the setting of the simulation model (e.g. considering homogeneous agents while in the real world they are not exactly homogeneous), this finding is considered relevant when the issue is observed from a market perspective. This finding also conforms several empirical work in SCM literature that contradicts the benefit of long-term collaboration, as presented in section 2. Having a very close partnership with long-term collaboration is not more advantageous than having shorter partnerships with less close relationship (Parker and Hartley 1997). The long-term partnerships can also lead suppliers to be more vulnerable as they tend to have lower control on prices. Moreover, Leeuw and Fransoo (2009) find that a close collaboration through long-term partnerships reflects an analogy that is "one size does not fit all". This means that a successful collaboration practice of a company does not fit all enterprises. Squire et al. (2009) also suggest that although the *duration of collaboration* can improve manufacturer's responsiveness, the overlong *duration of collaboration* turns the manufacturer to be dependent on the supplier. This situation could result in an adverse impact on the overall supply chain performance. A similar finding is also provided by Wagner (2011), and Sun and Debo (2014), who suggest that the length of collaboration does not affect supply chain performance. This perspective is supported by several experts in strategic management, such as Porter (1990; 1997), Grayson and Ambler (1999), and Anderson and Jap (2005). They suggest that long-term partnership with supplier could hinder the benefit of competition, which is encouraging innovation in business. These studies provide evidence that not all firms in the real world obtain advantages from longer duration of collaboration even though they have not considered a market perspective yet.

With respect to the model mechanism, this emergent outcome can be explained as follows. In the experiment, the suppliers have no *trust* towards their collaborating manufacturer, so this feature makes the supplier move away from its current manufacturer to attract another manufacturer. This movement is continuously performed until the simulation time reaches the end of *duration of collaboration*. Thus, a longer duration of collaboration leads the distance between the collaborating agents (supplier and manufacturer) to be larger than a shorter term of collaboration. This large distance causes supplier to have a higher risk to lose the opportunity to re-establish collaboration with the previous manufacturer, particularly when the supplier does not manage to find another manufacturer to collaborate. This situation represents a reality when suppliers will tend to be less cautious in making decision for their strategic move because they believe the longer partnerships have secured their business for the future long run. In addition, a longer term of collaboration will limit manufacturer strategic movement as well as *manufacturer's life*, if the supplier turns to be less efficient and/or less responsive during the collaboration period. It reflects a circumstance where *long-term* collaboration leads the manufacturer to become dependent on the supplier.

In contrast, the short duration of collaboration can prevent the supplier from moving further from the current manufacturer (i.e. preventing from being too different from the manufacturer, in terms of supply chain capability). This occurs when the supplier cannot find another manufacturer with whom to collaborate and the previous manufacturer is still the closest agent to the supplier. In this situation, when the duration of collaboration ends, the supplier will move back to the previous strategic position to attract the previous linked manufacturer to rebuild the collaboration link.

This effect of shorter *duration of collaboration* becomes prominent to demand fulfilment and survivability of supply chains when the supplier can collaborate with more than one manufacturer. In this situation, the extremely *short-term* collaboration is found to provide improved demand fulfilment and survivability of supply chains compared to the longer *duration of collaboration*. The reason for this is that although the suppliers have a longer "life" to exist in the system when they work with more than one manufacturer, this expected advantage is not significant when a longer *duration of collaboration* is applied.

To our knowledge, no study has attempted to compare demand fulfilment rate, as a representation of aggregated supply chain performance, by varying the duration of collaboration. These findings provide a new perspective in understanding the significance of the long-term effect of the longer *duration of collaboration*s. Companies which currently consider establishing long-term partnerships with their suppliers may require rethinking the plan. This is because maintaining long-term collaboration involves investment as well as changes in the working culture that can be significant to the supply chain whereas it cannot guarantee the supplier to be always more efficient and/or responsive than the manufacturer. In addition, when massive firms adopt a long period of collaboration with the supplier, it may also lead to the emergence of the anticompetitive environment, even though this possible effect is not specifically investigated in this research. These findings may also confirm the view of strategic management, which regards operational effectiveness is not a strategy to achieve a sustainable competitive advantage (Porter 2006). Meanwhile, most SCM work observes collaboration issue from an operational perspective – without taking into account the emergent behaviour of the market.

7.4.2 The effect of *number of partnerships* of both manufacturer and supplier (*Hypothesis B.2*)

Similar to the results of the *duration of collaboration*, the experimental outcomes show that the *number of partnerships* tends to have no significant effect on both demand fulfilment and survivability of supply chains for the long term. When the short *duration of collaboration* applies, the lowest outputs of supply chain survivability are resulted under *two-to-two* or *dual relationships* (i.e. both the manufacturer and the supplier can collaborate with two firms at the same time), although this scenario has no significant effect on demand fulfilment rate for the long-term (Table I.5 and Table I.6 in Appendix I). It suggests that *dual-sourcing* is not suggested for the manufacturer when the suppliers can link with more than one manufacturer. Meanwhile, when the long *duration of collaboration* is implemented, *one-to-one relationships* provide better demand fulfilment and survivability of supply chains (Table I.7 and Table I.8 in Appendix I).

However, this experimental factor has a low sensitivity to the model outputs (demand fulfilment and survivability of supply chains). It is shown by the number of significant difference in the comparison test for each experiment is no more than 40% difference from the total comparisons, with respect to the inferential assessment with Mann-Whitney U test (Table I.5, Table I.6, Table I.7, and Table I.8 in Appendix I). Moreover, with regards to the boxplots presented in Figure 6.7 and 6.8, the *dual-sourcing* strategy with *two-to-two relationships* (*dual-partnerships* – scenario P-2) tends to have a slight difference with *single-sourcing* with *one-to-one relationships* (or *single-partnerships* – scenario P-1) in short-term collaboration. The *multi-sourcing* strategies with *many-to-many relationships* (scenario P-3, scenario P-4, and scenario P-5) seem to have a tendency to result in higher supply chain survivability than the other scenarios (Figure 6.8). This pattern appears to be plausible because *multi-sourcing* strategies allow manufacturers to "live" longer. When a manufacturer loses one supplier, it would still stay alive, unless all of the remaining suppliers that collaborate with the manufacturer turn to be less efficient and/or less responsive.

To test the robustness of the analysis results, particularly when short-term collaboration is implemented, the experiment of the *number of partnerships* were rerun with a different number of agents at the initial setup. The resulting outcomes suggest that *dual-sourcing* strategy has no different impact on supply chains when it is compared to *single-sourcing* strategy. Also, the *multi-sourcing* strategies with *multi-partnerships* (scenario P-3, scenario P-4, and scenario P-5) tend to have higher supply chain survivability significantly. This slight inconsistent conclusion with the formal experiments defined in this study (section 5.3.1.2) confirms that the degree of significance (or the sensitivity) of the experimental factor (*number of partnerships*) is low. It means that the effect of this factor tends to be insignificant to the supply chains as a market.

As the variable sensitivity tends to be low, it can also be suggested that having *multi-partnership* (*many-to-many relationship*, including *multi-sourcing*) may have a similar effect to either *single-partnership* (*single-sourcing* with the *one-to-one relationship*) or *dual-partnership* (*dual-sourcing*) on the long-term demand fulfilment and survivability of supply chains. This finding contradicts the current belief in SCM literature, which suggests *single* and/or *dual-sourcing* to improve supply chain performance. The reason for this is that less number of partnerships reduces the variation of product quality and lead time, particularly in *single-sourcing* strategy (Christopher 2000; Chopra and Meindl 2007; Vereecke and Muylle 2006). Meanwhile, compared to *single-sourcing* approach, some research finds that *dual-sourcing* strategy is considered to be more efficient (Ramasesh et al. 1991; Lyon 2006) and leads to better supply chain performance (Chiang and Benton 1994). Nonetheless, other findings suggest that *single-sourcing* outweighs the benefit of *dual-sourcing*, such as Tyworth and Ruiz-Torres (2000). They show analytically that *dual-sourcing* in logistics practice results in lower efficiency than *single-sourcing*. Through an analytical approach, Yu et al. (2009) also show that *dual-sourcing* only provides more benefit than *single-sourcing* when the material price is sensitive to the partnerships and supply disruption can be predicted. However, both studies do not take into consideration the *duration of collaboration* in examining the problem. Nevertheless, these studies do not address the issue with regards to the *duration of collaboration*.

In addition, most research on *number of partnerships* focuses on comparing the supply chain performance of *single* and *dual-sourcing* strategy, which suggests that these two strategies have dominated SCM perspective in setting up the *number of partnerships*. Studies which discuss *multi-sourcing* strategies are not as much as research of *single* and *dual-sourcing* although several studies find that *multi-sourcing* strategies lead to better supply chain performance than single and *dual-sourcing* approaches, such as Burke et al. (2007).

All of these studies regard the issue of *number of partnerships* only from the manufacturer's perspective, despite the supplier's viewpoint. This perspective leads to the use of the term *number of sourcing* in SCM, instead of *number of partnerships* in supplier-manufacturer relationships. Moreover, these work do not take competition and market perspective into the analysis. This suggests that the partial perspective provided in SCM literature may only be true for the particular situation defined in the study, but it could not apply to achieve the overall company performance and survivability for the long-term. This finding tends to have a similar perspective to Mintzberg et al. (2005) who suggest that strategy should not be viewed partially. This partial view is often demonstrated in most literature in business strategy. The partial perspective of strategy is also often practised in SCM research, which commonly ignores supplier's point of view in examining the supply chain strategies. This SCM view of operational effectiveness as a strategy also opposes to a suggestion proposed by Porter (2006).

Despite the complexity of the agent's interactions illustrated in Figure 7.1, a higher *number of partnerships* of both manufacturers and suppliers are expected to enhance the agent's survivability for a long-term, as presented in Figure 5.6. The logic for this is that both manufacturers and suppliers would not easily lose their ability to survive (the *manufacturer's life* and *supplier's life* in Figure 7.1) as they have more opportunities to create collaboration with many firms. However, with respect to the model mechanism, as manufacturer and supplier are not loyal to each other (i.e. do not *trust*), the higher *number of partnerships* leads to a risk that makes supplier moves more dynamically to approach another manufacturer which has not linked with the agent. However, this negative side of this factor only affects supply chains significantly when the *number of partnerships* of manufacturer and supplier is two firms, particularly when the applied *duration of collaboration* is short. This is a novel finding as this result is examined from a market perspective. Thus, no empirical literature perfectly fits this outcome.

Meanwhile, when long-term collaboration is applied to all agents, the *one-to-one relationships* provide better performance and survivability for the supply chains. This result conforms with most collaboration suggestions, such a Christopher (2000), Vereecke and Muylle (2006), and Chopra and Meindl (2007). These studies recommend that *single-sourcing* for long-term collaboration would benefit supply chain, and the supplier is also expected to intensively collaborate with the manufacturer.

With respect to the model mechanism, the long-term collaboration is more risky for the manufacturer to profit loss as the suppliers have no *trust*. The *no loyal* suppliers would continuously move away from the manufacturer with whom they currently link to attract another manufacturer during the collaboration period. If the suppliers turn to be less efficient and/or less responsive than the manufacturer, the supplier movement will not only limit the manufacturer's strategic change but also reduce the manufacturer's "life". This drawback is significant when the manufacturer links with more than one supplier in a long time period. Furthermore, the higher number of supplier's partnerships makes the suppliers consistently move further from their current manufacturers and previously-linked manufacturers without returning to the previous position. This continual movement leads the supplier to be more aggressive in approaching another manufacturer and makes most suppliers in the market tend to be less efficient and/or less responsive than the manufacturers. This means that this emergent behaviour will reduce the manufacturer's "life". As most of the manufacturers cannot survive for long-term, most supply chains in the market are also easier to collapse. Thus, when the long *duration of collaboration* is applied, the *one-to-one partnerships* can reduce the emergence of this risk significantly because manufacturer's strategic movement and manufacturer's life are affected by one supplier only.

To sum up, the results of this experiment indicates that companies may not need to spend much investment to maintain a single or two suppliers to sustain or boost their supply chain competitiveness for the long-term. Establishing partnerships with *many-to-many partnerships* could be not as disadvantageous as suggested by most SCM literature, particularly when the duration of collaboration is extremely short. However, maintaining *one-to-one partnerships* seems to be more beneficial to supply chains than other scenarios of *number of partnerships* when the duration of partnerships is extremely long even though.

7.4.3 The effect of *trust* (*Hypothesis B.3*)

The expected positive effect of *trust*, which is represented as *loyalty* in the model, is to minimise the risk of losing the relationships. The *manufacturer trust* and the *supplier trust* are supposed to be an effective approach to maintain the partnerships as well as improve the demand fulfilment and survivability of supply chains over the long-term. This presumption also applies to the *customer loyalty* towards manufacturer, where the higher *customer trust/loyalty* assists the long-term performance and survivability for the supply chains. Nevertheless, the model shows that this expected outcome does not always emerge in a higher degree of *trust*. The *manufacturer trust* seems to have more significant impact on supply chains rather than *supplier trust*, and this finding is counterintuitive to SCM focus, which more concentrates on improving *supplier trust* towards manufacturer than vice versa. Moreover, *customer loyalty* is found to be sensitive to demand fulfilment and survivability of supply chains. This finding is novel as this factor has not been considered yet in SCM literature. The discussion of this factor for each agent's type (manufacturer, supplier, and customer) is presented in the following subsections.

7.4.3.1 *Hypothesis B.3.1*: ***Manufacturer trust of the supplier*** **(the *manufacturer trust*)**

The higher *manufacturer trust* is intended to improve the long-term demand fulfilment and survivability of supply chains. Nevertheless, with respect to the model mechanism, it also has a risk to the manufacturer. When the manufacturer collaborates with less efficient and/or responsive supplier, higher *manufacturer trust* not only limits the manufacturer strategic movement but also manufacturer's "life" or survivability. This is the reason why the higher *manufacturer trust of the supplier* does not always lead to better impacts to the supply chain, with regards to long-term survivability and performance.

When short-term collaboration applies, the extremely loyal manufacturers (when the *manufacturer trust* is 100% - scenario T_M-5) can lead to better demand fulfilment rate, as a representation of supply chain performance in the market, as well as better long-term survivability for supply chains. This outcome is consistent with the concept of achieving supply chain collaboration success suggested by most supply chain experts, such as Chopra and Meindl (2007), Christopher (2000), Lee (2004), Simchi-Levi et al. (2000). They claim that a firm's *trust* is critical to support collaboration in supply chains to achieve better performance and resilience.

However, the extreme cautious, such as no *trust* or disloyal manufacturers (when the *manufacturer trust* is 0% - scenario T_M-1), also provide a better demand fulfilment and survivability of supply chains, as opposed to the intermediate degrees of *manufacturer trust*. This result is counterintuitive with the current SCM concept of achieving supply chain success through trust during collaboration period. A possible explanation for this is that when all manufacturers in the market are disloyal (i.e. do not *trust*) with the suppliers, it can support a perfect competition environment that benefits the supply chain as a system. In other words, extreme levels of *trust* (0% and 100%) can enhance the demand fulfilment rate, as a representation of supply chain performance, to serve the market. These extreme situations are resulted by assuming the suppliers do not trust to the manufacturers.

With regards to the model mechanism, the extreme level of *manufacturer trust* makes the manufacturers find a new supplier easier. When the 0% *manufacturer trust* is applied, all manufacturers continuously change the collaboration link in each *time unit*. It leads the supplier to be available to select in each *time unit*. Meanwhile, the extreme high *trust* (100%) can guarantee manufacturer to have a supplier forever. It means that the extreme levels of *manufacturer trust* can create the manufacturers to have greater opportunity to find or collaborate with a supplier which fits their preference.

In contrast, the intermediate levels of *trust* lead the supplier availability to be selected by a manufacturer, who is looking for collaboration partners, to become more uncertain. This uncertain situation of supplier availability makes it more difficult for the manufacturers to find a supplier to collaborate with. Supplier availability tends to be more limited as the probability of the *manufacturer trust* is higher. When a manufacturer decides to be not loyal to its previous supplier, the manufacturer will also find it difficult to have a new supplier as other suppliers are likely to continue collaborating with their competitors.

On the other hand, when the long-term collaboration is implemented to the supply chains, only the extremely high degree of *manufacturer trust* provides benefits to the supply chain. The no-*trust* and somewhat-*trust/loyal* manufacturers have no different effect on the demand fulfilment and survivability of supply chains significantly. This result supports the popular suggestion of supply chain collaboration in the literature, which suggests the implementation of a long-term collaboration with very high trust in achieving supply chain success, such as in Christopher (2000), Vereecke and Muylle (2006), and Chopra and Meindl (2007). However, none of the previous work has discussed *manufacturer trust* in supply chain collaboration. The existing literature emphasises trust issues from supplier side instead, such as Dyer and Ouchi (1993) and Kannan and Tan (2003).

7.4.3.2 *Hypothesis B.3.2*: *Supplier trust* towards supplier (the *supplier trust*)

Several studies suggest that *supplier trust* is critical in achieving supply chain success. Dyer and Ouchi (1993) find that *supplier trust of the manufacturer* plays a significant role to supply chain success. The suggestion is concluded based on comparisons between the U.S. and Japanese car manufacturers. The study finds that Japanese suppliers are more cooperative than U.S. firms. Kannan and Tan (2003) also suggest that the *supplier trust* is the key success of supply chain collaboration. However, these studies have drawn the conclusions when the manufacturer also trusts to the supplier.

By observing the model run, the *supplier trust* can result in a risk to supply chains. The logical explanation of this emergent impact is when the *loyal* supplier has no collaboration with a manufacturer and decides to keep attracting the manufacturer who previously links with them (although another manufacturer is closer and available to attract, the supplier will remain having no collaboration link with a manufacturer. This situation will make the supplier suffered continual losses.

The model results indicate that the *supplier trust* does not have a significant effect on maintaining demand fulfilment and survivability of supply chains. Even though in the long-term collaboration, the low level of *supplier trust* can lead to a better supply chain survivability, the effect is not always significant when it is compared to other degrees of *manufacturer trust*. This finding is contradicting with the existing literature, particularly in Dyer and Ouchi (1993) and Kannan and Tan (2003).

However, the outcomes of this research are limited by the assumption employed in the model and the behaviour space. One assumption is that the manufacturers do not have any *trust* to the supplier. Moreover, the value of *supplier trust* is set as a constant probability - it could not be updated during competition. Nevertheless, despite the model limitations, this study does not analyse the result under different model setup. The last limitation is regarded as the essential limitations of the resulting findings of this behavioural factor.

7.4.3.3 *Hypothesis B.3.3*: *Customer loyalty* towards supplier (the *customer loyalty*)

According to the resulting behaviour, it can be suggested that higher *customer loyalty* towards does not consistently have a positive impact on demand fulfilment and survivability of supply chains for the long-term. It potentially leads to more supply chain failures in the long term. It suggests that the reluctance of customers to switch to another manufacturer may lead competition among firms to be of limited benefit.

With regards to demand fulfilment rate – represented as *supply chain fill rate*, a 100% *customer loyalty* results in the highest demand fulfilment rate, following by the 0% *customer loyalty* as the second highest demand fulfilment rate. However, the 0% *customer loyalty* results in significantly better survivability for the supply chains, whereas the 100% *customer loyalty* leads to the lowest supply chain survivability. Meanwhile, the intermediate levels of *customer loyalty* do not benefit the supply chains significantly, both for demand fulfilment and survivability of supply chains. These findings are contradictory to the common belief that *customer loyalty* can maintain long-term business profitability, such as suggested by Irmen and Thisse (1998), Turnbull et al. (2000), and Reeves and Deimler (2011).

Concerning the mechanism of the model, the manufacturers are prone to compete more intensely when customers are less likely change their buying decisions to a new manufacturer. Higher *customer loyalty* makes the manufacturer moves further to attract another customer. This behaviour causes manufacturer position become less overlaps with the other manufacturers although it is still relatively close to the others. Although the less-overlap market structure enhances the demand fulfilment rate (indicated by higher *supply chain fill rate*), it enlarges the supply chain strategic gap between manufacturer and supplier. The larger gap is created because the suppliers follow the manufacturer's aggressive movements. As a result, the supplier positions become more disperse in the market and reduce manufacturer's opportunity to find a supplier with whom the manufacturer can collaborate. This no-collaboration situation can reduce both manufacturer's and supplier's "life".

Although this conclusion is limited due to the assumptions made in the model, considering *customer loyalty* in understanding the impact of competition and collaboration on supply chains has provided a new insight in SCM. In this study, the *customer trust/loyalty* is defined as an independent factor that is not related to the manufacturer performance, as suggested by Hallowell (1996). However, this simplification is considered appropriate to obtain intuitions on *customer loyalty* towards supply chains in the market.

7.4.4 The effect of individual *firm survivability* (*Hypothesis B.4*)

Supply chain robustness has been a critical issue in SCM to maintain supply chain survivability. However, as addressed in Chapter 2, all literature in *supply chain robustness* only associates the issue with supply disruption. Instead of making the supplier "collapse" or "die", this study has simulated how the individual firm's ability to cope with loses (i.e. survivability) affects *supply chain robustness,* in terms of *supply chain survivability*.

The model results show that the *manufacturer survivability* has a high sensitivity to supply chain survivability, but it is not significant in improving demand fulfilment rate. Moreover, only the extremely low level of *manufacturer survivability* has a significant impact on the lower demand fulfilment and survivability of supply chains. A higher level of *manufacturer survivability* does not significantly influence demand fulfilment and survivability of supply chains.

On the other hand, compared to the *manufacturer survivability*, the *supplier survivability* has a low sensitivity on both demand fulfilment and survivability of supply chains. The extremely low level of *supplier survivability* has a significant impact on the supply chain, but the higher degree of *supplier survivability* does not provide better demand fulfilment and survivability of supply chains. In general, these results support the generic SCM suggestion that considers both supplier and manufacturer survivability to cope with loses in supporting *supply chain robustness*. However, this suggestion is frequently raised as a critical part of coping with supply failures, such as discussed by Dyer and Ouchi (1993), Rice and Galvin (2006), and Yu et al. (2009).

With regards to the experimental design, the higher level of individual survivability does not always enhance the model outputs because the collaboration length applied in the experiment is short-term. Moreover, both the manufacturer and the supplier are not loyal to each other. Higher individual survivability may be beneficial when the manufacturer and/or supplier are loyal, and the *duration of collaboration* is long. It can minimise the risk of "life reduction" of the agents, particularly for the manufacturers which collaborate with less efficient and/or less responsive supplier.

In summary, this finding contradicts the current SCM focus in the literature. This finding suggests that the *manufacturer survivability* has a high sensitivity on demand fulfilment and survivability of supply chains whereas most studies pay more attention on *supplier robustness* or *survivability* rather than *manufacturer survivability* to secure the supply flow of supply chain. Even the factor of *supplier survivability* can be an essential element in the process of supplier selection. The factor is commonly represented as supplier's financial stability and staying power (Kannan and Tan 2003), financial strength (Çebi and Bayraktar 2003), and other measures of financial and commercial competencies (Cox 2004). Improving the *supplier survivability* also often becomes the main focus of government policy to protect the nation's economy, such as practised by the Japanese government in protecting firms which stay in the upstream level of supply chains (Dyer and Ouchi

1993). None research investigates and compares the effect of manufacturer and supplier *survivability* on supply chains over the long-term.

7.4.5 Manufacturer ***strategic mutation*** **(*Hypothesis B.5*)**

The idea of this experimental factor is making a manufacturer have an ability to “jump” to a strategic space to fulfil demand that has not been served by competitors. In social science, this strategic movement is discussed as a part of strategic flexibility. This approach is generally understood to assist an enterprise to win the competition by being completely different from the competitor, such as described by Kim and Mauborgne (1997; 2005; 2008). Meanwhile, this approach has not been discussed much in SCM. Instead, strategic flexibility in SCM has more operational scope than in social science. For example, Chopra and Meindl (2007) describes supply chain flexibility as a part of being a responsive supply chain.

This study finds that the *strategic mutation* is highly sensitive to the both demand fulfilment and survivability of supply chains. Based on the experimental results, the highest outcomes are achieved when no *strategic mutation* applies to the system. The reason for this is that the extreme strategic movement taken by the manufacturer does not consider the supplier availability in the new strategic position. The movement is determined only based on the position of the unserved customer. Therefore, the *strategic mutation* modelled can lead the manufacturer to have no supplier when it decides to move to a new position which is relatively far from its previous position.

When a manufacturer moves to a new strategic position, the gap between the manufacturer and the available suppliers in the market becomes extremely big. This situation makes the manufacturer hard or not possible to establish a collaboration. This suggests that the *strategic mutation* is only beneficial to the manufacturer when it can find an appropriate supplier to support its strategic position. It also means that manufacturer *strategic mutation* may be worth if the suppliers follow the manufacturer strategic movement and have the similar ability to mutate.

However, it should be noted that creating a *blue ocean* through *strategic mutation* cannot guarantee a company's position in the market to be inimitable or unreachable by its competitors for the long-term. A firm can be considered successful in making a *strategic mutation* if there is more than one supplier which is available in the new strategic position and not possible to serve the firm's competitors. If there is only one supplier is available in the new strategic position of the manufacturer mutated, and the supplier is difficult to be loyal and maintain a consistent performance, the strategic mutation would risk the manufacturer. However, this situation is hard to achieve as when the strategic mutation is made, the supply market generally has been concentrated in a strategic area where many manufacturers stay. In other words, the mutation should not only consider the competitor's position in the market but also the distribution of the supply market.

7.4.6 Summary of the results and input characteristics for *Hypotheses B*

With respect to the degree of significance in the model result (or the sensitivity level of the experimental factor), only four experimental factors have been found to have a high degree of significance on the model outputs, regarding long-term demand fulfilment and survivability of supply chains. They are the *manufacturer trust of the supplier*s – particularly when the short *duration of collaboration* is applied, the *customer loyalty* towards manufacturers, the *manufacturer survivability* to work with less efficient and/or less responsive supplier, and the manufacturer *strategic mutation*. These factors are considered sensitive to supply chains as it produces statistical significant differences consistently.

This finding contrasts with the common suggestions in SCM, which believe that the *duration of collaboration*, the *number of partnerships*, and *trust* are critical to supply chain success. In this study, *duration of collaboration* and *number of* *partnerships* are found not to be significant to the demand fulfilment and survivability of supply chains in the long-term. The *supplier trust* of the manufacturer is also suggested as an insensitive factor to maintain demand fulfilment and survivability of supply chains, whereas the *manufacturer trust* is considered significant to support performance and survivability of supply chains in the market. It means that manufacturer companies may require to performing self-assessment which can lead them to maintain the firm performance and survivability for the long-term.

Contrary to the expectations, the other aspects that are hardly considered in SCM literature are shown to be important to sustain long-term performance and *survivability* for supply chains; these factors are *customer loyalty*, *manufacturer survivability*, and manufacturer strategic movement. Low *customer loyalty*, the intermediate-high level of *manufacturer survivability*, and no *strategic mutation* in manufacturer strategic movement can assist supply chains in a market to perform and survive better under a competitive environment. This outcome provides a new insight to SCM analyst to consider as these factors have not been considered yet in the current SCM literature.

Furthermore, these findings strengthen strategic management view that considers operational effectiveness is not a strategy to maintain competitive advantage (Porter 2006). This view contradicts with SCM literature, which regards operational strategies as the key driver of business success. Nevertheless, it does not mean that SCM suggestions on collaboration approach are not precise and inapplicable. The recommended collaboration approach is true, but it may be limited to a particular situation or perspective. The partial scope of view is often employed in SCM analysis, and this fragmentary analysis results in conflicting findings in the literature. As suggested by Mintzberg et al. (2005), strategy should not be viewed partially, which is often demonstrated in most literature in business strategy – with regards to SCM and strategic management.

A summary of the main aspects discussed in section 7.3, with regards to *Hypotheses set A*, is presented in Table 7.2. It encapsulates the effect of each experimental factor or input on demand fulfilment and survivability of supply chains. The effect is categorised into two possible aspects: the positive effect (the benefit) which has been expected during the modelling process, and the negative effect (the risk) that is resulted through simulation run. The positive effect can enhance the supply chain survivability, which is expected to be an enabler to maintain a better demand fulfilment in the market. Meanwhile, the negative effect will decrease the survivability of the supply chains, which leads to a lower rate of demand fulfilment.

Table 7.2 Summary of the effect of each experimental factor for *Hypotheses set A*

Strategic approach: *A Higher level of...*	**The effect**	
	Positive *(the benefit expected)*	**Negative** *(the resulting risk)*
1. *Duration of collaboration*	Prevent the manufacturer and the supplier from having no firm to collaborate with.	Cause the supplier to move more aggressively to approach a new manufacturer.
2. *Number of partnerships*, for manufacturer and supplier	Same as in the *duration of collaboration*.	Same as in the *duration of collaboration*.
3. *Trust*		
a. *Manufacturer trust of the supplier*	Same as in the *duration of collaboration*.	Same as in the *duration of collaboration*.
b. *Supplier trust of the manufacturer*	Same as in the *duration of collaboration*.	If a supplier has no collaboration link and decides to keep attracting the manufacturer who previously links with it, while another closer manufacturer is available to attract, the supplier would keep suffering losses.
c. *Customer trust/loyalty* towards manufacturer	Prevent manufacturer from having no customer to buy its product. It also can improve demand fulfilment rate as more demand is fulfilled.	Cause the manufacturer to move more aggressively to approach a new customer. This behaviour causes manufacturer positions becomes less similar/concentrated/overlaps but still relatively close to the others. This

Strategic approach: *A Higher level of...*	**The effect**	
	Positive *(the benefit expected)*	**Negative** *(the resulting risk)*
		pattern enlarges the gap between the collaborating supplier and manufacturer. The gap can reduce manufacturer's profitability and, as a consequence, its survivability.
4. Survivability		
a. *Manufacturer survivability*	Can improve *manufacturer survivability* to work with less efficient and/or less responsive supplier.	No negative effect is resulted.
b. *Supplier survivability*	Can improve *supplier survivability* to cope with loses in finding a manufacturer to collaborate.	No negative effect is resulted.
5. Manufacturer *strategic mutation*	Can improve demand fulfilment rate in fulfilling the unmet customer demand.	Gap between manufacturer and supplier becomes larger, so it is difficult or not possible to establish collaboration.

When all of these effects are viewed from a less specific perspective, all the experimental factors have a similar resulting influence on the supply chains. The scenarios with better outputs, presented in Table 7.1, lead the firms to be more available for partnerships. These scenarios make both the manufacturers and the suppliers exist and stay in the strategic positions that are required by the market, so the supply chain collaboration can be continuously established, or maintained for a long-term. This pattern suggests that the agent's behaviour, with regards to collaboration strategies and *customer trust/loyalty*, affects the competitive movement of the firms. The company competitive movement, with respect to the manufacturer *strategic mutation*, also has an impact on the collaboration decision in the supply chains.

However, all these findings are influenced by model and/or experimental design limitations. Table 7.3 addresses the main limitation of the resulting analysis for achieving objective 2. Most limitations are driven by limited experiments to allow interaction analysis. Several behavioural factors that are found to be not sensitive in this study may have a significant effect on supply chains under different model setup. However, *supplier survivability* is considered to have no limitation that can affect the results. Furthermore, the resulting finding of manufacturer *strategic mutation* is regarded to be mainly caused by the model assumption; the *mutation* movement is only driven by the unserved customer, without considering supplier availability in the new strategic position.

Table 7.3 Main limitation of each experiment for *Hypotheses set A*

Experimental factor	Findings	Main limitation
1. *Duration of collaboration*	***It tends to be not significant to supply chains.***	No interaction analysis with other factors.
2. *Number of partnerships*, for manufacturer and supplier	***This factor has a low significant impact on supply chains.***	Limited interaction analysis with other factors.
3. *Trust*		
a. *Manufacturer trust of the supplier*		Limited interaction analysis with other factors.
b. *Supplier trust of the manufacturer*		Limited interaction analysis with other factors.
c. *Customer trust/loyalty* towards manufacturer		Limited interaction analysis with other factors.
4. Survivability		
c. *Manufacturer survivability*		Limited interaction analysis with other factors, particularly with *duration of collaboration*; the longer collaboration period would enable further investigations on this factor.
d. *Supplier survivability*		Limited interaction analysis with other factors.
5. Manufacturer *strategic mutation*		The *mutation* movement does not consider supplier availability in the new strategic position.

7.5 Study limitations

Having considered the findings of this study and the way of achieving the research objectives, several limitations of this study should be taken into account. Besides the limitations driven by the modelling assumptions and simplifications expressed in section 5.2.4, the model outcomes and conclusions are also significantly influenced by the model setup or experimental design limitations, and model outputs used. However, these limitations indicate opportunities for further work. The detail of the study limitations is discussed in the next subsections.

7.5.1 Modelling approach limitations

With respect to the modelling approach, the competition and collaboration in *two-stage* supply chains is modelled in a simplified way. All agents are homogeneous, bounded-rational, and do not have learning ability to change their behaviour. They have no intelligence for learning from the previous actions and are acquisitive. Both manufacturers and suppliers do not have an ability to create a backup plan when they are difficult to find a new firm with whom they can collaborate. The suppliers are assumed to supply a critical component to the manufacturer, so when a manufacturer could not find a supplier to collaborate, it would die. When a manufacturer decides to be loyal to a supplier, it will maintain the collaboration link with the supplier despite the *supplier trust*. For the customer agents, they have a fixed preference that could not be influenced by manufacturer behaviour. They have a *willingness to compromise* to their preference, but it would be not applicable when the customer decides to be loyal to a manufacturer. The competitive strategic landscape is also defined in two dimensions, with respect to efficiency and responsiveness. The model has incorporated the relationship between efficiency and responsiveness by defining the applicability zone of supply chain strategy (section 2.3.2.1 and Figure 2.3), but it does not affect customer's perspective on price and product value.

These characteristics have been listed as a part of modelling assumptions and simplifications in the conceptual modelling process (section 5.2.4). These features have a significant effect on the agent's behaviour, particularly on how the agents make decisions. Moreover, these assumptions and simplifications leads the model developed to be simple. However, it was adequate to study the phenomena discussed and useful to separate the impact of factors due to simplicity of the model.

7.5.2 Model setup limitations

Secondly, the experimental design of this research is restricted to a limited number of scenarios. Each experimental factor is examined under 5 different levels of inputs, or 5 scenarios, which have been empirically chosen. More scenarios with more incremental values may provide information to the findings of this study.

Furthermore, most experimental factors are investigated in isolation. Even though several factors or inputs have been examined in two situations of the *duration of collaboration* (*short-term* and *long-term* collaboration), this was designed to assist the author in considering future research that looks at interactions between behaviour factors. The results indicate that the emergent pattern of several experimental factors (regarding the *number of partnerships* and *trust*) is distinctive between different *duration of collaboration*. Hence, allowing multi-factorial analysis between the experimental factors could be a potential future research

7.5.3 Analysis limitations

The third limitation is related to the model outputs. This study employs *supply chain fill rate* (or demand fulfilment rate) as a simplification of supply chain performance, and the *number of supply chains in the market* to assess the number of supply chains that can survive for long period of competition. Adding several performance measurements, such as collaboration cost and revenue may offer better analysis in understanding the effect of competition and collaboration. For example, having a long term relationship is generally understood to be more efficient than the shorter duration of relationship, since it can reduce the cost of transaction, supplier selection process, and may also reduce the variability of lead time and product quality (Kraljic 1983; Matthyssens and Van den Bulte 1994). However, to develop an effective long-term collaboration needs very high investments. In other words, costs of collaboration are very complicated to measure as it highly depends on more detail characteristics of supply and demand market. One reason for this is that most risks and benefits of partnerships are intangible and do not turn up explicitly in a firm financial report (Gadde and Snehota 2000).

In addition, with regards to interpreting the results, it is considered that a higher demand fulfilment rate (the *supply chain fill rate*) is better for the market because it indicates more demand is fulfilled. Meanwhile, the more supply chains that can survive in the competition (the *number of supply chains in the market*) is also preferred as it reflects more supply chains with long-term survivability. However, a higher number of supply chains that can survive in the market are not always advantageous for the market, particularly when many supply chains can survive in a business competition share the market segment. This situation could limit the surviving companies to optimise their revenue.

Lastly, for the analysis, the sample size used in this study is 50. It may affect the normality pattern of the outputs. However, the nonparametric approach has been applied to minimise the biased interpretation of the non-normal outcome.

7.6 Summary

With regards to the objectives of this Thesis, all objectives designed in Chapter 4 have been achieved. An agent-based model of competition and collaboration in supply chains has been developed. The model shows that micro behaviour of individual firms affects performance and survivability of all supply chains in the system. The model also enables the researcher to explore the impact of competition in supply chains. Moreover, explorations into the effect of firm's competitive and collaborative behaviour on supply chain are performed in this study. Overall, it can be suggested that this study provides a new insight both to SCM and strategic management.

CHAPTER 8 CONCLUSIONS

8.1 Introduction

This study was set out to understand the effect of competition and collaboration on supply chains. It focuses on the influence of competitive and collaborative behaviour of the individual firms on the overall supply chains, taking from a market-level perspective. With respect to this issue, the overall summary and conclusions of this Thesis are presented in this chapter.

8.2 Research objectives, hypotheses, and the findings

The findings of this study are objectives specific which is detailed in several hypotheses described in section 4.2 and section 4.3 of Chapter 4. This section synthesises the findings to achieve the research's three objectives.

8.2.1 Summary of research objectives

This study is performed with the aim to understand the effect of competition and collaboration on supply chains. The following objectives, as well as the related hypotheses, have been expressed to achieve that aim.

Objective 1:

> To develop an agent-based model that explores the effect of competition and collaboration on supply chains.

Objective 2:

> To explore the effect of competition on supply chains and market structure, with regards to the demand fulfilment and survivability of supply chains for the long-term.

Objective 3:

> To explore the effect of competition and collaboration strategy on the market, in terms of demand fulfilment and survivability of supply chains over the long-term. The following factors are considered to describe the competition and collaboration strategies:
>
> 1) *Duration of collaboration*
> 2) *Number of partnerships*
> 3) *Trust*
> 4) Individual firm's survivability
> 5) Strategic movement, considering the *strategic mutation*

The first objective focuses on the development of the agent-based model, which is described in Chapter 5. The model development adopts a theory-driven approach based on the literature of competition and collaboration in supply chain, which is reviewed in Chapter 2. The experimental factors or the behaviour space is defined subject to the gap found in the literature. The second objective aims to observe the impact of competition on supply chains, in terms of market demand fulfilment and survivability of supply chain. This objective is set because the literature suggests different opinions on this issue. Lastly, the third objective highlights the competitive and collaborative behaviour of individual firms. Five behavioural elements are simulated in this study: the *duration of collaboration*, the *number of partnerships*, *trust*, individual firm's *robustness* or *survivability*, and manufacturer *strategic mutation* (or *strategic leap*). These behavioural factors are defined based on the gap found in the reviewed literature (Chapter 2).

8.2.2 Summary of hypotheses

As objective 2 and objective 3 require model explorations, the following hypotheses represent the expected outcomes on the results of the model.

Objective 2: The influence of competition

Hypothesis A:

"Competition can be beneficial to supply chains, with respect to long-term competition".

Objective 3: The effect of firm competitive and collaborative behaviour

Hypothesis B.1: Duration of collaboration

"Adopting longer *duration of collaboration* does not lead to a better long-term demand fulfilment and survivability of supply chains".

Hypothesis B.2: Number of partnerships of both manufacturer and supplier

"Having a lower number of partnerships does not improve long-term demand fulfilment and survivability of supply chains".

Hypothesis B.3: Trust

Hypothesis B.3.1: The manufacturer trust of the supplier

"Higher *manufacturer trust* of the supplier does not enhance long-term demand fulfilment and survivability of supply chains".

Hypothesis B.3.2: The supplier trust of the manufacturer

"Higher *supplier trust* towards manufacturer does not improve long-term demand fulfilment and survivability of supply chains".

Hypothesis B.3.3: The customer's trust/loyalty towards manufacturer

"Higher *customer trust/loyalty* towards manufacturer does not improve long-term demand fulfilment and survivability of supply chains".

Hypothesis B.4: Individual firm survivability

Hypothesis B.4.1: Manufacturer survivability

"Higher *manufacturer survivability* does not enhance long-term demand fulfilment and survivability of supply chains".

Hypothesis B.4.2: Supplier survivability

"Higher *supplier survivability* does not improve long-term demand fulfilment and survivability of supply chains".

Hypothesis B.5: Manufacturer strategic movement (the strategic mutation)

"The competition approach suggested in strategic management, regarding the strategic mutation, does not improve demand fulfilment and survivability of supply chains for the long-term".

8.2.3 Summary of findings

The findings of each above research objective are summarised as follows.

Objective 1: To develop an agent-based model that explores the effect of competition and collaboration on supply chains.

1. An agent-based model of competition and collaboration in supply chains has been developed in this research. The theory-driven approach adopted in the modelling approach helps the author to lead the study as well as obtaining insights from the results. The model has been found effective in elaborating a contemporary insight in understanding the conflicting conclusions exist in the previous study, by observing the competition and collaboration issue from market-level perspective.

2. A generic emergent pattern of the model is competition can lead to the form of the market structure (section 5.3.3). The firm strategic positions converge to particular strategic location and create several market concentrations. These market concentrations can be represented as market segments with different target customers. This resulting emergent pattern is similar to a classical competition model proposed by Hotelling (1929), who predicts that competing companies would end on the same or very close strategic locations. As the results match Hotelling's model, this generic outcome is considered as a part of model validation in section 5.3.2.2 (Chapter 5). As the firms tend to become more concentrated or overlaps during the competition, overall demand fulfilment rate also has a tendency to decrease over the competition period.

Objective 2: To explore the influence of competition on supply chains, in terms demand fulfilment and survivability of supply chains for a long-term.

3. Competition can have both positive and negative impacts on supply chains. The positive effect of competition is that competition can assist strategic alignment within supply chains, while the drawback is that competition can lead to extreme *shakeouts*, particularly in monopoly. Thus, it can be suggested that *Hypothesis A* is supported, which is

   "Competition can be beneficial to supply chains, with respect to long-term competition".

   Nevertheless, surprisingly, the extreme *shakeouts* (the monopoly) do not worsen the demand fulfilment rate significantly. This suggests that *shakeouts* do not affect the level of demand fulfilment in aggregate. In addition, supply chain strategic alignment is hard to emerge when most suppliers in the system are highly more efficient and responsive than the manufacturers. The extreme *shakeouts* could also be less likely to appear when supply chains in the market stay in completely different market clusters; yet, it is difficult to control the competition as companies are trying to grow larger and increase profits through competition.

Objective 3: To explore the effect of firm competition and collaboration strategy on supply chains, in terms of demand fulfilment and survivability of supply chains over the long-term.

4. Overall, only four experimental factors have a significant effect on the model outputs, which are demand fulfilment and survivability of supply chains. They are:
   a. the *manufacturer trust* of the supplier – particularly when it is run under the short *duration of collaboration*,
   b. the *customer loyalty* towards manufacturer,

c. the *manufacturer survivability* to work with less efficient and/or less responsive supplier, and
d. the manufacturer strategic movement (*strategic mutation*).

The extremely low and high *manufacturer trust* towards the supplier assists the supply chains to have a better performance and survivability for the long-term. Meanwhile, the *customer loyalty*, the manufacturer *strategic mutation*, and the extremely low *manufacturer survivability* lead to negative results in the demand fulfilment and survivability of supply chains. These factors lead the competition tension to be higher by encouraging the firms to have further strategic movements.

5. Most of the suggestions of this research contradict the popular recommendations in SCM, which commonly focuses on the *duration of collaboration*, the *number of partnerships*, the *trust* of both supplier and manufacturer, and the supplier stability (represented as *supplier survivability*) in the supply chain. These findings indicate that companies that currently have a plan on investing a long-term partnership with their supplier should rethink this program because it may not worth for the long-term performance and survivability improvements. The *number of partnerships* also does not improve the demand fulfilment and survivability of supply chains significantly for the long-term, unless the long *duration of collaboration* applies to the supply chains. Under the adoption of long-term collaboration strategy, the *one-to-one partnerships* seem to be beneficial to demand fulfilment and survivability of supply chains.

   Meanwhile, the *manufacturer trust*, the *customer loyalty*, and the manufacturer *strategic mutation* are sensitive to demand fulfilment and survivability of supply chains, which have not been considered in the existing literature. It suggests that manufacturer enterprises may require to assessing their current behaviour towards their supplier (or self-assessment) which can assist them to maintain their long-term performance and survivability. SCM research also necessitates to considering *customer loyalty* in supply chain decisions and analysis as well as the extreme decision in strategic change in supply chain (the *strategic mutation*).

These unexpected findings obtained in this study approve analysis in both SCM and strategic management should cover more comprehensive scope to avoid fragmentary inference in strategy.

6. *Hypothesis B.1* is supported, which is

   "Adopting longer *duration of collaboration* does not lead to a better long-term demand fulfilment and survivability of supply chains".

   When *one-to-one partnerships* apply to the system, the length of collaboration does not provide a significant effect on both long-term demand fulfilment and survivability of supply chains. Meanwhile, when manufacturers are only able to collaborate with one supplier at one time and suppliers can link to more than one manufacturer, the short-*duration of collaboration* results in better demand fulfilment and survivability of supply chains. However, this result seems to have low sensitivity to influencing supply chains performance and survivability over the long-term competition.

7. *Hypothesis B.2* is supported, which is

   "Having a lower number of partnerships does not improve long-term demand fulfilment and survivability of supply chains".

   When the short-term *duration of collaboration* applies, better demand fulfilment and survivability of supply chains can be achieved in *single-sourcing* and *multi-sourcing* strategy. The *dual-sourcing* is found to result in the lowest supply chain survivability, but it has no significant effect on demand fulfilment rate. However, the significance degree of this negative impact of *dual-sourcing* on supply chains seems to be low. When this result was investigated with different experiment setup, the *dual-sourcing* seems to be not different significantly from other sourcing strategies.

   Meanwhile, when the long-term *duration of collaboration* applies to the market, *single-sourcing* strategy with one-to-one relationships generates better results in both long-term demand fulfilment and survivability of supply chains. However, the significance degree of this one-to-one relationships' positive effect is low. It suggests that the benefit of *single-sourcing* strategy under long-term collaboration may not be significant under different model setup.

8. *Hypothesis B.3.1* is supported, which is
   "Higher *manufacturer trust* of the supplier does not enhance long-term demand fulfilment and survivability of supply chains".
   Compared to the intermediate level of *manufacturer trust*, both the extremely high *loyalty* (the 100% *loyalty*) and the extremely low *loyalty* (i.e. no *loyalty* at all or 0% *loyalty*) result in better demand fulfilment rate and long-term survivability. The 100% *manufacturer trust* generates the highest demand fulfilment and survivability of supply chains, while the 0% *loyalty* results in the second highest performance and survivability for supply chains. Both extreme *loyalty* levels provide a high degree of significance difference compared to the non-extreme levels of the *manufacturer trust*. This situation applies when short-term collaboration is operated.
   However, when long-term collaboration is adapted, only the 100% *manufacturer trust* provides a better long-term demand fulfilment and survivability of supply chains. The other degrees of *loyalty* are found to provide no significant difference.

9. *Hypothesis B.3.2* is supported, which is
   "Higher *supplier trust* towards manufacturer does not improve long-term demand fulfilment and survivability of supply chains".
   The *supplier trust* is found to be insignificant to overall supply chain long-term profitability/performance and survivability when the short *duration of collaboration* is implemented to the system. Nevertheless, this factor seems to be important when the long-term *duration of collaboration* is applied. A somewhat disloyal degree of *supplier trust*, surprisingly, appears to be beneficial to maintain supply chain survivability for long-term, even though it

has no effect on demand fulfilment rate. However, this *supplier trust* level has a low significance degree in affecting demand fulfilment and survivability of supply chains. It suggests that this *loyalty* level may not essentially support the long-term survivability for the supply chains.

10. *Hypothesis B.3.3* is supported, which is
"Higher *customer loyalty* towards manufacturer does not improve long-term demand fulfilment and survivability of supply chains".
No loyal customers are shown beneficial in maintaining long-term survivability for all supply chains in the market although the no loyal customers do not assist supply chains to the highest demand fulfilment rate in the experiment. The highest demand fulfilment rate is resulted by the extremely high *customer loyalty* (100% *loyalty*), but it potentially leads to an extreme *shakeout*. Thus, it can be suggested that the no loyal customers seem to be beneficial to supply chains, particularly in maintaining long-term survivability for supply chains without degrading their performance over the long-term. With regards to its degree of significance, the *customer loyalty* has high significance levels both to the demand fulfilment and survivability of supply chains. It indicates that *customer loyalty* is sensitive to supply chains.

11. *Hypothesis B.4.1* is supported, which is
"Higher *manufacturer survivability* does not enhance long-term demand fulfilment and survivability of supply chains".
Manufacturer ability to cope with loss when it collaborates with less efficient and/or responsive suppliers, represented as *manufacturer survivability* in this study, affects both demand fulfilment and survivability of supply chains. It has a high degree of significance effect, which suggests that the factor is sensitive to supply chains.
However, higher *manufacturer survivability* does not always lead to a better demand fulfilment and survivability of supply chains. Intermediate levels to the extremely high level of survivability do not seem to be advantageous to

supply chains for the long-term. The only extremely low level of survivability provides the significant lowest demand fulfilment rate. Meanwhile, higher *manufacturer survivability* seems to be more sensitive to enhance supply chain survivability, even though this impact is not linearly proportional to the level of survivability.

12. *Hypothesis B.4.2* is supported, which is

    "Higher *supplier survivability* does not improve demand fulfilment and survivability of supply chains over the long-term ".

    Supplier survivability represents supplier ability to tackle losses when it could not find an appropriate manufacturer to collaborate. The results indicate that this factor has a low degree of significance in maintaining long-term supply chain survivability, and it seems to have no impact on demand fulfilment rate. Moreover, only the extremely low level of survivability has a significant effect on supply chains, particularly in supply chain survivability. The intermediate levels and extremely high level of *supplier survivability* do not appear to be sensitive to supply chains.

13. *Hypothesis B.5* is supported, which is

    "The competition approach suggested in strategic management, regarding the strategic mutation, does not improve demand fulfilment and survivability of supply chains for the long-term ".

    The *strategic mutation* of the manufacturer is shown to be detrimental to supply chains. This effect has high significance degree on both demand fulfilment and survivability of supply chains. Thus, no *strategic mutation* is expected to be a better approach to maintain the long-term performance and survivability for all supply chains in the operated market.

8.2.4 Achievement of objectives

Having summarised the objectives as well as the findings of this study, the achievement of each objective of this Thesis can be encapsulated as follows.

8.2.4.1 The development of agent-based model of competition and collaboration in supply chains (objective 1)

The agent-based model developed in this study has shown to be able to model and simulate competition and collaboration in supply chains. The agent-based modelling approach enables the researcher to investigate several issues of supply chain competition and collaboration found in the literature. The theory-driven approach adopted in the model also enriches model ability to incorporate supply chain strategic decisions in collaboration, in terms of defining the agent's competitive environment and behavioural rules described in Chapter 5.

The model is simplified, yet the interactions between the agents create high complexity relationships - as illustrated in Figure 7.1. A state of an agent changes dynamically as the agent receives feedback or information from other agent's action. However, each agent's is rationally bounded in understanding the feedback or information from the other agents. When all agents have similar limitations on bounded rationality, it creates system-level behaviour, with respect to market-level perspective. The emergent outcomes may have been predicted intuitively in business, but it is hard to explain empirically. The complex relationships occur in competition and collaboration may be the reason for the emergence of conflicting findings and suggestions in the previous studies.

8.2.4.2 To explore the competition influence on supply chains and market structure, in terms demand fulfilment and survivability of supply chains for a long-term (objective 2)

The agent-based model developed in this study has examined the generic impact of competition on supply chains as a market. By observing the generic emergent patterns in all experiments - including the base run and the behaviour space, it is found that competition results in two effects on supply chains: strategic alignment within supply chains as a positive impact, and *shakeouts* as the negative impact.

However, competition also creates other generic emergent patterns that are not considered in *Hypothesis A*. Assuming the customer preference is fixed, the model indicates that competition can be a significant driver to the form of the market structure; all firms in the system tends to have almost similar strategic position with their competitors within long run of competition. This emergent behaviour also seems to have a similar outcome as Hotelling's model, which predicts that equilibrium state is achieved when company's strategic position is relatively not different from others. This similar resulting pattern is produced although the modelling assumption used in this study is different from Hotelling's model. These results denote that the model is reliable to use as a base in understanding and observing the impact of competition on supply chains, particularly in innovative product markets.

8.2.4.3 To explore the effect of firm competition and collaboration strategy on supply chains, in terms of demand fulfilment and survivability of supply chains over the long-term (objective 3).

The model has assisted the researcher to observe and explore competitive and collaborative behaviour, which are identified as important issues in the literature gap (Chapter 2). The competitive and collaborative that are considered are the *duration of collaboration*, the *number of partnerships* of manufacturer and supplier, *trust*, individual *firm survivability* (or *robustness*), and *strategic mutation*. The exploration of each behavioural element is performed in isolation. It enables the researcher to obtain explanation and intuition on the independent effect of each factor, which could not be explored in an empirical approach.

On the other hand, isolated exploration provides limited interpretations to relate it with real supply chain practices. Therefore, several issues, considering the *number of partnerships* and *trust*, have been run under several levels of the *duration of collaboration*: short-term and long-term collaboration. This is because these factors are occasionally considered as unseparated elements in achieving collaboration success, with regards to a long-term collaboration with *single-sourcing* (one-to-one partnership) and high *trust* between collaborating firms. In short, this study has performed the exploration for understanding the impact of firm competitive and collaborative behaviour on long-term demand fulfilment and survivability of supply chains.

8.3 Thesis contributions

A central theme of this Thesis is "to explore the impact of competition and collaboration on supply chains from a market perspective". This theme involves three research disciplines: supply chain management (SCM), strategic management, and agent-based modelling (ABM). This research also implicates operational research (OR) through the use of ABM for the modelling process and operations management (OM) for the analysis. With respect to the findings and the modelling approach, this Thesis provides two main contributions. They are related to implications to knowledge and practice, and the agent-based model of competition and collaboration in supply chains. The following subsections summarise the detail of these contributions.

8.3.1 Implications to knowledge and practice

This study has two contributions to knowledge and practice. They are insight on competition and collaboration, and the fundamental for supply chain collaboration, which are explained in the following sections.

Insights on competition and collaboration

In strategic management, competition can be considered as a barrier creation to prevent new firms to enter the market (Porter 1990). However, in fact, competition always naturally emerges in business, despite the threat of new entrants. When companies operate in the same market, they will compete to be the strongest firm and tend to 'destroy' their competitors. This study simulates this situation, where competition exists without allowing new firms to penetrate the market.

The use of market-level analysis in this study provides a contemporary approach to view and evaluate competition and collaboration strategy, taking a system perspective. It offers a new insight in SCM, particularly to think about the impact of particular supply chain strategies for the long-term. This is a novel approach that has not been considered by previous studies in the SCM literature. An essential insight obtained from the application of market-level perspective in this study is that "what is good for a single company may not be rewarding for the market". It indicates that a supply chain strategy may have led a firm to be a market leader, but it could be detrimental once it applies to all firms. If this situation is not immediately predicted by policy makers, an extreme *shakeout* could emerge in the market, such as monopoly. This critical finding corresponds to the real SCM practices because only a few companies can benefit the supply chain strategies recommended in the literature.

The simulation results also suggest that the manufacturer's strategy or behaviour in collaboration affects the supplier's competitive movements, and vice versa. This is because the manufacturer's strategic position affects the manufacturer's decision to select the appropriate supplier to collaborate, while, at the same time, the supplier's competitive movement influences the manufacturer's strategic position is highly affected by the supplier's capability during the collaboration period. These mean that competition and collaboration strategy has a reciprocal impact which affects the tension level of competition in the market. An extremely high tension of competition will lead to an extreme *shakeout*, which results in monopoly. In other words, the less aggressive competitive movements of companies could maintain the market stability, in terms of market demand fulfilment and survivability of supply chains. This long-term stability is possible to acquire when most of the suppliers are not far more efficient and/or responsive than the manufacturers.

In addition, this study provides some initial analysis that explains the occurrence of *shakeout* phenomenon. Most discussions of *shakeouts* are often discussed in strategic management, but none of them has tried to explain it by considering SCM point of view. The results of the model show that the extreme *shakeout* (monopoly) can be more likely to occur when most suppliers are far more efficient and/or responsive than the manufacturers. However, it is hard to control the distribution of firm strategic position in reality. It indicates that an advance strategic management approach to regulate the market is required to prevent it from extreme *shakeouts*.

With respect to the effect of competition and collaboration strategy, this Thesis contributes a new insight on strategy in both SCM and strategic management context. In strategic management, strategy is viewed in many different perspectives. Strategy can be considered as, for example, an action plan, an adaptation process, and a prescription to a business problem (Mintzberg et al. 2005). However, in reality, none of these perspectives is able to provide the best strategy that leads to a consistent outcome to any company. All of these views are correct, but each of them has limited scope to explain and discuss strategy in a complete and perfect perspective. This situation makes the discussion on strategy seem never ends, and various suggestions on the most 'correct' and 'powerful' strategy emerges in the literature and business practices. This also deals with the nature of human being that different people always look the same thing differently. This 'natural' limitation could be a reason why the 'most logical' strategy is not consistently effective and does not fit all firms. This situation could be simply illustrated by using analogy of a wrong medication prescription from the 'most logical' diagnosis approach.

Conforming to these conflicting opinions on strategy in strategic management and SCM, the result of this study shows that most suggested strategies in both research fields do not provide benefit to supply chains for a long-term. For instance, experts in strategic management regard strategies to improve operational effectiveness are not the real strategy for competition (Porter 2006), while SCM believes that operational strategies are critical to business success. Both opinions are supported by case studies that prove the arguments of both perspectives are true. However, each of them applies in different situations. This study shows that when a good strategy is applied by all firms, it could be detrimental to the market, indicated by the occurrence of extreme *shakeouts*. This means that a strategy that leads a single or several companies to success might have an adverse effect to other enterprises.

In other words, this study could remind academics and strategy makers that no strategy is superior in business. It does not mean that the available strategies in the literature are impractical, but selecting a strategy requires not only logical approach but also intuitions. The intuition can be enhanced by observing the market behaviour and identifying its characteristics, with respect to the supply and demand market. Even though a perfect perspective to obtain the 'whole look of the elephant' of strategy would be hard to achieve, considering different perspectives would be worthwhile to obtain a better knowledge and intuitions in strategy selection.

Moreover, market regulators may need to create a policy if most firms in a market show a tendency to apply a similar strategy that can increase the uncertainty of the market, such as practising *strategic mutation* or *big leap* strategy or imposing a *customer loyalty* program in a massive scale. When one of these strategies is implemented by all firms in the market, it could lead the companies to be extremely aggressive and increase the tension of competition. One of the consequences of this circumstance is the occurrence of extreme *shakeouts*.

Insights on the fundamental factors for supply chain collaboration

This research indicates that several behavioural factors, which have never been discussed in SCM literature, are found to be sensitive to maintaining demand fulfilment and survivability of supply chains (or *robustness*) for a long-term. The *manufacturer trust* is suggested to be a sensitive behaviour to supply chains, whilst the *supplier trust* is insensitive. This finding contradicts current discussions on *trust*, which focus more on improving *supplier trust* towards the manufacturer rather than vice versa. Meanwhile, surprisingly, no loyal customers provide a significant enhancement for the better long-term supply chain survivability. Although high degrees of *customer loyalty* can increase demand fulfilment rate or profitability, it significantly costs supply chain survivability as a consequence. Lastly, the manufacturer *strategic mutation* can potentially lead to more supply chain failures in the market if the movement is determined without considering the competition in the supply market.

In contrast, the popular collaboration issues raised in SCM literature do not provide significant support to explain the resulting impact on the long-term demand fulfilment and survivability of supply chains. The popular collaboration issues here refer to considering the *duration of collaboration* and *number of partnerships*. Although this study has limitations described in section 7.5, all these findings are worthwhile to consider in making supply chain strategic decisions for business managers.

Moreover, the isolation analysis provides a better understanding of the independent effect of competitive and collaborative behaviour to supply chains. Even though experiments in isolation can cause limited analysis on comprehending the interaction between behavioural factors, the biased of the findings has been reduced by performing several experiments with different *duration of collaboration*, with regards to the factor of the *number of partnerships* and *trust*.

8.3.2 Agent-based model of competition and collaboration with an advancement of the Hotelling's model

The use of ABM in this study offers an effective approach to consolidate the different perspective between SCM and strategic management. The bottom-up modelling approach enables exploration and analysis for a macro-level behavioural pattern that emerges from micro-level behaviour. It demonstrates that ABM has the capability to be a new approach to both SCM and strategic management to study the business dynamic, particularly in comprehending competition and collaboration impacts in a more comprehensive perspective.

This study also provides a further advancement of Hotelling's competition model that has been studied in ABM literature. By allowing two layers of competition (competition in manufacturer level and supplier level), the agent-based model developed in this study enriches the development of dynamic competition model in ABM. Also, the SCM perspective incorporated into the model enhances the competition model in offering more comprehensive analysis to the business dynamics. The use of competition dimensions of efficiency and responsiveness are new, and the rules of competition and collaboration are coeval.

In short, this research provides a high originality of the contribution for ABM model. Although the model employed in this study is still highly simplified, it can be a basis of the use of ABM as an alternative approach to studying conflicting issues in SCM and strategic management. This study also demonstrates that the use of ABM in consolidating SCM and strategic management is contemporary and promising. Moreover, the findings of this Thesis suggest that Hotelling's model is generally reliable to provide intuitions in predicting the long-term effect of competition on innovative product markets. This indicates that the modelling and simulation of supply chain competition and collaboration are useful and important. Hence, there is merit modelling the issue through ABM.

8.4 Research limitations

As addressed in section 7.5 (Chapter 7), this study has three sources of limitations: modelling approach limitations, model setup limitations, and analysis limitations. These limitations can be considered as the potential improvements for the future research.

The modelling approach limitations are driven by the model contents. The feature of the model that may significantly contribute to the experimental results is that the interactions are defined in a very simplified way. All agents are homogeneous, and they do not have learning ability to change their behaviour. Also, the agent's rules described in the experimental factors are assumed to be independent. These characteristics have been listed as a part of modelling assumptions and simplifications in the conceptual modelling process (section 5.2.4).

The study limitation also comes from the behaviour space, or model setup. The scenarios defined in this study are limited to only 5 levels, and most experiments are undertaken in isolation. Although several inputs have been undertaken under two different levels of the *duration of collaboration*, analysis to understand the effect of interactions between the experimental factors is still limited.

The analysis limitations deal with model outputs used in this study. Incorporating costs, such as collaboration cost and strategic change cost, may provide better interpretations to the results. Nevertheless, adding more output measures may also increase complexity to the model.

8.5 Future work

While this study provides a novel approach and insights to understand competition and collaborations in supply chains, the model offers potential extensions to generate further valuable comprehensions and intuitions in this topic. Moreover, the findings of this study can lead to further hypotheses that enhance current knowledge in SCM and strategic management. The improvements of this research could be addressed by elaborating the unused features that are available in the current computer model, and/or relaxing the current limitation studies mentioned in section 8.4

8.5.1 Optimising the use of current model feature

Possible further research that could be undertaken in the nearest time is by optimising the features of the present agent-based model. The detail unexplored features in the computer model are provided in Appendix F.

1. Investigating the interactions between competition and collaboration factors with multi-factorial analysis to provide more comprehensive insights into competition and collaboration effect in supply chains.

2. The computer model used in this study also has several features to allow the agents to be heterogeneous, by applying different *duration of collaboration* in each manufacturer agent.

3. The current computer model has been coded to allow an agent, either manufacturer or supplier, to behave differently, in terms of competitive and collaborative behaviour. This approach could provide a basis for recommending an appropriate strategy of supply chain collaboration that incorporates business competition.

4. The last available unused feature of the computer model is that the model can be used to examine whether allowing new entrants to the competition

would change the emergent behaviour and prevent the market from *shakeouts*.

8.5.2 Relaxing the current study limitations

Future work could be performed by addressing the limitations of this study, with regards to the modelling limitations, model setup limitations, and analysis limitations. Potential studies that could be considered are:

1. Defining the agents to act heterogeneously by adding a learning capability and intelligence in making decisions. This meta-behavioural rule can allow several experimental factors to be less independent and dynamically adjusted during the simulation run.
2. Elaborating costs of collaboration and strategic change to improve the assessment of the current model output of demand fulfilment rate.
3. Considering the position of suppliers to the rule of manufacturer *strategic mutation*. This additional logic will provide a more comprehensive insight in exploring the effect of *strategic mutation* on supply chains in the market.

8.6 Summary and final comments

There is a vast body of literature in collaboration and competition strategies to improve business performance and *survivability*, yet contradicting opinions continuously appear and remain unexplained. The issue is related to the *duration of collaboration*, the *number of partnerships*, *trust,* survivability of individual firm, and the manufacturer *strategic mutation*. Many studies suggest these factors are critical to improve supply chain's competitiveness, while other work finds that not all of them are significant. When the factor is concluded significant, different suggestions emerge to the literature. The gap in the literature becomes more explicit when this issue is viewed from strategic management perspective.

The agent-based model developed in this study offers a new approach to SCM and strategic management to bridge the gap in the previous work. The approach provides new insight into understanding the effect of competition and collaborations on supply chains, where several findings are counterintuitive with what it is generally understood in SCM and strategic management. This research initiates a contemporary perspective to connect SCM and strategic management to sharpen academics, policy makers, business manager's intuitions about competitive and collaborative behaviour that are happening in the market. Further research opportunities are widely available for improvements to answer further complex relationships in this issue.

This study has made the present researcher realised that science begins as parable and ends as a probability. Simplified models are often found to be more useful and easier to explain a complex system that involves real and imaginary elements. The real elements are likely measurable and observable through quantitative and/qualitative information, but the imaginary aspects remain hard to explore and explain. Moreover, people tend to see things and understand problems in different ways. This makes a real issue for one person may look imaginary for the others, and vice versa. These characteristics represent a complex system that may drive the conflicting suggestions in much research, including in SCM, strategic management, and ABM. This feature is also the reason why a simple model is frequently more useful to assist complex analysis for learning and obtaining insights. Furthermore, the constraints of competition and collaboration success could be as a result of the system-level emergence of individual firm behaviour. In short, the researcher feels a great excitement during this study. The researcher is also highly motivated to improve and encourage other scholars to enhance this study for more comprehensive perspective and analysis.

REFERENCES

Acs, Z.J. and Audretsch, D.B., 1987. Innovation, market structure, and firm size. *The Review of Economics and Statistics*, 69(4), pp.567–574.

Ahn, H.J., Lee, H. and Park, S.J., 2003. A flexible agent system for change adaptation in supply chains. *Expert Systems with Applications*, 25(4), pp.603–618.

Akanle, O.M. and Zhang, D.Z., 2008. Agent-based model for optimising supply-chain configurations. *International Journal of Production Economics*, 115(2), pp.444–460.

Alhabeeb, M.J., 2007. On consumer trust and product loyalty. *International Journal of Consumer Studies*, 31(1), pp.609–612.

Altug, M.S. and van Ryzin, G., 2013. Product quality selection: Contractual agreements and supplier competition in an assemble-to-order environment. *International Journal of Production Economics*, 141(2), pp.626–638.

Alvarado, U.Y. and Kotzab, H., 2001. Supply chain management: The integration of logistics in marketing. *Industrial Marketing Management*, 30, p.183.

Anderson, E. and Jap, S.D., 2005. The dark side of close relationships. *MIT Sloan Management Review*, 46(3), pp.75–83.

Arunachalam, R. and Sadeh, N.M., 2005. The supply chain trading agent competition. *Electronic Commerce Research and Applications*, 4(1), pp.66–84.

Axelrod, R., 1997a. *The complexity of cooperation: Agent-based models of competition and collaboration*, New Jersey: Princeton University Press.

Axelrod, R., 1997b. The dissemination of culture: A model with local convergence and global polarization. *Journal of Conflict Resolution*, 41(2), pp.203–226.

Axtell, R.L., 2007. What economic agents do: How cognition and interaction lead to emergence and complexity. *The Review of Austrian Economics*, 20(2-3), pp.105–122.

Babich, V., 2006. Vulnerable options in supply chains: Effects of supplier competition. *Naval Research Logistics*, (August 2004), pp.656–673.

Baden-Fuller, C.W.F., 1989. Exit from declining industries and the case of steel castings. *Economic Journal*, 99(398), p.949.

Barbuceanu, M., 1999. Role of obligations in multiagent coordination. *Applied Artificial Intelligence*, 13(1-2), pp.11–38.

Barbuceanu, M., Teigen, R. and Fox, M.S., 1997. Agent based design and simulation of supply chain systems. In *Proceedings of IEEE 6th Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises*. Los Alamitos, California: The Institute of Electrical and Electronics Engineers, Inc., pp. 36–41.

Barratt, M., 2004. Understanding the meaning of collaboration in the supply chain. *Supply Chain Management: An International Journal*, 9(1), pp.30–42.

Bender, R. and Lange, S., 2001. Adjusting for multiple testing - When and how? *Journal of Clinical Epidemiology*, 54(4), pp.343–349.

Bensaou, M., 1999. Portfolios of buyer-supplier relationships. *MIT Sloan Management Review*, pp.1–12.

Bititci, U.S., Ackermann, F., Ates, A., and Davies, J., 2011. Managerial processes: Business process that sustain performance, *International Journal of Operations & Production Management*, 31(8), pp.851-891.

Bititci, U.S. Ackermann, F., Ates, A., Davies, J., Gibb, S., Macbryde, J., MacKay, D., Maguire, C., van der Meer, R., and Shafti, F., 2008. Manage processes - What are they ? *SIOM Research Paper Series*, 001.

Bititci, U.S. Ackermann, F., Ates, A., Davies, J., Gibb, S., Macbryde, J., MacKay, D.,Maguire, C., van der Meer, R., and Shafti, F., 2011. Managerial processes: An operations management perspective towards dynamic capabilities. *Production Planning and Control*, 22(2), pp.1–41.

Blackburn, J., 2012. Valuing time in supply chains: Establishing limits of time-based competition. *Journal of Operations Management*, 30(5), pp.396–405.

Boddy, D. Cahill, C., Charles, M., Fraser-Kraus, H., and Macbeth, D., 1998. Success and failure in implementing supply chain partnering: an empirical study. *European Journal of Purchasing and Supply Management*, 4, pp.143–151.

Bonaccorsi, A. and Giuri, P., 2000. When shakeout doesn't occur: The evolution of the turboprop engine industry. *Research Policy*, 29, pp.847–870.

Burke, G.J., Carrillo, J.E. and Vakharia, A.J., 2007. Single versus multiple supplier sourcing strategies. *European Journal of Operational Research*, 182(1), pp.95–112.

Burton, R.M., 2003. Computational laboratories for organization science: Questions, validity and docking. *Computational and Mathematical Organization Theory*, 9(2), pp.91–108.

Cachon, G.P. and Lariviere, M.A., 2005. Supply chain coordination with revenue-sharing contracts: Strengths and limitations. *Management Science*, 51(1), pp.30–44.

Caldart, A.A. and Ricart, J.E., 2007. Corporate strategy: An agent-based approach. *European Management Review*, 4, pp.107–120.

Caniëls, M.C.J. and Gelderman, C.J., 2005. Purchasing strategies in the Kraljic matrix—A power and dependence perspective. *Journal of Purchasing and Supply Management*, 11(2-3), pp.141–155.

Cao, M. and Zhang, Q., 2011. Supply chain collaboration: Impact on collaborative advantage and firm performance. *Journal of Operations Management*, 29(3), pp.163–180.

Caridi, M., Cigolini, R. and De Marco, D., 2005. Improving supply-chain collaboration by linking intelligent agents to CPFR. *International Journal of Production Research*, 43(20), pp.4191–4218.

Casti, J.L., 1997. Can you trust it? On the reliability of computer simulation and the validity of models. *Complexity*, 2 (January 1995), pp.1995–1998.

Çebi, F. and Bayraktar, D., 2003. An integrated approach for supplier selection. *Logistics Information Management*, 16(6), pp.395–400.

Chen, X. Ong, Y.S., Tan, P.S., Zhang, N.S., and Li, Z., 2013. Agent-based modeling and simulation for supply chain risk management - A survey of the state-of-the-art. In *International Conference on Systems, Man, and Cybernetics*. IEEE, pp. 1294–1299.

Cheng, R., 2011. A study on multi-agent based supply chain collaboration operation model facing time of delivery. *Proceedings - 2011 8th IEEE International Conference on e-Business Engineering, ICEBE 2011*, pp.102–104.

Chiang, C. and Benton, W.C., 1994. Sole sourcing versus dual sourcing under stochastic demands and lead times. *Naval Research Logistics*, 41(5), pp.609–624.

Childe, S.J., Maull, R.S. and Bennett, J., 1994. Frameworks for understanding business process re-engineering. *International Journal of Operations and Production Management*, 14(12), pp.22–34.

Chopra, S. and Meindl, P., 2007. *Supply chain management: Strategy, planning, and operation*, New Jersey: Pearson Education, Inc.

Chopra, S. and Sodhi, M.S., 2004. Managing risk to avoid supply-chain breakdown. *MIT Sloan management review*, 46, pp.53–61.

Choudhary, A.K., Singh, K.A. and Tiwari, M.K., 2006. A statistical tolerancing approach for design of synchronized supply chains. *Robotics and Computer-Integrated Manufacturing*, 22(4), pp.315–321.

Christopher, M., 2000. The agile supply chain: Competing in volatile markets. *Industrial Marketing Management*, 1(29), pp.37–44.

Christopher, M., 2005. *Logistics and supply chain management: Creating value-adding networks*, Prentice Hall - Financial Times.

Collier, N., 2003. RePast : An extensible framework for agent simulation. *The University of Chicago's Social Science Research*, 36, pp.371–375.

Collin, J. and Lorenzin, D., 2006. Plan for supply chain agility at Nokia: Lessons from the mobile infrastructure industry. *International Journal of Physical Distribution and Logistics Management*, 36(6), pp.418–430.

Cox, A., 2004. The art of the possible: relationship management in power regimes and supply chains. *Supply Chain Management: An International Journal*, 9(5), pp.346–356.

D'Amours, S. and Guinet, A., 2003. *Intelligent agent-based operations management*, London: Kogan Page Science.

Dapiran, P., 1992. Benetton — Global logistics in action. *International Journal of Physical Distribution and Logistics Management*, 22(6), pp.7–11.

Day, G., 1997. Strategies for surviving a shakeout. *Harvard Business Review*, (March-April).

Diehl, E. and Sterman, J.D., 1995. Effects of feedback complexity on dynamic decision making. *Organizational Behavior and Human Decision Processes*, 62(2), pp.198–215.

Dimitriou, S., 2010. *The impact of prices on boundedly rational decision makers in supply chains*. The University of Warwick.

Dimitriou, S., Robinson, S. and Kotiadis, K., 2009. The impact of human decision makers' individualities on the wholesale price contract's efficiency: Simulating the newsvendor problem. *Proceedings of the 2009 Winter Simulation Conference (WSC)*, pp.2353–2364.

Duclos, L.K., Vokurka, R.J. and Lummus, R.R., 2003. A conceptual model of supply chain flexibility. *Industrial Management and Data Systems*, 103(6), pp.446–456.

Dugundji, E.R. and Gulyás, L., 2008. Sociodynamic discrete choice on networks in space: impacts of agent heterogeneity on emergent outcomes. *Environment and Planning B: Planning and Design*, 35(6), pp.1028–1054.

Dyer, J.H. and Ouchi, W.G., 1993. Japanese-style partnerships : Giving companies a competitive edge. *MIT Sloan Management Review*, pp.1–17.

Farmer, J.D. and Foley, D., 2009. The economy needs agent-based modelling. , 460(7256), pp.685–686.

Fawcett, S.E. and Magnan, G.M., 2002. The rhetoric and reality of supply chain integration. *International Journal of Physical Distribution and Logistics Management*, 32(5), pp.339–361.

Fingleton, E., 2012. Who's winning : The Japanese or the Koreans ? *The Economist*. Available at: http://www.forbes.com/sites/eamonnfingleton/2012/06/12/whos-winning-the-japanese-or-the-koreans/#4dad1e591cb4 [Accessed April 14, 2016].

Fisher, D., 2011. Japan disaster shakes up supply-chain strategies. *Harvard Business School Working Knowledge*, May, pp.1–2.

Fisher, M.L., 1997. What is the right supply chain for your product ? *Harvard business review*, 75(2), pp.105–116.

Forker, L.B. and Stannack, P., 2000. Cooperation versus competition: do buyers and suppliers really see eye-to-eye? *European Journal of Purchasing and Supply Management*, 6(1), pp.31–40.

Forrester, J.W., 1962. *Industrial dynamics*, MIT Press.

Fourtane, S., 2015. Nokia networks leads in supply chain operations excellence. *Eye for Transport*. Available at: http://www.eft.com/technology/nokia-networks-leads-supply-chain-operations-excellence-0 [Accessed April 15, 2016].

Fu, J. and Fu, Y., 2012. Case-based reasoning and multi-agents for cost collaborative management in supply chain. *Procedia Engineering*, 29, pp.1088–1098.

Gadde, L.-E. and Snehota, I., 2000. Making the most of supplier relationships. *Industrial Marketing Management*, 29(4), pp.305–316.

Ganesan, S., 1994. Determinants of long-term in buyer-seller orientation relationships. *Journal of Marketing*, 58(2), pp.1–19.

García-Flores, R., Wang, X.Z. and Goltz, G.E., 2000. Agent-based information flow for process industries' supply chain modelling. *Computers and Chemical Engineering*, 24, pp.1135–1141.

Gardner, M.J. and Altman, D.G., 1986. Confidence intervals rather than P-values: Estimation rather than hypothesis testing. *British medical journal (Clinical research ed.)*, 292(6522), pp.746–750.

Gelderman, C.J. and van Weele, A., 2005. Purchasing portfolio models: A critique and update. *The Journal of Supply Chain Management: A Global Review of Purchasing and Supply*, (August), pp.19–28.

Ghasemi, A. and Zahediasl, S., 2012. Normality tests for statistical analysis: A guide for non-statisticians. *International Journal of Endocrinology and Metabolism*, 10(2), pp.486–489.

Gibson, B.J., Mentzer, J.T. and Cook, R.L., 2005. Supply chain management: The pursuit of a consensus definition. *Journal of Business Logistics*, 26(2), pp.17–25.

Gilbert, N., 2004. Agent-based social simulation: Dealing with complexity, pp.1–14. Available at: http://cress.soc.surrey.ac.uk/web/resources/ABSS - dealing with complexity-1-1.pdf.

Gilbert, N., 2008. Agent-based models. *SAGE Publications*, 153(153), p.98.

Gilbert, N. and Terna, P., 2000. How to build and use agent-based models in social science. *Mind and Society*, 1(1), pp.57–72.

Gjerdrum, J., Shah, N. and Papageorgiou, L.G., 2001. A combined optimization and agent-based approach to supply chain modelling and performance assessment. *Production Planning and Control*, 12(1), pp.81–88.

Grayson, K. and Ambler, T.I.M., 1999. The dark side of long-term relationships in marketing services. *Journal of Marketing Research*, XXXVI(1992), pp.132–141.

Groebner, D.F. Shannon, P.W., Fry, P.C., and Smith, K.D., 2011. *Business statistics: A decision-making approach* 8th edition., New Jersey: Prentice Hall.

Gross, D. and Strand, R., 2000. Can agent-based models assist decisions on large-scale practical problems? A philosophical analysis. *Complexity*, 5(6), pp.26–33.

Ha, B.-C., Park, Y.-K. and Cho, S., 2011. Suppliers' affective trust and trust in competency in buyers: Its effect on collaboration and logistics efficiency. *International Journal of Operations and Production Management*, 31(1), pp.56–77.

Hall, K., 2009. Why Korean tech firms make money but Japanese tech firms don't. *Business Week*. Available at: http://www.businessweek.com/globalbiz/blog/eyeonasia/ archives/2009/07/why_korean_tech.html [Accessed April 14, 2016].

Hallowell, R., 1996. The relationships of customer satisfaction, customer loyalty, and profitability : An empirical study. *International Journal of Service Industry Management*, 7(4), pp.27–42.

Hamel, G., 2013. Competition for competence and inter-partner learning within international. *Strategic Management Journal*, 12(1 991), pp.83–103.

Hart, S.L. and Christensen, C.M., 2002. The great leap : Driving innovation from the base of the pyramid. *MIT Sloan Management Review*, 44(1).

He, Z., Wang, S. and Cheng, T.C.E., 2013. Competition and evolution in multi-product supply chains: An agent-based retailer model. *International Journal of Production Economics*, 146(1), pp.325–336.

Heath, B.L. and Hill, R.R., 2010. Some insights into the emergence of agent-based modelling. *Journal of Simulation*, 4(3), pp.163–169.

Hilscher, R., 2005. *Agent Based Models of Competitive Speciation*. University of Sussex.

Hollensen, S., 2013. The Blue Ocean that disappeared – The case of Nintendo Wii. *Journal of Business Strategy*, 34(5), pp.25–35.

Holweg, M. Disney, S., Holmström, J., and Småros, J., 2005. Supply chain collaboration: Making sense of the strategy Continuum. *European Management Journal*, 23(2), pp.170–181.

Horppu, M, Kuivalainen, O., Tarkiainen, A., and Ellonen, H.K., 2008. Online satisfaction, trust and loyalty, and the impact of the offline parent brand. *Journal of Product and Brand Management*, 17(6), pp.403–413.

Hotelling, H., 1929. Hotelling - Stability in competition. *The Economic Journal*, 39(153), pp.41–57.

Hsieh, F.S. and Lin, J.B., 2014. A multiagent approach for managing collaborative workflows in supply chains. *Proceedings of the 2014 IEEE 18th International Conference on Computer Supported Cooperative Work in Design, CSCWD 2014*, pp.71–76.

Humphreys, P.K., Shiu, W.K. and Chan, F.T.S., 2001. Collaborative buyer-supplier relationships in Hong Kong manufacturing firms. *Supply Chain Management: An International Journal*, 6(4), pp.152–162.

Huo, B., Zhao, X. and Zhou, H., 2014. The effects of competitive environment on supply chain information sharing and performance: An empirical study in China. *Production and Operations Management*, 23(4), pp.552–569.

Ihlwan, M., 2009. Samsung earnings soar thanks to TVs. *Business Week*. Available at: http://www.businessweek.com/globalbiz/content/jul2009/gb20090724_872194.htm [Accessed April 14, 2016].

Inkpen, A.C. and Beamish, P.W., 1997. Knowledge, bargaining power, and the instability of international joint ventures. *Academy of Management Review*, 22(1), pp.177–202.

Irmen, A. and Thisse, J.-F., 1998. Competition in multi-characteristics spaces: Hotelling was almost right. *Journal of Economic Theory*, 78(1), pp.76–102.

Jahangirian, M. Eldabi, T., Naseer, A., Stergioulas, L.K., and Young, T., 2010. Simulation in manufacturing and business: A review. *European Journal of Operational Research*, 203(1), pp.1–13.

Jennings, N.R., Sycara, K. and Wooldridge, M., 1998. A roadmap of agent research and development. *Autonomous Agents and Multi-Agent Systems*, 1, pp.7–38.

Jiao, J., You, X. and Kumar, A., 2006. An agent-based framework for collaborative negotiation in the global manufacturing supply chain network. *Robotics and Computer-Integrated Manufacturing*, 22(3), pp.239–255.

Joanes, D.N. and Gill, C. a., 1998. Comparing measures of sample skewness and kurtosis. *Journal of the Royal Statistical Society: Series D (The Statistician)*, 47(1), pp.183–189.

Johnson, C. and Lauritzen, M., 2015. How three external challenges made Nokia's supply chain stronger. *McKinsey and Company*, (July 2015). Available at: http://www.mckinsey.com/business-functions/operations/our-insights/how-three-external-challenges-made-nokias-supply-chain-stronger.

Julka, N., Srinivasan, R. and Karimi, I., 2002. Agent-based supply chain management—1: framework. *Computers and Chemical Engineering*, 26(12), pp.1755–1769.

Kaihara, T., 2003. Multi-agent based supply chain modelling with dynamic environment. *International Journal of Production Economics*, 85(2), pp.263–269.

Kannan, V.R. and Tan, K.C., 2003. Attitudes of US and European managers to supplier selection and assessment and implications for business performance. *Benchmarking: An International Journal*, 10(5), pp.472–489.

Kauffman, S.A., 1993. *The origins of order: self-organization and selection in evolution*, New York: Oxford University Press.

Kim, W.C. and Mauborgne, R., 1997. Value innovation: the strategic logic of high growth. *Harvard Business Review*, (August).

Kim, W.C. and Mauborgne, R., 2005. Value innovation: a leap into the blue ocean. *Journal of Business Strategy*, 26(4), pp.22–28.

Kim, W.C. and Mauborgne, R., 2008. Blue ocean strategy. *Harvard business review*, 86(12), pp.70–80. Available at: www.hbr.org.

Klepper, S. and Simons, K.L., 2005. Industry shakeouts and technological change. *International Journal of Industrial Organization*, 23(1-2), pp.23–43.

Kotabe, M. and Omura, G.S., 1989. Sourcing strategies of European and Japanese multinationals: A comparison. *Journal of International Business Studies*, 20(1), pp.113–130.

Kraljic, P., 1983. Purchasing must become supply management. *Harvard Business Review*.

Kwon, O., Im, G.P. and Lee, K.C., 2007. MACE-SCM: A multi-agent and case-based reasoning collaboration mechanism for supply chain management under supply and demand uncertainties. *Expert Systems with Applications*, 33(3), pp.690–705.

Kwon, O., Im, G.P. and Lee, K.C., 2011. An agent-based web service approach for supply chain collaboration. *Scientia Iranica*, 18(6), pp.1545–1552.

Lambert, D.M. and Cooper, M.C., 2000. Issues in supply chain management. *Industrial Marketing Management*, 29(1), pp.65–83.

Laver, M., 2005. Policy and the dynamics of political competition. *American Political Science Review*, 99(02), pp.263–281.

LeBaron, B., 2000. Agent-based computational finance: Suggested readings and early research. *Journal of Economic Dynamics and Control*, 24(5-7), pp.679–702.

LeBaron, B., 2001. Evolution and time horizons in an agent-based stock market. *Macroeconomic Dynamics*, 5, pp.225–254.

LeBaron, B., 2011. Active and passive learning in agent-based financial markets. *Eastern Economic Journal*, 37, pp.35–43.

Lee, H.L., 2004. The triple-A supply chain. *Harvard business review*, 82(10), pp.1–11. Available at: http://www.ncbi.nlm.nih.gov/pubmed/15559579.

Leeuw, S. De and Fransoo, J., 2009. Drivers of close supply chain collaboration: one size fits all? *International Journal of Operations and Production Management*, 29(7), pp.720–739.

Leinwald, P. and Mainardi, C., 2010. Why can't Kmart be successful while target and Walmart thrive? *Harvard Business Review Blog Network*, Dec(Online), pp.1–2. Available at: https://hbr.org/2010/12/why-cant-kmart-be-successful-w.

Lenox, M.J., Rockart, S.F. and Lewin, A.Y., 2006. Interdependency, competition, and the distribution of firm and industry profits. *Management Science*, 52(5), pp.757–772.

Leombruni, R. and Richiardi, M., 2005. Why are economists sceptical about agent-based simulations? *Physica A: Statistical Mechanics and its Applications*, 355(1), pp.103–109.

Levinthal, D.A., 1997. Adaptation on rugged landscapes. *Management Science*, 43(7), pp.934–950.

Li, J. and Chan, F.T.S., 2013. An agent-based model of supply chains with dynamic structures. *Applied Mathematical Modelling*, 37(7), pp.5403–5413.

Li, J., Wang, S. and Cheng, T.C.E., 2010. Competition and cooperation in a single-retailer two-supplier supply chain with supply disruption. *International Journal of Production Economics*, 124(1), pp.137–150.

Li, S. Ragu-Nathan, B., Ragu-Nathan, T. S., and Rao S.S., 2006. The impact of supply chain management practices on competitive advantage and organizational performance. *Omega*, 34(2), pp.107–124.

Lieberman, M.B., 1990. Exit from declining industries: “shakeout” or “stakeout”? *RAND Journal of Economics*, 21(4), pp.538–554. Available at: http://search.ebscohost.com/login.aspx?direct=trueanddb=bthandAN=5160606andsite=ehost-live.

Louie, M. a. and Carley, K.M., 2008. Balancing the criticisms: Validating multi-agent models of social systems. *Simulation Modelling Practice and Theory*, 16(2), pp.242–256.

Loury, G.C., 1979. Market structure and innovation. *The Quarterly Journal of Economics*, 93(3), pp.395–410.

Ludbrook, J., 1998. Multiple comparison procedures updated. *Clinical and experimental pharmacology and physiology*, 25(12), pp.1032–7.

Lyon, T.P., 2006. Does dual sourcing lower procurement costs? *Journal of Industrial Economics*, 54(2), pp.223–252.

Macal, C.M. and North, M.J., 2011. Introductory tutorial: Agent-based modeling and simulation. In M. F. S. Jain, R.R. Creasey, J. Himmelspach, K.P. White, ed. *Proceedings of the 2011 Winter Simulation Conference*. The Institute of Electrical and Electronics Engineers, Inc., pp. 1451–1464.

Macy, M.W. and Willer, R., 2002. From factors to actors: Computational sociology and agent-based modeling. *Annual Review of Sociology*, 28(1), pp.143–166.

Margolis, J., Goode, J. and Bernier, D., 2003. The need for strategic flexibility. , 290(12).

Matopoulos, A. Vlachopoulou, M., Manthou, V., and Manos, B., 2007. A conceptual framework for supply chain collaboration: Empirical evidence from the agri-food industry. *Supply Chain Management: An International Journal*, 12(3), pp.177–186.

Matthyssens, P. and Van den Bulte, C., 1994. Getting closer and nicer: Partnerships in the supply chain. *Long Range Planning*, 27(1), pp.72–83.

Mauborgne, R. and Kim, W.C., 1999. Creating new market space. *Harvard Business Review*, 77(1), pp.83–93. Available at: http://search.ebscohost.com/login.aspx?direct=trueanddb=bthandAN=1405644andsite=ehost-liveandscope=cite.

McCray, J.P., Gonzalez, J.J. and Darling, J.R., 2011. Crisis management in smart phones: The case of Nokia vs Apple. *European Business Review*, 23(3), pp.240–255.

Melody, W.H., 1999. Telecom reform: progress and prospects. *Telecommunications Policy*, 23(1), pp.7–34.

Meng, J. and Layton, R. a., 2011. Understanding managers' marketing strategy choice in a collaborative competition industry. *European Business Review*, 23(5), pp.477–501.

Mintzberg, H., Ahlstrand, B. and Lampel, J., 2005. *Strategy safari: A guided tour through the wilds of strategic management*, London: Prentice Hall.

Mohamed, M.I., Omar, S.S. and Wei, L.C., 2015. Trustworthiness in buyer-supplier relation on supply chain collaboration among SMEs. In *International Symposium on Technology Management and Emerging Technologies*. Langkawi, Kedah, Malaysia, pp. 454–458.

Montreuil, B., Frayret, J.M. and D'Amours, S., 2000. A strategic framework for networked manufacturing. *Computers in Industry*, 42(2-3), pp.299–317.

Morris, B., 2012. What does the future hold for Japan's electronics firms ? *BBC News*. Available at: http://www.bbc.co.uk/news/business-17688322 [Accessed April 14, 2016].

NIST/SEMATECH, 2003. Measures of skewness and kurtosis. In *e-Handbook of statistical methods*. National Institute of Standards and Technology, U.S.

Department of Commerce. Available at: http://www.itl.nist.gov/div898/handbook/eda/section3/ eda35b.htm.

North, M.J. and Macal, C.M., 2007. *Managing business complexity: Discovering strategic solutions with agent-based modeling and simulation*, New York, USA: Oxford University Press.

Nyaga, G.N., Whipple, J.M. and Lynch, D.F., 2010. Examining supply chain relationships: Do buyer and supplier perspectives on collaborative relationships differ? *Journal of Operations Management*, 28(2), pp.101–114.

O'Cass, A. and Carlson, J., 2012. An e-retailing assessment of perceived website-service innovativeness: Implications for website quality evaluations, trust, loyalty and word of mouth. *Australasian Marketing Journal*, 20(1), pp.28–36.

Onggo, B.S., 2016. An introduction to agent-based simulation as a decision-support tool. In A. Anagnostou, K. Hoad, and M. Kunc, eds. *Proceedings of the Operational Research Society Simulation Workshop 2016*. pp. 1–12.

Onggo, B.S. and Karatas, M., 2015. Agent-based model of maritime search operations: A validation using test-driven simulation modelling. In L. Yilmaz, Chan, W.K.V., Moon, I., Roeder, T.M.K., Macal, C., and Rossetti, M D., eds. *Proceedings of the 2015 Winter Simulation Conference*. IEEE, pp. 254–265.

Parker, D. and Hartley, K., 1997. The economics of partnership sourcing versus adversarial competition: a critique. *European Journal of Purchasing and Supply Management*, 3(2), pp.115–125.

Parunak, H.V.D., Savit, R. and Riolo, R.L., 1998. Agent-based modeling vs equation-based modeling: A case study and users' guide. *Lecture Notes in Computer Science*, 1534, pp.10–25.

Pavón, J., Arroyo, M., Hassan, S., and Sansores, C., 2008. Agent-based modelling and simulation for the analysis of social patterns. *Pattern Recognition Letters*, 29(8), pp.1039–1048.

Porter, M.E., 1990. *Competitive advantage of nations: Creating and sustaining superior performance*, New York: First Free Press Edition.

Porter, M.E., 1997. Competitive strategy. *Measuring Business Excellence*, 1(2), pp.12–77.

Porter, M.E., 1998. Clusters and the new economics of competition. *Harvard Business Review*, (November), pp.77–90.

Porter, M.E., 2006. What is strategy? In M. Mazzucato, ed. *Strategy for business*. Oxford: Sage Publications, Inc., pp. 10–30.

Porter, M.E. and Millar, V.E., 1985. How information gives you competitive advantage. *Harvard Business Review*, 63(4), p.149.

Prajogo, D. and Olhager, J., 2012. Supply chain integration and performance: The effects of long-term relationships, information technology and sharing, and logistics integration. *International Journal of Production Economics*, 135(1), pp.514–522.

Purwaningrum, F., Evers, H.-D. and Yaniasih, 2012. Knowledge flow in the academia-industry collaboration or supply chain linkage? Case study of the automotive industries in the Jababeka cluster. *Procedia - Social and Behavioral Sciences*, 52, pp.62–71.

Railsback, S.F., Lytinen, S.L. and Jackson, S.K., 2006. Agent-based simulation platforms: review and development recommendations. *Simulation*, 82(9), pp.609–623.

Ramanathan, U. and Gunasekaran, A., 2014. Supply chain collaboration: Impact of success in long-term partnerships. *International Journal of Production Economics*, 147, pp.252–259.

Ramasesh, R.V., Ord, J.K., Hayya, J.C., and Pan, A., 1991. Sole versus dual sourcing in stochastic lead-time (s,Q) Inventory Models. *Management Science*, 37(4), pp.428–443.

Rathi, A., 2014. To encourage innovation, make it a competition. *Harvard Business Review*. Available at: https://hbr.org/2014/11/to-encourage-innovation-make-it-a-competition.

Reeves, M. and Deimler, M., 2011. Adaptability: The new competitive advantage. *Harvard Business Review*, (July), pp.135–141.

Ren, Z.J. Cohen, M.A., Ho, T.H., and Terwiesch, C., 2010. Information sharing in a long-term supply chain relationship: The role of customer review strategy. *Operations Research*, 58(1), pp.81–93.

Rice, J. and Galvin, P., 2006. Alliance patterns during industry life cycle emergence: The case of Ericsson and Nokia. *Technovation*, 26(3), pp.384–395.

Rice, J.B. and Hoppe, R.M., 2001. Supply chain vs supply chain. The hype and the reality. *Supply Chain Management review*, (September/October), pp.46–54. Available at: http://web.mit.edu/supplychain/repository/scvssc.pdf.

Rich, N. and Hines, P., 1997. Supply-chain management and time-based competition: The role of the supplier association. *International Journal of Physical Distribution and Logistics Management*, 27(3/4), pp.210–225.

Richardson, J., 1993. Parallel sourcing and supplier performance in the Japanese automobile industry. *Strategic Management Journal*, 14, pp.339–350.

Rivkin, J.W., 2000. Imitation of complex strategies. *Management Science*, 46(6), pp.824–844.

Robertson, D.A., 2003. The strategy hypercube: Exploring strategy space using agent-based models. *Lecture Notes in Computer Science*, 2927, pp.182–192.

Robertson, D.A., 2004. A dynamic model of inter-firm competitive strategy. In *ICCS Conference*. Boston, pp. 16–21.

Robertson, D.A. and Caldart, A.A., 2008. Natural science models in management: Opportunities and challenges. *Emergence: Complexity and Organization*, 10(2), pp.61–75.

Robertson, D.A. and Caldart, A.A., 2009. *The dynamics of strategy: Mastering strategic landscapes of the firm*, New York, New York, USA: Oxford University Press.

Robinson, S., 1997. Simulation model verification and validation: Increasing the users' confidence. In S. Andradottir, K.J. Healy, D.H., Withers, and B.L. Nelson., eds. *Proceedings of the 1997 Winter Simulation Conference*. pp. 53–59.

Robinson, S., 2008. Conceptual modelling for simulation Part I: Definition and requirements. *Journal of the Operational Research Society*, 59(3), pp.278–290.

Robinson, S., 2014. *Simulation: The practice of model development and use* Second., Palgrave Macmillan.

Sahay, B.S., 2003. Supply chain collaboration: the key to value creation. *Work Study*, 52(2), pp.76–83.

Santos, T., Coutinho, C., Cretan, A., and Jardim-Goncalves, R., 2013. Agents and rules for the negotiation of interoperability solutions. *Proceedings of the IEEE*

International Technology Management Conference and 19th ICE Conference (ICE 2013), The Hague, Netherlands.

Sargent, R.G., 2013. Verification and validation of simulation models. *Journal of Simulation*, 7(1), pp.12–24.

Satariano, B.A. and Burrows, P., 2011. Apple' s supply-chain secret ? Hoard lasers. *Bloomberg Businessweek*.

Schelling, T.C., 1969. Models of segregation. *The American Economic Review*, 59(2), pp.488–493.

Scherer, F.M., 1965. Firm size, market structure, opportunity, and the output of patented inventions. *The American Economic Review*, 55(5), pp.1091–1125.

Selldin, E. and Olhager, J., 2007. Linking products with supply chains: Testing Fisher's model. *Supply Chain Management: An International Journal*, 12(1), pp.42–51.

Shen, W. and Norrie, D.H., 1999. Agent-based systems for Intelligent manufacturing: A state-of-the-art survey. *Knowledge and Information Systems*, 1, pp.129–156.

Siebers, P. and Onggo, B.S.S., 2014. Graphical representation of agent-based models in Operational Research and Management Science using UML. In B. S. Onggo C. Heavey, T. Monks, B. Tjahjono, and D-J. van der Zee., eds. *Proceedings of the Operational Research Society Simulation Workshop 2014 (SW14)*.

Siebers, P.O., Macal, C.M., Garnett, J., Buxton, D., and Pidd, M., 2010. Discrete-event simulation is dead, long live agent-based simulation! *Journal of Simulation*, 4(3), pp.204–210.

Simatupang, T.M. and Sridharan, R., 2004. Benchmarking supply chain collaboration: An empirical study. *Benchmarking: An International Journal*, 11(5), pp.484–503.

Simatupang, T.M., Wright, A.C. and Sridharan, R., 2002. The knowledge of coordination for supply chain integration. *Business Process Management Journal*, 8(3), pp.289–308.

Simchi-Levi, D., Kaminsky, P. and Simchi-Levi, E., 2000. *Designing and managing the supply chain: Concepts, strategies, and case studies*, The McGraw-Hill Companies, Inc.

Singh, J. and Sirdeshmukh, D., 2000. Agency and trust mechanisms in consumer satisfaction and loyalty judgments. *Journal of the Academy of Marketing Science*, 28(1), pp.150–167.

Soosay, C. A. and Hyland, P., 2015. A decade of supply chain collaboration and directions for future research. *Supply Chain Management: An International Journal*, 20(6), pp.613–630.

Spekman, R.E., Jr, J.W.K. and Myhr, N., 1998. An empirical investigation into supply chain management: A perspective on partnerships. *Supply Chain Management: An International Journal*, 3(2), pp.53–67.

Squire, B., Cousins, P.D., Lawson, B., and Brown, S., 2009. The effect of supplier manufacturing capabilities on buyer responsiveness: The role of collaboration. *International Journal of Operations and Production Management*, 29(8), pp.766–788.

Stank, T.P., Keller, S.B. and Daugherty, P.J., 2001. Supply chain collaboration and logistical service performance. *Journal of Business Logistics*, 22(1), pp.29–48..

Sterman, J.D., 2000. *Business dynamics: Systems thinking and modeling for a complex world*, McGraw-Hill Companies, Inc.

Stevens, G.C. and Johnson, M., 2015. Integrating the supply chain ... 25 years on. *International Journal of Physical Distribution and Logistics Management*, 45(7), pp.652–673.

Stewart, G., 1997. Supply-chain operations reference model (SCOR): the first cross-industry framework for integrated supply-chain management. *Logistics Information Management*, 10(2), pp.62–67.

Stuart, J., 1991. Strategic flexibility for high technology manoeuvres: A conceptual framework. *Journal of Management Studies*, 28.

Stucke, M.E., 2013. Is competition always good? *Journal of Antitrust Enforcement*, 1(1), pp.162–197.

Sun, J. and Debo, L., 2014. Sustaining long-term supply chain partnerships using price-only contracts. *European Journal of Operational Research*, 233(3), pp.557–565.

Supply Chain Council, 2010. The supply chain operations reference-model (SCOR). Available at: supply-chain.org/scor.

Swafford, P.M., Ghosh, S. and Murthy, N., 2008. Achieving supply chain agility through IT integration and flexibility. *International Journal of Production Economics*, 116(2), pp.288–297.

Swaminathan, J.M., Smith, S.F. and Sadeh, N.M., 1998. Modeling supply chain dynamics: A multiagent approach. *Decision Sciences*, 29(3), pp.607–632.

Tako, A.A. and Robinson, S., 2012. The application of discrete event simulation and system dynamics in the logistics and supply chain context. *Decision Support Systems*, 52(4), pp.802–815.

Taylor, S.J.E., 2014. Introducing agent-based modeling and simulation. In S. J. Taylor, ed. *Agent-based modeling and simulation*. London: Palgrave Macmillan, p. 2.

Thatte, A.A., 2007. *Competitive advantage of a firm through supply chain responsiveness and SCM practices*. The University of Toledo.

Tracey, M., Lim, J.-S. and Vonderembse, M. a., 2005. The impact of supply-chain management capabilities on business performance. *Supply Chain Management: An International Journal*, 10(3), pp.179–191.

Turker, D. and Altuntas, C., 2014. Sustainable supply chain management in the fast fashion industry: An analysis of corporate reports. *European Management Journal*, 32(5), pp.837–849.

Turnbull, P.W., Leek, S. and Ying, G., 2000. Customer confusion: The mobile phone market. *Journal of Marketing Management*, 16(1-3), pp.143–163.

Tyworth, J.E. and Ruiz-Torres, A., 2000. Transportation's role in the sole- versus dual-sourcing decision. *International Journal of Physical Distribution and Logistics Management*, 30(2), pp.128–144.

Varga, L., 2009. *The coevolution of the firm and the supply network: A complex systems perspective*. Cranfield University. Available at: http://scholar.google.com/scholar?hl=enandbtnG=Searchandq=intitle:Cranfield+university#5.

Vereecke, A. and Muylle, S., 2006. Performance improvement through supply chain collaboration in Europe. *International Journal of Operations and Production Management*, 26(11), pp.1176–1198.

Wagner, S.M., 2011. Supplier development and the relationship life-cycle. *International Journal of Production Economics*, 129(2), pp.277–283.

Wakabayashi, D., 2012. How Japan lost its electronics crown. *The Wall Street Journal*. Available at: http://www.wsj.com/articles/SB100008723963 90444840104577551972061864692 [Accessed April 14, 2016].

Walker, G. and Weber, D., 1987. Supplier competition, uncertainty, and make-or-buy decisions. *Academy of Management Journal*, 30(3), pp.589–596.

Walley, K., 1998. Competition: what does it really mean? *The TQM Magazine*, 10(3), pp.186–189.

Wang, J. and Shin, H., 2015. The impact of contracts and competition on upstream innovation in a supply chain. *Production and Operations Management*, 24(1), pp.134–146.

Wang, W. and Brooks, R.J., 2007. Empirical investigations of conceptual modeling and the modeling process. *Proceedings - Winter Simulation Conference*, pp.762–770.

Watts, C. and Gilbert, N., 2014. *Simulating innovation: Computer-based tools for rethinking innovation*, Cheltenham: Edward Elgar Publishing Limited.

Wilensky, U., 2013. NetLogo user manual. *19 December 2013*. Available at: http://ccl.northwestern.edu/netlogo/docs/.

Wilhelm, M.M., 2011. Managing coopetition through horizontal supply chain relations: Linking dyadic and network levels of analysis. *Journal of Operations Management*, 29(7-8), pp.663–676.

Wingfield-Hayes, R., 2013. What happened to Japan's electronics giants ? *BBC News*. Available at: http://www.bbc.co.uk/news/world-asia-21992700 [Accessed April 14, 2016].

Wooldridge, M. and Jennings, N.R., 1995. Intelligent agents: theory and practice. *The Knowledge Engineering Review*, 10(2), pp.115–152.

Wu, D.Y. and Chen, K.-Y., 2014. Supply chain contract design: Impact of bounded rationality and individual heterogeneity. *Production and Operations Management*, 23(2), pp.253–268.

Xiao, T., Shi, J. and Chen, G., 2014. Price and leadtime competition, and coordination for make-to-order supply chains. *Computers and Industrial Engineering*, 68, pp.23–34.

Xue, X., Li, X., Shen, Q., and Wang, Y., 2005. An agent-based framework for supply chain coordination in construction. *Automation in Construction*, 14(3), pp.413–430.

Yu, H., Zeng, A.Z. and Zhao, L., 2009. Single or dual sourcing: Decision-making in the presence of supply chain disruption risks. *Omega*, 37(4), pp.788–800.

Zarandi, M.H.F., Pourakbar, M. and Turksen, I.B., 2008. A fuzzy agent-based model for reduction of bullwhip effect in supply chain systems. *Expert Systems with Applications*, 34(3), pp.1680–1691.

Zenobia, B., Weber, C. and Daim, T., 2009. Artificial markets: A review and assessment of a new venue for innovation research. *Technovation*, 29(5), pp.338–350.

Zhang, D.Z., Anosike, A.I., Lim, M.K., and Akanle, O.M., 2006. An agent-based approach for e-manufacturing and supply chain integration. *Computers and Industrial Engineering*, 51(2), pp.343–360.

Zhu, X., 2008. *Agent based modeling for supply chain management: Examining the impact of information sharing*. Kent State University.

APPENDIX A: THE INEFFECTIVE USE OF PARAMETRIC STATISTICS AND COMMON RANDOM NUMBERS IN INFERENTIAL ANALYSIS

(An example of the *supply chains fill rate* of *manufacturer strategic mutation*)

A.1 THE CONFIDENCE INTERVALS WITH BONFERRONI CORRECTIONS, BY CONSIDERING THE USE OF COMMON RANDOM NUMBERS

Table A.1 summarises the test for the use of common random numbers. It compares the variance of difference (S_D) in the left hand side with the sum of variances ($S_1^2 + S_2^2$) in the right hand side (Robinson, 2014). If the conclusion proves the variance is "*Reduced" ($S_D < S_1^2 + S_2^2$)*, the paired-t confidence interval is conducted to compare the scenarios; when it is concluded as *"Not Reduced"*, it means that the standard t confidence intervals is suggested. As shown by the table, paired-t confidence interval would be used to compare: scenario 1 with scenario 3, scenario 1 with scenario 5, scenario 2 with scenario 3, scenario 2 with scenario 4, and scenario 3 with scenario 5. The rest comparisons would be constructed by using standard t confidence intervals; they are the comparison between: scenario 1 and scenario 2, scenario 1 and scenario 4, scenario 2 and scenario 5, scenario 3 and scenario 4, and scenario 4 and scenario 5.

Table A.1 The conclusion of the common random numbers check through variance reduction analysis for *supply chain fill rate* of manufacturer *strategic mutation*

Scenario	**2 (2%)**	**3 (5%)**	**4 (7%)**	**5 (10%)**
1 (0%)	27.67 > 25.01 *Not Reduced*	22.93 < 24.74 *Reduced*	32.15 > 29.82 *Not Reduced*	30.61 < 31.1 *Reduced*
2 (2%)		17.04 < 18.75 *Reduced*	21.03 < 23.82 *Reduced*	25.63 > 25.1 *Not Reduced*
3 (5%)			24.53 > 23.56 *Not Reduced*	19.74 < 24.84 *Reduced*
4 (7%)				36.37 > 29.91 *Not Reduced*

According to this table, the parametric confidence intervals with overall level of significance 10% for ten comparisons were constructed, as summarised in Table A.2. If the interval includes zero, it concludes insignificant difference between the scenarios. If the confidence interval is completely less than zero, it is concluded that the first scenario significantly provides lower output than the second scenario.

The same concluding approach is applied when the confidence interval is completely more than zero; the conclusion would be that the first scenario has significant higher output than the second scenario.

From the table, it is shown that scenario 1 (0% - no *mutation*) provides higher *supply chain fill rate* than other scenarios, while scenario 5 (10%) results in lowest *supply chain fill rate*. Other scenarios, which are scenario 2 until scenario 4, are statistically considered to have no significant difference with each other. These conclusions are consistent with the Mann-Whitney U test provided in Appendix I.

Table A.2 Confidence interval comparison of *supply chain fill rate* between all scenarios of probability manufacturer *strategic mutation* (with overall confidence level ≥ 90%)

Scenario	**2 (2%)**	**3 (5%)**	**4 (7%)**	**5 (10%)**
1 (0%)	(1.86, 5.57) *Scen.1 > Scen.2*	(1.57, 5.2) *Scen.1 > Scen.3*	(2.11, 6.17) *Scen.1 > Scen.4*	(4.21, 8.4) *Scen.1 > Scen.5*
2 (2%)		(-1.89, 1.24) *No significant difference*	(-1.31, 2.17) *No significant difference*	(0.73, 4.45) *Scen.2 > Scen.5*
3 (5%)			(-1.05, 2.56) *No significant difference*	(1.23, 4.6) *Scen.3 > Scen.5*
4 (7%)				(0.13, 4.19) *Scen.4 > Scen.5*

A.2 NORMALITY ANALYSIS ON SIMULATION OUTPUTS

1. Central tendency

The central tendency analysis for the *supply chain fill rate* of each scenario of *manufacturer strategic position* is summarised in Table A.3. Only scenario 1 has nine modals; they are 5.4%, 6.4%, 7.3%, 7.8%, 8.5%, 9%, 9.3%, 9.6%, and 12.8%. Each modal appears twice in the data set. These modal makes the data distribution relatively broad, or not normal.

2. Data shape

A normal distributed data is defined by zero skewness, and any symmetric data should be made up of skewness near zero. Negative skewness indicates the data are right-skewed, that means the longer tail is at the right side. Similarly, positive skewness represents left-skewed distribution that the left tail is relatively longer than the right tail. The sign of skewness is affected by multi-modal if it exists (NIST/SEMATECH 2003).

Table A.3 The central tendency measures for the *supply chain fill rate* of each scenario of *manufacturer strategic position*

Central tendency measures	**Scenario**				
	1 (0%)	**2 (2%)**	**3 (5%)**	**4 (7%)**	**5 (10%)**
Mean	10.47	6.76	7.09	6.33	4.17
Median	9.3	6.9	7.15	6.65	5.6
Modal:					
unimodal/ multimodal/ no modal?	multimodal	unimodal	unimodal	unimodal	unimodal
value (if unimodal)	-	0	0	0	0

As well as skewness, a normal bell-shaped data should have zero *excess kurtosis*, known as *mesokurtic*. A data distribution with *excess kurtosis* less than zero is called *platykurtic* and data with kurtosis more than zero known as *leptokurtic*. A *platykurtic* distribution has a lower central peak, fatter size, and shorter and thinner tails; whereas *leptokurtic* distribution represents higher and sharper peak with longer and fatter tails.

An inferential approach for population skewness and kurtosis is performed to conclude whether the population is very likely normal, especially when the sample does not have normal shape. A two-tailed test of skewness and kurtosis are implemented at 0.05 level of significant, so the critical value is ± 1.96 as suggested by Ghasemi and Zahediasl (2012).

The skewness is inferred as follows.

- If the Z value of population skewness (Z_{g_1}) is less than -1.96, it indicates that the population is significantly or very likely left-skewed.
- If Z_{g_1} is more than 1.96, it suggests that the population is significantly or very likely right-skewed.
- If Z_{g_1} is between -1.96 and 1.96, population of the data is insignificantly skewed, or probably symmetric.

Meanwhile, the kurtosis is measured as this following.

- If the Z value of population kurtosis (Z_{g_2}) is less than -1.96, it indicates that the population is significantly or very likely *platykurtic*.
- If Z_{g_2} is more than 1.96, it suggests that the population is significantly or very likely *leptokurtic*.
- If Z_{g_2} is between -1.96 and 1.96, population of the data is probably *mesokurtic* (zero kurtosis, or normal bell-shaped).

The result of the normality shape is presented in Table A.4. Only scenario 4 likely has symmetric and *mesokurtic* shape, which is close to normal distribution shape. Scenario 1, 2, and 3 of *manufacturer strategic movement* are very likely skewed (asymmetric), while scenario 5 is probably symmetric. For the kurtosis, scenario 1, 2, and 3 probably have *mesokurtic* shape (normal bell curve) and scenario 5 is very likely platykurtic.

Table A.4 The shape measures for the *supply chain fill rate* of each scenario of *manufacturer strategic position*

Shape measures	Scenario				
	1 (0%)	**2 (2%)**	**3 (5%)**	**4 (7%)**	**5 (10%)**
- *Skewness*					
Coeff.(G1)	0.74	-0.95	-0.93	-0.48	0.09
Std. error	0.34	0.34	0.34	0.34	0.34
Z statistics	2.19	-2.81	-2.76	-1.44	0.27
Conclusion*	very likely right-skewed	very likely left-skewed	very likely left-skewed	possibly symmetric	possibly symmetric
- *Kurtosis*					
Coeff.(G2)	-0.17	0.56	0.90	-0.68	-1.62
Std. error	0.66	0.66	0.66	0.66	0.66
Z statistics	-0.26	0.84	1.36	-1.02	-2.44
Conclusion*	possibly *mesokurtic*	possibly *mesokurtic*	possibly *mesokurtic*	possibly *mesokurtic*	very likely *platykurtic*

**This is a two-tailed test at 0.05 level of significance (the critical value is ±1.96)*

3. Outliers

As presented in Table A.5, scenario 2 and 3 has six and five weak outliers respectively. All of these outliers are the modal of the scenarios; the value of the modal is 0%. The 0% for the *supply chain fill rate* represents no customer demand is fulfilled in the market. This output occurs when the remaining manufacturer and supplier could not create a supply chain. These outliers can distort the conclusion of the parametric approach constructed in Table A.2.

.

Table A.5 The outliers of the *supply chain fill rate* for each scenario of *manufacturer strategic position*

Measures	Scenario				
	1 (0%)	**2 (2%)**	**3 (5%)**	**4 (7%)**	**5 (10%)**
Any outliers?	no	yes	yes	no	no
Strong outliers	-	0	0	-	-
Weak outliers	-	6	5	-	-

In scenario 2, for example, the *supply chain fill rate* ends with zero per cent in seed number 10, 27, 29, 38, 46, and 49. In these seeds, the *number of supply chains in the market* is also zero. It means that the *supply chain fill rate* comes with zero because no supply chain exists in the market. To observe how these seeds lead to zero outputs, the model is rerun under these seed numbers.

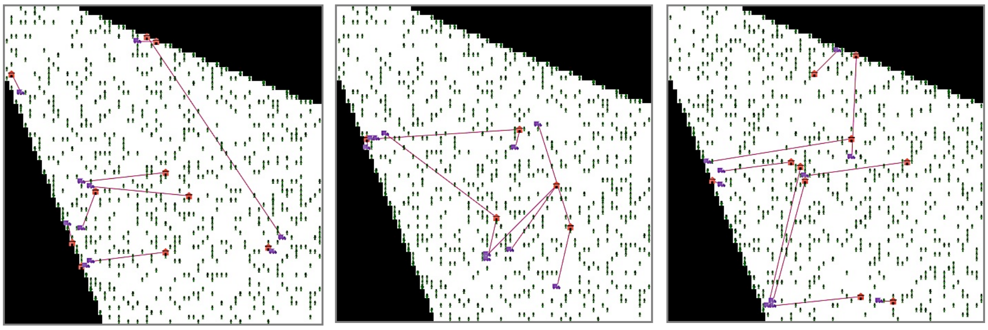
A.3 TESTING THE USE OF COMMON RANDOM NUMBERS

To check the extent of controlling the seed number in NetLogo to lower the output variance, two simple inspections are performed. The first check is observing the setup behaviour, by investigating how the platform sets up the agents. The second check is observing the agent's movement. Both tests apply the same seed number while the experimental factors are varied.

1. Observing the mechanism of NetLogo setup

The first inspection is testing whether the agents should be arranged in similar positions although the setup parameters are varied. In this test, three different setups are performed for seed number 10. The variable to define the seed number is represented as *SeedNumber* in the computer model. The first setup is conducted by setting up the number of customers to 1000, the number of manufacturers to 10, the number of suppliers to 10, and both manufacturers and suppliers have maximum *number of partnerships* only up to one link (represented as *MaxSource* for the manufacturers, and *MaxLinks* for the suppliers). The initial condition (at *time unit* 0) of this setup is shown by Figure A.1.a. The second setup is set by changing the number of manufacturers to five and the maximum number of manufacturer partnership (*MaxSource*) to two, as illustrated by Figure A.1.b. The third setup is setting up the model as the first setup, but the number of customers is adjusted to 999, as presented in Figure A.1.c.

As can be seen in the Figure, it is clearly shown that changing the number of the agents as well as the maximum *number of partnerships* provides different agents' distribution on the NetLogo space. A change of the quantity and/or the maximum *number of partnerships* of an agent type affects agents' position. Even though the control of the seed number is coded at the early stage of setup procedure (see appendix G), it does not always lead to a consistent setup.



a) b) c)

Figure A.1 Visual setup testing of the use of common random number in NetLogo:
a) Setup 1 – the base setup ; b) Setup 2 – the number of manufacturers is reduced and the maximum number of manufacturer partnerships is increased;
c) Setup 3 – the number of customers is reduced

2. Observing the NetLogo mechanism in running the simulation

To obtain more confidence about the failure of the use of common random numbers in the previous check, observation on agents' movement under a same seed number with a different input level is conducted. Instead of changing the values of the number of agents, the variables that control the agents' movement are altered. The base run with seed number 10 is employed as the basis of comparison and the resulting agents' movement is compared with other parameter setting run.

Figure B.2 illustrates the comparison of this check between the base run (scenario 1) and scenario 2 of *manufacturer strategic movement*. As the number of all agents' types and the *number of partnerships* are not different in both runs, the agents' positions are identical at the initial condition or *time unit* = 0. Even though all agents' movement are compared in each *time unit*, the figure only focuses on two particular agents to simplify the illustration. In the figure, supplier agent number 1010 and 1014, which are inside the circle, are selected for this illustration. These agents are collaborated with similar manufacturers in both scenarios. They also have similar closest manufacturers (the target manufacturer) to be approached or attracted in both scenarios at the early stage of simulation run.

From the figure, it can be seen that since *time unit* 1, both agents have different steps or moves in these runs. It means that even though the agents' position is identical at the initial condition or *time unit* zero, controlling the seed number does not mean producing the same agents' movements when a parameter is varied.

Based on both checks of agent setup and movement, it can be concluded that the common random numbers approach could not be adopted in NetLogo. Controlling the seed number in NetLogo only allows observer to reproduce the run, but it does not generate a similar sequence of agent's movement. In other words, even though some experiments show variance reduction, it does not necessarily mean that the common random numbers work properly in NetLogo.

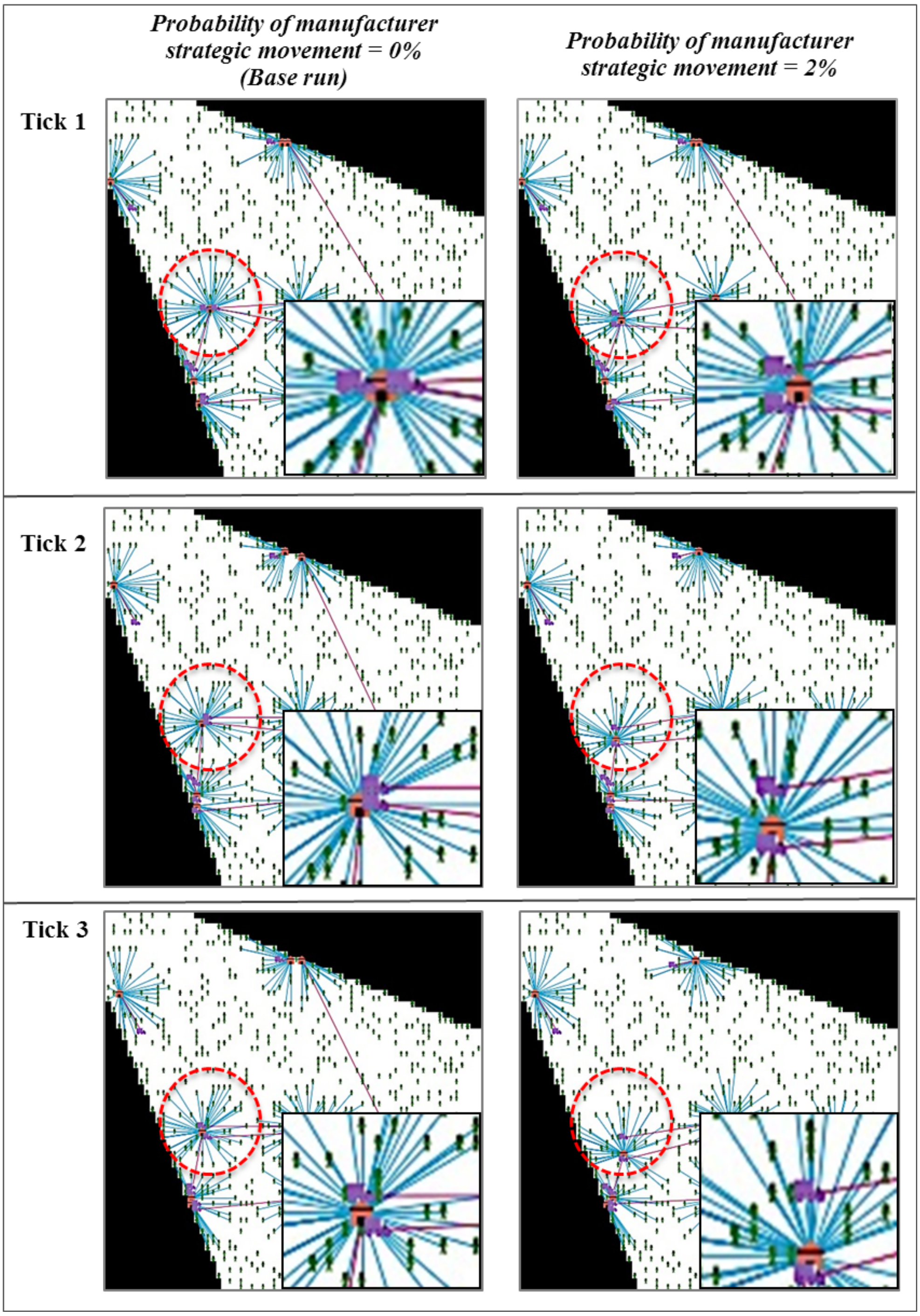


Figure A.2 Visual testing of common random number in NetLogo through agents' movement observation.

APPENDIX B: THE COMPUTER MODEL

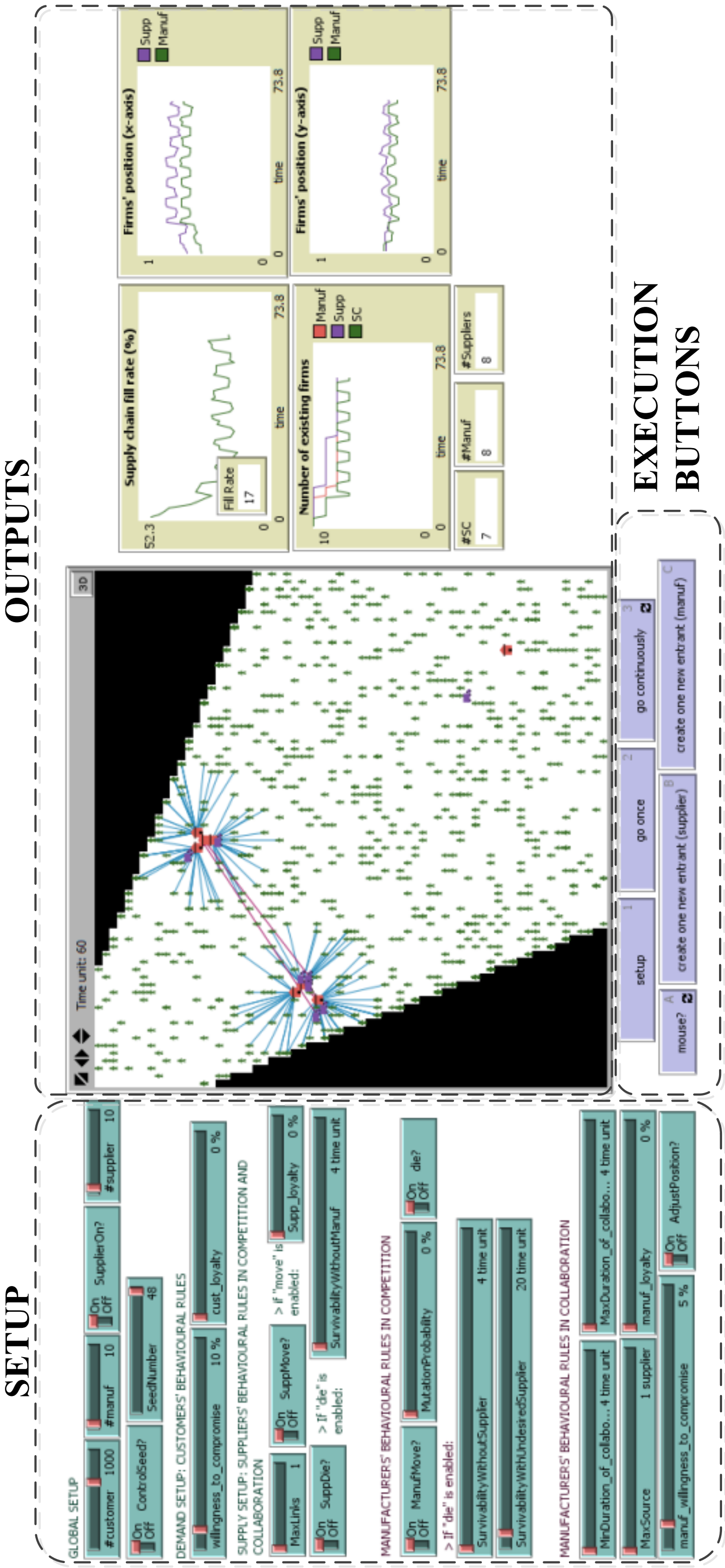


Figure B.1 The interface

The interface of the computer model is shown in Figure B.1. It consists of three main parts: setup, outputs, and execution buttons. The setup is composed of inputs or experimental factors, and non-inputs or constant setup. The definition of inputs and non-inputs has been provided in Chapter 5. The outputs provide visualisation of the results, which covers the NetLogo world or space, and graphical representation of the outputs. The last part of the computer model interface is the execution buttons.

APPENDIX C: VARIABLE DESCRIPTION IN NETLOGO

C.1. The setup

As illustrated in Figure B.1, the interface for setting up the model is organised into five groups. They are classified as *global setup*, *demand setup*, *supply setup*, *manufacturers' behavioural rules in competition*, and *manufacturers' behavioural rules in collaboration*.

C.1.1 Global setup

#customer : the number of customer agents.

#manuf : the number of manufacturer agents.

SupplierOn? : ON, if supplier agents are simulated, or
OFF, if supplier agents are not simulated.

#supplier : the number of supplier agents.

ControlSeed? : ON, if the value of random seed is determined by user, or
OFF, if the value of random seed is determined by NetLogo based on the current date and time.

SeedNumber : the value of random seed, if random seed is determined by user.

C.1.2 Demand setup: Customers' behavioural rules

willingness_to_compromise : the selection radius of customer agents to decide a manufacturer agent that is closest to their position. The radius is represented as a percentage of diagonal length of NetLogo world (the simulation space).

cust_loyalty : the probability that customer agents would choose the same manufacturer agent as selected previously.

C.1.3 Supply setup: Suppliers' behavioural rules of competition and collaboration

MaxLinks	: the maximum number of collaboration links that supplier agents can have.
SuppMove?	: ON, if supplier agents move (competitive), or OFF, if supplier agents do not move (not competitive).
Supp_loyalty	: the probability that supplier agents would follow the manufacturer strategic movement to maintain their current relationships.
SuppDie?	: ON, if supplier agents are allowed to die, or OFF, if supplier agents are always alive.
SurvivabilityWithoutManuf	: the length of supplier to survive in *time unit* when it does not have a link with manufacturer agent at all.

C.1.4 Manufacturers' behavioural rules in competition

ManufMove?	: ON, if manufacturer agents move (competitive), or OFF, if supplier agents do not move (not competitive).
MutationProbability	: the probability of manufacturer agents to create a *big leap* in changing their position.
die?	: ON, if manufacturer agents can die, or OFF, if supplier agents are always alive.
SurvivabilityWithoutSupplier	: the length of manufacturer to survive in *time unit* when it does not have a link with supplier agent at all.
SurvivabilityWithUndesiredSupplier	: the length of manufacturer to survive in *time unit* when it collaborates with less efficient and/or responsive supplier/s.

C.1.5 Manufacturers' behavioural rules in collaboration

MinDuration_of_collaboration	: the minimum *duration of collaboration* between linked manufacturers and suppliers, defined in *time unit*.
MaxDuration_of_collaboration	: the maximum *duration of collaboration* between linked manufacturers and suppliers, defined in *time unit*.
MaxSource	: the maximum number of collaboration links that manufacturer agents can create.
manuf_loyalty	: the probability that manufacturer agents would choose the same supplier agent as selected previously.
manuf_willingness_to_compromise	: the selection radius of manufacturer agents to decide which supplier/s who are closest to their position. The radius is represented as a percentage of diagonal length of NetLogo world (the simulation space).
AdjustPosition?	: ON, if manufacturers' position is affected by their suppliers' position, or OFF, if manufacturers' position is not affected by their supplier/s.

C.2. The outputs

<u>*Main outputs*</u>

Supply chain fill rate (%)	: the percentage of served customers, to represent the market service level generated by the existing supply chains. It is presented in a time series plot.
Number of existing firms	: the number of existing firms (manufacturer and supplier agents) and supply chains in the system at the current *time unit*. It is presented in a time series plot.
#SC	: the number of existing supply chains at the current *time unit*.
#Manuf	: the number of existing manufacturer agents at the current *time unit*.

#Suppliers : the number of existing supplier agents at the current *time unit*.

<u>*Supporting outputs*</u>

Firms' position (x-axis) : the position of firms (manufacturer and supplier agents) in *x-axis* to represent efficiency level at the current *time unit*. It is presented in a time series plot.

Firms' position (y-axis) : the position of firms (manufacturer and supplier agents) in *x-axis* to represent responsiveness level at the current *time unit*. It is presented in a time series plot.

As explained in the conceptual model (Chapter 5), the higher coordinate of *x*-axis represents less efficient operations and the higher y-axis reflects the less *responsive supply chains*. The manufacturer agent's position in the supporting outputs is normalised into a dimensionless value between 0 and 1, where the lowest efficiency and responsiveness is represented by 0, and the highest efficiency and responsiveness is converted to 1.

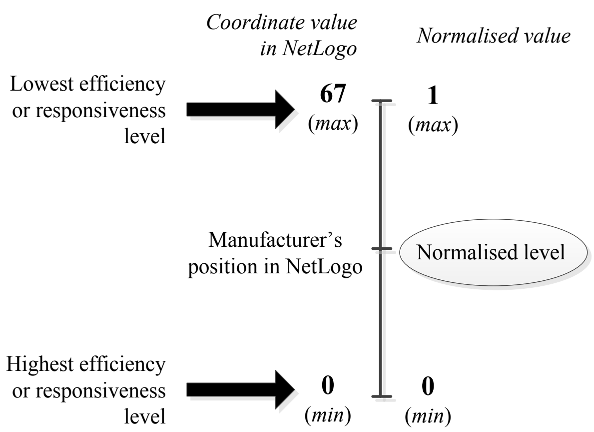


Figure C.1 Illustration on how to normalize the position of an agent in the level of efficiency and responsiveness relative

$$Normalised\ level\ of\ supply\ chain\ efficiency = \frac{(max\ coordinate\ of\ x - axis) - (manufacturer's\ position\ in\ x\ axis)}{(max\ coordinate\ of\ x - axis)}$$

$$Normalised\ level\ of\ supply\ chain\ responsiveness = \frac{(max\ coordinate\ of\ y - axis) - (manufacturer's\ position\ in\ y\ axis)}{(max\ coordinate\ of\ y - axis)}$$

Where the maximum coordinate of both x-axis and y-axis in the NetLogo space is 67.

C.3. The execution buttons

The last part of the computer model interface is the execution buttons. It is arranged by 5 main commands: *setup*, *go once*, *go continuously*, *mouse?*, *create one new entrant (supplier)*, and *create one new entrant (manufacturer)*. They were useful to perform verification and visual investigation for the descriptive analysis.

setup (keyboard shortcut: 1)	: to setup the agents.
go once (keyboard shortcut: 2)	: to execute the simulation once.
go continuously (keyboard shortcut: 3)	: to execute the simulation over and over.
mouse? (keyboard shortcut: A)	: to move an agent to a new location for a manual intervention.
create one new entrant (supplier) (keyboard shortcut: B)	: to add a new supplier agent to the NetLogo space.
create one new entrant (manufacturer) (keyboard shortcut: C)	: to add a new manufacturer agent to the NetLogo space.

In this study, the function of creating a new entrant of supplier or manufacturer was not investigated even though the last two buttons of new entrants had been verified. The reason for this is that the scope of this study does not consider the situation where interventions on adding one or several new entrants are allowed. However, this feature can be used for further experiments in supply chain competition and collaboration.

APPENDIX D: BASE RUN AND BEHAVIOURAL SETUP

D.1. The base run setup

Global setup

#customer	: 1000
#manuf	: 10
SupplierOn?	: true
#supplier	: 10
ControlSeed?	: true
SeedNumber	: from 1 to 50 (50 replications)

Demand setup: Customers' behavioural rules

willingness_to_compromise	: 10%
cust_loyalty	: 0%

Supply setup: Suppliers' behavioural rules of competition and collaboration

MaxLinks	: 1
SuppMove?	: ON (or "true")
Supp-loyalty	: 0%
SuppDie?	: ON (or "true")
SurvivabilityWithoutManuf	: 4 *time unit* (equals to one year)

Experimental factor for competition: Manufacturers' competitive behavioural rules

ManufMove?	: ON (or "true")
MutationProbability	: 0
die?	: ON (or "true")
SurvivabilityWithoutSupplier	: 4 *time units* (equals to one year)

SurvivabilityWithUndesiredSupplier : 20 *time units* (equals to 5 years)

Experimental factor for collaboration: Manufacturers' collaborative behavioural rules

MinDuration_of_collaboration : 4 *time units* (equals to one year)
MaxDuration_of_collaboration : 4 *time units* (equals to one year)
MaxSource : 1
manuf_loyalty : 0%
manuf_willingness_to_compromise : 5%
AdjustPosition? : ON (or "true")

D.2. The behavioural space setup

The behavioural setup is the base run with one or several variables set into several values as The scenarios for the hypothesis. The varied variables are described below.

1. Investigating the competitive behavioural rules

1.1 Manufacturer *strategic mutation*

MutationProbability : 0, 2, 5, 7, 10 (%)

1.2 *Manufacturer survivability*

SurvivabilityWithUndesiredSupplier : 12, 16, 20, 24, 28 (*time units*)

1.3 *Supplier survivability*

SurvivabilityWithoutManuf : 1, 2, 4, 6, 8 (*time units*)

1.4 Manufacturer *strategic mutation* and survivability

MutationProbability : 0, 1, 2, 5 (%)
SurvivabilityWithUndesiredSupplier : 12, 16, 20, 24, 28 (*time units*)

2. Investigating the collaboration strategy

2.1 *Duration of collaboration*

2.2.1 With single-link suppliers

MinDuration_of_collaboration : 4, 20, 40, 60, 80 (*time units*)

MaxDuration_of_collaboration : 4, 20, 40, 60, 80 (*time units*)

2.2.2 With dual-link suppliers

#supplier : 10

MaxLinks : 2

MinDuration_of_collaboration : 4, 20, 40, 60, 80 (*time units*)

MaxDuration_of_collaboration : 4, 20, 40, 60, 80 (*time units*)

2.2 The *number of partnerships*

2.2.1 In short-term collaboration

- Single sourcing with a single-link supplier: the base run setup
- Dual sourcing with dual-link suppliers

  MaxSource : 2 ; *MaxLinks* : 2
- Multi sourcing with 3-link suppliers

  MaxSource : 3 ; *MaxLinks* : 3
- Multi sourcing with 4-link suppliers

  MaxSource : 4 ; *MaxLinks* : 4
- Multi sourcing with 5-link suppliers

  MaxSource : 5 ; *MaxLinks* : 5

2.2.2 In long-term collaboration

MinDuration_of_collaboration : 80

MaxDuration_of_collaboration : 80

- Single sourcing with a single-link supplier

  MaxSource : 1 ; *MaxLinks* : 1
- Dual sourcing with dual-link suppliers

  MaxSource : 2 ; *MaxLinks* : 2
- Multi sourcing with 3-link suppliers

  MaxSource : 3 ; *MaxLinks* : 3
- Multi sourcing with 4-link suppliers

  MaxSource : 4 ; *MaxLinks* : 4
- Multi sourcing with 5-link suppliers

  MaxSource : 5 ; *MaxLinks* : 5

3. **Investigating the collaboration behaviour**

3.1 *Manufacturer trust*

manuf_loyalty : 0, 25, 50, 75, 100

3.1.1 In short-term collaboration

MinDuration_of_collaboration : 4

MaxDuration_of_collaboration : 4

3.1.2 In ten-year collaborations

MinDuration_of_collaboration : 40

MaxDuration_of_collaboration : 40

3.1.3 In long-term collaboration

MinDuration_of_collaboration : 80

MaxDuration_of_collaboration : 80

3.1 *Supplier trust*

Supp_loyalty : 0, 25, 50, 75, 100

3.1.1 In short-term collaboration

MinDuration_of_collaboration : 4

MaxDuration_of_collaboration : 4

3.1.2 In long-term collaboration

MinDuration_of_collaboration : 80

MaxDuration_of_collaboration : 80

4. **Investigating customer *trust/loyalty***

cust_loyalty : 0, 25, 50, 75, 100

APPENDIX E: THE LOGIC FLOW FOR EACH PROCEDURE IN NETLOGO

E.1. Initial condition (setup procedure)

The idea of setting up the model is explained as follows. At the initial condition or *time unit* 0, both manufacturers and suppliers are set in scattered positions in the feasible regions. All manufacturers have to be linked with suppliers and vice versa. It makes the positions of suppliers and manufacturers are not completely random; the supplier's position is driven by manufacturer's position and vice versa.

To model this initial condition, the setup procedure was coded as this following logic sequence. First of all, all agents, patches, and links are cleared or reset. Then, all the initial values for the global variables given by the setup parameters are set, including the seed number used (*ControlSeed?* and *SeedNumber*), the manufacturer maximum number of sourcing (*MaxSource*) and supplier maximum *number of partnerships* (*MaxLinks*). This step is followed by setting up the layout or the environment of the agents. After that, customers are created placed randomly in the feasible patches in the NetLogo space. It is followed by creating manufacturers and locating them randomly in the feasible patches. Then, if suppliers are simulated, they are generated and placed within the range of *manufacturer's willingness to compromise* by randomly selecting a manufacturer who is targeted by each supplier. After that, the manufacturers decide which suppliers they want to collaborate with, by creating links with the selected supplier/s. After the collaboration links between manufacturers and suppliers are created, manufacturers adjust their strategic position based on their *willingness to compromise* if they link with less efficient and responsive suppliers. This code is to ensure the distance between manufacturer and the less efficient and/or responsive supplier/s is not more than *manufacturer's willingness to compromise*.

To make all manufacturers and suppliers are linked since the beginning, the parameters must be set proportionately. The sensitive parameters for this initial condition are the *number of manufacturers* (*#manuf*), *number of suppliers* (*#supplier*), and the number of allowable links for each agent (*MaxLinks* for suppliers and *MaxSource* for manufacturers).

The following example illustrates a situation of an imbalance setting. The setting for the number of manufacturers (*#manuf*) is 15, the number of suppliers (*#supplier*) is 10, and the maximum number of links for both manufacturers (*MaxSource*) and suppliers (*MaxLinks*) are 1. With this setup, all firms would create no link when the *setup* button is clicked. This is because to enable a simulation with 15 manufacturers, it requires 15 suppliers in the model while only 10 suppliers are set. At the same time, the *Command Center* would also show a message or suggestion to add 5 more suppliers to make the supply side meet the required supply of the manufacturer.

Another case of inappropriate setting is when the model requires more manufacturers to setup the simulation. For instance, the number of manufacturers (*#manuf*) is set to 15, the number of suppliers (*#supplier*) is 10, the maximum *number of partnerships* for manufacturers (*MaxSource*) is 1 and suppliers (*MaxLinks*) is 2. When the *setup* button is pressed, the *Command Center* would show a message or instruction to add 5 more manufacturers. This suggestion is based on the supply capacity, which is 10 supplier x 2 link/supplier = 20 link, is 5 link more than the manufacturer demand, which is 15 manufacturer x 1 link/manufacturer = 15 link. Alternatively, the simulation would be able to run if 10 manufacturer agents with *MaxSource* of 2 are assigned. The flowchart of the setup logic is presented in Figure E.1a and E.2b.

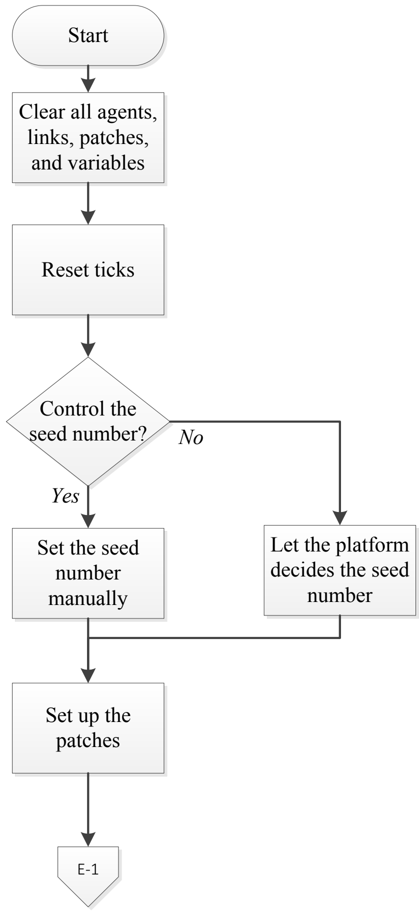


Figure E.1a The setup procedure

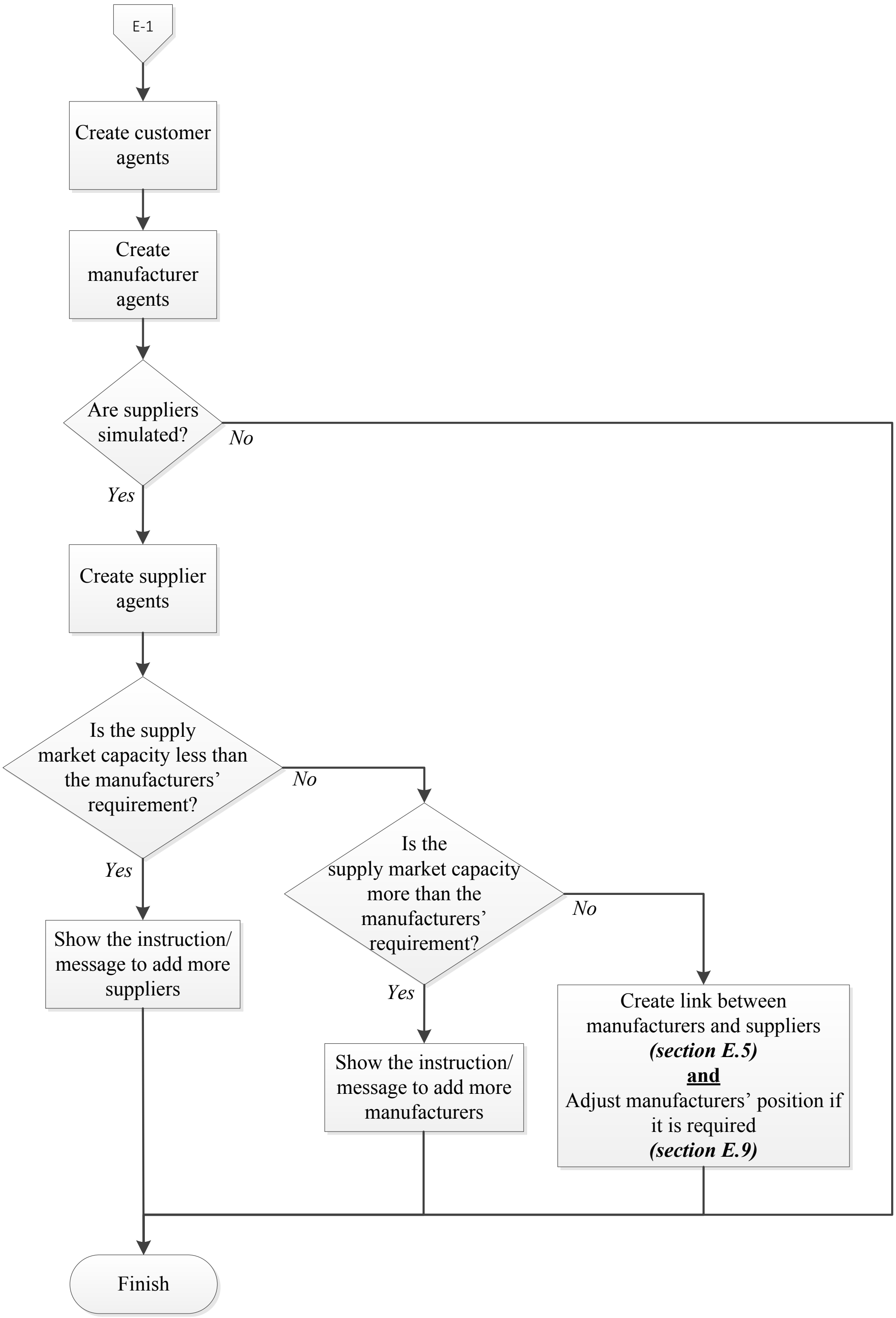


Figure E.1b The setup procedure

E.2. Parent or *go* procedure to run the simulation

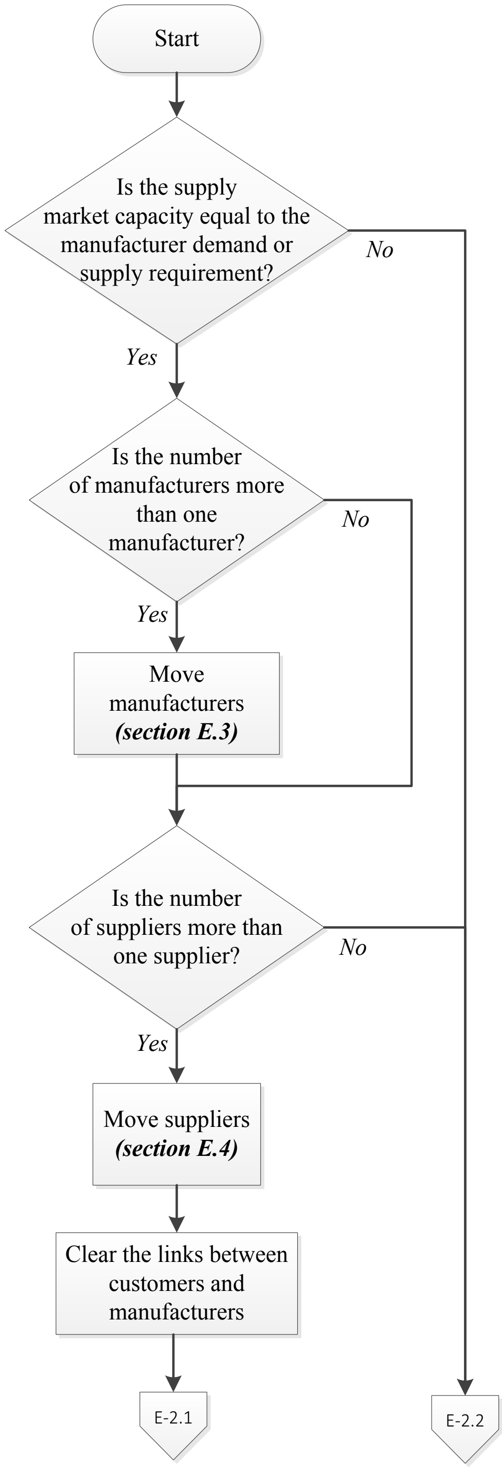


Figure E.2a The parent procedure for running the experiments

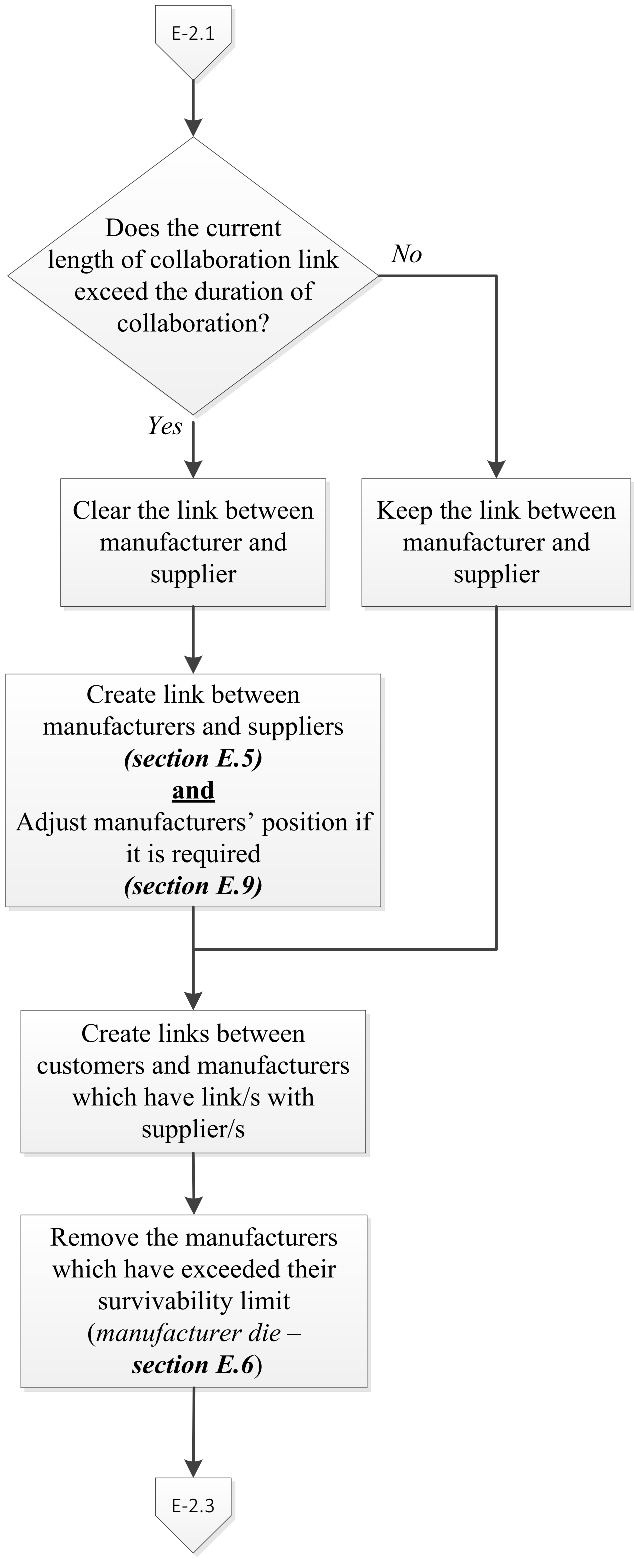


Figure E.2b The parent procedure for running the experiments

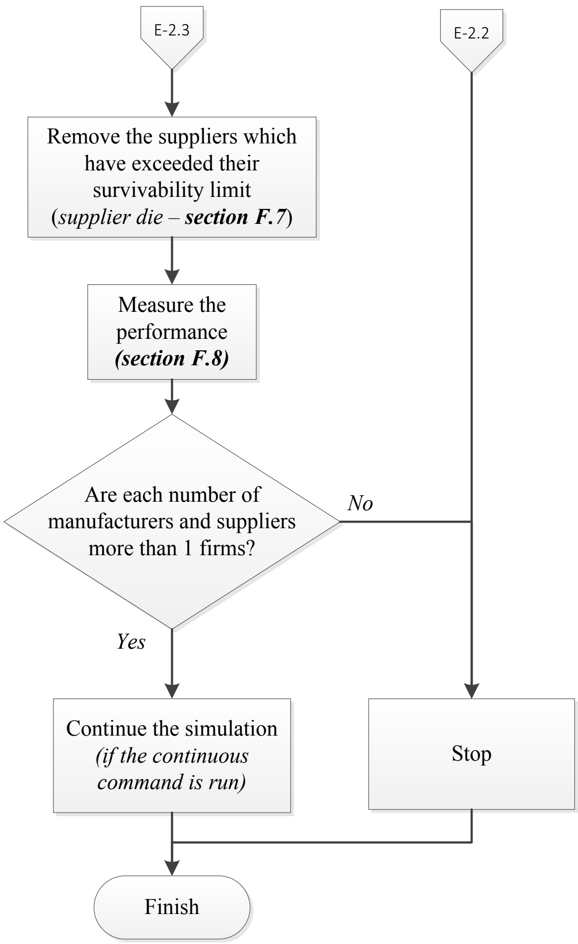


Figure E.2c The parent procedure for running the experiments

E.3. Procedure to move manufacturers

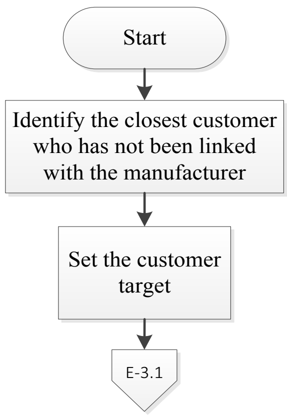


Figure E.3a The procedure to move manufacturers

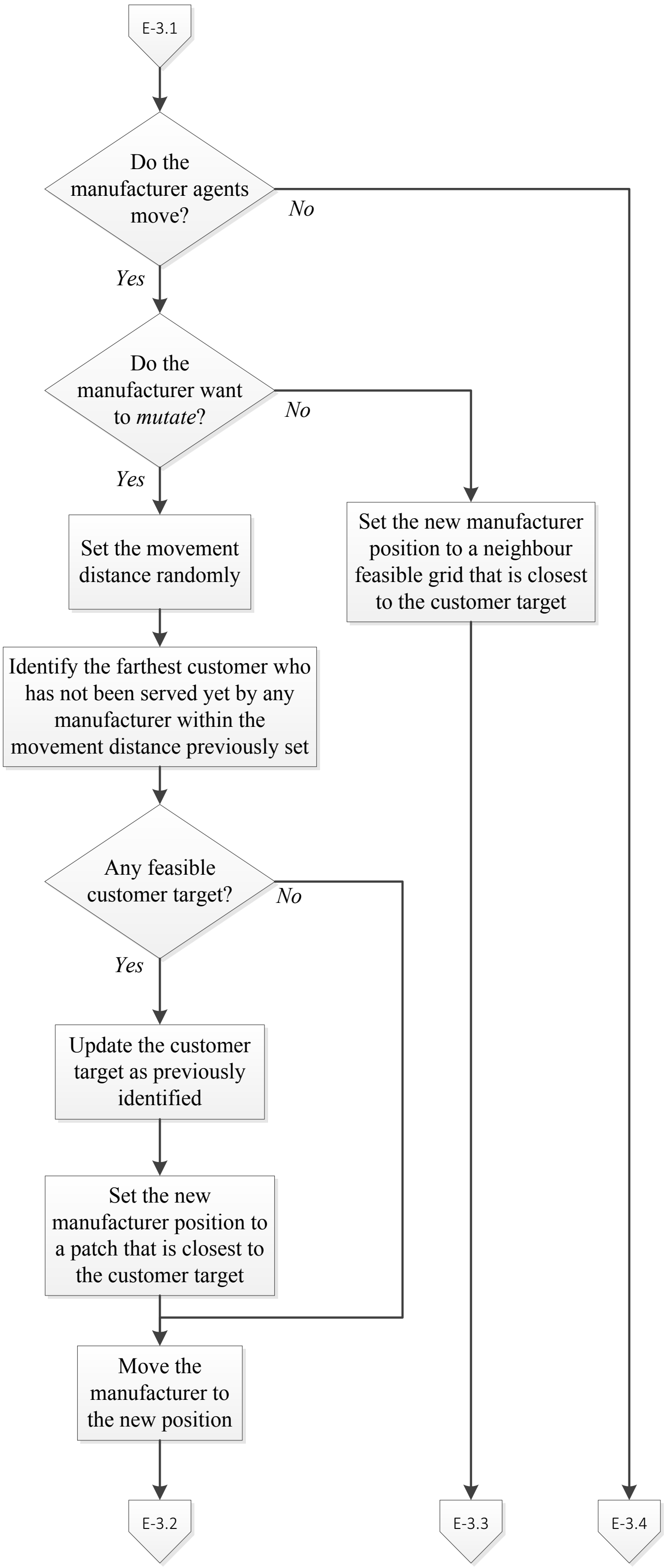


Figure E.3b The procedure to move manufacturers

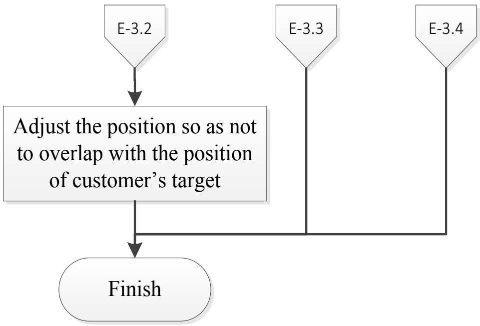


Figure E.3c The procedure to move manufacturers

E.4. Procedure to move suppliers

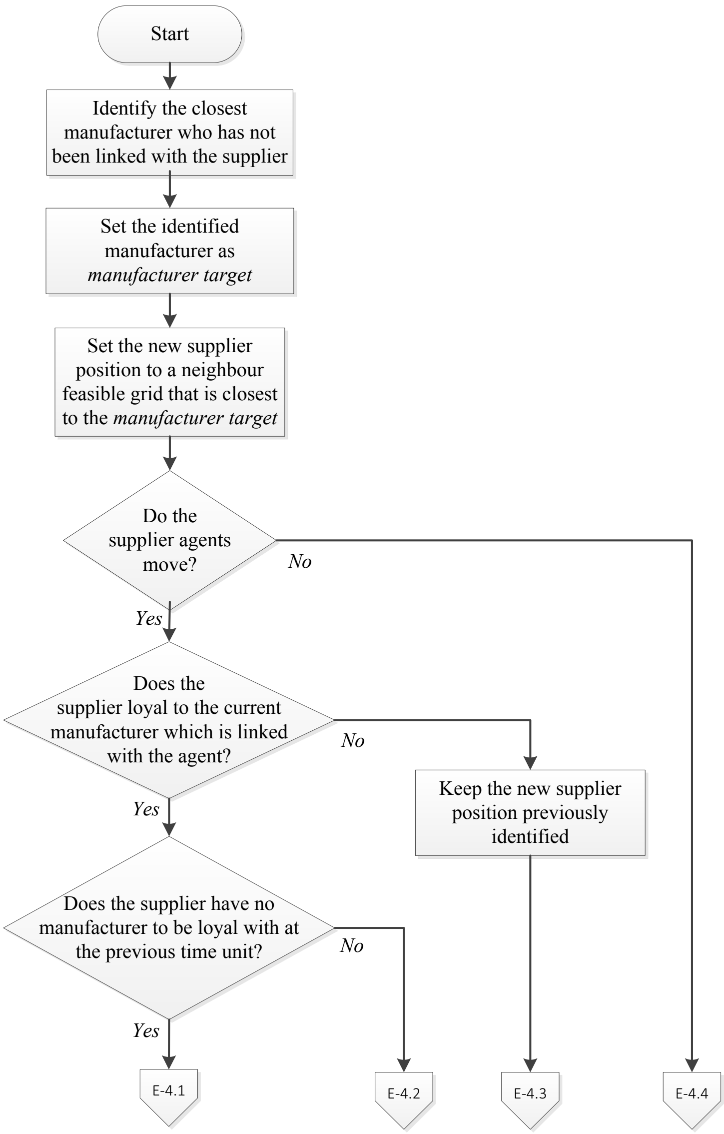


Figure E.4a The procedure to move suppliers

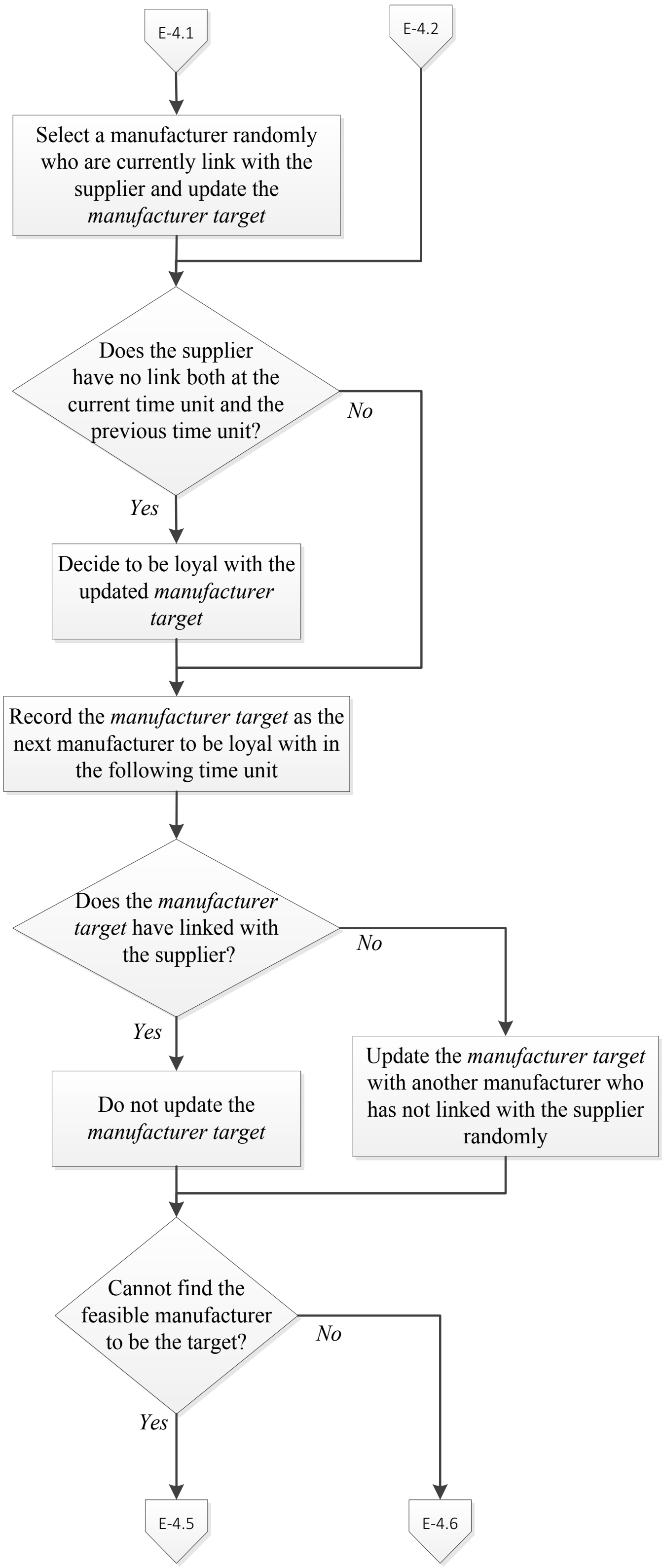


Figure E.4b The procedure to move suppliers

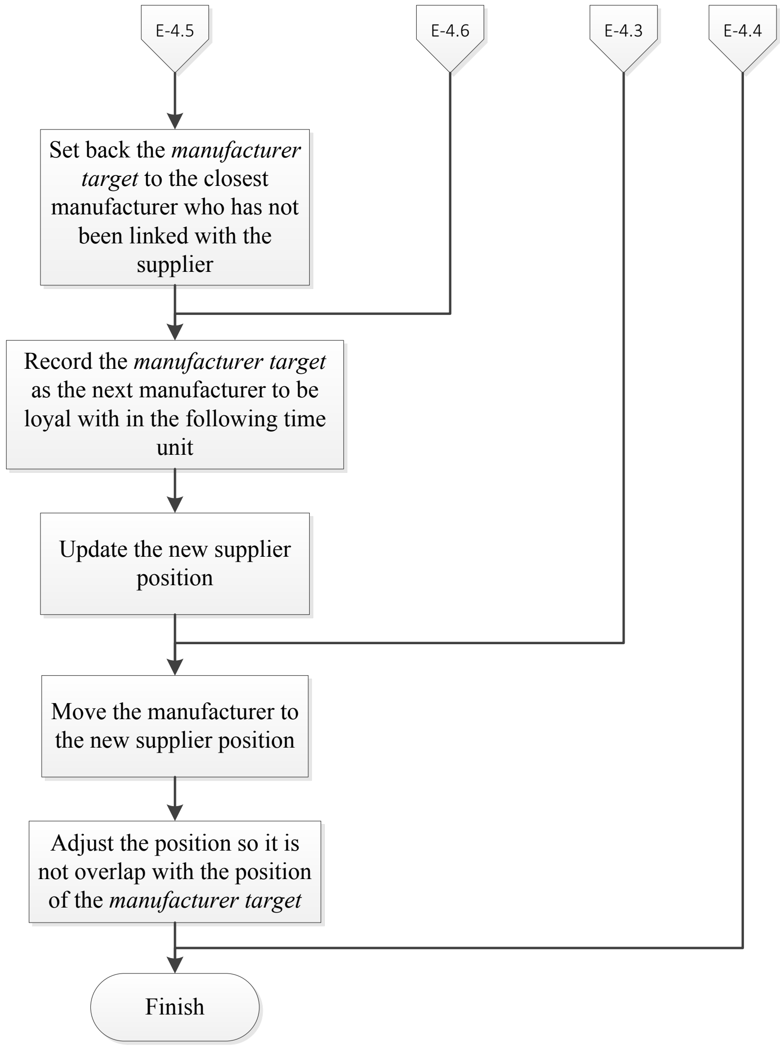


Figure E.4c The procedure to move suppliers

F.5. Procedure to create manufacturer-supplier links

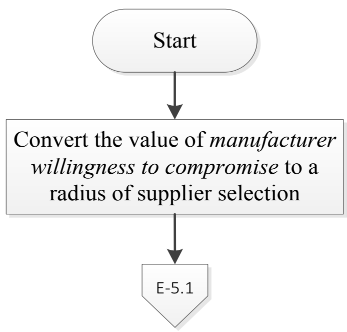


Figure E.5a The procedure to create links between manufacturer and supplier

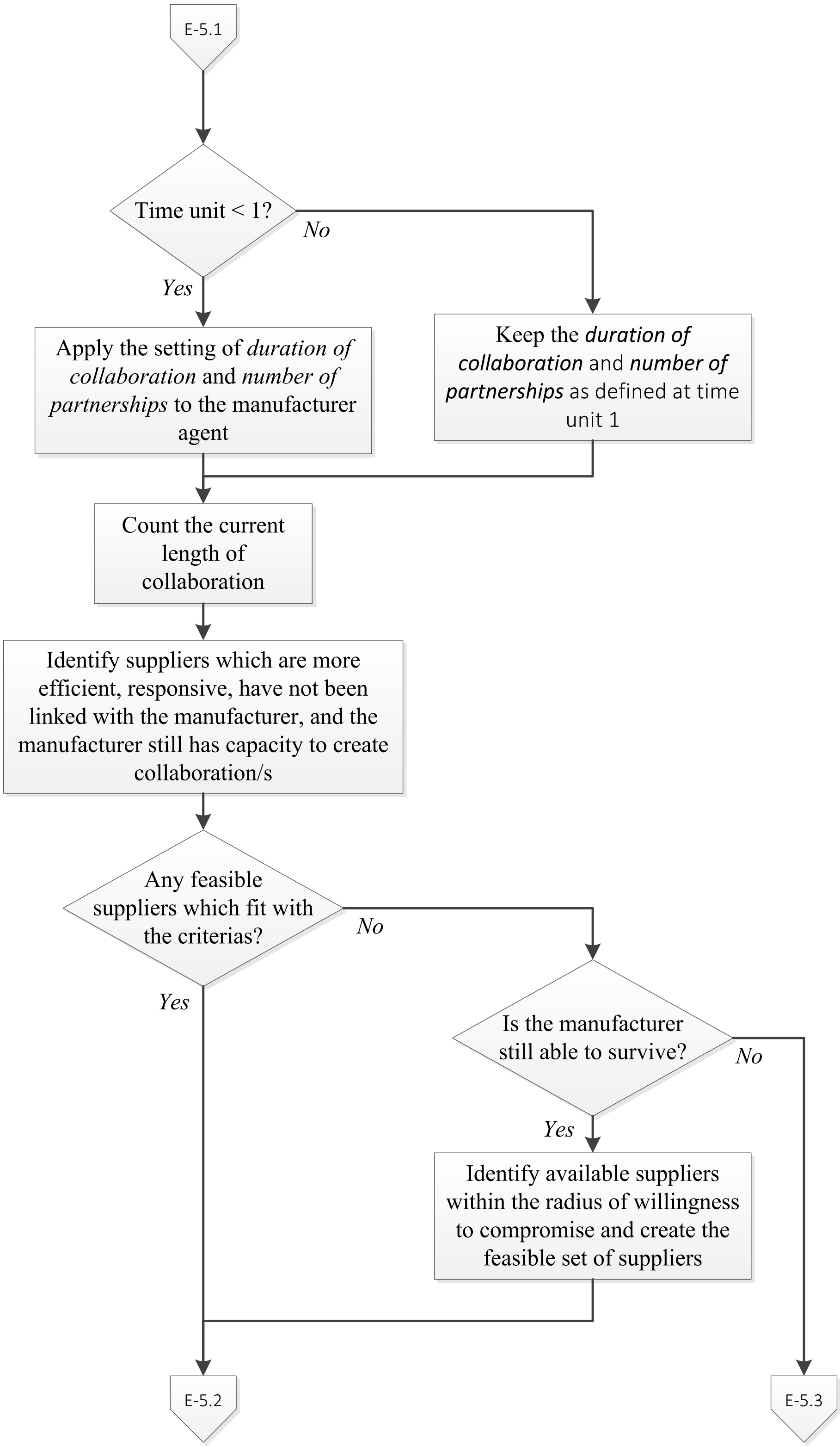


Figure E.5b The procedure to create links between manufacturer and supplier

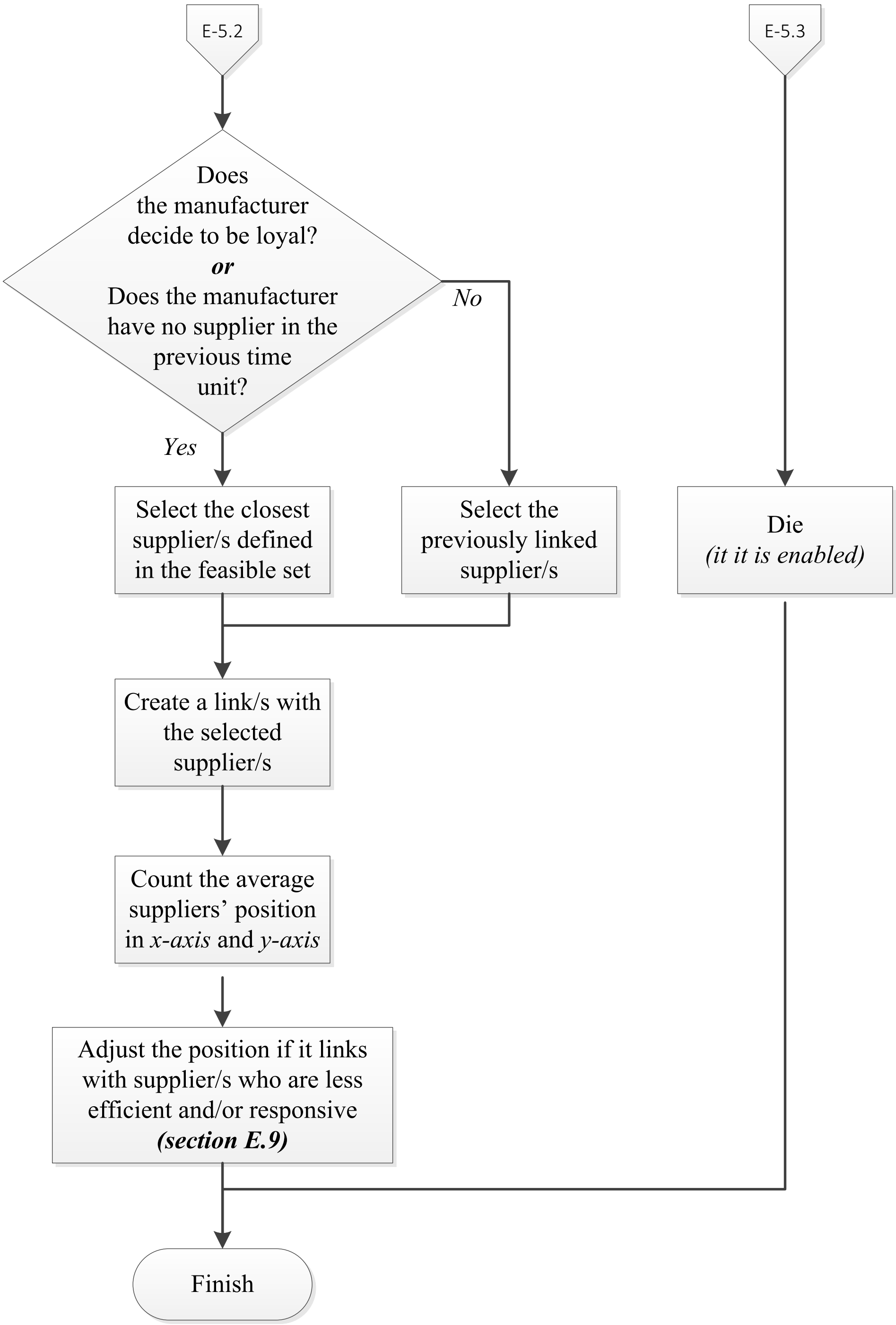


Figure E.5c The procedure to create links between manufacturer and supplier

E.6. Procedure of *manufacturer die*

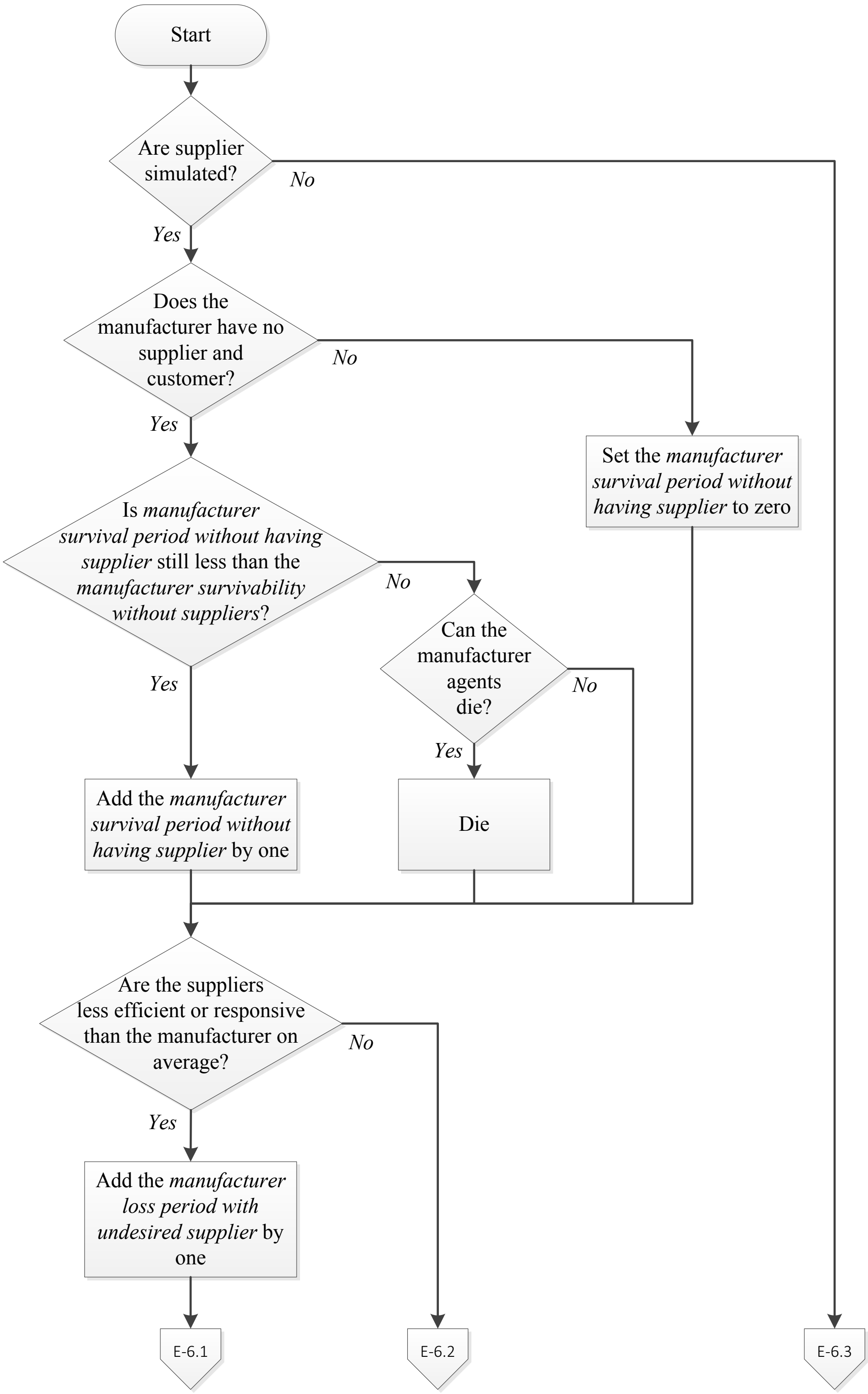


Figure E.6a The procedure to allow manufacturers to die

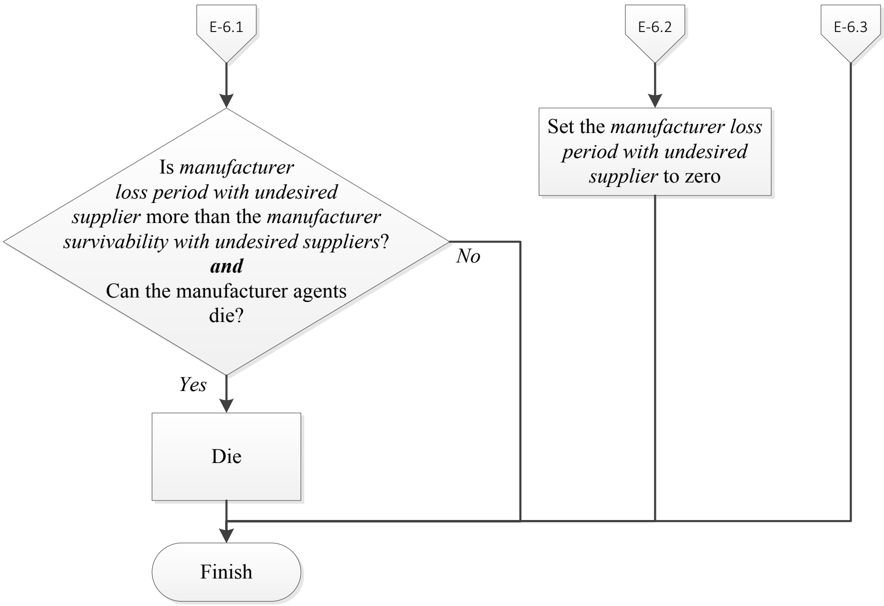


Figure E.6b The procedure to allow manufacturers to die

E.7. Procedure of *supplier die*

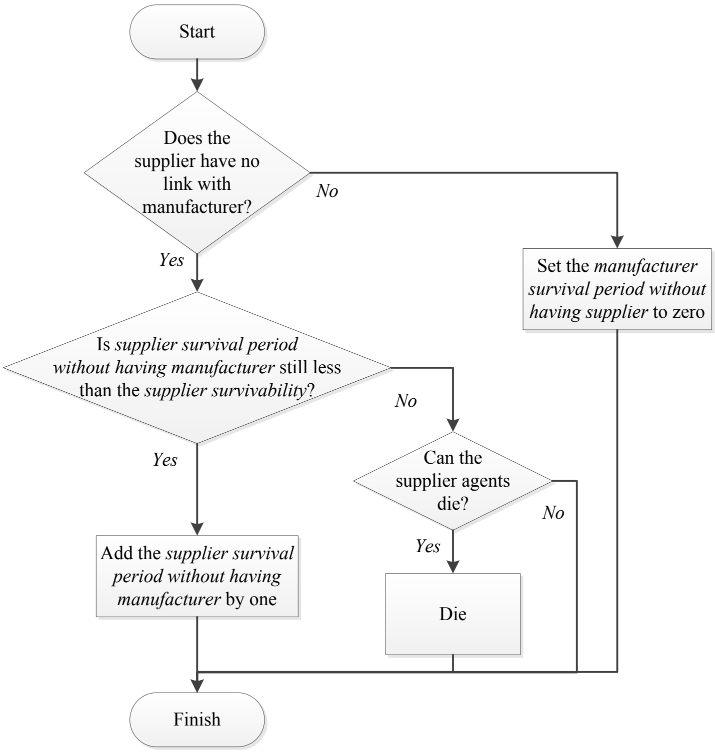


Figure E.7 The procedure to allow suppliers to die

E.8. Procedure to measure the performance

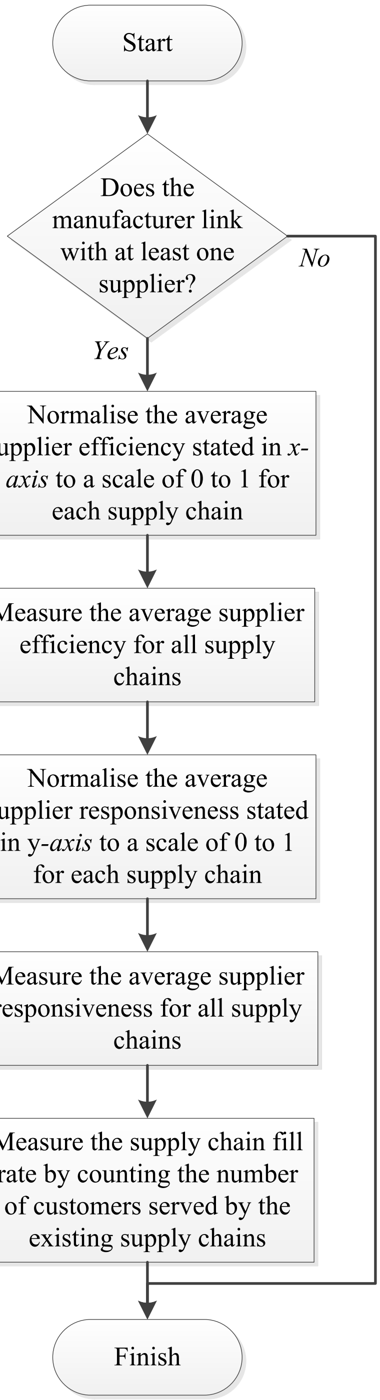


Figure E.8 The procedure of performance measurement

E.9. Procedure to adjust manufacturers' position

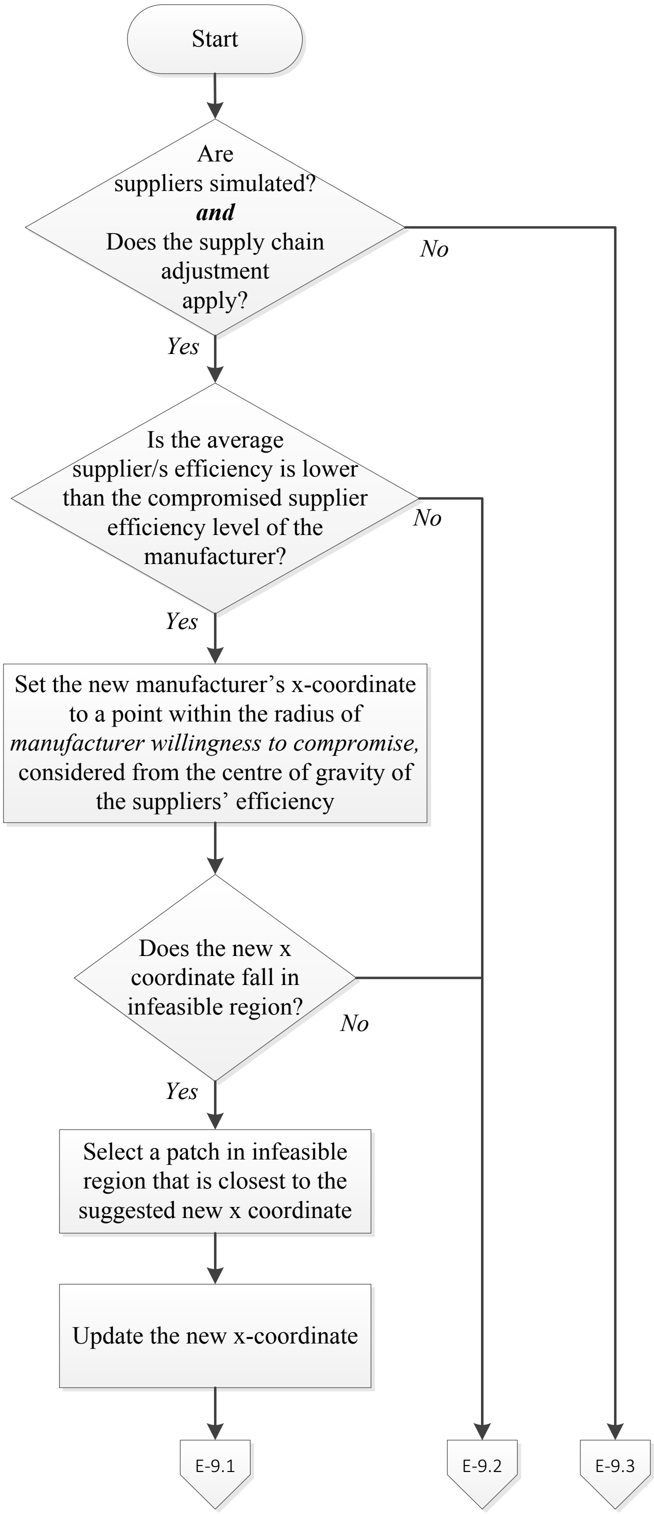


Figure E.9a The procedure of position adjustment for manufacturers

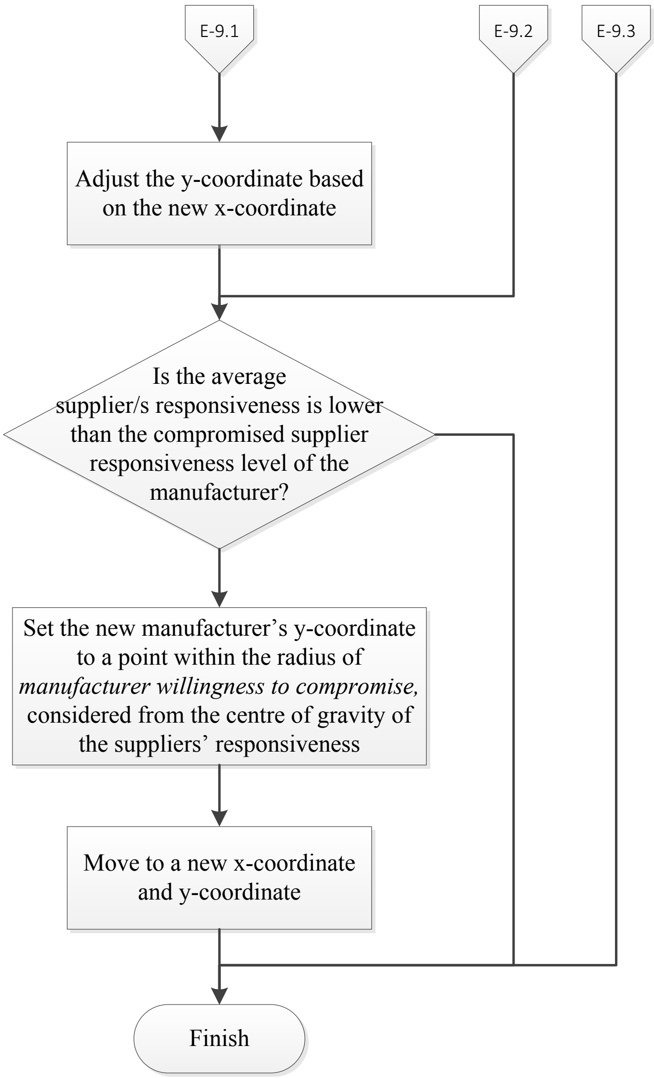


Figure E.9b The procedure of position adjustment for manufacturers

APPENDIX F: UNEXPLORED FEATURES IN THE COMPUTER MODEL - A FURTHER RESEARCH

F.1. New entrant analysis

The model can be used to analyse the effect of new entrants to the market. This feature is represented by these following buttons in the NetLogo interface.

- *create one new entrant (supplier)* (keyboard shortcut: B)	: to add a new supplier agent to the NetLogo space.
- *create one new entrant (manufacturer)* (keyboard shortcut: C)	: to add a new manufacturer agent to the NetLogo space.

F.2. Individual agent analysis

The model enables us to play with agent/s by making them behave differently from others. The parameters of this features can be found by inspecting the selected agent. It is performed by pointing the agent, then pressing the right click, and select "inspect agent". The variables that can be adjusted during simulation run are as follows.

- Manufacturer agents

1. *duration_of_collaboration*
   The length of collaboration created between manufacturer and supplier linked.
2. *#Intended_source*
   The number of sourcing of each manufacturer.
3. *followGlobalmanuf_loyalty?*
   The default string for this variable is ”yes“, which means the agent's *loyalty* would follow the global setup of *manufacturer trust*. Otherwise, any string other than ”yes“, such as ”no“, would activate the individual *loyalty* adjustment, by changing the value in *individual_manuf_loyalty*.
4. *individual_manuf_loyalty*
   The probability of the manufacturer trust/loyalty that can be set individually.
5. *%ProbabilityOfJumping*
   A probability set individually to each manufacturer to make a jump to different market segment that has not been served by competitors.

Each manufacturer agent also has an individual demand fulfilment rate measure represented by *%sc_marketshare.* It represents the percentage of customers who are underserved relative to the total number of customers who are served by all supply chains in the market.

- Supplier agents

1. *followGlobalsupp_loyalty?*
   The default string is "yes", which means the agent's *loyalty* would follow the global setup of *supplier trust*. Otherwise, any string other than "yes", such as "no", would activate the individual *loyalty* adjustment, by changing the value in *individual_supp_loyalty*.
2. *individual_supp_loyalty*
   The probability of the supplier trust/loyalty that can be set individually.

APPENDIX G: EXAMPLE OF VERIFICATION PROCEDURE

1. Customer's willingness to compromise

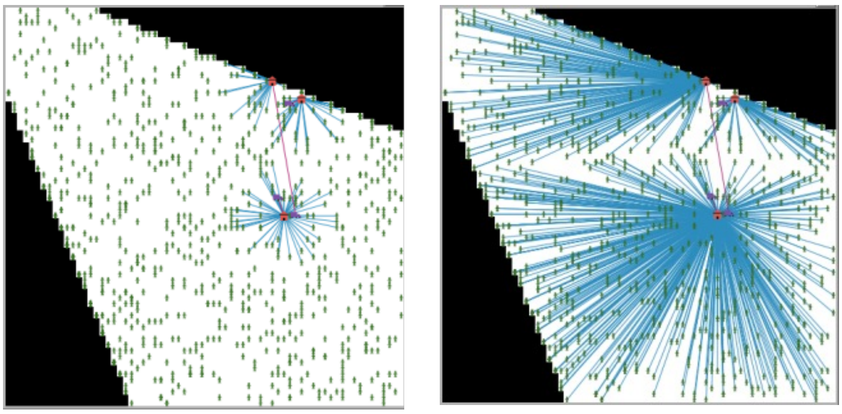
1.1 **Verification procedure.**

a. Setting up any number of customers, manufacturers, and suppliers. Supplier can be switched "on" or "off". In this example, the number of customers is 1000, the number of manufacturers is 3, and the number of supplier is 3.
b. Checking the length of the links carefully, by clicking "go once" button to enable observation in each *time unit*. While observing the simulation run in a controllable click, the value of *willingness to compromise* is slightly changed from the minimum value (0 %) to the maximum value (100%).
c. Repeating step (a) and (b) several times with different combination of number of agents.

1.2 Result: verified.

Description:

Higher customer's willingness to compromise produces longer links from customer to supplier. Figure G.1.a illustrates a lower customer's willingness to compromise (10%) limits firms revenue significantly, in terms of unit of customer. Meanwhile, Figure G.1.b illustrates 50% *willingness to compromise* and it shows that the links customers who stay further generate links to the manufacturers in Figure G.1.a.



a) 15% customer willingness to compromise

b) 50% customer willingness to compromise

Figure G.1. Verification of customer's willingness to compromise

2. *Customer loyalty*

2.1 Verification procedure.

a. Setting up any number of customers, manufacturers, and suppliers. Supplier can be switched "on" or "off", but it would be easier for the observation if it is turned "off". In this example, the number of customers is 1000, the number of manufacturers is 3, and the supplier agents are switched "off".
b. The manufacturer movement ("ManufMove?") can be switched "off" to make them static and easier for observing the behaviour.
c. Checking the frequency of changing link, by clicking the "go once" button, or clicking "go" button with a very slow speed, while slightly changing the value of *loyalty*, from the minimum value (0 %) to the maximum value (100%).
d. Enabling the manual intervention by clicking the "mouse?" button. The intercession is required to move a manufacturer to a different coordinate. Reiterating step (c) several times while observing the customer links.
e. Repeating step (a) to (d) several times with different combination of number of agents.
f. Repeating step (a), (c), and (d) by switching the manufacturer movement "on".

2.2 Result: verified.

Description:

The generated behaviour conform to the expectation since the frequency of changing the link is getting fewer once the *loyalty* is getting higher. At the extreme values of *loyalty*, the model also produces behaviour as it is expected. The zero *loyalty* results in most frequent of link changes, and the highest *loyalty* (100%) results in consistent link or constant connections between customer and manufacturer.

Figure G.2 represents an example of simulation outputs of *customer loyalty* with 10% *customer's willingness to compromise*. In Figure G.2.a and G.2.b show the behavioural results of 0% *customer loyalty*. When a manufacturer is moved manually from position a (Figure G.2.a) to b (Figure G.2.b), the previous customers are no longer linked with the manufacturer. In contrast, when customer *trust*/*loyalty* is set into 50%, and a manufacturer is moved from c (Figure G.2.c) to d (Figure G.2.d), several customer links that are previously generated are stay connected to the manufacturer.

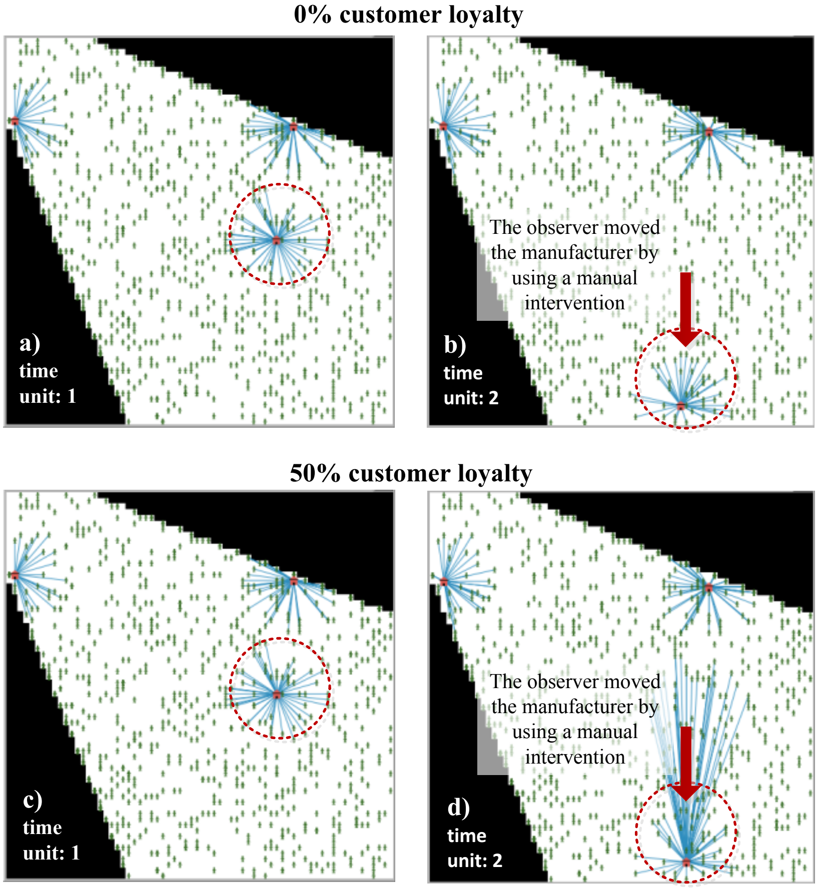


Figure G.3 Verification of *customer loyalty*.

3. Manufacturer's willingness to compromise.

3.1 Verification procedure.

a. Setting up two manufacturers, many customers, and several suppliers. Then, clicking "setup" button.
b. Switching both the manufacturer and supplier movement ("ManufMove?" and "SuppMove?") "off".
c. Using "mouse?" button for doing manual intervention. Selecting a manufacturer and locating one or several suppliers in more efficient and responsive space than the manufacturer. Meanwhile, surrounding another manufacturer with remaining suppliers which are set in less efficient and/or responsive than the manufacturer.
d. Checking the links between manufacturers and suppliers, by clicking the "go once" button, or clicking "go" button with a very slow speed, while slightly changing the value of Manufacturer's willingness to compromise from the minimum value (0 %) to the maximum value (100%).
e. Repeating step (a) to (d) several times with different combination of number of agents.
f. Repeating step (a), (c), and (d) by switching the manufacturer movement "on".

3.2 Result: verified.

Description:

Manufacturers always try to find suppliers who have better supply chain capability than theirs. If they could not find any supplier who is more efficient and/or responsive, they would select suppliers who are less efficient and/or responsive than theirs within their *willingness to compromise*. Figure 6 is the illustration of the concept of logic of manufacturer's willingness to compromise. Figure H.3 is an example of simulation run for verifying manufacturer's willingness to compromise. It implements 5% of manufacturer's willingness to compromise.

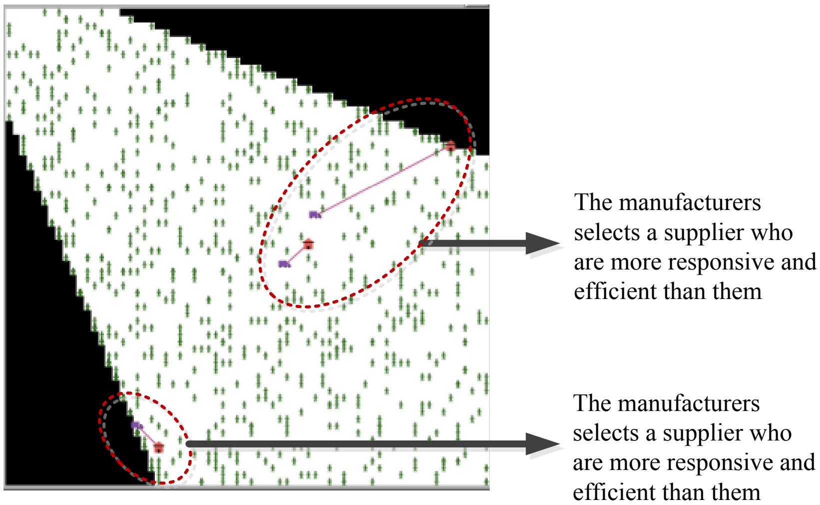


Figure G.3 Verification of manufacturer's willingness to compromise

APPENDIX H: COMPUTER CODE

```
breed [ customers customer ]
breed [ manufacturers manufacturer ]
breed [ suppliers supplier ]

customers-own [
  nearestmanuf  ; Closest manufacturer, from the customer
preference's perspective.
  manufcandidateset ; A set of manufacturers that can be chosen
by customer.
  ]

manufacturers-own [
  ;;The adjustable variables of individual behaviour setup, which
allowing a supplier behaves differently.
  duration_of_collaboration ; The length of collaboration created
between manufacturer and supplier linked.
  #Intended_source    ; The number of sourcing of each
manufacturer.
                      ; The value of this variable can be adjusted
individually during simulation run to make manufacturer behaves
differently.
  followGlobalmanuf_loyalty? ; A string variable to activate the
manual adjustment of "individual_manuf_loyalty".
                              ; The default string is "yes", which
means "individual_manuf_loyalty" follows the global value of
manufacturer trust. Otherwise, any string but "yes" (such as
"no") means "individual_manuf_loyalty" can be individually
adjusted.
  individual_manuf_loyalty      ; The probability of the
manufacturer trust/loyalty that can be set individually. This
enables the observer to see whether behave differently is
beneficial to the selected manufacturer.
  %ProbabilityOfJumping ; A probability set individually to each
manufacturer to make a jump to different market segment that has
not been served by competitors.

  ;;The performance variables of individual manufacturer.
  each_manuf_servedcustomers ; The number of served customers by
the manufacturer.
  ;;The performance variables of individual SUPPLY CHAIN.
   ; Supply chain is defined based on the point of view of
manufacturer since manufacturers have direct interaction with
customers. Thus, the variables of single supply chain performance
belong to manufacturer agent.
  each_sc_servedcustomers   ; The number of served customers by
the supply chain.
  %sc_marketshare  ;  The marketshare of each supply chain,
compared to competitor.
  each_sc_fillrate% ; The fill rate contributed by the supply
chain.
  #Real_source ; This variable reflects the number of links of a
manufacturer. The more links a manufacturer results in higher
transactional cost with the suppliers.
```

```
                ; However, since this model do not define the
amount of transactional cost, this variable
                ;   only   provides   the   fluctuation   of   the
transactional cost.

  ;;The control variables for monitoring individual manufacturer.
These variables are used not only to keep
   ;the information of individual manufacturer but also to verify
the rules.
  nearestsupp  ;  A  supplier  that  has  closest  supply  chain
capabilities with manufacturer preference.
  possiblesupp ; A list of possible suppliers.
  manufsurvivalperiod   ; A dummy variable to count the period
of having no supplier for each manufacturer.
  manuflossperiod   ; A dummy variable to count the period of
having less efficient or/and less responsive suppliers.
                     ; If the manufacturer linked with more than
one supplier, the efficiency and responsiveness level of the
                     ; suppliers are considered in average axis
value of suppliers.
  manufperiod  ; A dummy variable to count the cooperation period
that has been running.
  StepDistance  ;  Variable  to  show  the  step  distance  for  the
MUTATION strategy.

  ;;The   control   variables   for   monitoring   supply   chains
individually.
  MeanXcorSuppliers ; The mean efficiency of suppliers linked
with the manufacturer, in units of x-axis.
  MeanYcorSuppliers ; The mean responsiveness of suppliers linked
with the manufacturer, in unit of y-axis
  MySupp_efficiency ; The mean efficiency of suppliers linked
with the manufacturer. The value is dimensionless
                     ; and normalised between 0 (lowest degree of
efficiency) and 1 (highest degree of efficiency).
  MySupp_responsiveness ; The mean responsiveness of suppliers
linked with the manufacturer. The value
                         ;   is   dimensionless   and   normalised
between 0 (the lowest degree of responsiveness) and
                         ;   1   (the   highest   degree   of
responsiveness).
  each_sc_responsiveness   ; Each supply chain responsiveness.
The value is dimensionless and between 0 (the
                           ;  lowest  degree  of  responsiveness)
and 1 (the highest degree of responsiveness).
  each_sc_efficiency  ;  Each  supply  chain  efficiency,  in  a
dimensionless value of between 0 (the lowest
                      ;  degree  of  responsiveness)  and  1  (the
highest degree of responsiveness).
  previousMarketShare ; The total market share of previous agents
who are calculated by NetLogo before
                      ;calculating this agent.
  ]
suppliers-own [
  ;;The variables of individual behaviour setup, which allowing
a manufacturer behaves differently.
```

```
  followGlobalsupp_loyalty? ; A string variable to activate the
manual adjustment of "individual_supp_loyalty".
                            ; The default string is "yes", which
means "individual_supp_loyalty" follows the
                            ; global value of supplier trust.
                            ; Otherwise, any string but "yes"
(such as "no") means "individual_supp_loyalty"
                            ; can be individually adjusted.
  individual_supp_loyalty ; The probability of loyalty that is
set individually. This enables the observer to see
                            ; whether behave differently is
beneficial to the selected supplier.

  ;;The control variables for monitoring suppliers individually.
  each_supp_servedcustomers    ; The number of served customers
by the supplier.
  each_supp_responsiveness    ; Each supplier responsiveness, in
a dimensionless value, which is between 0 (the lowest degree
                            ; of responsiveness) and 1 (the
highest degree of responsiveness).
  suppsurvivalperiod  ; A dummy variable to count the period of
having no manufacturer linked for each supplier.
  previouschoosenmanuf ; the previous choosen manufacturer to be
approached (if the supplier decides to be not loyal) or follow
                       ; (if it decides to be loyal to a
particular manufacturer)
  ]

undirected-link-breed [ cmlinks cmlink ]
undirected-link-breed [ smlinks smlink ]
globals [
  ;;;THE MAIN MEASURES FOR THE SYSTEM
     %SCs_fillrate   ; Supply chains fill rate, to represent the
whole service level in the market
                     ; It is delineated by the percentage of
served customers.
     mean_sc_servedcustomers ; The mean of number of served
customers by all supply chains.
     #sc ; The number of existing supply chains.
     mean_manuf_servedcustomers ; The mean of number of served
customers by all manufacturers.
     mean_supp_servedcustomers ; The mean of number of served
customers by all suppliers.
     mean_sc_responsiveness ; Mean of all supply chain
responsiveness.
     mean_supp_responsiveness ; Mean of all suppliers
responsiveness, in dimensionless values.
     mean_sc_efficiency ; Mean of all supply chain efficiency.
     mean_supp_efficiency ; Mean of all supplier responsiveness,
in dimensionless values.
     gap_supp_manuf_responsiveness ; The mean of responsiveness
gap between supplier and manufacturer in supply chains.
     gap_supp_manuf_efficiency ; The mean of efficiency gap
between supplier and manufacturer in supply chains.

  ;;:TO PLOT THE OUTPUT OF ALL MANUFACTURERS PERFORMANCE;;
```

```
     list_manuf_revenue ; The list of all manufacturers revenue,
in units of customer.
     #manuf_die ; Number of died manufacturers in a particular
period or time unit.

  ;;;TO PLOT THE OUTPUT OF ALL SUPPLIERS PERFORMANCE;;
     list_supp_revenue ; The list of all suppliers revenue, in
units of customer.
     list_supp_responsiveness ; The list of all suppliers
responsiveness, in dimensionless values.
     list_supp_efficiency ; The list of all supplier efficiency,
in dimensionless values.

  ;;;TO PLOT THE OUTPUT OF ALL SUPPLY CHAIN PERFORMANCE;;
     total_sc_revenue ; The total revenue of all existed supply
chains.
     list_sc_Revenue ; A list of all supply chains revenue, in
units of customer.
     list_sc_responsiveness ; A list of all supply chains
responsiveness.
     list_sc_efficiency ; Mean of all supply chain efficiency.
     MeanLengthCustManuf ; A variable to measure the mean length
of cmlinks. This variable is only useful for verification,
                         ; to ensure whether the simulated links
are generated as expected.
     previous%SCs_fillrate ; Variable to record the
"%SCs_fillrate" in the previous time unit.
     accumdecay_rate ; Variable to accumulate the decay rate of
"%SCs_fillrate".
     meanaccumdecayrate ; Variable to calculate the rate of
decline of supply chains fill rate.

   ;;;TO SET GLOBAL SETUP FOR THE MODEL
     maxpreference ; Diagonal distance of the NetLogo world, it
affects the distance of preference of customers and
                   ; manufacturers in selecting their trading
partner.
     mincor ; Minimum coordinate, this is a fixed variable to
setup the layout.
     divider ; A fixed variable to setup the layout.
     DummyForTime unit ; A dummy variable to control the initial
distribution of agents during setup.
     MY ;; The maximum willingness to compromise which represents
in radius of preference
  ]
patches-own [
  pvalue ; The value of the patch. This variable is used to
identify the active patch as feasible area. Value "1"
         ; (one) represents the feasible area for placing and
simulating the agents, and "0" (zero) reflects
         ; the infeasible area.
  ]
;;=============================================================
;;TO SETUP THE SIMULATION

to setup
```

```
  ca
  reset-time unit

  if ControlSeed? [ random-seed SeedNumber]
  ; We can keep the same random seed or using common random
numbers

  ;; COUNTING THE 'WIDTH' OF THE 'WORLD'
  set maxpreference sqrt ( (max-pxcor ^ 2) + (max-pycor ^ 2) )
    ; Maximum distance of the preference is defined as the
diagonal length of the NetLogo space.

  set MY (( manuf_willingness_to_compromise / 100) *
maxpreference)
    ;To set the maximum willingness to compromise which
represents in radius of preference.
    ;"Maximum willingness to compromise" is defined as the
maximum adjustment distance that is calculated from the
    ; maximum patch coordinate

    set mincor 15 set divider 2.5
    ask patches [
    ; The logic is based on the basic straight line equation : Y
= a + bX.
    ; Since the line is going down (i.e. the slope or gradient,
b, is negative), so the equation becomes: Y = A - bX.
    ; The "divider" in the code refers to the negative slope.
    ifelse (( pycor < (max-pycor - mincor) ) and ( pxcor < ((
max-pycor - mincor - pycor ) / divider ) ))
    ; To define the lower infeasible area, which is based on this
logic: Y < ( max-Y - mincor ) and
    ;X < (( max-Y - mincor - Y ) / divider).
    [ set pvalue 0 set pcolor black ]
    [ ifelse (( pxcor > mincor ) and ( pycor > ( max-pxcor + (
(mincor - pxcor ) / divider )  ) ))
      ; To define the upper infeasible area, which is based on
the following logic: pycor > mincor + ( divider*pxcor ),
      ; or Y > mincor + (divider*X).
      [ set pvalue 0 set pcolor black]
      ; The infeasible area is black,
      [ set pvalue 1 set pcolor white ] ]
      ; The feasible area is white.
  ]
  ;;CREATING AGENTS;;
  create-customers #customer [
    set shape "person" set size 1.1
    setxy random-xcor random-ycor
    ; The customers are set with human-shape and randomly
distributed on the strategic space.
    let closestposition min-one-of (patches with [ pvalue = 1] )
[distance-nowrap myself]
    move-to closestposition
    set color 53 move-to patch-here]
    ; The customers are set in a blue-person shape and randomly
distributed in the strategic space.
```

```
  create-manufacturers #manuf [ setupManuf ]

  ;;The following command is to enable "suppliers" in the model.
  if SupplierOn? [
    create-suppliers #supplier [setupSupplier ]

    ;;    TO    CONTROL    THE    NUMBER    OF    AGENTS    DURING
SETUP...............................................
    if  ((MaxLinks  *  count  suppliers)  <  (MaxSource  *  count
manufacturers) ) [
      print   (word   "Please   add   "   ((MaxSource   *   count
manufacturers) - (MaxLinks * count suppliers) )
           " more suppliers.")
      stop ]

    if ((MaxSource * #manuf) < (MaxLinks * #supplier) ) [
      print  (word  "Please  add  "  ((MaxLinks  *  #supplier)  -
(MaxSource * #manuf))
           " more manufacturers.")
      stop]

;;...........................................................
    set DummyForTime unit 0
    ask manufacturers [ CreateLinksManufSupp]
    set DummyForTime unit 1
    set #sc ( count (manufacturers with [count my-smlinks > 0 ]
) )
  ]
end

; The logic sequence of the setup is described as follows.
; First of all, the initial values for the global variables, such
as the random-seed used, "maxpreference",
; and MY, are set.
; Then, the layout is set based on the selected layout in the
"GLOBAL SETUP" in the model interface.
; After that, customers are created placed randomly in the
feasible area of the NetLogo space.
; It is followed by creating manufacturers and located randomly
in the feasible patches.
; Then, suppliers are generated and placed within radius of
"manufacturer's willingness to compromise",
; by randomly selecting a manufacturer who is targeted.
; After that, manufacturers decide which suppliers they want to
collaborate with, by creating links with
; the selected supplier/s.
; After the collaboration links between manufacturers and
suppliers are created,
; manufacturers adjust their strategic position based on their
willingness to compromise.

; The duration of collaboration and intended number of sourcing
has been decided in this stage, but these
; variables have not run yet.
; This procedure ensures that all created firms have collaborated
with other agents since the beginning
```

```
; of simulation.

;;=============================================================
;;TO RUN THE SIMULATION
to go;this procedure is VERIFIED
  ;; TO CONTROL SETUP
    if ((MaxLinks * #supplier) < (MaxSource * #manuf)) [
      print (word "Please add " ((MaxSource * #manuf) - (MaxLinks
* #supplier) )
           " more suppliers in the Global Setup.")
      stop ]

    if ((MaxSource * #manuf) < (MaxLinks * #supplier) ) [
      print  (word  "Please  add  "  ((MaxLinks  *  #supplier)  -
(MaxSource * #manuf))
           " more manufacturers in the Global Setup.")
      stop
      ]
    ; We allow to set the number of supplier more than it should
be

;;.............................................................
  if count manufacturers > 1 [ MoveManufacturers ]
  ; Manufacturers would be moving for competition if there is at
least 2 manufacturers exist.

  if count suppliers > 1 [ MoveSuppliers ]
  ;  Suppliers  would  be  moving  for  competition  if  there  is  at
least 2 suppliers exist.

  ask cmlinks [die]
  ; the links between customers and manufacturers are reseted,
or deleted.

  ask manufacturers [
    if ( manufperiod >= ( duration_of_collaboration ) )
    [ ask my-smlinks [die] ] ]
      ; the previous collaboration link set to die.

  set maxpreference maxpreference
  ; This code is to keep the value of the variable constant during
simulation run.
  SetSCPerformance
  ; To reset all values in SC performance in every time unit.

  ;;The following command is to enable "suppliers" in the model.
  if SupplierOn?
  [ ask manufacturers [
      CreateLinksManufSupp] ]
    ;  If  suppliers  are  enabled,  the  link  between  manufacturers
and suppliers are generated.

  CreateLinksManufCustomer
  ; To create links between manufacturers and customers.
  manuf_die
```

```
  ; To make manufacturers who have no supplier for more than
"SurvivabilityWithoutSupplier" period,
  ; or manufacturers who have less responsive or/and efficient
supplier for more than
  ; "SurvivabilityWithUndesiredSupplier" period die.
  supplier_die
  ; To make suppliers who have no manufacturer for more than
"SurvivabilityWithoutManuf" period die.
  CountMarketFillRate
  ; To count market fill rate.
  CountManufPerformance
  ; To count manufacturers performance.
  CountSuppPerformance
  ; To count suppliers performance.
  count_AveragePosition
  ; To count the average position of each manufacturer's
suppliers, in terms of efficiency and
  ; responsiveness.
  CountIndividualSCPerformance
  ; To count supply chains performance

    if (count manufacturers < 2  and count suppliers < 2 ) or
     (count manufacturers = 0) or (count suppliers = 0) [stop]
     ;If there is only one manufacturer and one supplier exist,
the simulation would be stopped.

  set DummyForTime unit 2

  time unit
end
;;============================================================
;; SUPPORTING PROCEDURES FOR "SETUP" AND "GO"
;;============================================================
;;------------------------------------------------------------
;;  SETTING UP THE DETAIL OF MANUFACTURERS AND SUPPLIERS ;;
verified
;;----------------------------------------------------------
;; 1. TO SET UP MANUFACTURERS
to setupManuf
    set shape "house" set size 1.8 setxy random-xcor random-ycor
    ; The manufacturers are set in red-house shape and randomly
allocated in the space
    let closestposition min-one-of (patches with [ pvalue = 1] )
[distance-nowrap myself]
    move-to closestposition
    findposition set color 16 move-to patch-here
    set individual_manuf_loyalty manuf_loyalty
    set %ProbabilityOfJumping MutationProbability
    set StepDistance 1
; The manufacturers are represented in a red-house shape and
randomly allocated in the strategic space.
end

;; 2. TO SET UP SUPPLIERS
to setupSupplier
    set shape "truck" set size 1.8 setxy random-xcor random-ycor
```

```
    ; The suppliers are set in brown-truck shape and randomly
distributed in the space.
    let closestmanufacturer min-one-of manufacturers [distance-
nowrap myself]
    let possiblepositions [patches in-radius MY ] of
closestmanufacturer
    let closestposition one-of (possiblepositions with [ pvalue
= 1] )
    move-to closestposition
    ; The suppliers are located within radius of manufacturer’s
willingness to compromise,
    ; by selecting a manufacturer randomly to approach.
    findposition set color 115 move-to patch-here
    set individual_supp_loyalty Supp_loyalty
    set previouschoosenmanuf nobody
    ; The suppliers are set in a brown-truck shape.
end

;; 3. THE PROCEDURE TO MAKE SURE THAT THE POSITION OF THE FIRMS
IS NOT OVERLAPPING WITH EACH OTHER
      ; This procedure allows all firms to stay unique in the
strategic space, even they are really
      ; close with each other.
to findposition
  if any? other manufacturers-here or any? other suppliers-here
  [ move-to one-of neighbors with [ pvalue = 1]
    findposition]
end

;;--------------------------------------------------------------
;;LINKS GENERATION PROCEDURES;;
;;--------------------------------------------------------------
;; 4. TO CREATE LINKS BETWEEN CUSTOMERS AND MANUFACTURERS.
to CreateLinksManufCustomer ;;VERIFIED!
  ask customers [
    let CY ( ( willingness_to_compromise / 100) * maxpreference
)
    ;To set the maximum willingness to compromise that is
represented in radius of preference.
    set manufcandidateset nobody

    ;;The following command is to enable suppliers in the model.
    ifelse SupplierOn?
    [ set manufcandidateset manufacturers with [ count my-smlinks
> 0] in-radius CY ]
    ;;Customers are only able to link with manufacturers who have
suppliers.
    [ set manufcandidateset manufacturers in-radius CY ]
    ;;If suppliers are ignored, so the customer just select a
manufacturer using the previous conditional logic.

   ifelse ( (random-float 1) > (cust_loyalty / 100) ) or ( time
unit < 1 ) or ( nearestmanuf = nobody )
   ; Once a customer decides to not being loyal in the end of
duration of relationship,
```

```
   ; it changes their preference based on its willingness to compromise.
   [
     set nearestmanuf min-one-of manufcandidateset [distance-nowrap myself]
      ; The customer would select a firm which is nearest to their initial preference.
    ]
   [ set nearestmanuf nearestmanuf ]

   ifelse SupplierOn?
   [ if nearestmanuf != nobody and [count my-smlinks] of nearestmanuf > 0
      ;Customers are only able to link with manufacturers who have suppliers and meet the minimum number of
      ;required supplier.
      [ create-cmlink-with nearestmanuf [ set thickness 0.1 set color sky ] ] ]
   [ if nearestmanuf != nobody
      [ create-cmlink-with nearestmanuf [ set thickness 0.1 set color sky ] ] ]
        ; Customer can only create connection with a firm who stay inside their willingness to compromise
  ]
end

;; 5. TO CREATE LINKS BETWEEN MANUFACTURERS AND SUPPLIERS
to CreateLinksManufSupp ;VERIFIED!

    set MY (( manuf_willingness_to_compromise / 100) * maxpreference)
    ;To set the maximum willingness to compromise which represents in radius of preference.
    ;"Maximum willingness to compromise" is defined as the maximum adjustment distance that is calculated
    ; from the maximum patch coordinate.
    ; This variable (MY) is updateable during simulation run. In other words, MY is set as adjustable constant.

;;.............................................................
    ;;TO SET THE DURATION OF RELATIONSHIP BETWEEN MANUFACTURER AND SUPPLIERS

      ifelse time unit < 1 and DummyForTime unit = 0
      [ set #Intended_source MaxSource
        ; This code determines the number of sourcing uniformly to all manufacturers.
        ; This rule is set to understand how sourcing strategy, in terms of deciding the number of sourcing,
        ; affects supply chain collaboration.
        ; In SCM, it is believed that having single-sourcing for the main material can significantly support
        ; supply chain collaboration (..., ..)
        ; However, other research argue that single-sourcing does not always enhance supply chainperformance ( .., ..).
```

```
        ; This rule also represents sourcing limitation for the
firm.
        ; When the "minimum number of sourcing" is applied,
manufacturers would only be able to link with
        ; customers if their suppliers is at least the "minimum
number of sourcing".
        ; In this model, the number of sourcing would not affect
the manufacturer capacity.
        ; Once the manufacturer set their strategy of number of
sourcing, it would be applied constantly
        ; as the time progressing.
        set duration_of_collaboration random
(MaxDuration_of_collaboration - MinDuration_of_collaboration +
1)
                                        +
MinDuration_of_collaboration ;verified
        ; To determine the length of collaboration based on
random function
        ; It implements the "random between" logic >> random
between by: random ( max - min +  1) + min, for min < x <= max.
        set followGlobalmanuf_loyalty? "yes"
      ]
      [ set duration_of_collaboration duration_of_collaboration
        set #Intended_source #Intended_source
        set followGlobalmanuf_loyalty?
followGlobalmanuf_loyalty?]
        ; the length of collaboration and intended number of
sourcing would remain the same once it is set up at time unit 1,
        ; unless it is adjusted manually for selected
manufacturer.

           ;FOR VERIFICATION.................(checking the code
behaviour)
                ;show duration_of_collaboration
                ;show [duration_of_collaboration] of
manufacturers
           ;.................................
;;.............................................................

  ifelse followGlobalmanuf_loyalty? = "yes"
  [ set individual_manuf_loyalty manuf_loyalty ]
  [ set individual_manuf_loyalty individual_manuf_loyalty]

  ifelse ( manufperiod >= ( duration_of_collaboration ) )
         ; once the duration of collaboration has reached its end
         or manufsurvivalperiod > 0 or (time unit < 1)
         ; or manufacturer has no supplier in previous time unit.
  [ set manufperiod 1
    ; the manufacturer renew their collaboration agreement
    support_CreateLinksManufSupp
    if DummyForTime unit = 0
    [ set nearestsupp min-n-of (min list (#Intended_source)
(count possiblesupp)) possiblesupp [distance-nowrap myself]]

    ifelse ( ((random-float 1) > (individual_manuf_loyalty /
100))
```

```
      ; And once manufacturer decides to not being loyal to the
previous linked supplier
      or nearestsupp = nobody )
      ;or count nearestsupp = 0)
      ; or manufacturer has no supplier in previous time unit.
      and ( DummyForTime unit != 1)
      ; and the simulation state is not in the setup stage.

    [  set  nearestsupp  min-n-of  (min  list  (#Intended_source)
(count possiblesupp)) possiblesupp [distance-nowrap myself] ]
      ; If the Selection_Mode is "Closest firm", manufacturers
would select n suppliers
      ; that are closest to their initial preference.
    [  set nearestsupp nearestsupp
    ]
     ;  If  manufacturer  decides  to  be  loyal  to  the  previous
suppliers,
     ;it would keep linking with the previous suppliers.
  ]
  [ set manufperiod manufperiod + 1 ]

       ;VERIFIED..!!
       ;FOR  VERIFICATION.................(checking  the  code
behaviour)
            ;show duration_of_collaboration
            ;show [duration_of_collaboration] of manufacturers
       ;..............................
;;.....................................................
    ;; TO CREATE LINKS

    if nearestsupp != nobody
    [ create-smlinks-with nearestsupp with [count my-smlinks <
MaxLinks] [ set thickness 0.1 set color magenta ]
      ; Similar as customer, the manufacturer can only create
connection with a firm who stay inside their
      ; willingness to compromise.
       ]

    if time unit < 1 and (count my-smlinks < #Intended_source )
    [  set  possiblesupp  (suppliers  with  [count  my-smlinks  <
MaxLinks] )
      create-smlinks-with  n-of  (min  list  (  #Intended_source  -
(count my-smlinks )) (count possiblesupp))
                          possiblesupp [ set thickness 0.1  set
color magenta ] ]
    ; this logic is to adjust manufacturers' initial strategic
position. They would be located in a space
    ; where a supplier is available.

;;.....................................................
   ;  This  logic  is  to  measure  the  level  of  efficiency  and
responsiveness of the suppliers.
    let set_ofsupp suppliers with [link-with myself != nobody]
    ifelse count set_ofsupp > 0
    [ set MeanXcorSuppliers round (mean [xcor] of set_ofsupp)
      set MeanYcorSuppliers round (mean [ycor] of set_ofsupp) ]
```

```
    [ set MeanXcorSuppliers 0
      set MeanYcorSuppliers 0 ]

    set nearestsupp set_ofsupp

    Adjustposition
end

;; 6. PROCEDURE TO SUPPORT "CreateLinksManufSupp"
to support_CreateLinksManufSupp
  let suppcandidateset nobody

    set suppcandidateset suppliers with [
      ; To set a set of suppliers (as a local agentset) who
        xcor <= [xcor] of myself and
        ; are more efficient and
        ycor <= [ycor] of myself and
        ; responsive,
        count my-smlinks < MaxLinks and
        ; still have available capacity (represented by number
of links)
        link-with myself = nobody
        ; and have not linked with the manufacturer.
        ]

      ; VERIFIED!! -- By checking the length of the generated
links and link directions.

      if (count suppcandidateset = 0 ) or (manufsurvivalperiod >
0 ); and count suppcandidateset = 0)

       ; If there is no available supplier that is suitable with
manufacturer's preference,
       ; which is indicated by "manufsurvivalperiod",
       ; they would relax their preference and would to have
supplier which is less efficient or less responsive.

       [ set suppcandidateset suppliers with [
           link-with myself = nobody
           and count my-smlinks < MaxLinks
           ] in-radius MY
         ]
     set possiblesupp suppcandidateset

       ;FOR VERIFICATION ...................... (VERIFIED!)
       ;show list suppcandidateset possiblesupp
       ;show manufsurvivalperiod
       ;.......................................
end

;;-------------------------------------------------------------
;;DIE PROCEDURES;;
;;-------------------------------------------------------------

;; 7. TO MAKE MANUFACTURERS THAT HAVE NO CUSTOMERS, WHICH ALSO
MEANS HAVING NO SUPPLIERS, FOR CERTAIN PERIODS DIE
```

```
to manuf_die ;VERIFIED!
  ask manufacturers [
    ifelse count my-smlinks = 0
    ; If a manufacturer has no customer,
    [ ifelse manufsurvivalperiod < (
SurvivabilityWithoutSupplier )
      ; and if the length of manufacturer's existence is still
less than the allowed duration of survival without
      ; having supplier,
      [ set manufsurvivalperiod manufsurvivalperiod + 1 ]
      ; it would exist in the next time unit
      [ if die? [die] ] ]
      ; Otherwise, once the duration of manufacturer's existance
without supplier exceeds the maximum
      ; duration allowed, the manufacturer would die.
    [ set manufsurvivalperiod 0 ]
     ; Once a manufacturer has customer, it does not need to
count the survival period.

    ;;TO MAKE MANUFACTURERS THAT HAVE LESS RESPONSIVE OR
EFFICIENT SUPPLIERS DIE AFTER CERTAIN PERIODS
    ifelse ( MeanYcorSuppliers > ycor ) or ( MeanXcorSuppliers >
xcor )
    ; If the mean of suppliers' responsiveness or efficiency is
less than the manufacturer,
    [ set manuflossperiod manuflossperiod + 1
      ; the period of being loss working with the undesired
supplier would be counted.
      if manuflossperiod > SurvivabilityWithUndesiredSupplier
and die? [ die ] ]
      ; If the period exceeds the tolerable period defined
    [ set manuflossperiod 0 ]
    ; the period of being loss working with the undesired supplier
would be reset to zero.
     ]
end

;; 8.TO MAKE SUPPLIERS THAT HAVE NO MANUFACTURERS TO WORK WITH
FOR CERTAIN PERIODS DIE.
to supplier_die  ; VERIFIED!
  ask suppliers [
    ifelse count my-smlinks = 0
    ; if a supplier do not manage to have a manufacturer
    [ ifelse suppsurvivalperiod < ( SurvivabilityWithoutManuf )
      ; before it reaches the "survival ability without
manufacturer" set,
      ;( the "survival ability without manufacturer" is the
allowed duration to survive without manufacturer)
      [ set suppsurvivalperiod suppsurvivalperiod + 1 ]
      ; its survival period would be counted and accumulated.
      [ if SuppDie? [die] ] ]
    ; However, if its survival period has reached the "survival
ability without manufacturer"
    ; the supplier would die.
    [ set suppsurvivalperiod 0 ] ]
```

```
  ; If a supplier has collaborated with a manufacturer, its
survival period would be reset to zero.
end

;;----------------------------------------------------------------
;;FIRMS MOVEMENT (CHANGING STRATEGY);;
;;----------------------------------------------------------------

;; 9. TO MOVE THE MANUFACTURERS IN TERMS OF CHANGING THEIR
STRATEGY
to MoveManufacturers ;VERIFIED!
  ask manufacturers [
    let nextclosestcust min-one-of (customers with [ link-with
myself = nobody] ) [distance-nowrap myself]
    let nextcust nextclosestcust
    ; The default selection of new customer target is the closest
customer who is not served yet by the manufacturer

    let positioncandidate patch-here
    let new_manuf_position patch-here ;nobody
;;................................................................
    ; Started in the line below, we enable the "Jumping Strategy"
or "MUTATION" for the selected manufacturer.

    set %ProbabilityOfJumping %ProbabilityOfJumping

    if nextcust != nobody and ManufMove? ;VERIFIED
    ;It represents if the manufacturers want to change their
strategy and they have a customer target,
    ;the manufacturers would move around the space.
     [ ifelse ( ( %ProbabilityOfJumping > 0 ) and ( (random-float
1) < ( %ProbabilityOfJumping / 100 )  ))
       ; Each manufacturer has "probability of jumping" expressed
in percentage to represent the probability of the
       ; firm to "jump" into a new market segment.
       ; We can adjust the value of the variable for each
individual agent.
       [ let MovementDistance_%ofWorld ( (random-float 1) * 100
)
         set StepDistance ((MovementDistance_%ofWorld / 100) *
maxpreference)

         set nextcust max-one-of (customers in-radius (
StepDistance ) with
                                         [ count my-cmlinks = 0 ] )
[distance-nowrap myself] ;VERIFIED!
         ; If a manufacturer is set to have a willingness to jump
into a new market segment (with a certain probability),
         ; it needs defining the distance of the leap.
         ; We assume that onve the manufacturer "jump", they
approach the customer who has not been served yet by its
competitors.
         if nextcust != nobody
         [ set positioncandidate min-one-of (patches in-radius
((MovementDistance_%ofWorld / 100) * maxpreference)
```

```
                                  with [ pvalue = 1]) [ distance-nowrap nextcust ] ]
       ]
      [ set positioncandidate min-one-of neighbors with [ pvalue = 1] [ distance-nowrap nextcust ]]
        ; If the "Jumping strategy" is not applied to the manufacturer
        ; the manufacturer would move around in the space by one grid.
      set new_manuf_position positioncandidate  ]

    if ManufMove? and new_manuf_position != nobody
    [ move-to new_manuf_position ] ;VERIFIED

    findposition

;...............................................................
  ]
end

;; 10. TO MOVE THE SUPPLIERS IN TERMS OF CHANGING THEIR STRATEGY
to MoveSuppliers ;VERIFIED!
  ask suppliers [
    let nextclosestmanuf nobody
    let supppositioncandidate patch-here
    let new_supp_position nobody
         ;;; Supplier moves like manufacturers ;;VERIFIED
    set nextclosestmanuf min-one-of (manufacturers with [ link-with myself = nobody]) [distance-nowrap myself]
    ; "nextclosestmanuf" is the closest manufacturer who has no link with the supplier.

    if nextclosestmanuf != nobody
    ;It represents the suppliers can change their strategy, by moving around in the space with at least one grid movement.
    [ set supppositioncandidate min-one-of neighbors with [ pvalue = 1] [ distance-nowrap nextclosestmanuf ]

    ifelse time unit < 1
    [ set followGlobalsupp_loyalty? "yes"]
    [ set followGlobalsupp_loyalty? followGlobalsupp_loyalty? ]

    ifelse followGlobalsupp_loyalty? = "yes"
    [ set individual_supp_loyalty supp_loyalty ]
    [ set individual_supp_loyalty individual_supp_loyalty]

    ifelse SuppMove?
    [ if (random-float 1) < (individual_supp_loyalty / 100)
      ; Once the supplier decides being loyal to the manufacturer linked with it
      [ let choosenmanuf nobody
        if (previouschoosenmanuf = nobody )
        ; If the supplier had no manufacturer to link with before,
        ; (which happens in the early model run)
```

```
        [ set choosenmanuf one-of manufacturers with [ link-with
myself != nobody ]
          ; but it has linked with manufacturer/s,
          ; it would select a manufacturer who is currently
linked with the firm.
          if choosenmanuf = nobody [ set choosenmanuf
nextclosestmanuf ]
          ; if at the moment the supplier has no manufacturer to
collaborate with, it would follow the closest
          ; targeted manufacturer to attract the manufacturer to
link with it.
          set previouschoosenmanuf choosenmanuf ]
          ; If there is no manufacturer has no link with the
supplier ("nextclosestmanuf" is nobody,
          ; it would not move. It means that all manufacturers
have been linked with the supplier.

        ifelse ( [count my-smlinks ] of previouschoosenmanuf > 0
)
        ; If the supplier has a link with the selected previous
manufacturer to be loyal to
        [ set choosenmanuf previouschoosenmanuf ]
          ; the "chosenmanuf" is the previous manufacturer who
the firm loyal to.
        [ set choosenmanuf one-of manufacturers with [ link-with
myself != nobody ] ]
          ; if the supplier is not linked with the previous manuf,
it would be loyal to one of
          ; manufacturers who is collaborating with the firm.

        if choosenmanuf = nobody [ set choosenmanuf
nextclosestmanuf ]
        ; if the supplier has no link with any manufacturer, it
would approach the a targeted manufacturer.
        set supppositioncandidate min-one-of (patches in-radius
([StepDistance] of choosenmanuf) with [pvalue = 1])
                                  [distance-nowrap choosenmanuf
]
        ; once the supplier decides to be loyal to the selected
manufacturer, regardless whether it has collaborated with
        ; the manufacturer, it would follow the manufacturer's
movement.
        set previouschoosenmanuf choosenmanuf
        ; updating the "previouschoosenmanufacturer"
         ]
        set new_supp_position supppositioncandidate]

    [ set new_supp_position patch-here ]
    ;; If suppliers are not able to move


    if SuppMove?
    ; This conditional function enables us to treat a particular
supplier agent to stay or not move.
    [ move-to new_supp_position
    findposition ]
```

```
  ] ]
end

;;------------------------------------------------------------
;; FIRMS REVENUE;;
;;------------------------------------------------------------
;; 11.TO CALCULATE MANUFACTURER'S PERFORMANCE, IN THE NUMBER OF SERVED CUSTOMERS
to CountManufPerformance ; VERIFIED!
  ask manufacturers [
    set each_manuf_servedcustomers (count my-cmlinks)
    ; Each link from customer contributes one unit Revenue to the firm

       ;FOR VERIFICATION...............
         ;show each_manuf_servedcustomers
       ;..............................

    set list_manuf_Revenue (lput each_manuf_servedcustomers list_manuf_Revenue )
    set mean_manuf_servedcustomers mean list_manuf_Revenue
    ;; Showing these variables below, it lets me know that the 'mean' considers the zero Revenue as well before averaging
       ;;FOR VERIFICATION...................
         ;show mean_manuf_servedcustomers
         ;show list_manuf_Revenue
       ;; .................................
    ]
end

;; 12.TO CALCULATE SUPPLIER'S PERFORMANCE, IN NUMBER OF SERVED CUSTOMERS.
to CountSuppPerformance ; VERIFIED!
  ask suppliers [
    let set_ofmanuf manufacturers with [link-with myself != nobody] ; verified
    ; Creating a list of manufacturers linked with the supplier. We can say this an agentset.
    let A 0

    if set_ofmanuf != nobody
    [ set A sum [count my-cmlinks / ( count my-smlinks )] of set_ofmanuf ]

    set each_supp_servedcustomers A
    ; The assumption is each supplier has similar contribution to the manufacturer
    ; "each_supp_servedcustomers" is the variable Revenue, the more unit sold by manufacturer, the more unit sold by the supplier
    ; A is the sum of the number of unit sold by each manufacturer (linked with the supplier) divided by
    ; the number of suppliers supplied the manufacturer. The division calculation is counted for each manufacturer
    ; (linked with the supplier)
    ; A = sigma [ ( the number of unit sold by manufacturer / the number of suppliers of manufacturer) of
```

```
    ; each manufacturer that is linked with the supplier ]
       ;FOR VERIFICATION...........
         ;show each_supp_servedcustomers
       ;............................
    set   list_supp_Revenue   (lput   each_supp_servedcustomers
list_supp_Revenue ) ; >> if each_supp_servedcustomers = 0, the
do not count it
    set mean_supp_servedcustomers mean list_supp_Revenue
      ;FOR VERIFICATION..............
        ;show mean_supp_servedcustomers
      ; ..............................
  ]
end
;;---------------------------------------------------------------
;;SUPPLY CHAIN PERFORMANCE;;
;;---------------------------------------------------------------
;; 13. TO RESET THE PREVIOUS CALCULATION
to SetSCPerformance
  set list_manuf_Revenue []
  set list_supp_Revenue []
  set list_sc_Revenue []
  set list_supp_responsiveness []
  set list_sc_responsiveness []
  set list_supp_efficiency []
  set list_sc_efficiency []
end


;; 14. TO CALCULATE THE MEAN EFFICIENCY AND RESPONSIVENESS FOR
EACH AND ALL SUPPLY CHAINS
to count_AveragePosition ;VERIFIED!! HAPPYYY!!
; It's an old saying, but it's true: a chain is only as strong
as its weakest link. So does the supply chains.
; The capabilities of the suppliers are considered as the utmost
importance to the entire supply chain performance.
;  If  a  manufacturer,  or  a  company,  has  suppliers  that  have
irrelevant capabilities with its business strategy,
; which refers to supply chain strategy in this case,
; the entire chain could lapse and the customers immediately feel
its affects.
; Representing this situation, in this study, the manufacturer's
responsiveness reflects the supply chain responsiveness
; since it interacts with downstream customers directly.

ask manufacturers [
  ;; Manufacturers who have no suppliers or less than minimum
requirement are not considered.
  set #Real_source count my-smlinks
  ifelse count my-smlinks >= 1
  [
    ;;  Counting  aggregated  supplier  responsiveness  (Y)  and
efficiency (X) of each manufacturer relative to the world
    ; We only consider suppliers who have links with manufacturer
    set MySupp_responsiveness (max-pycor - MeanYcorSuppliers) /
max-pycor
```

```
    set MySupp_efficiency (max-pxcor - MeanXcorSuppliers) / max-
pxcor
    set list_supp_responsiveness (lput MySupp_responsiveness
list_supp_responsiveness )
    set list_supp_efficiency (lput MySupp_efficiency
list_supp_efficiency )
    set mean_supp_responsiveness mean list_supp_responsiveness
    set mean_supp_efficiency mean list_supp_efficiency

    ;; SC responsiveness (which is similar manufacturer's
responsiveness)
    set each_sc_responsiveness (max-pycor - ycor ) / max-pycor
    set list_sc_responsiveness (lput each_sc_responsiveness
list_sc_responsiveness )
    set mean_sc_responsiveness mean list_sc_responsiveness

    ;; SC efficiency (which is similar manufacturer's efficiency)
    ;; we do not consider manufacturers who have no suppliers
    set each_sc_efficiency (max-pxcor - xcor) / max-pxcor
    set list_sc_efficiency (lput each_sc_efficiency
list_sc_efficiency )
    set mean_sc_efficiency mean list_sc_efficiency

    ;; However, we consider manufacturers who have no supplier
(since "each_manuf_servedcustomers" has been
     ; calculated in procedure number 11.
    set each_sc_servedcustomers each_manuf_servedcustomers
    set list_sc_Revenue (lput each_sc_servedcustomers
list_sc_Revenue )

    set total_sc_revenue sum list_sc_Revenue
  ]
  [ set MySupp_responsiveness 0
    set MySupp_efficiency 0
    set each_sc_responsiveness 0
    set each_sc_efficiency 0
    set each_sc_servedcustomers 0
    set list_sc_Revenue (lput each_sc_servedcustomers
list_sc_Revenue )
    ; If the manufacturer has no collaboration with any supplier,
its efficiency and responsiveness are not
    ; considered in the system or market.
  ]
  ; The average of efficiency and responsiveness gap between
manufacturer and supplier
  set gap_supp_manuf_responsiveness (mean_supp_responsiveness -
mean_sc_responsiveness)
  set gap_supp_manuf_efficiency (mean_supp_efficiency -
mean_sc_efficiency)
]
end

;; 15. TO CALCULATE THE PERFORMANCE OF EACH SUPPLY CHAIN
INDIVIDUALLY
to CountIndividualSCPerformance
ask manufacturers [
```

```
  ifelse total_sc_revenue > 0 [
    set %sc_marketshare precision ( (each_sc_servedcustomers *
100) / total_sc_revenue ) 3 ]
  [ set %sc_marketshare 0 ]
  set each_sc_fillrate% precision (( each_sc_servedcustomers /
#customer ) * 100) 3
  set mean_sc_servedcustomers mean list_sc_Revenue ]
set #sc ( count (manufacturers with [count my-smlinks > 0 ] ) )
end


;; 16.TO CALCULATE THE MARKET FILL RATE
to CountMarketFillRate
  set %SCs_fillrate (count customers with [count my-cmlinks > 0]
/ #customer ) * 100
end
;;--------------------------------------------------------------
;; POSITION ADJUSTMENT FOR MANUFACTURERS ;;
;---------------------------------------------------------------
;; 17. TO ADJUST MANUFACTURERS' POSITION BASED ON ITS SUPPLIERS'
CAPABILITY
to AdjustPosition
  ; This procedure represents suppliers affect the capabilities
of supply chains through
  ; manufacturers strategic position.
  ; The tolerated degree of this effect is determined by
"manuf_willingness_to_compromise". The variable is defined as
  ; a percentage of diagonal distance of the NetLogo space to
reflect the allowed capability gap between manufacturers
  ; and suppliers.
  ; This effect limits manufacturers' strategic movement for the
competition.

  ; The mechanism of this procedure is illustrated as follows.
  ; For example, a manufacturer stays in a coordinate of (20,25).
  ; It has 10% of "manuf_willingness_to_compromise", which means
it is able to select less responsive or/and less
  ; efficient suppliers within radius or distance 9.475 grids.
  ; The radius or the distance is obtained by these calculations:
  ; - The diagonal distance of the NetLogo space = sqrt ( (maximum
x-axis)^2 + (maximum y-axis)^2 ))
  ;                                                = sqrt ( (67)^2
+ (67)^2 ) = 94.75
  ;   (then, we call this value as "maxpreference" on the NetLogo
code).
  ;   - The tolerated or allowed capability gap =
"manuf_willingness_to_compromise" x "maxpreference"
  ;   We note this variable as "MY" on the NetLogo code.
  ;   If "manuf_willingness_to_compromise" is 10%, so MY = 10% x
94.75 = 9.475 grids

  ; Then, the manufacturer decides to collaborate with a supplier
who stays in coordinate (15,34)
  ; for 4-period collaboration length. This supplier is selected
because it stays within the manufacturer's willingness
  ; to compromise.
```

```
  ; In terms of efficiency, the supplier has a better efficiency
than the manufacturer, since X-value of the supplier (15)
  ; is less than X-value of manufacturer (20). Then, the
manufacturer do not need to adjust its efficiency capability.
  ; However, the responsiveness of its supplier is lower than the
manufacturer,
  ; since the Y-value of the supplier (34) is higher than
manufacturer (25).

  ; In the next time unit, the supplier moves to a patch in
coordinate (15,35) and the manufacturer moves to coordinate
(20,24).
  ; With the new position, the responsiveness gap between the
manufacturer and supplier is 35 - 24 = 11 grids, which falls
  ; outside allowed capability gap (9.475 grids).
  ; Since the manufacturer still collaborates with the supplier,
its strategic movement is affected by the supplier.
  ; In other words, even though the manufacturer has decided to
move to patch (15,35), it is not able to stay in the desired
  ; patch due to its supplier position.
  ; Thus, the manufacturer has to adjust its strategic position
by round (11 - 9.475) = round (1.525) = 2 grids.
  ; As a result, the manufacturer's new position is in coordinate
(20,26), which is 2 grids, or 2 degrees less responsive
  ; than its desire.

  if SupplierOn? and AdjustPosition? [
    let newxcor round xcor
    let newycor round ycor

    let newxcorShouldBe ( MeanXcorSuppliers - MY )
    ; "newxcorShouldBe" represents suppliers' influence on
efficiency towards manufacturers or supply chains
    ; efficiency.
    let newycorShouldBe ( MeanYcorSuppliers - MY )
    ; "newycorShouldBe" represents suppliers' influence on
responsiveness towards manufacturers or supply chains
    ; responsiveness.

    if MeanXcorSuppliers > ( xcor + MY)
    [ set newxcor round newxcorShouldBe
      ; If, on average, the supplier/s are less efficient than
manufacturer, the manufacturer would move to
      ; the efficiency level of the supplier.
      ; If the suppliers, on average, are more responsive than
the manufacturer, manufacturer would maintain the current
      ; level of responsiveness.
      ; The "newxcorShouldBe" only applies once the manufacturer
is on the left of the supplier, which means once the
      ; manufacturer is more efficient than its supplier.
      ; Thus, tere is a possibility that the manufacturer would
end-up in the infeasible area.
      ; If it is happen, the manufacturers would move to the
nearest point of efficiency (x-axis) possible on
      ; the edge of the infeasible area.
     ]
```

```
    ; If the suppliers are less efficient than the manufacturer, they would make the manufacturer less efficient
    ; than its real capability.
    ; However, if the manufacturer is less efficient than the suppliers, the suppliers capability would not
    ; affect manufacturer capability.
    ; This logic represents 'the strength of a supply chain is the weakest firm in that supply chain.

    let YPatchesCandidate1 nobody
    let YcorCandidate1 0

    if ([pvalue] of (patch newxcor newycor) = 0)
    ; if the new suggested location falls in infeasible area,
    [ let xcorcandidate1 max [pxcor] of patches with [pvalue = 1 and pycor = newycor  ]
      if xcorcandidate1 = nobody [set xcorcandidate1 max-pxcor ]
      set newxcor round xcorcandidate1 ]
      ; the "newxcor" is redefined, by selecting a patch where is in feasible area and closest to the
      ; suggested X coordinate.

    if (MeanYcorSuppliers > ( ycor + MY ) )
    [ set YcorCandidate1 max [pycor] of patches with [ pvalue = 1 and pxcor = newxcor]
      if YcorCandidate1 = nobody [set YcorCandidate1 max-pycor]
      set newycor round ( min list (round newycorShouldBe) YcorCandidate1 ) ]
    ; If the suppliers are less responsive than the manufacturer, they would make the manufacturer less responsive
    ; than its real capability.
    ; However, if the manufacturer less responsive than the suppliers, the suppliers capability would not
    ; affect manufacturer capability.

        ;;FOR VERIFICATION ..................................
           ;;show newycor
           ;;show newycorShouldBe
           ;show YPatchesCandidate1
        ;;...................................................
    ;; FOR VERIFICATION .........................
      ;show newxcor
      ;show newxcorShouldBe

      ;show newycor
      ;show newycorShouldBe
      ;show YcorCandidate1
    ;; .........................................
    move-to patch newxcor newycor
    findposition
  ]
end
;;-------------------------------------------------------------
;;MANUAL INTERVENTION: ADDITIONAL FEATURE;;
;;-------------------------------------------------------------
```

```
;; 18.TO ENABLE THE MANUAL INTERVENTION TO THE AGENTS
to mousedown
  if mouse-down? [
    ask turtles with-min [distancexy mouse-xcor mouse-ycor]
    [ setxy mouse-xcor mouse-ycor ]
    ]
end
;;---------------------------------------------------------------
;; PLOTTING OUTPUTS ;;
;;---------------------------------------------------------------
;; 19. TO PLOT DECAY RATE OF SUPPLY CHAINS FILL RATE
; Decay rate is defined as the cumulative decline rate of supply
chain fill rate at the current time unit.
to accumdecayrate
  let decay_rate (previous%SCs_fillrate - %SCs_fillrate) / 100
  set accumdecay_rate accumdecay_rate + decay_rate
  if time unit > 2
  [ set meanaccumdecayrate ( accumdecay_rate / time unit )
    plotxy time unit meanaccumdecayrate ]
        ;;FOR VERIFICATION ..................................
           ;;    print    (word    "previous%SCs_fillrate    "
previous%SCs_fillrate )
        ;;...................................................
  set previous%SCs_fillrate %SCs_fillrate
        ;;FOR VERIFICATION ..................................
           ;; print (word "%SCs fill rate " %SCs_fillrate )
           ;; print (word "decay rate " decay_rate )
           ;; print (word "accumdecayrate " accumdecay_rate )
           ;;     print     (word     "meanaccumdecayrate     "
meanaccumdecayrate )
        ;;...................................................
end

;;---------------------------------------------------------------
;; CREATING NEW FIRMS DURING SIMULATION RUN ;; verified
;;---------------------------------------------------------------
;; 20. TO CREATE A NEW MANUFACTURER IN THE MODEL, AS A NEW ENTRANT
to CreateOneManuf
  create-manufacturers 1 [
    setupManuf
    if SupplierOn?
    [ set #Intended_source MaxSource
      set           duration_of_collaboration            random
(MaxDuration_of_collaboration - MinDuration_of_collaboration +
1)
                                              +
MinDuration_of_collaboration
      set nearestsupp nobody
      if time unit > 0 [
        CreateLinksManufSupp
        if (count my-smlinks < #Intended_source )
        [ set possiblesupp (suppliers with [count my-smlinks <
MaxLinks] )
          create-smlinks-with n-of (min list ( #Intended_source
- (count my-smlinks )) (count possiblesupp))
```

```
                                    possiblesupp [ set thickness
0.1 set color magenta ] ]
        ; this logic is to adjust manufacturers' initial
strategic position. They would be located in a space where a
supplier is available.
      ]
      AdjustPosition ] ]
end

;; 21. TO CREATE A NEW SUPPLIER IN THE MODEL, AS A NEW ENTRANT
to CreateOneSupp
  ;;the following command is to enable suppliers in the model
  if SupplierOn? [
  create-suppliers 1 [
    setupSupplier
    ]
  ]
end
```

APPENDIX I: DECAY RATE OF DEMAND FULFILMENT FOR EACH EXPERIMENTAL FACTOR

Table I.1 The decay rate of *supply chain fill rate*

No	Experimental factor	Scenario				
		1	2	3	4	5
Manufacturer competitive behaviour						
1	*Duration of collaboration*					
	- with single-link supplier	79.50%	78.84%	75.86%	80.71%	83.25%
	- with dual-link supplier	80.05%	83.80%	82.48%	82.48%	84.24%
2	Manufacturer number of sourcing and supplier *number of partnerships*					
	- in short-term collaboration (4 time unit)	79.50%	82.03%	81.15%	78.51%	81.15%
	- in long-term collaboration (80 time unit)	83.25%	100.00%	92.51%	93.17%	100.00%
3	*Manufacturer trust*					
	- in short-term collaboration (4 time unit)	79.50%	80.38%	83.03%	84.13%	68.48%
	- in medium-long-term collaboration (40 time unit)	75.86%	82.92%	80.93%	79.28%	71.01%
	- in long-term collaboration (80 time unit)	83.25%	74.32%	79.39%	80.16%	67.82%
4	*Manufacturer survivability*	84.13%	80.49%	79.50%	77.40%	75.42%
5	Manufacturer strategic movement	79.50%	84.79%	84.24%	85.34%	87.66%
Supply and demand market behaviour						
1	*Supplier trust*					
	- in short-term collaboration (4 time unit)	79.50%	78.40%	79.83%	79.61%	78.29%
	- in long-term collaboration (80 time unit)	83.25%	80.05%	82.92%	77.85%	82.81%
2	*Supplier survivability*	80.16%	79.28%	79.50%	75.97%	74.87%
3	*Customer loyalty*	79.50%	79.28%	81.37%	83.47%	69.36%

APPENDIX J: THE MANN-WHITNEY U-TEST RESULTS

This appendix shows the results of the Mann-Whitney U test, which are presented as follows.

J.1 *Duration of collaboration*

Table J.1 The Mann-Whitney U test of *supply chain fill rate* between all scenarios of *duration of collaboration* with *single-link firms* (with critical value -2.33)

Scenario	2 (20 *time unit*)	3 (40 *time unit*)	4 (60 *time unit*)	5 (80 *time unit*)
1 (4 *time unit*)	Z stat = -0.25 Do not reject H_0 *No significant difference*	Z stat = -1.05 Do not reject H_0 *No significant difference*	Z stat = -0.89 Do not reject H_0 *No significant difference*	Z stat = -1.5 Do not reject H_0 *No significant difference*
2 (20 *time unit*)		Z stat = -1.59 Do not reject H_0 *No significant difference*	Z stat = -0.75 Do not reject H_0 *No significant difference*	Z stat = -1.39 Do not reject H_0 *No significant difference*
3 (40 *time unit*)			Z stat = -1.93 Do not reject H_0 *No significant difference*	Z stat = -2.38 Reject H_0 *Scen.3 > Scen.5*
4 (60 *time unit*)				Z stat = -0.67 Do not reject H_0 *No significant difference*

Table J.2 The Mann-Whitney U test of the *number of supply chains in the market* between all scenarios of *duration of collaboration* with *single-link firms* (with critical value -2.33)

Scenario	2 (20 *time unit*)	3 (40 *time unit*)	4 (60 *time unit*)	5 (80 *time unit*)
1 (4 *time unit*)	Z stat = -1.41 Do not reject H null *No significant difference*	Z stat = -0.99 Do not reject H null *No significant difference*	Z stat = -1.47 Do not reject H null *No significant difference*	Z stat = -1.75 Do not reject H null *No significant difference*
2 (20 *time unit*)		Z stat = -0.4 Do not reject H null *No significant difference*	Z stat = -0.11 Do not reject H null *No significant difference*	Z stat = -0.5 Do not reject H null *No significant difference*
3 (40 *time unit*)			Z stat = -0.43 Do not reject H null *No significant difference*	Z stat = -0.77 Do not reject H null *No significant difference*
4 (60 *time unit*)				Z stat = -0.42 Do not reject H null *No significant difference*

Table J.3 The Mann-Whitney U test of *supply chain fill rate* between all scenarios of *duration of collaboration* with *dual-link firms* (with critical value -2.33)

Scenario	2 (20%)	3 (40%)	4 (60%)	5 (80%)
1 (4%)	Z stat = -2.51 Reject H_0 *Scen.1 > Scen.2*	Z stat = -2.21 Do not reject H_0 *No significant difference*	Z stat = -1.39 Do not reject H_0 *No significant difference*	Z stat = -2.41 Reject H_0 *Scen.1 > Scen.5*
2 (20%)		Z stat = -0.4 Do not reject H_0 *No significant difference*	Z stat = -0.93 Do not reject H_0 *No significant difference*	Z stat = -0.13 Do not reject H_0 *No significant difference*
3 (40%)			Z stat = -0.62 Do not reject H_0 *No significant difference*	Z stat = -0.2 Do not reject H_0 *No significant difference*
4 (60%)				Z stat = -0.78 Do not reject H_0 *No significant difference*

Table J.4 The Mann-Whitney U test of the *number of supply chains in the market* between all scenarios of *duration of collaboration* with *dual-link firms*

Scenario	2 (20%)	3 (40%)	4 (60%)	5 (80%)
1 (4%)	Z stat = -2.06 Do not reject H_0 *No significant difference*	Z stat = -3.33 Reject H_0 *Scen.1 > Scen.3*	Z stat = -2.93 Reject H_0 *Scen.1 > Scen.4*	Z stat = -3.5 Reject H_0 *Scen.1 > Scen.5*
2 (20%)		Z stat = -1.45 Do not reject H_0 *No significant difference*	Z stat = -1.03 Do not reject H_0 *No significant difference*	Z stat = -1.63 Do not reject H_0 *No significant difference*
3 (40%)			Z stat = -0.3 Do not reject H_0 *No significant difference*	Z stat = -0.03 Do not reject H_0 *No significant difference*
4 (60%)				Z stat = -0.22 Do not reject H_0 *No significant difference*

J.2 *Number of partnerships*

Table J.5 The Mann-Whitney U test of *supply chain fill rate* between all scenarios of *number of partnerships* in *short-term* partnerships (with critical value -2.33)

Scenario	2 (2%)	3 (3%)	4 (4%)	5 (5%)
1 (1%)	Z stat = -2.22 Do not reject H null *No significant difference*	Z stat = -0.35 Do not reject H null *No significant difference*	Z stat = -0.68 Do not reject H null *No significant difference*	Z stat = -0.58 Do not reject H null *No significant difference*
2 (2%)		Z stat = -1.25 Do not reject H null *No significant difference*	Z stat = -2.19 Do not reject H null *No significant difference*	Z stat = -1.38 Do not reject H null *No significant difference*
3 (3%)			Z stat = -0.47 Do not reject H null *No significant difference*	Z stat = -0.06 Do not reject H null *No significant difference*
4 (4%)				Z stat = -0.78 Do not reject H null *No significant difference*

Table J.6 The Mann-Whitney U test of the *number of supply chains in the market* between all scenarios of *number of partnerships* in *short-term* partnerships (with critical value -2.33)

Scenario	2 (2%)	3 (3%)	4 (4%)	5 (5%)
1 (1%)	Z stat = -1.62 Do not reject H_0 *No significant difference*	Z stat = -1.47 Do not reject H_0 *No significant difference*	Z stat = -1.69 Do not reject H_0 *No significant difference*	Z stat = -1.69 Do not reject H_0 *No significant difference*
2 (2%)		Z stat = -2.83 Reject H_0 *Scen.2 < Scen.3*	Z stat = -3.06 Reject H_0 *Scen.2 < Scen.4*	Z stat = -3.07 Reject H_0 *Scen.2 < Scen.5*
3 (3%)			Z stat = -0.26 Do not reject H_0 *No significant difference*	Z stat = -0.05 Do not reject H_0 *No significant difference*
4 (4%)				Z stat = -0.16 Do not reject H_0 *No significant difference*

Table J.7 The Mann-Whitney U test of *supply chain fill rate* between all scenarios of *number of partnerships* in *long-term* partnerships (with critical value -2.33)

Scenario	2 (2%)	3 (3%)	4 (4%)	5 (5%)
1 (1%)	Z stat = -4.66 Reject H null *Scen.1 > Scen.2*	Z stat = -5.14 Reject H null *Scen.1 > Scen.3*	Z stat = -4.22 Reject H null *Scen.1 > Scen.4*	Z stat = -4.5 Reject H null *Scen.1 > Scen.5*
2 (2%)		Z stat = -0.19 Do not reject H null *No significant difference*	Z stat = -0.41 Do not reject H null *No significant difference*	Z stat = -0.08 Do not reject H null *No significant difference*
3 (3%)			Z stat = -0.73 Do not reject H null *No significant difference*	Z stat = -0.38 Do not reject H null *No significant difference*
4 (4%)				Z stat = -0.37 Do not reject H null *No significant difference*

Table J.8 The Mann-Whitney U test of the *number of supply chains in the market* between all scenarios of *number of partnerships* in *long-term* partnerships (with critical value -2.33)

Scenario	**2 (2%)**	**3 (3%)**	**4 (4%)**	**5 (5%)**
1 (1%)	Z stat = -5.39 Reject H_0 *Scen.1 > Scen.2*	Z stat = -5.68 Reject H_0 *Scen.1 > Scen.3*	Z stat = -6.12 Reject H_0 *Scen.1 > Scen.4*	Z stat = -5.27 Reject H_0 *Scen.1 > Scen.5*
2 (2%)		Z stat = -0.08 Do not reject H_0 *No significant difference*	Z stat = -0.15 Do not reject H_0 *No significant difference*	Z stat = -0.07 Do not reject H_0 *No significant difference*
3 (3%)			Z stat = -0.25 Do not reject H_0 *No significant difference*	Z stat = -0.01 Do not reject H_0 *No significant difference*
4 (4%)				Z stat = -0.2 Do not reject H_0 *No significant difference*

J.3 Manufacturer's *trust* of the supplier (*manufacturer trust*)

Table J.9 The Mann-Whitney U test of *supply chain fill rate* between all scenarios of the *manufacturer trust* in short-term collaboration (with critical value -2.33)

Scenario	**2 (25%)**	**3 (50%)**	**4 (75%)**	**5 (100%)**
1 (0%)	Z stat = -0.97 Do not reject H null *No significant difference*	Z stat = -2.54 Reject H null *Scen.1 > Scen.3*	Z stat = -3.52 Reject H null *Scen.1 > Scen.4*	Z stat = -3.21 Reject H null *Scen.1 < Scen.5*
2 (25%)		Z stat = -1.64 Do not reject H null *No significant difference*	Z stat = -2.53 Reject H null *Scen.2 > Scen.4*	Z stat = -3.8 Reject H null *Scen.2 < Scen.5*
3 (50%)			Z stat = -0.85 Do not reject H null *No significant difference*	Z stat = -4.86 Reject H null *Scen.3 < Scen.5*
4 (75%)				Z stat = -5.58 Reject H null *Scen.4 < Scen.5*

Table J.10 The Mann-Whitney U test of the *number of supply chains in the market* between all scenarios of the *manufacturer trust* in short-term collaboration (with critical value -2.33)

Scenario	2 (25%)	3 (50%)	4 (75%)	5 (100%)
1 (0%)	Z stat = -2.87 Reject H_0 *Scen.1 > Scen.2*	Z stat = -3.83 Reject H_0 *Scen.1 > Scen.3*	Z stat = -5.08 Reject H_0 *Scen.1 > Scen.4*	Z stat = -2.34 Reject H_0 *Scen.1 < Scen.5*
2 (25%)		Z stat = -1.34 Do not reject H_0 *No significant difference*	Z stat = -2.72 Reject H_0 *Scen.2 > Scen.4*	Z stat = -4.84 Reject H_0 *Scen.2 < Scen.5*
3 (50%)			Z stat = -1.15 Do not reject H_0 *No significant difference*	Z stat = -5.53 Reject H_0 *Scen.3 < Scen.5*
4 (75%)				Z stat = -6.51 Reject H_0 *Scen.4 < Scen.5*

Table J.11 The Mann-Whitney U test of *supply chain fill rate* between all scenarios of the *manufacturer trust* in long-term collaboration (with critical value -2.33)

Scenario	2 (25%)	3 (50%)	4 (75%)	5 (100%)
1 (0%)	Z stat = -1.65 Do not reject H_0 *No significant difference*	Z stat = -1.44 Do not reject H_0 *No significant difference*	Z stat = -0.6 Do not reject H_0 *No significant difference*	Z stat = -3.82 Reject H_0 *Scen.1 < Scen.5*
2 (25%)		Z stat = -0.49 Do not reject H_0 *No significant difference*	Z stat = -1.54 Do not reject H_0 *No significant difference*	Z stat = -2.79 Reject H_0 *Scen.2 < Scen.5*
3 (50%)			Z stat = -0.99 Do not reject H_0 *No significant difference*	Z stat = -2.8 Reject H_0 *Scen.3 < Scen.5*
4 (75%)				Z stat = -3.68 Reject H_0 *Scen.4 < Scen.5*

Table J.12 The Mann-Whitney U test of the *number of supply chains in the market* between all scenarios of the *manufacturer trust* in long-term collaboration (with critical value -2.33)

Scenario	2 (25%)	3 (50%)	4 (75%)	5 (100%)
1 (0%)	Z stat = -1.13 Do not reject H_0 *No significant difference*	Z stat = -0.63 Do not reject H_0 *No significant difference*	Z stat = -0.23 Do not reject H_0 *No significant difference*	Z stat = -4.17 Reject H_0 *Scen.1 < Scen.5*
2 (25%)		Z stat = -0.64 Do not reject H_0 *No significant difference*	Z stat = -0.98 Do not reject H_0 *No significant difference*	Z stat = -3.3 Reject H_0 *Scen.2 < Scen.5*
3 (50%)			Z stat = -0.37 Do not reject H_0 *No significant difference*	Z stat = -3.83 Reject H_0 *Scen.3 < Scen.5*
4 (75%)				Z stat = -4.16 Reject H_0 *Scen.4 < Scen.5*

J.4 Supplier's *trust* towards manufacturer (*supplier trust*)

Table J.13 The Mann-Whitney U test of *supply chain fill rate* between all scenarios of the *supplier trust* in *short-term* collaboration (with critical value -2.33)

Scenario	2 (25%)	3 (50%)	4 (75%)	5 (100%)
1 (0%)	Z stat = -0.11 Do not reject H null *No significant difference*	Z stat = -0.26 Do not reject H null *No significant difference*	Z stat = -1.03 Do not reject H null *No significant difference*	Z stat = -0.2 Do not reject H null *No difference*
2 (25%)		Z stat = -0.3 Do not reject H null *No difference*	Z stat = -1.01 Do not reject H null *No difference*	Z stat = -0.32 Do not reject H null *No difference*
3 (50%)			Z stat = -0.71 Do not reject H null *No difference*	Z stat = -0.04 Do not reject H null *No difference*
4 (75%)				Z stat = -0.77 Do not reject H null *No difference*

Table J.14 The Mann-Whitney U test of the *number of supply chains in the market* between all scenarios of the *supplier trust* in *short-term* collaboration (with critical value -2.33)

Scenario	2 (25%)	3 (50%)	4 (75%)	5 (100%)
1 (0%)	Z stat = -0.45 Do not reject H null *No significant difference*	Z stat = -0.9 Do not reject H null *No significant difference*	Z stat = -1.23 Do not reject H null *No significant difference*	Z stat = -0.58 Do not reject H null *No difference*
2 (25%)		Z stat = -0.53 Do not reject H null *No difference*	Z stat = -0.83 Do not reject H null *No difference*	Z stat = -0.14 Do not reject H null *No difference*
3 (50%)			Z stat = -0.3 Do not reject H null *No difference*	Z stat = -0.47 Do not reject H null *No difference*
4 (75%)				Z stat = -0.63 Do not reject H null *No difference*

Table J.15 The Mann-Whitney U test of *supply chain fill rate* between all scenarios of the *supplier trust* in *long-term* collaboration (with critical value -2.33)

Scenario	2 (25%)	3 (50%)	4 (75%)	5 (100%)
1 (0%)	Z stat = -1.08 Do not reject H null *No significant difference*	Z stat = 0 Do not reject H null *No significant difference*	Z stat = -1.42 Do not reject H null *No significant difference*	Z stat = -0.13 Do not reject H null *No significant difference*
2 (25%)		Z stat = -1.38 Do not reject H null *No significant difference*	Z stat = -0.09 Do not reject H null *No significant difference*	Z stat = -1.44 Do not reject H null *No significant difference*
3 (50%)			Z stat = -1.83 Do not reject H null *No significant difference*	Z stat = -0.18 Do not reject H null *No significant difference*
4 (75%)				Z stat = -1.91 Do not reject H null *No significant difference*

Table J.16 The Mann-Whitney U test of the *number of supply chains in the market* between all scenarios of the *supplier trust* with *long-term*

Scenario	2 (25%)	3 (50%)	4 (75%)	5 (100%)
1 (0%)	Z stat = -1 Do not reject H_0 *No significant difference*	Z stat = -1.45 Do not reject H_0 *No significant difference*	Z stat = -0.78 Do not reject H_0 *No significant difference*	Z stat = -1.76 Do not reject H_0 *No significant difference*
2 (25%)		Z stat = -2.39 Reject H_0 *Scen.2 > Scen.3*	Z stat = -1.7 Do not reject H_0 *No significant difference*	Z stat = -2.77 Reject H_0 *Scen.2 > Scen.5*
3 (50%)			Z stat = -0.63 Do not reject H_0 *No significant difference*	Z stat = -0.2 Do not reject H_0 *No significant difference*
4 (75%)				Z stat = -0.85 Do not reject H_0 *No significant difference*

J.5 *Customer loyalty*

Table J.17 The Mann-Whitney U test of *supply chain fill rate* between all scenarios of the *customer trust/loyalty* (with critical value -2.33)

Scenario	2 (25%)	3 (50%)	4 (75%)	5 (100%)
1 (0%)	Z stat = -0.57 Do not reject H_0 *No significant difference*	Z stat = -2 Do not reject H_0 *No significant difference*	Z stat = -3.59 Reject H_0 *Scen.1 > Scen.4*	Z stat = -3.71 Reject H_0 *Scen.1 < Scen.5*
2 (25%)		Z stat = -1.25 Do not reject H_0 *No difference*	Z stat = -2.81 Reject H_0 *Scen.2 > Scen.4*	Z stat = -3.97 Reject H_0 *Scen.2 < Scen.5*
3 (50%)			Z stat = -1.9 Do not reject H_0 *No difference*	Z stat = -5.31 Reject H_0 *Scen.3 < Scen.5*
4 (75%)				Z stat = -6.22 Reject H_0 *Scen.4 < Scen.5*

Table J.18 The Mann-Whitney U test of the *number of supply chains in the market* between all scenarios of the *customer trust/loyalty* (with critical value -2.33)

Scenario	2 (25%)	3 (50%)	4 (75%)	5 (100%)
1 (0%)	Z stat = -2.38 Reject H_0 *Scen.1 > Scen.2*	Z stat = -4.26 Reject H_0 *Scen.1 > Scen.3*	Z stat = -6.51 Reject H_0 *Scen.1 > Scen.4*	Z stat = -7.62 Reject H_0 *Scen.1 > Scen.5*
2 (25%)		Z stat = -2.1 Do not reject H_0 *No difference*	Z stat = -5.03 Reject H_0 *Scen.2 > Scen.4*	Z stat = -6.63 Reject H_0 *Scen.2 > Scen.5*
3 (50%)			Z stat = -3.75 Reject H_0 *Scen.3 > Scen.4*	Z stat = -5.96 Reject H_0 *Scen.3 > Scen.5*
4 (75%)				Z stat = -2.66 Reject H_0 *Scen.4 > Scen.5*

J.6 The *manufacturer survivability*

Table J.19 The Mann-Whitney U test of *supply chain fill rate* between all scenarios of *manufacturer survivability* (with critical value -2.33 and 0% manufacturer *strategic mutation*)

Scenario	2 (16 *time unit*)	3 (20 *time unit*)	4 (24 *time unit*)	5 (28 *time unit*)
1 (12 *time unit*)	Z stat = -2.12 Do not reject H_0 *No significant difference*	Z stat = -3.39 Reject H_0 *Scen.1 < Scen.3*	Z stat = -3.52 Reject H_0 *Scen.1 < Scen.4*	Z stat = -3.98 Reject H_0 *Scen.1 < Scen.5*
2 (16 *time unit*)		Z stat = -1.23 Do not reject H_0 *No significant difference*	Z stat = -1.51 Do not reject H_0 *No significant difference*	Z stat = -1.93 Do not reject H_0 *No significant difference*
3 (20 *time unit*)			Z stat = -0.54 Do not reject H_0 *No significant difference*	Z stat = -0.85 Do not reject H_0 *No significant difference*
4 (24 *time unit*)				Z stat = -0.24 Do not reject H_0 *No significant difference*

Table J.20 The Mann-Whitney U test of the *number of supply chains in the market* between all scenarios of *manufacturer survivability* (with critical value -2.33 and 0% manufacturer *strategic mutation*)

Scenario	2 (16 *time unit*)	3 (20 *time unit*)	4 (24 *time unit*)	5 (28 *time unit*)
1 (12 *time unit*)	Z stat = -4.45 Reject H_0 *Scen.1 < Scen.2*	Z stat = -6.28 Reject H_0 *Scen.1 < Scen.3*	Z stat = -6.29 Reject H_0 *Scen.1 < Scen.4*	Z stat = -6.86 Reject H_0 *Scen.1 < Scen.5*
2 (16 *time unit*)		Z stat = -3.53 Reject H_0 *Scen.2 < Scen.3*	Z stat = -3.96 Reject H_0 *Scen.2 < Scen.4*	Z stat = -4.83 Reject H_0 *Scen.2 < Scen.5*
3 (20 *time unit*)			Z stat = -0.94 Do not reject H_0 *No significant difference*	Z stat = -1.63 Do not reject H_0 *No significant difference*
4 (24 *time unit*)				Z stat = -0.61 Do not reject H_0 *No significant difference*

J.7 The *supplier survivability*

Table J.21 The Mann-Whitney U test of *supply chain fill rate* between all scenarios of probability of *supplier survivability* (with critical value -2.33)

Scenario	2 (2 *time unit*)	3 (4 *time unit*)	4 (6 *time unit*)	5 (8 *time unit*)
1 (1 *time unit*)	Z stat = -0.92 Do not reject H_0 *No significant difference*	Z stat = -1.3 Do not reject H_0 *No significant difference*	Z stat = -1.68 Do not reject H_0 *No significant difference*	Z stat = -2.38 Reject H_0 *Scen.1 < Scen.5*
2 (2 *time unit*)		Z stat = -0.24 Do not reject H_0 *No significant difference*	Z stat = -0.77 Do not reject H_0 *No significant difference*	Z stat = -1.1 Do not reject H_0 *No significant difference*
3 (4 *time unit*)			Z stat = -0.47 Do not reject H_0 *No significant difference*	Z stat = -0.82 Do not reject H_0 *No significant difference*
4 (6 *time unit*)				Z stat = -0.35 Do not reject H_0 *No significant difference*

Table J.22 The Mann-Whitney U test of the *number of supply chains in the market* between all scenarios of *supplier survivability* (with critical value -2.33)

Scenario	2 (2 *time unit*)	3 (4 *time unit*)	4 (6 *time unit*)	5 (8 *time unit*)
1 (1 *time unit*)	Z stat = -1.99 Do not reject H_0 *No significant difference*	Z stat = -3.15 Reject H_0 *Scen.1 < Scen.3*	Z stat = -3.04 Reject H_0 *Scen.1 < Scen.4*	Z stat = -4.1 Reject H_0 *Scen.1 < Scen.5*
2 (2 *time unit*)		Z stat = -1.24 Do not reject H_0 *No significant difference*	Z stat = -1.19 Do not reject H_0 *No significant difference*	Z stat = -2.26 Do not reject H_0 *No significant difference*
3 (4 *time unit*)			Z stat = -0.02 Do not reject H_0 *No significant difference*	Z stat = -1.06 Do not reject H_0 *No significant difference*
4 (6 *time unit*)				Z stat = -1.01 Do not reject H_0 *No significant difference*

J.8 Manufacturer strategic movement

Table J.23 The Mann-Whitney U test of *supply chain fill rate* between all scenarios of *manufacturer strategic movement*

Scenario	2 (16 *time unit*)	3 (20 *time unit*)	4 (24 *time unit*)	5 (28 *time unit*)
1 (12 *time unit*)	Z stat = -2.12 Do not reject H null *No significant difference*	Z stat = -3.39 Reject H null *Scen.1 < Scen.3*	Z stat = -3.52 Reject H null *Scen.1 < Scen.4*	Z stat = -3.98 Reject H null *Scen.1 < Scen.5*
2 (16 *time unit*)		Z stat = -1.23 Do not reject H null *No difference*	Z stat = -1.51 Do not reject H null *No difference*	Z stat = -1.93 Do not reject H null *No difference*
3 (20 *time unit*)			Z stat = -0.54 Do not reject H null *No difference*	Z stat = -0.85 Do not reject H null *No difference*
4 (24 *time unit*)				Z stat = -0.24 Do not reject H null *No difference*

Table J.24 The Mann-Whitney U test of the *number of supply chains in the market* between all scenarios of *manufacturer strategic movement*

Scenario	**2 (16 *time unit*)**	**3 (20 *time unit*)**	**4 (24 *time unit*)**	**5 (28 *time unit*)**
1 (12 *time unit*)	Z stat = -4.45 Reject H null *Scen.1 < Scen.2*	Z stat = -6.28 Reject H null *Scen.1 < Scen.3*	Z stat = -6.29 Reject H null *Scen.1 < Scen.4*	Z stat = -6.86 Reject H null *Scen.1 < Scen.5*
2 (16 *time unit*)		Z stat = -3.53 Reject H null *Scen.2 < Scen.3*	Z stat = -3.96 Reject H null *Scen.2 < Scen.4*	Z stat = -4.83 Reject H null *Scen.2 < Scen.5*
3 (20 *time unit*)			Z stat = -0.94 Do not reject H null *No difference*	Z stat = -1.63 Do not reject H null *No difference*
4 (24 *time unit*)				Z stat = -0.61 Do not reject H null *No difference*