



**THE UNIVERSITY  
of LIVERPOOL**

**THE DEVELOPMENT OF A MULTI-TIER SUPPLY CHAIN  
PERFORMANCE MEASUREMENT SYSTEM FOR THE  
AUTOMOTIVE INDUSTRY**

Thesis submitted in accordance with the requirement of the  
University of Liverpool for the degree of Doctor of Philosophy

By

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献给我的父亲(丘日光), 母亲(林锦花)

与弟妹们(静怡, 静玲, 国奕)

## **ABSTRACT**

“Future Supply Innovations” (FUSION) is a research initiative based in the University of Liverpool to explore the best SC solution for mass customisation industry, especially the automotive SCs. This research is to find a SCPM system to facilitate FUSION research purpose. However, the extensive literature review shows that all the major SCPM systems were not suitable for FUSION research purpose for one or more than one of the following reasons:

1. Single-tier or dyadic measures.
2. Single-measure systems that focus on one specific SC performance. In other words, these measurement systems are not balanced approach.
3. Based on theoretical concepts that have not been verified by empirical study.
4. Emphasis on qualitative assessment like survey and questionnaire, which solely depend on individual’ subjective judgement to assess performance.
5. Too lengthy and complicated procedure, thus are not practical to be applied in commercial environment.

Therefore, the main contribution of this research is the provision of a systematic and quantitative multi-tier SCPM system without these drawbacks. This measurement system was presented in scorecard format and the measures were selected based on the SC strategies adopted by the automotive SCs in the case studies – cost reduction and responsiveness enhancement. There are four measurement groups within the scorecard, each assesses SC performance from different perspectives - demand synchronisation, responsiveness, reliability and cost. Each measurement group contains two metrics that focus on individual SC level performance. Then the collective performance of these individual SC level provides the performance indication for the entire SC. The empirical results from the case studies have verified the feasibility and applicability of this SCPM scorecard. A toolkit was also included to assist user to develop or replicate the scorecard.

In summary, the main knowledge contributions from this research are:

- A unique SCPM scorecard that provides a systematic, multi-tier, balanced and empirically proven quantitative method to evaluate automotive SC performance, which fulfils the 11 SCPM success factors identified in the literature review.
- The 11 SCPM system success factors identified can be used as a concise guideline to facilitate SCPM design process, helping industrialists and researchers to build their own SC measures, or to improve an existing measurement system. Apart from that, it can also serve as a generic improvement guideline for companies from any industries that seek to enhance their SC performance.
- This research has also revealed that cost reduction and responsiveness enhancement are the accepted automotive SC strategies, and the scorecard provides an additional, sophisticated input.
- The case studies results has also provided empirical evidence on the design elements that affect an automotive SC performance in demand synchronisation, responsiveness, reliability and cost – SILS, IS and the proximity between SC members.

Although the measurement scorecard was only tested on automotive SCs, the author is confident that the scorecard is also applicable to other non-automotive SCs. This is because automotive SC is one of the most complicated SCs in the business world. As long as the measures are carefully selected according to the SC strategies, the scorecard can be adopted to measure other SCs. This scorecard will also be useful for both automotive (vehicle manufacturers, suppliers in the automotive industry, third party logistics service providers) and non-automotive parties (researchers, consultants).

During the literature review, the author has also identified 11 factors that can help to design an effective SCPM system. The significant influences of these factors to achieve an effective SCPM system are supported by other researchers. These identified factors served as a concise guideline to facilitate SCPM design process and were taken into account during the scorecard development process in this research.



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# **TABLE OF CONTENTS**

## **DECLARATION**

<b>ABSTRACT</b>	<b>i - ii</b>
-----------------	---------------

<b>ACKNOWLEDGEMENTS</b>	<b>iii</b>
-------------------------	------------

<b>TABLE OF CONTENTS</b>	<b>v - viii</b>
--------------------------	-----------------

<b>LIST OF FIGURES</b>	<b>ix - x</b>
------------------------	---------------

<b>LIST OF TABLES</b>	<b>xi - xiii</b>
-----------------------	------------------

<b>LIST OF EQUATIONS</b>	<b>xiv</b>
--------------------------	------------

<b>ACRONYMS</b>	<b>xv</b>
-----------------	-----------

<b>CHAPTER ONE: INTRODUCTION. ....</b>	<b>1 - 24</b>
--	---------------

1.1 Introduction	1
1.2 Research Background	2
1.2.1 Supply Chain	2
1.2.2 Automotive Supply Chain	4
1.2.3 Supply Chain Performance Measurement	6
1.3 Research Questions	9
1.4 Research Objectives	10
1.5 Research Methodology	11
1.5.1 Literature Review Methodology	12
1.5.2 SCPM Framework Development Methodology	13
1.5.3 Case Study Methodology	15
1.6 Thesis Overview	21
1.7 Chapter Summary	24

<b>CHAPTER TWO: LITERATURE REVIEW.....</b>	<b>25 - 152</b>
--	-----------------

2.1 Introduction	25
2.2 Supply Chain Management	26
2.2.1 What is a Supply Chain?	26
2.2.2 What is Supply Chain Management?	28
2.2.3 Significance of Supply Chain Management	34
2.3 Supply Chain Performance Measurements	35
2.3.1 Introduction	35
2.3.2 Historic Review	39
2.3.3 SCPM Success Factors	42
2.3.4 Measurement Type	54
2.3.5 Multi-Measure Measurements	56
2.3.5.1 Vendor Rating System/Supplier Performance Measurement	58
2.3.5.2 The Supply Chain Excellence's Keys proposed by Stewart (1995)	60

2.3.5.3	SCOR Model (Supply Chain Council)	62
2.3.5.4	Process Quality Model (Beamon and Ware, 1998)	66
2.3.5.5	van Hoek's Approach (1998)	67
2.3.5.6	Strategic Audit Framework (Gilmour, 1999)	70
2.3.5.7	Beamon's Approach (1999)	73
2.3.5.8	Shin et al., 2000	74
2.3.5.9	Balanced Scorecard (Brewer and Speh, 2000)	76
2.3.5.10	Supply Chain Metrics Framework (Lambert and Pohlen, 2001)	78
2.3.5.11	Gunasekeran et al.'s Framework (2001)	79
2.3.5.12	Balanced Measurement Approach (Bullinger et al., 2002)	80
2.3.4.13	Supply Chain Audit Check Sheets (Waller, 2003)	83
2.3.5.14	Process Based Approach (Chan and Qi, 2003-a,b,c)	84
2.3.6	Single-Measure Measurements	86
2.3.6.1	Bullwhip Effect	87
2.3.6.2	Cost	97
2.3.6.3	Cash-to-Cash (C2C) Cycle Time	108
2.3.6.4	Logistics	109
2.3.6.5	Integration Level	119
2.3.6.6	Responsiveness	126
2.3.6.7	Inventory	131
2.3.7	Literature Review Summary	133
2.4	Information Sharing	136
2.4.1	Introduction	136
2.4.2	Benefits of Information Sharing	138
2.4.3	Factors that Affect Information Sharing	144
2.4.4	Development of Information Sharing	147
2.5	Chapter Summary	151

### **CHAPTER THREE: DEVELOPMENT OF SUPPLY CHAIN PERFORMANCE MEASUREMENT FRAMEWORK.....153 - 180**

3.1	Introduction	153
3.2	The Scorecard	154
3.2.1	Introduction	154
3.2.2	Demand Synchronisation Measures	156
3.2.3	Responsiveness Measures	158
3.2.4	Reliability Measures	159
3.2.5	Cost Measures	161
3.2.6	Summary Scorecard	164
3.3	The SCPM Success Factors	164
3.3.1	Strategy Alignment	165
3.3.1.1	SC Strategies in Automotive Industry	165
3.3.1.2	Demand Synchronisation Measures	166
3.3.1.3	Responsiveness Measures	167
3.3.1.4	Reliability Measures	171
3.3.1.5	Cost Measures	173
3.3.2	Balanced Measurement	174
3.3.3	Appropriate Quantity Metrics	175

3.3.4	Quantifiable Metrics	175
3.3.5	Compatible Metrics	176
3.3.6	System Thinking	176
3.3.7	Universality	177
3.3.8	Involvement	177
3.3.9	Understanding of Existing SCPM Systems	178
3.3.10	Corporate Culture	178
3.3.11	Distinction Between Metrics Level	179
3.4	Chapter Summary	179

## **CHAPTER FOUR: CASE STUDIES.....181 - 233**

4.1	Introduction	181
4.2	Case Study Methodology	182
4.3	Sequenced In Line Supply (SILS)	184
4.4	Seat Module Supply Chain	187
4.5	Case Study 1 – SC A	188
4.5.1	Background Information	188
4.5.2	Supply Chain Information Sharing System	192
4.5.3	Results	193
4.5.3.1	Demand MAD	193
4.5.3.2	Bullwhip Coefficient	196
4.5.3.3	Inventory Level	198
4.5.3.4	Dock-to-Dock Time	200
4.5.3.5	Stockout and Backorder Level	201
4.5.3.6	Transportation Cost	201
4.5.3.7	Inventory Carrying Cost	202
4.6	Case Study 2 – SC B	204
4.6.1	Background Information	204
4.6.2	Supply Chain Information Sharing System	206
4.6.3	Results	208
4.6.3.1	Demand MAD	208
4.6.3.2	Bullwhip Coefficient	210
4.6.3.3	Inventory Level	212
4.6.3.4	Dock-to-Dock Time	214
4.6.3.5	Stockout and Backorder Level	214
4.6.3.6	Transportation Cost	215
4.6.3.7	Inventory Carrying Cost	216
4.7	Case Study 3 – SC C	218
4.7.1	Background Information	218
4.7.2	Supply Chain Information Sharing System	221
4.7.3	Results	223
4.7.3.1	Demand MAD	223
4.7.3.2	Bullwhip Coefficient	225
4.7.3.3	Inventory Level	227
4.7.3.4	Dock-to-Dock Time	229
4.7.3.5	Stockout and Backorder Level	229
4.7.3.6	Transportation Cost	230
4.7.3.7	Inventory Carrying Cost	230
4.8	Case Study Results Summary	232

4.9 Chapter Summary	233
---------------------	-----

## **CHAPTER FIVE: DISCUSSION.....234 - 264**

5.1 Introduction	234
5.2 Performance Analysis and Comparison	234
5.2.1 Introduction	234
5.2.2 Demand Synchronisation	236
5.2.3 Responsiveness	238
5.2.4 Reliability	241
5.2.5 Cost	242
5.2.6 Performance Summary	244
5.3 Supply Chain Elements for Optimum Performance	247
5.3.1 SILS	247
5.3.2 Information Sharing	248
5.3.2.1 Schedule Stability	249
5.3.2.2 Trust and Commitment	252
5.3.3 SC proximity	255
5.4 Novel Aspects and Applications of The Scorecard	256
5.5 Research Limitations	260
5.6 Chapter Summary	263

## **CHAPTER SIX: CONCLUSIONS.....265 - 274**

6.1 Introduction	265
6.2 Research Questions (Response)	266
6.3 Contributions to Knowledge	270
6.4 Further Work	272
6.5 Chapter Summary	274

## **REFERENCES.....275 – 294**

## **APPENDICIES.....205 – 320**

Appendix A: The SCOR Model Process Map	295
Appendix B: The Interpretation of Acronyms in the Petri net	296
Appendix C: Case Study Questionnaire	298
Appendix D: Daily Call In (DCI) Screenshot for SC A and B	300
Appendix E: An example of TLS Information for SC A and B	301
Appendix F: An example of CAT-3 Information for SC C	302
Appendix G: An example of WRA for SC C	303
Appendix H: SC A Inventory Carrying Cost without 3rd tier Supplier	304
Appendix I: SC B Inventory Carrying Cost without 3 <sup>rd</sup> tier Supplier	305

Appendix J: Conference Paper: Coleman, J.; Khoo, C.; Lyons, A. and Kehoe, D. (2002) "The Significance of Schedule Stability in e-Enabled Supply Chains", <i>Proceedings of the Production and Operations Management Society Conference</i> , San Francisco, April 2002	306
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Appendix K: Conference Paper: Khoo, C.W., Lyons, A.C. and Kehoe, D., "Supply Chain Performance Measurement", *Proceedings of the 18<sup>th</sup> International Conference on Computer-Aided Production Engineering*, Professional Engineering Publishing, March, 2003, pp. 279-288 307

Appendix L: Conference Paper: Khoo, C.W., Lyons, A.C., Mondragon, A.C. and Kehoe, D.F. (2003) "Supply chain performance measurement for the automotive industry", *Proceedings of the 2<sup>nd</sup> International Workshop on Supply Chain Management and Information Systems*, Hong Kong, July 2004 308

Appendix M: The Toolkit to Develop Scorecard 309

## **LIST OF FIGURES**

Figure 1.1: Concept of Supply Chain.....	3
Figure 1.2: Research Methodology.....	11
Figure 1.3: Case Study Methodology.....	18
Figure 1.4: Data Collected for Measurement.....	20
Figure 1.5: Thesis Overview.....	22
Figure 2.1: Supply Chain Research Overview (Beamon, 2003).....	30
Figure 2.2: Supply Chain Management Framework (Lambert <i>et al.</i> , 1998).....	31
Figure 2.3: Supply Chains Overlapping (Lambert <i>et al.</i> , 1998).....	41
Figure 2.4: Supply Chain Performance Measurement Methods Categorisation.....	57
Figure 2.5: The five Management Processes in the SCOR Model (Supply Chain Council, 2004).....	63
Figure 2.6: Three Level of Process Detail in SCOR Model (Supply Chain Council, 2004).....	64
Figure 2.7: The Process Quality Model (Beamon and Ware, 1998).....	67
Figure 2.8: Preliminary Framework for Supply Chain Performance System (van Hoek, 1998).....	69
Figure 2.9: The Gilmour's Supply Chain Audit Framework (Gilmour, 1999).....	71
Figure 2.10: Links Between Supply Chain Management to the Balanced Scorecard (Brewer and Speh, 2000).....	76
Figure 2.11: The Balanced Measurement Methodology (Bullinger <i>et al.</i> , 2002).....	81
Figure 2.12: An Example of PPMH Chan and Qi (2003-a).....	85
Figure 2.13: Supply Chain Management Costs (adapted from Morton, 1997).....	100
Figure 2.14: Supply Chain Costing Model by Mena <i>et al.</i> (2002).....	107
Figure 2.15: Supply Chain 2000 Framework (Bowersox <i>et al.</i> , 2000).....	111
Figure 2.16: Structure Of Dekker and Van Goor Model (2000).....	115
Figure 2.17: Rafele's Reference Framework (2004).....	116

Figure 2.18: Supply Chain Agility Audit Result (Adapted from van Hoek <i>et al.</i> , 2001).....	130
Figure 2.19: Supply Chain Inventory (Lambert and Bennion, 1982).....	133
Figure 4.1: SC A Seat Module Variety.....	188
Figure 4.2: Seat Module SC A (Khoo <i>et al.</i> , 2004).....	189
Figure 4.3: SC A Value Stream Map (Khoo <i>et al.</i> , 2003).....	191
Figure 4.4: The SILS Material and Information Flows in SC A.....	193
Figure 4.5: Seat Module SC B (Khoo <i>et al.</i> , 2004).....	205
Figure 4.6: SC B Value Stream Map.....	207
Figure 4.7: SC C Seat Module Supply Chain.....	219
Figure 4.8: SC C Value Stream Map.....	220
Figure 4.9: The SILS Information Flows in SC C.....	222
Figure 5.1: Demand Synchronisation Metrics Comparison.....	238
Figure 5.2: The Influence of SILS on Automotive SC Performance.....	246
Figure 5.3: Premium Freight vs. Schedule Adherence (Coleman <i>et al.</i> , 2002).....	251



## **LIST OF TABLES**

Table 2.1: Summary on SC Measurement Criteria (Adapted from Schmitz and Platts, 2003, a).....	40
Table 2.2: Common Metrics in Supplier Performance Measurement (Kemp, 2003) ..	59
Table 2.3: Summary of Vendor Rating System Literature.....	60
Table 2.4: Performance attributes and Top Level Metrics (Supply Chain Council, 2004).....	65
Table 2.5: The Supply Chain Capability Components (Gilmour, 1999).....	72
Table 2.6: Goals of Performance Measure Types (Beamon, 1999).....	73
Table 2.7: The SMO Survey Questionnaire (Shin <i>et al.</i> , 2000).....	75
Table 2.8: Supply Chain Performance Metrics Framework (Gunasekaran <i>et al.</i> , 2003).....	80
Table 2.9: Possible Supply Chain Performance Indicators (Bullinger <i>et al.</i> , 2002)...	82
Table 2.10: Financial Measurement Analysis (Waller, 2003).....	84
Table 2.11: The Causes and Counter-measures of the Bullwhip Effect (Lee <i>et al.</i> , 1997 a).....	89
Table 2.12: A Framework for SC Coordination Initiatives (Lee <i>et al.</i> , 1997 b).....	90
Table 2.13: Bullwhip Effect Measures at Different Aggregation Levels (Fransoo and Wouters, 200).....	94
Table 2.14: Bullwhip Across Two Observed Echelons Before and After the Improvement (McCullen and Towill, 2001).....	95
Table 2.15: The Total Cost Measurement (Viswanadham and Srinivasa Raghavan, 2000).....	105
Table 2.16: Performance Metrics used in Supply Chain 2000 Framework (Bowersox <i>et al.</i> , 2000).....	112
Table 2.17: The Example Metrics for Logistics Performance (Adapted from Rafele, 2004).....	118
Table 2.18: The Measure in Path Analysis (Kwon and Suh, 2005).....	123
Table 3.1: The Scorecard.....	155
Table 3.2: The Scorecard Balance Measurement.....	175

Table 4.1: Average Demand Volume of Seat Modules.....	187
Table 4.2: SC A Case Study Seat Modules.....	188
Table 4.3: Demand MAD Results for SC A.....	195
Table 4.4: Bullwhip Coefficient Results for SC A.....	197
Table 4.5: Inventory Level Results for SC A.....	199
Table 4.6: Dock-to-Dock Time Results for SC A.....	200
Table 4.7: Transportation Cost for SC A.....	202
Table 4.8: Inventory Carrying Cost for SC A.....	203
Table 4.9: SC B Case Study Seat Modules.....	204
Table 4.10: Demand MAD Results for SC B.....	209
Table 4.11: Bullwhip Coefficient Results for SC B.....	211
Table 4.12: Inventory Level Results for SC B.....	213
Table 4.13: Dock-to-Dock Time Results for SC B.....	214
Table 4.14: Transportation Cost for SC B.....	215
Table 4.15: Inventory Carrying Cost for SC B.....	217
Table 4.16: SC C Case Study Seat Modules.....	218
Table 4.17: Demand MAD Results for SC C.....	224
Table 4.18: Bullwhip Coefficient Results for SC C.....	226
Table 4.19: Inventory Level Results for SC C.....	228
Table 4.20 Dock-to-Dock Time Results for SC C.....	229
Table 4.21: Transportation Cost for SC C.....	230
Table 4.22: Inventory Carrying Cost for SC C.....	231
Table 4.23: Case Studies Scorecard.....	232
Table 5.1: Case Studies Scorecard.....	235
Table 5.2: Demand Synchronisation Performance Summary.....	236

Table 5.3: Responsiveness Performance Summary.....	238
Table 5.4: <i>Dock-to-Dock Time</i> Summary Table.....	240
Table 5.5: Cost performance Summary.....	242
Table 5.6: Cost Performance Summary without 3 <sup>rd</sup> tier Supplier.....	243
Table 5.7: Cost Per Unit Material.....	244
Table 5.8: Performance Summary Table.....	244
Table M.1: Table for Demand MAD.....	309
Table M.2: Table for Bullwhip Coefficient .....	311
Table M.3: Table for Inventory Level.....	312
Table M.4: Table for Dock-to-Dock Time.....	314
Table M.5: Table for Stockout Level and Backorder Level .....	314
Table M.6: Table for Transportation Cost.....	316
Table M.7: Table for Inventory Carrying Cost.....	317
Table M.8: Summary Scorecard.....	320

**LIST OF EQUATIONS**

Equation 2.1: Bullwhip Coefficient proposed by Fransoo and Wouters (2000).....92

Equation 2.2: Bullwhip Coefficient proposed by Fransoo and Wouters (2000).....92

Equation 2.3: Bullwhip Coefficient proposed by Fransoo and Wouters (2000).....92

Equation 2.4: Bullwhip measure proposed by Disney and Towill (2003).....96

Equation 3.1: Demand MAD.....156

Equation 3.2: Bullwhip Coefficient.....157

Equation 3.3: Inventory Level.....158

Equation 3.4: Stockout Level.....160

Equation 3.5: Backorder Level.....160

Equation 3.6: Transportation Cost (per unit).....161

Equation 3.7: Transportation Cost (per month).....161

Equation 3.8: Inventory Value.....162

Equation 3.9: Loss of Interest.....162

Equation 3.10: Storage Cost.....162

Equation 3.11: Obsolescence cost.....163

Equation 3.12: Opportunity cost.....163

## **ACRONYMS**

CPFR: Collaborative Planning, Forecasting and Replenishment

DCI: Daily Call In; One of the demand forecast information transmitted from the car manufacturers to their 1st tier supplier in SILS

EDI: Electronic Data Interchange

ERP: Enterprise Resource Planning

FG: Finished Goods

FUSION: Future Supply Innovations, a research conducted by Dr. A.C. Lyons and Prof. D.F. Kehoe in University of Liverpool

IS: Information sharing

JIT: Just In Time

MAD: Mean Absolute Deviation

MTS: Make To Stock

OEM: Original equipment manufacturer

POS: Point Of Sale

RM: Raw Materials

SC: Supply chain

SCM: Supply chain management

SCPM: Supply chain performance measurement

SILS: Sequence In Line Supply; also known as Sequenced Supply

TLS: Target Launch Sequence

VMI: Vendor managed inventory

VSM: Value stream map

## CHAPTER 1: INTRODUCTION

---

### 1.1 Introduction

Supply chain management (SCM) is an integrative philosophy to manage supply chains (SCs) (Cooper and Ellram, 1993). It helps companies to efficiently integrate suppliers, manufacturers, warehouses and stores, so that their product or service can be produced and distributed at the right quantities, to the right locations, and at the right time (Simchi-Levi *et al.*, 2000). In order to achieve an effective SCM system, a measurement system has to be included because “you cannot manage what you do not measure” (David Gravin, 1993; Lambert *et al.*, 1998). A supply chain performance measurement (SCPM) system is a cross-organisational assessment process on SC effectiveness and efficiency towards achieving pre-determined goals. This definition is derived based on Beamon’s (2003) and Amaratunga and Baldry’s descriptions of performance measurement (2003).

The pressure from globalisation and technology advancement has intensified the competition in the automotive industry due to over-capacity and stagnating demand (Mara and Wilson, 1999). As a result, the automotive industry has become highly competitive and the rivalry among vehicle manufacturers has risen (Mara and Wilson, 1999; Lapiedra *et al.*, 2004). This has motivated the industry to move forward and to improve faster than other industries. Hence, “*it is seen as a flagship sector that epitomises the health of the economy*” (Childerhouse *et al.*, 2003; Helper, 1991). Since the automotive industry is one of the leading industries, the research focus of this thesis is to develop a SCPM system for automotive SCs.

In summary, this thesis spans the knowledge area of SCM, SCPM and the automotive industry. The next sections in this chapter elaborate on the background information of this research (Section 1.2) and the research questions (Section 1.3). Then in Section 1.4, the main objectives of this research are explained. Finally, the chapter ends with an overview of the whole thesis (Section 1.6).

## **1.2 Research Background**

### **1.2.1 Supply Chain**

A SC is a series of processes and activities to convert raw materials into an end product to consumers, including product design, manufacturing, warehousing and distributing (Franks, 2000). The members of a SC can be suppliers, manufacturing plants, warehouses, customers and distributors (Duclos *et al.*, 2003). The next generation of manufacturing SC will need a more innovative information and material flow (Lyons and Kehoe, 2000). Firms are looking beyond their own borders to their suppliers, suppliers' suppliers and customers in order to achieve overall consumer value.

However, the term "supply chain" has been used inconsistently. Many studies refer to "supply chain" as a logistics and distribution link between companies (Weber, 2002; Milgate, 2001; Beamon, 1989; Gilmour, 1999). The Council of Logistics Management has made a clarification between the term "supply chain" and "logistics":

“Logistics is the part of the supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services, and related information from the point-of-origin to the point-of-consumption in order to meet customers’ requirements.” (Council of Logistics, 1998)

In accordance with the definition of a SC, a SC measure should include more than one tier of a SC (Handfield and Nichols, 1999; Caplice and Sheffi, 1995). It is actually part of a supply network, which is also known as a value system, value stream or extended enterprise (Smith and Lockamy, 2000), as illustrated in Figure 1.1. Many companies tried to measure their SC performance, but these efforts have been limited to evaluating the performance of tier one suppliers, customers, or third-party providers (Lambert and Pohlen, 2001; Lau *et al.*, 2002; Bommer *et al.*, 2001).

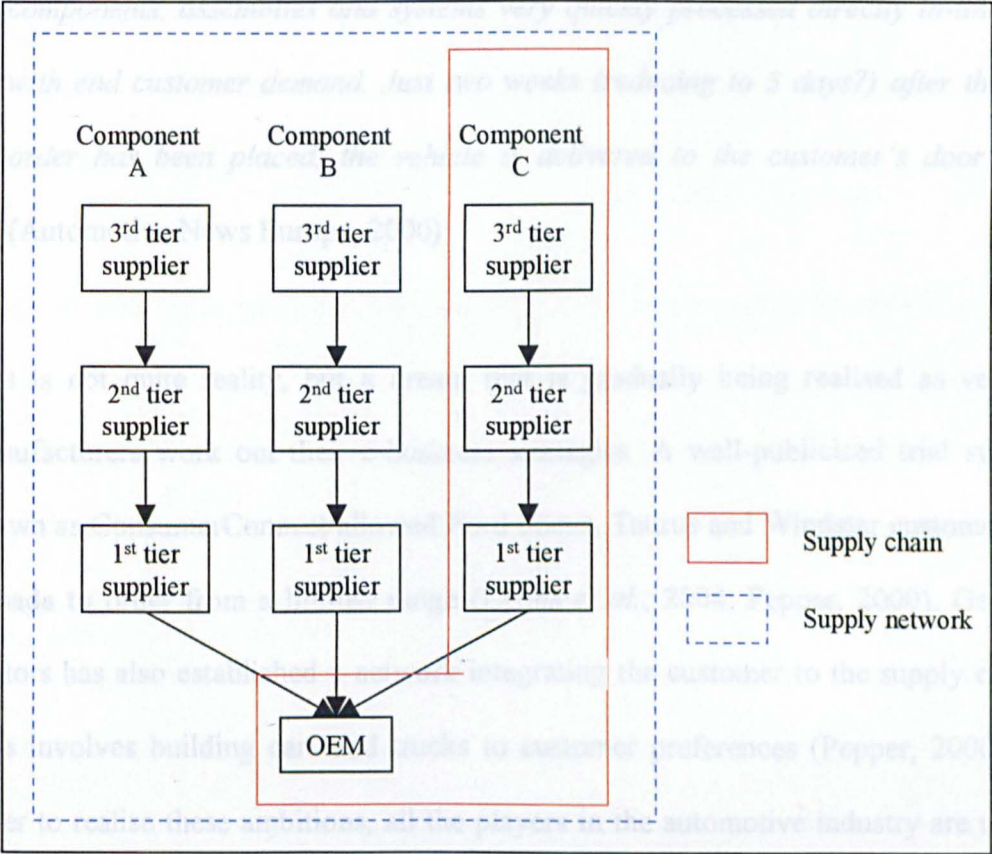


Figure 1.1: Concept of Supply Chain



### **1.2.2 Automotive Supply Chain**

The automotive industry has always been seen as the leader in supply management (Shin *et al.*, 2000) and an example for other industries (Childerhouse *et al.*, 2003; Helper, 1991). One of the most sophisticated applications of e-commerce to supply chain operations is envisaged by many within the world of automotive industry:

*... "A few quick clicks on the website, and the customer has chosen his perfect model, with the right engine, personalised in-car options, colour and trim. His order information has been instantaneously transmitted from the manufacturers website to suppliers, logistics partners and the assembly plant. Commodity deals are struck in an electronic market place, and components, assemblies and systems very quickly processed directly in-line with end customer demand. Just two weeks (reducing to 3 days?) after the order has been placed, the vehicle is delivered to the customer's door"*

(Automotive News Europe, 2000)

This is not quite reality, but a dream that is gradually being realised as vehicle manufacturers work out their e-business strategies. A well-publicised trial system known as ConsumerConnect allowed Ford Focus, Taurus and Windstar customers in Canada to order from a limited range (Lyons *et al.*, 2004; Pepper, 2000). General Motors has also established a network integrating the customer to the supply chain. This involves building cars and trucks to customer preferences (Pepper, 2000). In order to realise these ambitions, all the players in the automotive industry are under pressure to adopt new management techniques and new technologies, including

reengineering their SC structure, to maintain market share or just merely to survive (Childerhouse *et al.*, 2003).

Lyons and Kehoe's (2000) FUSION (Future Supply Innovations) research has stated five future trends of automotive SCs:

1. Automotive manufacturers will concentrate on core competencies while outsource non-core business to upstream suppliers.
2. The increase implementations of supplier parks and sequenced in-line supply (SILS).
3. A more extensive supplier implants where the suppliers will take control of inventory management and material handling, as well as take over part of the assembly process.
4. Suppliers will be assimilated into the vehicle manufacturers' virtual organisation.
5. Net-based supply chain for minimum SC inventory.

There are two distinctive characteristics that differentiate automotive SC from other industries' SC. The first characteristic is the state of technology. The automotive industry has the most advanced SCs of all manufacturing sectors (Compass, 2000), such as the continuous conveyer belt supply system in Ford supplier park in Spain and the SILS operated by some of Ford's assembly plants. These types of supply system require absolute precision and coordination between the suppliers and the OEM more than any other industries. Despite the technology, the wide product variety is the second characteristic that sets automotive SC apart from other industry. One of the automotive SCs studied in this research has more than 1 million different

combinations for a vehicle. This wide variation is not limited to end product, but also the materials or parts. A typical automotive production can involve more than 30,000 suppliers for both production and non-production materials (Schmitz and Platts, 2003-a; Dyer *et al.*, 1987;). By building a SCPM system based on a highly sophisticated SC structure such as automotive SC, the developed measurement system will be more versatile and adaptable to other non-automotive SCs with simpler structure.

Despite the industry leading status and the SC complexity, supply base is one of the key competences in automotive industry and performance measurement is one way to maintain this competency (Schmitz and Platts, 2003a; Lyons and Kehoe, 2000). Therefore, the author chose automotive SCs as the measurement subject in this research.

### **1.2.3 Supply Chain Performance Measurement**

A survey covering a wide range of industries showed that 30% of senior executives from some leading blue chip companies in the US do not have a formal system to measure their SC performance (The Economist Intelligence Unit and Meritus Consulting Services, 2000). Performance measurement is a process or a method to assess the effectiveness and/or efficiency of a system (Beamon, 2003). A well-structured and clearly defined performance measurement system for SCs is vital in SCM simply because “you cannot manage what you do not measure” (Garvin, 1993). By implementing a customised SCPM system, a SC may gain the following benefits and advantages:

1. Helps to visualise how SC members affect each other's performance and encourage cooperation between SC members (Lambert and Pohlen, 2001)
2. Helps the SC to meet customer expectations (Lee and Billington, 1992)
3. Identifies where opportunities exist to increase competitiveness (Lambert and Pohlen, 2001)
4. Support SCM (Lambert *et al.*, 1998)
5. Reduces the occurrence of conflicts caused by the variance between SC members' organisational objectives (Lambert and Pohlen, 2001).
6. Assesses the outcome of a new implementation in terms of individual SC members, as well as the entire SC (Lambert and Pohlen, 2001)
7. Helps to establish relationships between decision variables and performance outputs to create and maintain a high-performance system (Beamon, 2003)
8. Helps users to understand and control the measurement subject (Neely, 1998)
9. Provides information to stimulate appropriate action, encourage organisational learning and assist the decision-making process (Brignall and Ballantine, 1996).
10. Ensures that the end products meet customer expectations by synchronising the operations and processes throughout the SC (Lambert and Pohlen, 2001) because not all SC members have the opportunity of direct contact with the consumer.
11. Ensures that all the costs and profits are equally shared among the SC members and prevents local optimisation (Lambert and Pohlen, 2001).
12. Identifies areas that need to be improved or changed within the SC (Beamon, 1998)

Although the importance of performance measurement has been widely recognised, there is still a significant gap in theoretical and empirical knowledge (Schmitz and Platts, 2003, a). There is no generic SCPM solution that can suit all SCs because every SC has its unique characteristics, structure, operations and strategies that require a customised measurement system (Beamon, 1999; Rafele, 2004). Moreover, some existing SC measures are only focused on specific aspects of a SC, such as logistics or cost (Lambert and Polen, 2001). A SCPM should go beyond internal metric (Lee and Billington, 1992) and reach further than first tier suppliers (Lambert *et al.*, 1998). According to Bechtel and Jayaram (1997), there are no measures addressing a combination of integrated and non-integrated measures that can assess overall competitiveness of a SC using integrated measures, while enabling it to focus improvement efforts on individual SC level performance based on non-integrated measures. Most of the existing measurement systems are focused on particular segments of the chain and are not explicitly focused at, or applicable for, SC-wide measurement (LaLonde and Pohlen, 1996). The importance of a multi-tier SCPM is highlighted by the statement below:

*“Too often, assemblers focus only on their first tier suppliers when considering improvement initiatives, and they often fail to understand the implications of their decisions on the performance on those suppliers residing lower within the chain and therefore, are ignorant of the total cost to the whole system.”*

Lyons and Kehoe (2000)

### **1.3 Research Questions**

One of the research aims of FUSION research in University of Liverpool is to propose a performance measurement scorecard that span the entire SC and analyse its overall performance (Lyons and Kehoe, 2000). The main purpose of this thesis is to develop a SCPM system that corresponds to this FUSION research aims.

Although the importance of performance measurement has been widely recognised, there is still a significant gap in theoretical and empirical knowledge (Schmitz and Platts, 2003, a). There are few empirical analyses and case studies on performance metrics and measurements in a supply chain environment (Gunasekaran *et al.*, 2003; Lee and Billington, 1992; Lambert and Pohlen, 2001). Hence, more researches need to be carried out on SCPM (Cooper *et al.*, 1997; Beamon, 1999; Holmberg, 2000). In order to fulfill this knowledge gap and with all the background information stated in the Section 1.2 in mind, this research sought to answer the following questions:

1. What are the SC strategies deployed in automotive industry?
2. What are the criteria that facilitate an effective SCPM for automotive SCs?
3. Is there any existing SCPM system that is suitable to measure automotive SCs?
4. How to evaluate automotive SC performance?
5. What are the design elements that affect automotive SC performance?

## **1.4 Research Objectives**

The ultimate objective of this research is to provide an original multi-tier SCPM system. In order to answer the research questions and provides corresponding measurement solution to the FUSION research (Lyons and Kehoe, 2000), the following objectives have to be achieved:

1. To investigate the adequacy or appropriateness of existing supply chain performance measures
2. To investigate the design criteria to build an effective SCPM system.
3. To design an appropriate SCPM system customised for the automotive industry and applies the system in a range of automotive SCs.
4. To investigate the SC design elements that can help to achieve an optimum automotive SC performance in terms of cost and responsiveness.

1.5 Research Methodology

The main purpose of this section is to explain the research approach that was adopted to achieve the research objectives and answer the research questions. Figure 1.2 illustrates the research methodology that spans the Literature Review (Chapter Two), Development of Supply Chain Performance Measurement (SCPM) Framework (Chapter Three) and Case Studies (Chapter Four).

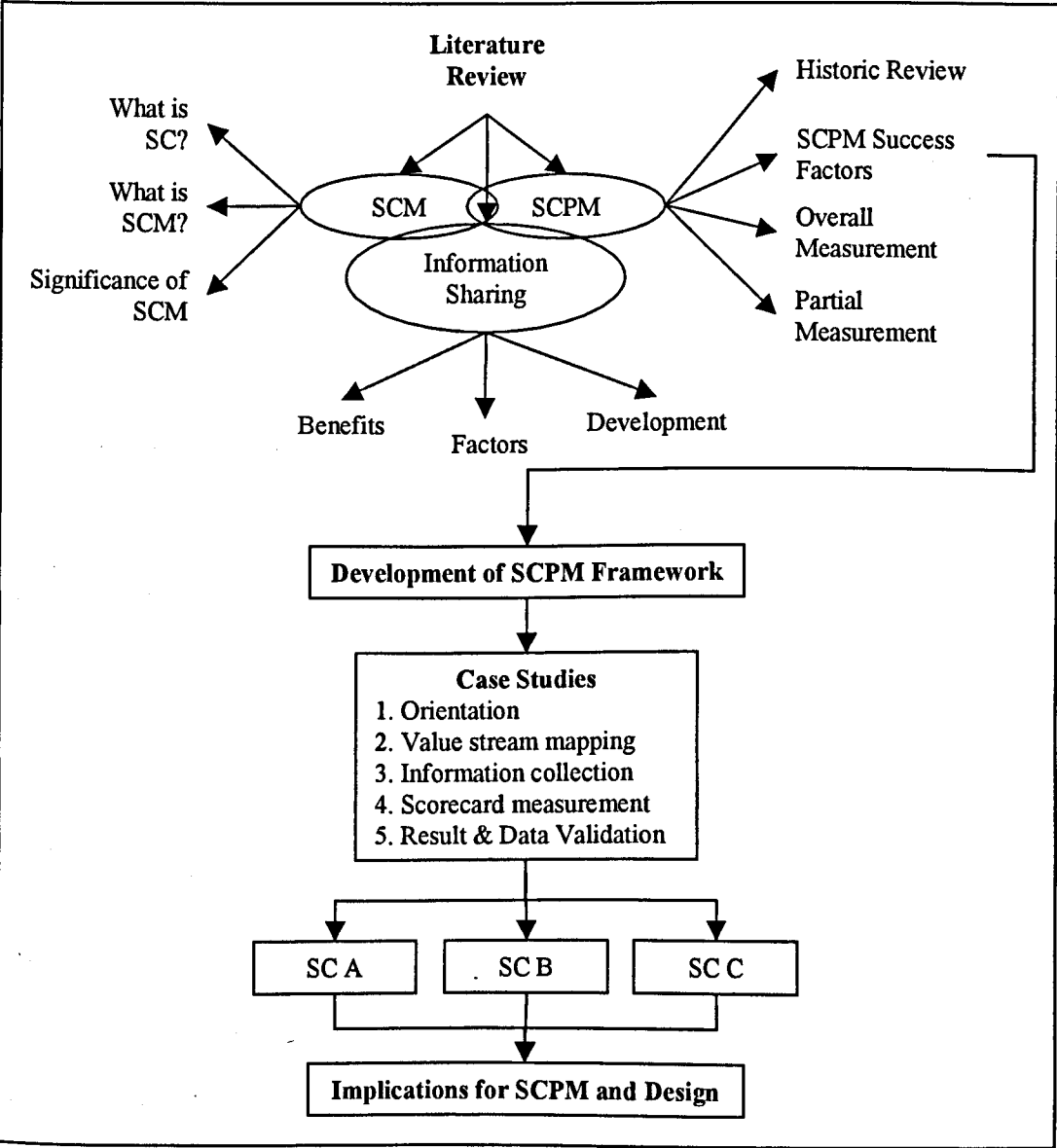


Figure 1.2: Research Methodology



As shown in Figure 1.2, the research methodology is broken down into three subcomponents, each with its own distinctive approach: the Literature Review, SCPM Scorecard Development and Case Study Methodology. The sections to follow present the approaches adopted for each subcomponent.

### **1.5.1 Literature Review Methodology**

The purpose of the literature review is to examine and appraise studies that were carried out and written by accredited scholars, researchers and practitioners to the knowledge areas that are relevant to this research. Therefore, the literature review started with the identification of all the topics that would need to be considered. Figure 1.2 shows the structure of the literature review process in this research. There are three theme topics in this literature review: supply chain management (SCM), SCPM and information sharing (IS).

The search process is to explore and collect all the literature for the relevant topics. Within these three topics, there are individuals and/or groups that are recognised experts. This became the first point of call for each of the topics. Then, the searching scope was extended to include other researchers' or scholars' works that also fall within the topic region.

An extensive search was carried out through the University library resources and other libraries resources (via Inter-Library Loan), including books, theses, journals, conference proceedings & papers, industrial magazines, both hard copy and electronic versions.

All the information and literature collected during the search were systematically organised according to the topics. Within each topic, the literature was reviewed in chronological order or grouped into specific clusters, as shown in Figure 1.2.

### **1.5.2 SCPM Framework Development Methodology**

As shown in Figure 1.2, one of the literature review topics concerned SCPM success factors. These are the criteria and features that many researchers and practitioners believe and advocate that a SCPM system should have to ensure an effective and successful measurement:

1. Alignment between strategy and measurement
2. Balanced measurement
3. Appropriate quantity of metrics
4. Quantifiable metrics
5. Compatible metrics
6. System thinking
7. Universality
8. Involvement
9. A thorough understanding of the existing measurement systems
10. Take into account the difference of corporate culture between SC members
11. A clear distinction between metrics at strategic, tactical, and operational levels

In this thesis, the SCPM scorecard was developed by taking these success criteria into consideration. The followings are a step-by-step description of the development process:

1. The measured groups were determined corresponding to the SC performance aspects that need to be measured in the measurement framework. (E.g. SC responsiveness, SC reliability)
2. Individual metrics were assigned to each measurement group. These metrics are the performance indicators of the measured aspect. The scorecard in this thesis contains two metrics in each measurement group. For example, the two metrics in the responsiveness measurement group are inventory level and dock-to-dock time. The details can be found in Chapter Three: Development of SCPM Framework.
3. Each metric was then defined in greater details, including how to perform the calculation, which data were needed for the calculations and where to obtain the data. This information can also be found in Chapter Three: Development of SCPM Framework.

### **1.5.3 Case Study Methodology**

Yin (1994) stated that the selection of research method is dependent on the type of research question, the influence level of the user on the events and the nature of research (either on contemporary or historical phenomenon). A case study approach has been adopted in this research. This is the method that uses case studies as its basis (Voss et al., 2002). Meredith (1998) defined case study research as:

*“...uses multiple methods and tools for data collection from a number of entities by a direct observer(s) in a single, natural setting that considers temporal and contextual aspects of the contemporary phenomenon under study, but without experimental controls or manipulations”.*

The case study approach is necessary to achieve the research objectives for the following reasons:

- The measurement scorecard developed in this research needs to be applied in a real life situation to justify its feasibility and validity. Case study approach evaluates the subject within its real-life context and natural settings (Benbasat *et al.*, 1987; Yin, 1994).
- This approach is suitable for research areas that are never been studied or the existing theory is inadequate (Eisenhardt, 1989). There are many existing SCPM models but there is no evidence of a multi-tier SC measurement system that is customised for automotive SC.

- This approach is also suitable for “how” and “why” research questions (Yin, 1994), which are the questions posed in this research.
- The approach allows user to have full understanding of the nature and complexity of the studied subject matter (Benbasat *et al.*, 1987). This is very beneficial to this research because automotive SCs are very complex, due to the number of organisations involved in the study, the SC technology and SC operations involved (e.g. SILS).
- The approach provides the possibility to gain insights that other approaches might not be able to provide (Rowley, 2002).

Three different cases were needed in this research in order to enhance the study's validity and prevent user bias (Voss *et al.*, 2002).

The case study methodology used in this research is depicted in Figure 1.3. There are five stages: orientation, value stream mapping, information collection, scorecard measurement, results and data validation.

The first stage (Orientation) sets out the foundation works to allow the case study to move forward. First, it starts by identifying and approaching the OEM (vehicle manufacturer) that was interested to take part in this research. Once the OEM agreed to participate in a case study, the OEM's supply network<sup>1</sup> was explored and the most suitable SC, usually the seat module SC, was selected as the case study subject. Then the members of this SC were contacted and invited to take part in the case study. This was generally expected that the downstream SC member (i.e. buyer) would initiate a request to its upstream SC member (i.e. supplier) to provide any help and

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<sup>1</sup> Supply network: A combination of different supply chains.

assistance necessary to complete the case study. With all the relevant SC members on board, project management guidelines were established to outline the persons to be consulted, sites visits, meetings and means of data collection. This was to ensure that:

- The requirements and directions of the case study was corresponded with the SC members objectives and target.
- All the parties involved were clear on the deliverables and potential outcomes from the study.
- The commitment from senior management was secured, in terms of resources and their support.

The second stage (Value Stream Mapping) is to organise, analyse and present the collected SC configuration information in a systematic manner. The output of this stage is a value stream map (VSM) that depicts the case study SC structure, in terms of material and information flow. The VSM serves as the case study blueprint to identify potential problem areas and provides a simplified illustration of the entire SC. A questionnaire (shown in Appendix C) was developed to collect the information required to construct VSM, such as company size, product range, production process, supply details and product delivery. However, the questionnaire is only used to gather initial information to identify which companies are suitable to be studied. It is not the core method to collect performance information.

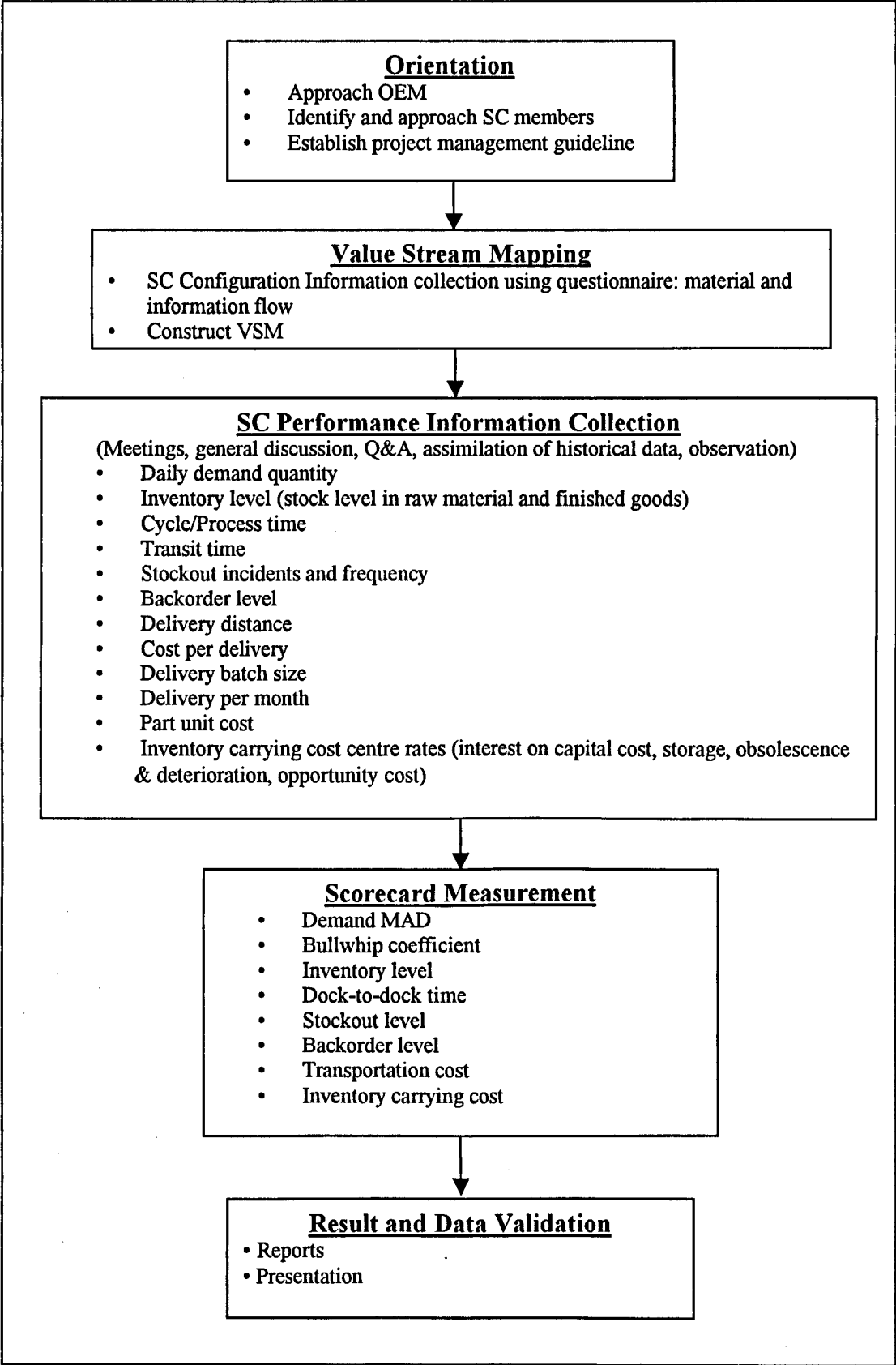


Figure 1.3: Case Study Methodology

The third stage (SC Performance Information Collection) is to collect all the information needed to perform the measurement process, as shown in Figure 1.3.

This was carried out by undertaking the following activities:

- Meeting with relevant personnel

After the initial meeting, another meeting was organised for the author to meet the supply chain team. This enabled the author to identify the relevant personnel that need to be involved in the case studies, especially for data collection purpose, and ensure that they are onboard to support the case study.

- General discussions or question & answer sessions

This method was employed when issues arose during the case studies. It is the most effective and efficient way to resolve queries with all level of personnel, from supply chain managers to shop floor workers.

- Assimilation of historical data

Historical data was collected to feed into the scorecard to reveal the SCs' performance. Some of the data shown in Figure 1.4 were collected or observed on daily basis such as the daily demand quantity, inventory level, stockout incident and backorder level. The entire measurement system is based on these actual data, which is the key strength of quantitative measure, because it provides a more objective performance indication.



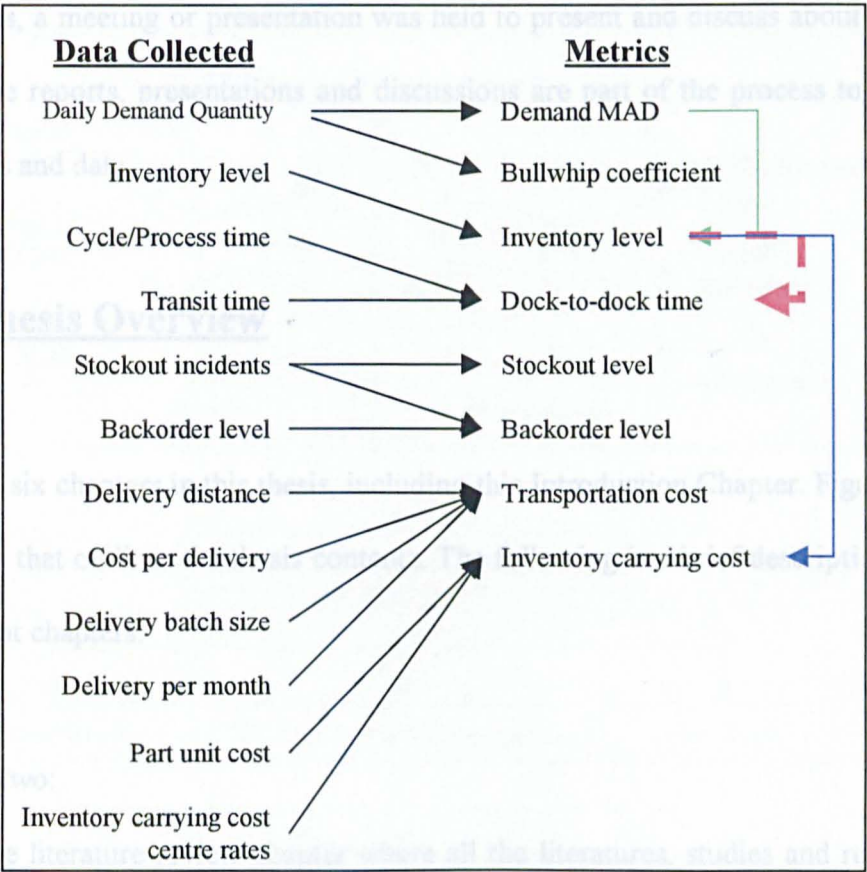


Figure 1.4: Data Collected for Measurement

The fourth stage is to perform the measurement calculations using the data collected in stage three, as shown in Figure 1.4. The outputs from some of the metrics act as an input for some metrics, as illustrated by the coloured line in the diagram. The green line indicates that the average daily demand quantity from Demand MAD is one of the inputs to calculate Inventory Level. The red dashed line and the blue line signify that the Inventory Level is also an input to generate Dock-to-dock Time and Inventory Carrying Cost respectively.

After the measurement, the results and data collected for the measurement were validated in two approaches. A report detailing the data, the measurement method and the measurement results was submitted to the companies involved. For some

companies, a meeting or presentation was held to present and discuss about the case study. The reports, presentations and discussions are part of the process to validate the results and data.

## **1.6 Thesis Overview**

There are six chapters in this thesis, including this Introduction Chapter. Figure 1.5 is a diagram that outlines the thesis contents. The following is a brief description of the subsequent chapters:

### **Chapter Two:**

This is the literature review chapter where all the literatures, studies and researches on the relevant topics that have been undertaken are presented. There are three main sections in this chapter. The first section is a review on SC and SCM. The second section concerns SCPM, including an historic review, existing SCPM systems and their success factors. Then the subsequent section reviews the benefits, performance factors and recent development of IS.

### **Chapter Three:**

This chapter focuses on the development of SCPM system in this research. The chapter describes the SCPM success factors identified during the literature review and integrated into the SCPM system development. Then the measurement system is elaborated upon in detail.

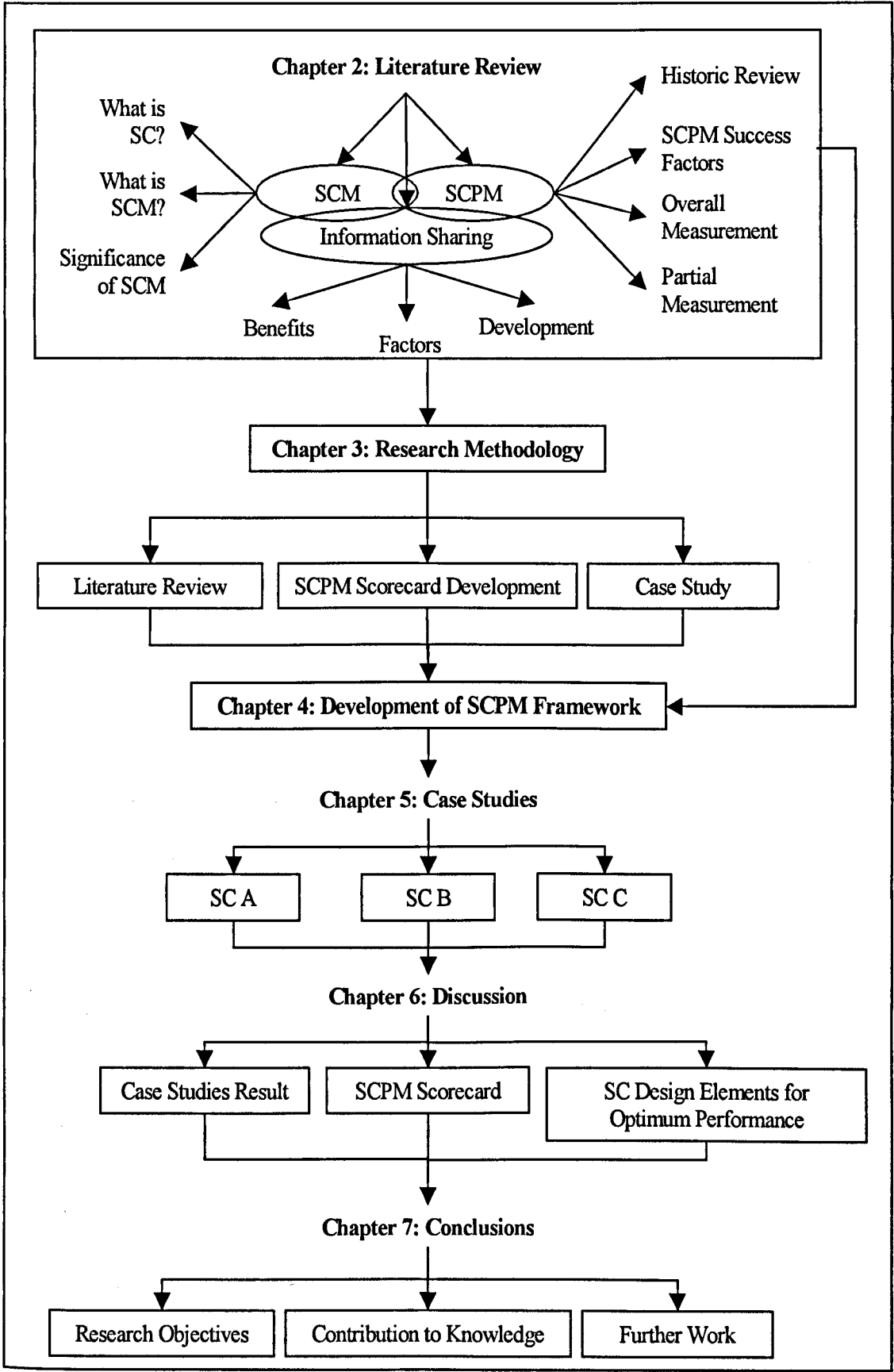


Figure 1.5: Thesis Overview

#### Chapter Four:

This chapter presents the three case studies undertaken within this research, using the SCPM system explained in Chapter Four. The first case study was a mid-volume highly customised luxury car manufacturer in the UK (SC A), the second case study was a high volume low customisation car manufacturer in Spain (SC B) and the third case study was a high volume low customisation car manufacturer in the UK (SC C).

#### Chapter Five:

This chapter contains the in depth discussions on the measurement results from the case studies, the SCPM scorecard developed in this research in terms of its applications, novel aspects and limitations, as well as the SC design elements that can help to achieve an optimum automotive SC performance.

#### Chapter Six:

This is the final chapter of this thesis. It contains the answer to the research questions stated in Section 1.3, the achievement of the research objectives and the contribution to knowledge. Recommendations for further work are also included in this chapter.

## **1.7 Chapter Summary**

This chapter provides a brief and concise introduction to this thesis and research. It includes detailed elaborations on the research background, questions and objectives, research methodology, as well as a brief overview on thesis contents. The work undertaken seeks to provide a customised SCPM system for the automotive industry with empirical evidence to demonstrate the validity and feasibility of the proposed measurement system.

## CHAPTER 2: LITERATURE REVIEW

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### 2.1 Introduction

As mentioned in Chapter 1, the main aim of this research is to develop a measurement system for automotive SCs. Therefore, it is vital to investigate the history, development and the success factors of SCPM. This is not only to provide the background theory for this research, but it also helps to clarify and validate the originality, rationale and significance of this research. Apart from SCPM, a review on SC, SCM and IS literatures are also included in this chapter.

Section 2.2 provides a brief review of the developments in SCM. The existing literature concerning different SCPM systems is systematically reviewed in Section 2.3. The core of the literature review, which is the investigation of existing SC measurement systems, is divided into two parts. The first consists of a review of the measurement systems that articulate SC performance from different perspectives (Section 2.3.5) while the second part includes SC measurement models with single performance measure (Section 2.3.6). Then there is a review on SC IS in terms of its benefits (Section 2.4.2), factors that affect IS (Section 2.4.3) and a historic review and recent development of IS (Section 2.4.4).

## **2.2 Supply Chain Management**

### **2.2.1 What is a Supply Chain?**

SCs are the subject of SCM. Therefore, it is necessary to look into the existing knowledge on SCs before the exploration of the SCM area. According to the Supply Chain Council Inc., a SC is defined as a system that *“encompasses every effort involved in producing and delivering a final product or service, from the supplier's supplier to the customer's customer”* (Supply Chain Council, 2004). It is a series of processes and activities to convert raw materials into an end product to consumers, including product design, manufacturing, warehousing and distributing (Franks, 2000). The members of a SC can be suppliers, manufacturing plants, warehouses, customers and distributors (Duclos *et al.*, 2003).

However, in today's research environment, the definition of a “supply chain” has become inconsistent. Many studies use the term “supply chain” in place of logistics and distribution (Weber, 2002). The announcement made by the Council of Logistics Management regarding a modified definition of logistics provides some clarification (Lambert *et al.*, 1998):

*“Logistics is that part of the supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services, and related information from the point-of-origin to the point-of-consumption in order to meet customers' requirements.” (Council of Logistics, 1998)*

Also, there are many new terms that appear to have similar definitions to “supply chain”, such as “value stream”, “value chain” and “extended enterprise”. Smith and Lockamy (2000) have provided a clear explanation to clarify this confusion:

*“Supply chain is a network of operating entities through which an organisation delivers products or services to a particular customer market (cf Poirier and Reiter, 1996). This network constitutes an indispensable portion of the business system that Porter (1985) originally referred to as the value system, which Womack and Jones (1996) later called value stream, and which cost management theorists and practitioners now refer to as either the extended enterprise (Ansari et al., 1997) or the value chain (Drury and McWatters, 1998; Shank and Govindarajan, 1993).”*

This definition shows that a SC is actually part of a supply network, which is also known as value system, value stream or extended enterprise as shown in Figure 1.1.

Waller (2003) stated that there are three flow streams (material, information and financial) and three subsystems (supplier/subcontractor, transformation/manufacturing and distributions) in a SC. The integration of these SC elements determines the extent to which the SC works as a unit to meet the performance objectives (Beamon, 1998). According to Rafele (2004), a SC can be broken down into intra-firm (internal to the firm) and inter-firm aspects (external, ties together supplier and buyer).



Lambert *et al.*'s (1998) studies prove that different SCs have different network structures, management components and business processes. The results highlighted the fact that every SC is unique. Many researchers and practitioners have strongly advocated this statement (Cox *et al.*, 2000; Beamon, 1999; Lambert and Pohlen, 2001; Rafele, 2004).

After this brief overview on SC, the subsequent sections contain a detailed exploration of SCM.

### **2.2.2 What is Supply Chain Management?**

Although there are many different definitions for SCM, one thing for sure is that it is not just supplier management (Balsmeier and Voisin, 1996). The following examples of SCM definitions have proven the validity of this statement:

*"A set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time..."* (Simchi-Levi *et al.*, 2000)

*"An integrative philosophy to manage the flow of a distribution channel from the supplier to the ultimate user"* (Cooper and Ellram, 1993)

*"Supply chain management includes managing supply and demand, sourcing raw materials and parts, manufacturing and assembly, warehousing and*

*inventory tracking, order entry and order management, distribution across all channels, and delivery to the customer” (Duclos et al., 2003)*

The emergence of the term SCM can be traced back as far back as Forrester to just before the 1960s (Rahman, 2002; Huan *et al.*, 2004). The phenomenal success of the Japanese automotive industry in the late 1970s has drawn attention and promoted the profile of SCM (Cox *et al.*, 2000). Firms are looking beyond their own borders to their suppliers, suppliers’ suppliers and customers in order to achieve overall consumer value. The competition focus has shifted from internal management of business processes to managing across organisations (Duclos *et al.*, 2003; Lambert *et al.*, 1998). This is mainly due to the changes in business environment (e.g. globalisation, higher demand, higher variety, more sophisticated requirements etc), where the competition is no longer between individual companies, but between SCs (Christopher, 1992).

According to Huan *et al.* (2004), the researches in SCM area can be classified into three types:

- Operational: to optimise the daily operations of SC members while meeting market demand. For example, inventory management, production planning and scheduling.
- Design: focus on the location of decision making and the SC’s objectives. For example IS system and integration among SC members.

- Strategic: to understand SC dynamic and develop SC objectives. This includes the identification of improvement opportunities for the entire SC, or the evaluation on alternative SC configuration.

On the other hand, Beamon (2003) summarised SC research in a wider scope, from three different branches: SC design, modelling approach and performance measure(s). A detail illustration can be found in Figure 2.1.

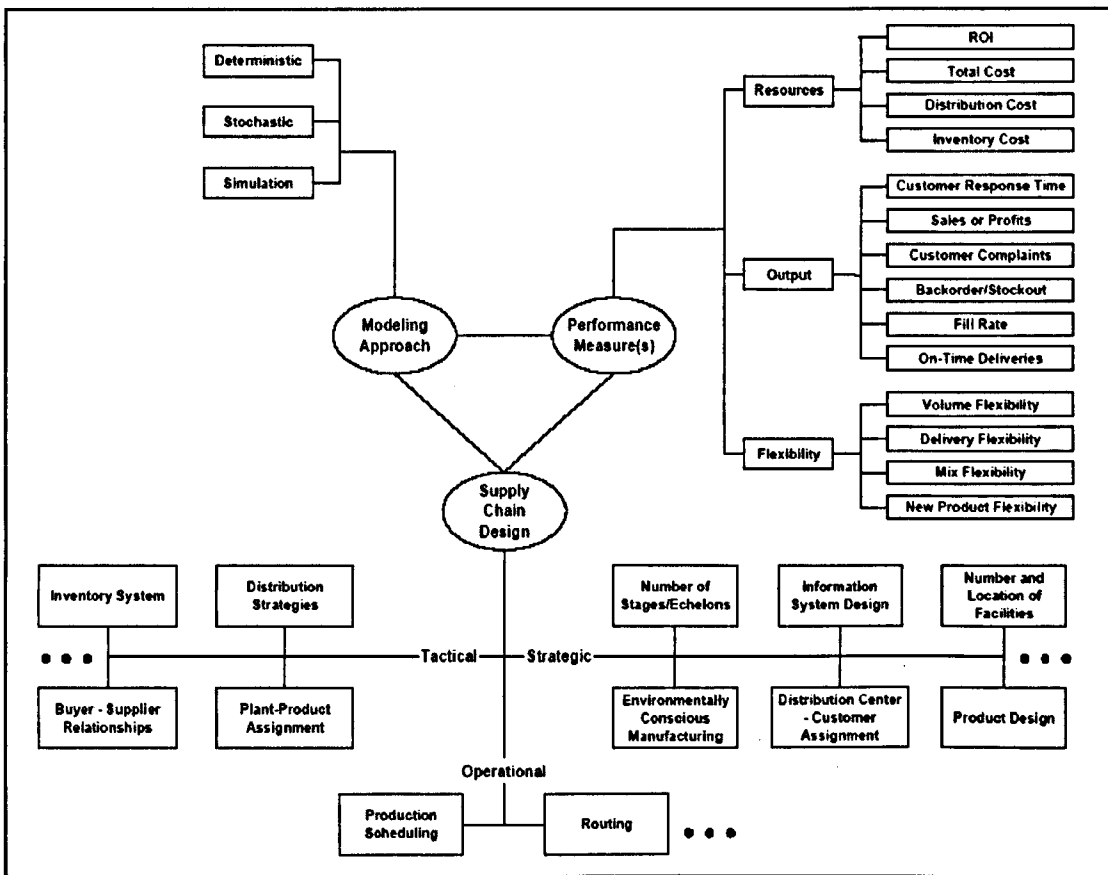


Figure 2.1: Supply Chain Research Overview (Beamon, 2003)

The Dutch Council of Logistics Management suggested that there are four types of SC integration - physical integration, information integration, control integration and infrastructure integration, from low to high intensity respectively (Dekker and Van Goor, 2000). However, Cooper et al. (1997) provided a more holistic conceptual

framework to explain SCM. It is also used as a guideline to implement SCM (Lambert *et al.*, 1998). This framework consists of three major and closely related SC elements, namely network structure, business processes and management components, as shown in Figure 2.2.

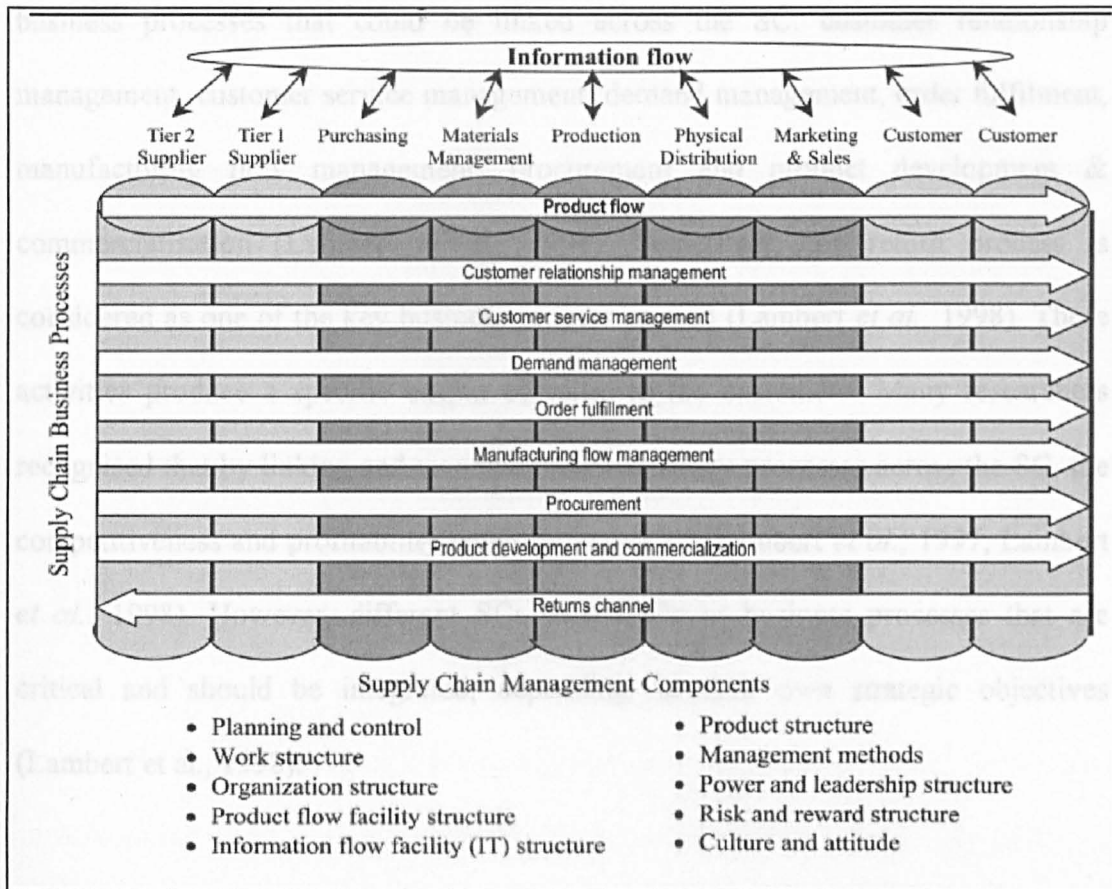


Figure 2.2: Supply Chain Management Framework (Lambert *et al.*, 1998)

The SC network structure is about the network of members and the links between SC members. It provides a guideline on how to distinguish between primary<sup>1</sup> and supporting<sup>2</sup> SC members, the three dimensional structure of SC (horizontal<sup>3</sup>, vertical<sup>4</sup>

<sup>1</sup> Primary members: Those who actually produce a specific output for a particular customer or market.

<sup>2</sup> Supporting members: Those that only provide resources and service for the primary members.

<sup>3</sup> Horizontal structure: The number of tiers across the supply chain.

<sup>4</sup> Vertical structure: The number of suppliers/customers represented within each tier.

and the horizontal position of the focal company) and the types of business process links between members (managed<sup>5</sup>, monitor<sup>6</sup>, not-managed<sup>7</sup> and non-member<sup>8</sup>).

The second element of the framework is SC business processes. There are seven key business processes that could be linked across the SC: customer relationship management, customer service management, demand management, order fulfilment, manufacturing flow management, procurement and product development & commercialisation (Lambert *et al.*, 1998). Sometimes, the return process is considered as one of the key business process as well (Lambert *et al.*, 1998). These activities produce a specific output of value to the customer. Many researchers recognised that by linking and managing these business processes across the SC, the competitiveness and profitability could be increased (Lambert *et al.*, 1997; Lambert *et al.*, 1998). However, different SCs have different business processes that are critical and should be integrated, depending on their own strategic objectives (Lambert *et al.*, 1998).

The third element mentioned in the framework is the management components of SCM. These are the managerial variables by which the business processes are integrated and managed across the SC. Lambert *et al.* (1998) have identified nine management components and there are certain components that are common across all business processes and SC members. They believe that these common

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<sup>5</sup> Managed process links: Process links where the focal company integrates a process with one or more customers/suppliers.

<sup>6</sup> Monitored process links: Process links are integrated and managed appropriately between other member companies.

<sup>7</sup> Not-managed process links: Process links that the focal company is not actively involved in, nor are they critical enough to use resources for monitoring.

<sup>8</sup> Non-member process links: Process links between members of the focal company's supply chain and non-members of the supply chain.

components are critical for successful SCM (Lambert et al., 1998). The nine identified components can be further divided into two groups:

- Physical and technical components:
  - Characteristics: Visible, tangible, measurable and easy to change
  - Group members: Planning & control methods, work flow/activity structure, organisation structure, communication & information flow facility structure, product flow facility structure
- Managerial and behavioural components:
  - Characteristics: Less tangible, less visible, and difficult to access or alter.
  - Group members: Management methods, power & leadership structure, risk & reward structure, culture & attitude

Similar to the other two elements in the framework, different SCs will have different combination and quantity of management components (Lambert *et al.*, 1998). The understanding on SCM components and their interdependence can greatly influence the success of SCM implementation (Hewitt, 1994). Most companies understand and insert effort in managing physical and technical components but the managerial and behavioural components are neglected most of the time (Lambert *et al.*, 1998).

### **2.2.3 Significance of Supply Chain Management**

The importance of SCM has been well recognised by both academics and practitioners (Cox *et al.*, 2000; Rahman, 2000; Cavinato, 1992). It is seen as a key element to secure competitive advantage (Cox *et al.*, 2000), especially among the big name companies like 3M, Ford, Hewlett Parkard, Procter & Gamble and Xerox (Cavinato, 1992). More than 86% of manufacturers in North America ranked SCM as one of the main factors for success (Witt, 1998). Some US manufacturers spent \$6.8 million and 1.6 years per SCM project (Radjou, 2004). This is mainly due to the transition of business competition from between individual companies to between SCs (Cox, 1999; Cokins, 1999; Duclos *et al.*, 2003).

The following is a brief summary of current and existing literature on the importance and the benefits brought by SCM:

- To bring competitive advantage to business by integrating all the activities and link all SC members into a seamless process (Duclos *et al.*, 2003).
- To achieve optimum SC performance, in terms of competitiveness, profitability, efficiency and effectiveness, by ensuring that all SC members operations are aligned towards the same objectives and strategies (Lambert and Pohlen, 2001; van Hoek, 1998).
- Reduce cash-to-cash cycle time (Smith and Lockamy, 2000).
- Increase value added per employee (Smith and Lockamy, 2000).
- Enhance delivery flexibility (Duclos *et al.*, 2003).

- Improve and facilitate the product innovation process throughout the SC (Duclos *et al.*, 2003).
- Reduce cost throughout the whole SC (Rahman, 2002), including logistics cost and inventory carrying cost (Smith and Lockamy, 2000)
- To meet the ever changing and increasing complicated market demand to achieve customer retention (Radjou, 2004).

These examples demonstrate that SCM is a vital element in today's business world. However, effective SCM has to be equipped with an appropriate measurement system that can assist the operations of SCs. Therefore, the next section concerns existing SCPM systems.

## **2.3 Supply Chain Performance Measurements**

### **2.3.1 Introduction**

Amaratunga and Baldry (2003) describe performance measurement as:

*“a process of assessing progress towards achieving pre-determined goals, including information on the efficiency by which resources are transformed into goods and services, the quality of those outputs and outcomes, and the effectiveness of organisational operations in terms of their specific contributions to organisational objectives.”*

Another definition is given by Beamon (2003), which defines performance measurement as *“a method to describe the effectiveness and/or efficiency of a*



*system*". By adapting these two definitions, supply chain performance measurement (SCPM) can be explained as a cross-organisational assessment process on supply chain effectiveness and efficiency towards achieving pre-determined goals.

The significance of performance measurement has always been recognised and emphasised by all industries. Phrases like "Anything measured improved", "What you measured is what you get", "You can't manage what you do not measure" (David Gravin, 1993) are the strongest proof to show the importance of performance measurement. Although many researchers and practitioners have derived different performance measurement approaches for different business levels (Kaplan and Norton, 1996; Adebajo and Mann, 1999; Adams *et al.*, 1995), there is a lack of SCPM systems (Lambert and Pohlen, 2003) due to many different reasons: the lack of SC orientation, the complexity of capturing metrics across multiple companies, the unwillingness to share information among SC members, the inability to capture performance by customer, product or SC, and the absence of an approach for developing and designing such measures.

The main purposes and benefits of implementing SCPM can be summarised as follow:

- It helps to establish relationships between decision variables and performance outputs to create and maintain a high-performance system (Beamon, 2003).
- It helps practitioners to understand and control the measurement subject (Neely, 1998).

- It provides information to stimulate appropriate action, encourage organisational learning and assist the decision-making process (Brignall and Ballantine, 1996).
- To ensure that the end products meet customer expectations by synchronising the operations and processes throughout the SC (Lambert and Pohlen, 2001).
- To make sure that all the costs and profits are equally and fairly shared among the SC members (Lambert and Pohlen, 2001). In other words, it prevents local optimisation.
- It helps the company to gain higher competitive advantages by allowing the company to assess the SC performance (Lambert and Pohlen, 2001). As mentioned before, it is a competition between SCs in today's business environment (Cox, 1999; Cokins, 1999; Duclos *et al.*, 2003).
- It reduces the occurrence of conflicts caused by the variance between SC members' organisational objectives (Lambert and Pohlen, 2001).

Generally, the existing SC measurement methods can be classified into two types. The first type is the measurement systems that have defined a set of metrics (Shin *et al.*, 2000; Stewart, 1995). These SC measurement systems are usually only applicable to a very specific SC structure. The second type provides a generic guideline or framework to help the users to build their own measurement models, based on their own situations and its SC requirements (Beamon and Ware, 1998; Lambert and Pohlen, 2001).

According to some researchers, an effective SCPM system should have met the following criteria (Beamon, 1999; Neely *et al.*, 1995):

- Inlusiveness: includes all relevant aspects of the SC, i.e. different levels of SC.
- Universality: allows comparison under a wide range of operating conditions so that different SCs can be compared.
- Measurability: the data should be measurable for accurate and timely assessment.
- Consistency: should be consistent with the overall goals of the organisation in order to provide meaningful insight into overall SC performance with respect to organisational goals.

Although there are many measurement systems that are deemed as SC measures, many of them are actually logistics measures (Lambert and Pohlen, 2001; Weber, 2002). These measures do not include other SC members' performance. This confusion has caused many companies to use internal logistics metrics, which obviously fail to capture SC performance information (Beamon1989; Gilmour, 1999). Also, some SC measurements are limited to evaluate the performance of the immediate SC members, including suppliers, customers or 3<sup>rd</sup> party service providers (Lambert and Pohlen, 2001; Stock and Lambert, 2001). Again, these measurement systems fail to present the actual SC performance because it does not view the entire SC as a whole.

### **2.3.2 Historic Review**

The history of SCPM was initiated with vendor rating systems or supplier performance measurement. It started in the 1960s when Dickson produced an analysis of vendor selection systems and decisions (Dickson, 1966). Since then, many researchers and industrialists have started to look at issues concerning vendor rating systems, such as vendor selection models (Weber *et al.*, 1991 a; Dickson, 1966) and the strategic importance of the vendor selection process (Kraljic, 1983; Burton, 1988; Benton and Krajewski, 1990). However, strictly speaking, a vendor rating system is not SC measurement because it only measures the immediate supplier, which is only part of a SC. This is a dyadic measurement. A SC measure should include more than one tier of a SC. Nevertheless, the research on vendor rating system initiated the study of SC measurement. Furthermore, vendor rating systems are still in use by companies to assess immediate supplier performance (Avery, 2003).

Although the concept of SCM was introduced in the 1960s, the research on SCPM only started after SCM became popular (Holmberg, 2000; Bechtel and Jayaram, 1997; Gunasekeran *et al.*, 2001). However, it is not an easy journey. Different researchers have different views on how SC measures are supposed to be, as shown in Table 2.1. Despite the diversity in the concept of measures, there are also many issues and obstacles in developing a perfect performance measurement system for SCs.

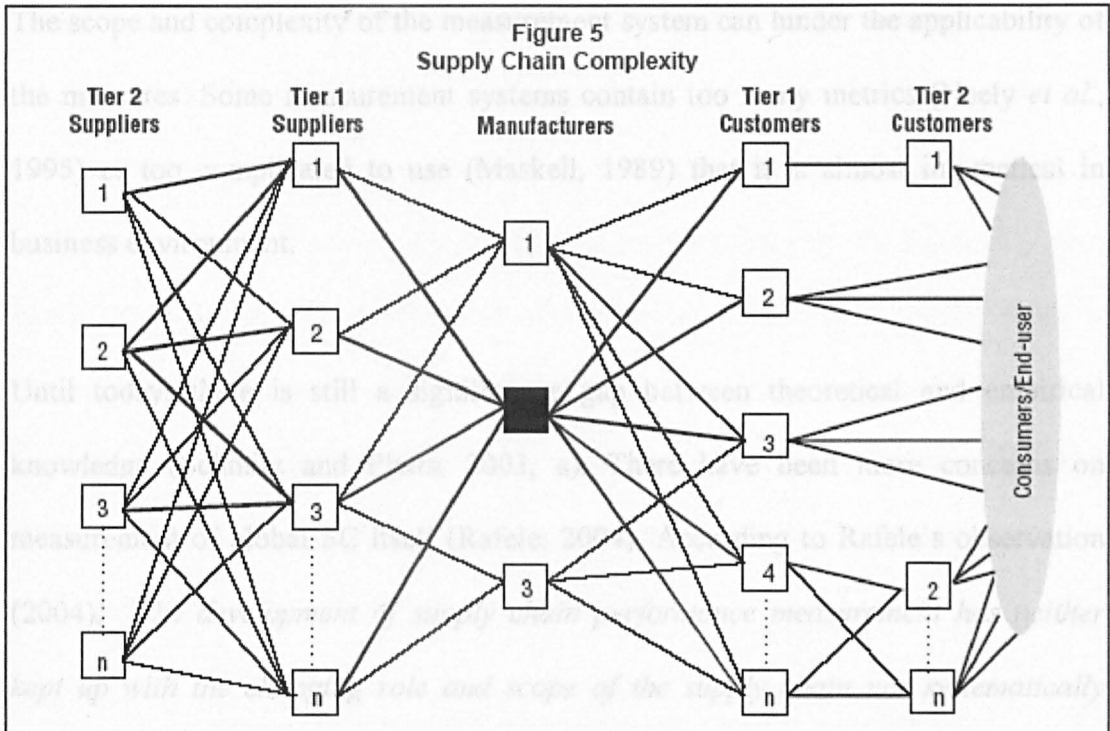
Authors	Measurement Issues
Handfield and Nichols, 1999 Caplice and Sheffi, 1995	<ul style="list-style-type: none"> <li>• Make sure that it measures the overall SC performance rather than individual SC members performance.</li> </ul>
Fawcett and Clinton, 1996	<ul style="list-style-type: none"> <li>• Measure inventory across the SC, in terms of the average volume held and the frequency of inventory turns</li> <li>• Measure the extent to which SC relationships are based on mutual trust</li> </ul>
Bello and Gilliland, 1997 Naylor <i>et al.</i> , 1999	<ul style="list-style-type: none"> <li>• Measure the adaptability of the SC as a whole to meet emergent customer needs</li> </ul>
Schmitz and Platts, 2003 (a)	<ul style="list-style-type: none"> <li>• <i>"Finding appropriate measures that can accurately measure SC"</i></li> <li>• <i>"What are appropriate ways to implement measures?"</i></li> </ul>
Handfield and Nichols, 1999	<ul style="list-style-type: none"> <li>• <i>"One central, overriding focus: Continual improvement of end customer service."</i></li> <li>• Helps managers to eliminate problems and improve performance of SCs.</li> </ul>
Beamon, 1996	<ul style="list-style-type: none"> <li>• Combining individual measures to create a more inclusive measure of SCs</li> </ul>
Lambert and Pohlen, 2001	<ul style="list-style-type: none"> <li>• Able to translate SC measures into shareholders value</li> </ul>

Table 2.1: Summary on SC Measurement Criteria (Adapted from Schmitz and Platts, 2003, a)

The confusion concerning the definition of "supply chain" is one of the obstacles. Some users comprehend "supply chain" as logistics and distribution. Therefore they measured SC performance with only logistical measures (Milgate, 2001; Beamon, 1989; Gilmour, 1999) and fail to measure beyond organisational boundaries (Gunasekaran *et al.*, 2001).

Another obstacle in SC measurement is the assessment scope. Ideally, a SC measurement system should measure across the SC levels to obtain the overall performance (Handfield and Nichols, 1999; Caplice and Sheffi, 1995). However, due to the difficulty in gathering data across multiple organisations and the lack of holistic SC orientation, some measurement systems only include one SC level, or

even no cross-organisational measures (Waller, 2003; Beamon 1989). In addition, the overlapping between different SCs makes it difficult to judge how each SC member is affecting the whole chain (Lambert and Pohlen, 2001). Figure 2.3 illustrated this situation, where some of the SC members are shared by different SCs.



**Figure 2.3: Supply Chains Overlapping (Lambert *et al.*, 1998)**

One of the main obstacles in SC measurement is the willingness to share information among the SC members (Cox *et al.*, 2000; Cokins, 1999). Quite often, the information needed to perform the measurement is sensitive data such as cost, price and strategy (Kwan and Suh, 2005). Hence, the process of gathering data for measurement purposes can be very difficult.

Balanced measurement is another concern in SC measurement. A good measurement system should measure the performance of an entity from different angles and perspectives to obtain an overall view on how well the entity has performed

(Bullinger *et al.*, 2002). However, there are some SC measurement systems that only measure certain characteristics of a SC, such as logistics (Milgate, 2001) and cost (Morton, 1997).

The scope and complexity of the measurement system can hinder the applicability of the measures. Some measurement systems contain too many metrics (Neely *et al.*, 1995) or too complicated to use (Maskell, 1989) that it is almost impractical in business environment.

Until today, there is still a significance gap between theoretical and empirical knowledge (Schmitz and Platts, 2003, a). There have been more concerns on measurement of global SC itself (Rafele, 2004). According to Rafele's observation (2004), *"The development of supply chain performance measurement has neither kept up with the changing role and scope of the supply chain nor systematically examined and evaluated this global process"*. There are not many researches on comprehensive theory and real application of SCPM (Schmitz and Platts, 2003, a).

### **2.3.3 SCPM Success Factors**

Baldwin and Clark (1992) stated that the major cause of the USA's competitive decline is directly due to inappropriate performance measurement systems. There are many different views on what are the factors that determine a successful SCPM. In summary, the 11 success factors that have been identified in order to achieve an effective SCPM are as follow:

### 1. Alignment between strategy and measurement:

The significance of aligning SCPM with SC strategy have been well recognised (Holmberg, 2000; Globerson, 1985; Beamon, 1999; Neely *et al.*, 1995; Lapide *et al.*, 2000; Tangen, 2003; Walke 1998). One of the problems with current performance measurement system is the lack of strategic focus (Hally, 1994). In order to achieve an effective SCPM, the purpose of each measure must be clear (Globerson, 1985). If the measurement initiative is not derived from strategy, the measurement results are most likely to be unrelated to the strategy and unable to support the business (Adam *et al.*, 1995). Surprisingly few number of companies measure the variables related to their business strategy (Eccles, 1991) and many are struggling with the issues of what are the most meaningful measures (Hinks and McNay, 1999; Douglas, 1994; Williams, 1999). The measurement initiatives that are aligned with SC strategies will bring the following benefits:

- Minimise the conflict of measurement and interest between the SC members (Fry and Cox, 1989).
- Prevent local optimisation (Holmberg, 2000; Tangen, 2003).
- Prevent metrics to be developed in isolation (Holmberg, 2000). The disconnection between strategy and performance measures contributes to many of the strategic level measures appearing unrelated or not actionable at operational level (Lambert and Pohlen, 2001).
- Help to set agreed-upon performance goals (Amaratunga and Baldry, 2003).
- Help to allocate and prioritise resources (Amaratunga and Baldry, 2003; Keebler *et al.*, 1999).



- Help the SC to meet the goals set in the SC strategy (Amaratunga and Baldry, 2003; Lapidé, 2000; Keebler *et al.*, 1999).
- Maintain consistency in decision-makings and actions (Neely *et al.*, 1995).
- Allow management to determine which improvement efforts produce the greatest impact on overall competitiveness (van Hoek, 1998).
- Encourages continuous improvement rather than just for monitor purpose (Neely *et al.*, 1995).

There are two major barriers in aligning measurement with SC strategy. The first barrier is the complexity of SC strategy. This is not only because of the cross-organisational nature of SC strategy, but also because SC strategy usually evolves as decisions are made and courses of action are pursued (Mintzberg, 1978). A good example will be if a company's strategy was to build profitably the highest quality product, but the purchasing manager decided independently to buy low quality materials for cost benefit (Neely *et al.*, 1995). This decision obviously contradicts with the business strategy. Therefore, it is very important to keep the consistency of the strategy through the entire organisation, as well as the SC. A strategy only exists if there is a consistent pattern of decisions and action (Neely *et al.*, 1995), not just within an individual organisation, but all the SC members that are involved in the effort. This leads to the second barrier, which is to incorporate the strategies, objectives and interest of individual SC members into the SC strategy (Walker, 1998). Quite often, the business objectives and strategies of individual SC members are fundamentally different or contradictory with each other's. Some SC members might put their emphasis on quality while other members are trying to reduce cost. It is very important to develop SC strategies that are agreed by and will benefit all the

involved SC members. Not only the advantages gained by the SC strategy implementation have to be shared fairly, the costs and burden of implementation should to be spread among the members as well (Cox *et al.*, 2000).

Throughout the literature review process, the author discovered that many measurement systems have failed to align the measures with the SC strategy. Among the 14 SCPM systems that have been reviewed in this chapter, some of them do not incorporate the concept of strategy alignment (Stewart, 1995; Gilmour, 1999; Beamon 1999; Shin *et al.*, 2000; Gunasekeran *et al.*, 2001; Waller, 2003; Chan and Qi, 2003 - a,b,c). These SCPM systems are easy options for users because a fixed set of metrics have been provided. However, this is also the major downfall of these measurement systems because every SC is unique. Not all SC can be measured by same measurement system.

Therefore, another branch of SCPM has emerged which provides guidelines and frameworks to help users to develop their own SCPM system (Supply Chain Council; Beamon and Ware, 1998; Beamon, 1999; Brewer and Speh, 2000; Lambert and Pohlen, 2001; Bullinger *et al.*, 2002; Chan and Qi, 2003-a,b,c). This guidelines and frameworks lead the users to build a SCPM system that is custom-made for their own SC, by taking the SC strategy into consideration. For instance, the SCOR model (Supply Chain Council), the SCM balanced scorecard proposed by Brewer and Speh (2000), the SC metrics framework by Lambert and Pohlen (2001) and the balanced measurement approach by Bullinger *et al.* (2002). However, the only downfall is the possibility where the users might misinterpret the guidelines and derive an unsuitable measurement system.

Some of the SCPM systems that claim to measure SC performance are actually logistics measures. The measurement systems proposed by van Hoek (1998), Gunasekeran *et al.* (2001) and Waller (2003) are typical examples of this. In these SCPM systems, the measurement scope does not include other SC members and only measures logistics performance of the focal company.

## 2. Balanced measurement:

A balanced measurement system measures the performance of an entity from different perspectives to obtain an overall view of how well the entity has performed (Beamon, 1999), which has been known as an important factor to achieve an effective measurement (Beamon, 1999; Adebajo and Mann, 1999; Tangen, 2003). There are many different views of how to achieve this balance. Fitzgerald *et al.* (1991) suggest that measurement systems should contain two basic types of metrics – those related to the result and those related to determinants of the results. Another view advocates that measures must integrate both financial and non-financial performance (JIPECR, 1994). However, there is a lack of balanced SCPM approach (Gunasekaran *et al.*, 2001). Some users prefer performance measurement model with single measure for its simplicity but it has a major downfall of inability to illustrate the SC performance adequately (Beamon, 1999). An example was raised by Beamon to explain this downfall (1999):

*“Consider an example in which a company decides to use cost as the measure of supply chain performance. Although the supply chain may be operating under minimum cost, it may simultaneously demonstrate poor*

*customer response time performance, or lack flexibility to meet random fluctuations in demand."*

Before the concept of balanced measurement emerged, most companies focused on measuring financial performance and neglected other performance aspects like productivity, customer service level etc. Cost was the performance measure of choice for many SC models (Cohen and Lee, 1988; Cohen and Moon, 1990; Pyke and Cohen, 1993). However, the tracking of financial performance is insufficient to show the actual performance. Performance should be judged from different perspectives, not just solely from a financial context (Bullinger *et al.*, 2002). There are some performance attributes that cannot be measured in financial terms, such as responsiveness, customer satisfaction and product quality. Most companies realise the importance of financial and non-financial performance measures but fail to represent them in a balanced framework (Gunasekaran *et al.*, 2003). Many companies rely too heavily on financial measures as their key performance indicators (Holmberg, 2000; Olve *et al.*, 1999). These financial information are usually based on traditional accounting method and has received many criticism problems such as too historical, lack of predictive power, focused on input rather than output, neglect some "difficult-to-quantify" resources such as intellectual capital, inability to incorporate strategy into measures and inflexible (Adebanjo and Mann, 1999). Therefore, non-financial measures should also be adopted to achieve a balanced measurement (Neely *et al.*, 1995; Tangen, 2003), to provide complete information, both financial and non-financial to support business decisions (Holmberg, 2000; Olve *et al.*, 1999).

Apart from the over emphasis on financial measure, another concern in balanced measurement is the use of single measure in some SC measurement model, such as the SC measurement model proposed by Cohen and Lee (1988), Lalonde and Pohlen, (1996) and Catalan and Kotzab (2003). Many users prefer to use these single measure methods in SCPM for its simplicity (Beamon, 1999). After an intensive evaluation on numerous SC single measure models, Beamon (1996) concluded that the most consistent weakness in these SCPM systems was inclusiveness, i.e. the ability to measure all pertinent aspects of the SC.

### 3. Appropriate quantity of metrics:

Some companies fail to realise that performance measurement can be better addressed using a good few metrics (Gunasekaran *et al.*, 2001). Many measurement systems tried to measure too many things (Holmberg, 2000; Gunasekaran *et al.*, 2001). Indeed it is so easy that quite often a firm can identify more than 100 different measures (Neely *et al.*, 1995). The quantity and variety of metrics tend to increase over time because metrics once introduced are too seldom removed (Holmberg, 2000). It is actually more difficult to reduce the list of potential measures to a manageable size than to identify what could be measured (Neely *et al.*, 1995). Too many metrics will distract the focus of measurement and make the measurement process too lengthy and complicated to put into practice (Maskell, 1989). Therefore it is vital to ensure that the size of measurement system is manageable (Lapide, 2000; Neely *et al.*, 1995, Holmberg, 2000; Rafele, 2004; Keegan *et al.*, 1989). The best way to narrow the metric quantity down is by referring to the business or SC strategy. By exploring the rationale underlying the measures, only the relevant and crucial metrics will be included in the measurement set (Neely *et al.*, 1995).

#### 4. Quantifiable metrics:

All metrics should be quantifiable (Holmberg, 2000; Beamon, 1999), simple, easy to use (Neely *et al.*, 1995) and can be easily understood (Tangen, 2003). All data required by the measurement system should be readily measurable (Beamon, 1999). The procedures on how to collect the data and how to perform the measure calculation have to be clearly defined (Globerson, 1985). There are many SC measurement methods that do not measure quantitatively. These measurement systems assess SC performance based on subjective judgement from buyers/supplier through interviews and questionnaires, such as the SCPM systems proposed by Gilmour (1999) and Shin *et al.* (2000).

#### 5. Compatible metrics:

A measurement system should acknowledge that measures change as circumstances do (Neely *et al.*, 1995) and it should have the ability to change in response to a dynamic market (Adebanjo and Mann, 1999) to provide timely and accurate feedback (Globerson, 1985). The quantity of metrics used in organisations tends to change, or more often increase over time. This is because metrics are seldom removed once introduced. Then these “old” metrics soon become obsolete as strategy and underlying activities continue to change. Hence, it is quite common to see some measurement approaches contain too many isolated and incompatible measures (Holmberg, 2000). In order to maintain the compatibility of measures, the metrics and the measurement method should be reviewed regularly (Adebanjo and Mann, 1999).

#### 6. System thinking:

The complexity of the SC arises from the number of levels in the chain and the number of facilities in each SC level (Beamon, 1999). Therefore, SCPM systems have to span across multiple business divisions (Lapide, 2000; Holmberg, 2000; Christopher and Jüttner, 2000; Lapide, 2000; Rafele, 2004). The concept of system thinking promotes that each component in the measurement system (i.e. performance model, measurement methods and metrics) must be considered throughout the entire SC, across the SC levels (Holmberg, 2000). A study conducted by Anderson Consulting (Anderson *et al*, 1997) showed that companies that have succeeded in SCPM have adopted a holistic view of the SC. They recognised that the outcome that counts is that of the entire SC, not that of single organisations. This is due to the shift of competition from between organisations to between SCs (Christopher, 1992). However, not every possible component can be included in the system for practical reasons. Therefore, only those closely related components relevant to the issue at hand are chosen (Holmberg, 2000) and it is necessary to sacrifice internal efficiencies to overall SC optimisation (van Hoek, 1998).

System thinking encourages SC integration (Chan and Qi, 2003 a) and helps companies to avoid optimisation at one point in the SC without considering potential consequences at other points in the chain (Jayaram, 1997). With the holistic visibility on the entire SC, the SCPM system could contribute to improving SC performance by taking waste out of the SC rather than moving it somewhere else in the SC pipeline (Holmberg, 2000), as illustrated by the example below:

*“For example, when firms use sales to intermediate customers as a measure of performance and actively try to maximize sales, they delimit the perspective and cut themselves off from the ones setting the pace in the supply chain. Because sales to intermediate customers does not show whether a final consumer pays for the product or not, it may lead to increased inventory build up and higher costs. Measuring local productivity and local costs has the same effect, i.e. an increased risk of sub-optimization of the supply chain. Again, it is important to adopt a wide enough scope of measurement activities to remove or at least reduce inefficiencies in the supply chain” (Holmberg, 2000).*

According to a survey conducted in the US (The Economist Intelligence Unit and Meritus Consulting Service, 2000), more than 47 senior executives in major blue chip companies believe that supplier/partner relationships, procurement and sourcing, inventory management, delivery management and cost reduction strategies are critical integration issues. However, none of these respondents is satisfied with the integration level within their organisation. The research on inter-organisational performance measurement is still rather rare (Schmitz and Platts, 2003-a). The need for integrative and holistic measures on SC performance is vital (Schmitz and Platts, 2003-a).

As previously noted, each SC member has its business objectives and strategies. Most of the time, these objectives are different or even in direct conflict with each other (Schmitz and Platts, 2003-a). Since the performance of individual SC members affects the overall performance of the entire SC (Duclos *et al.*, 2003), the SC



members have to understand the roles of other members to reduce conflict and achieve overall SC optimisation (Lambert and Bennis, 1982). All SC members should take ownership of SC metrics and be held responsible for the SC's performance (Lee and Corey, 1992; Waller, 2003). Therefore, the SC measures must be able to reflect the multi tiers characteristic of SCs (Lambert and Pohlen, 2001) to illustrate the overall competitiveness of a SC, thus helps SC members to determine what and where in the SC to improve for maximum benefits (van Hoek, 1998; Childerhouse *et al.*, 2003). The research study performed by Simatupang and Sridharan (2005) has also proved that implementation of system thinking can improve fulfilment levels, reduce inventory levels and increase responsiveness, which in turns bring the benefits of revenue enhancement, cost reductions and better operational flexibility. They have performed the study with some major companies like Hewlett Packard, IBM, Dell, and Procter & Gamble.

According to Simatupang and Sridharan (2005), there are two elements in system thinking – decision synchronisation and incentive alignment. Decision synchronisation refers to the joint decision making process in strategic and operational context among the SC members. Within the same SC, the SC members still have their own constituencies, objectives and metrics, which will impede the cooperation required to maintain SC strategy. Hence, it is very important to involve the SC members in the SC decision-making process to ensure that all of the members are working towards the same goals (Lambert and Pohlen, 2001). This is similar to the first barrier in strategy alignment. The second element is to ensure a fair share of costs, risks and benefits among the SC members (Lambert and Pohlen, 2001). This is also known as incentive alignment (Simatupang and Sridharan, 2005). Again, this is

parallel with the second barrier in strategy alignment, i.e. to incorporate the strategies, objectives and interest of individual SC members into the SC strategy (Walker, 1998).

#### 7. Universality:

An effective SCPM model should have high level of universality to allow for comparison of competing organisations or SCs (Beamon, 1999; Globerson, 1985). This is especially important nowadays because businesses are competing with each other on SC basis (Cox, 1999; Cokins, 1999; Duclos *et al.*, 2003).

#### 8. Involvement:

The involved parties and individuals should be consulted during the metrics selection process (Neely *et al.*, 1995) and fully committed to the measurement efforts (Blenkinsop and Davis, 1991). Measures should be understandable by all SC members (Schroeder *et al.*, 1986).

#### 9. A thorough understanding of the existing measurement systems, both formal and informal, spoken and unspoken, as they are perceived (Blenkinsop and Davis, 1991).

#### 10. An effective SCPM system must take into account the difference of corporate culture between SC members (Blenkinsop and Davis, 1991), especially if it has influence over the measurement process and results. This includes the company beliefs, values, business principles, traditions, ways of operating and internal working environment (Thompson and Strickland III, 2005).

11. Gunasekaran *et al.* (2001) stated that there should be a clear distinction between metrics at strategic, tactical, and operational levels so that each metric can be assigned to a level where it would be most appropriate.

### **2.3.4 Measurement Type**

This section is to briefly summarise the different ways to categorise the type of measures and measurement methods used in appraising SC performance. Generally, there are three ways to classify SC measures.

The first one is by looking at the numerical nature of the measures. According to Beamon (1999), the available performance measures can be categorised as either qualitative or quantitative:

- Qualitative performance measures have no single direct numerical measurement, although some aspects of them may be quantified. The measures that fall into this group are customer satisfaction, flexibility, information and material flow integration, risk management and supplier performance.
- The performance measures that can be directly described numerically are classed as quantitative measures, such as inventory cost, order fill rate and customer response time.

The second way is by differentiating the relations of the measures to the results (Fitzgerald *et al.*, 1991; Trimble, 1996):

- Performance metrics: Those that relate to results, such as competitiveness or financial performance.
- Diagnostic metrics: Those that focus on the determinants of the results, such as quality, flexibility, resource utilisation and innovation.

The third way to classify measurement types was again proposed by Beamon (1998). He suggested that there are four categories of SC design and analysis, based on the nature of the inputs and the objective of the study.

- Deterministic analytical models: the variables are known and specified.
- Stochastic analytical models: at least one of the variables is unknown and is assumed to follow particular probability distributions.
- Economic model: economic framework for modelling the buyer-supplier relationship in a SC. For instance, the 2x2 “SC relationship matrix” developed by Christy and Grout (1994) to identify conditions under which each type of relationship is desired, based on the process and product specificity.
- Simulation mode

In this literature review, the existing SCPM methods are grouped according to the measurement aspect. The measurement scope is the number of SC levels included in the measures, such as from end customer to the third tier supplier. Measurement aspect refers to measurement perspective taken to assess the SC characteristics, such as logistics, cost or responsiveness. The overview of the categorisation is shown in Figure 2.4. The multi-measure measurement refers to the SC measurement methods

that measure more than one SC characteristic (i.e. the measurement scope) such as cost, delivery and flexibility. The single-measure measurement refers to SC measurement models with single measure.

### **2.3.5 Multi-Measure Measurements**

SC performance depends on how well the SC members are performing. All the elements in a SC are interrelated to each other. The success in one element might arise from or result in a sacrifice in another element (Kaplan and Norton, 1992). Hence, in SC measurement, it is vital to measure across the SC members.

Among the existing SC measurement systems, 14 of them fall under the category of “Multi-measure Measurements”. As mentioned before, these are the measurement methods that measure more than one SC characteristic such as cost level and delivery efficiency etc. A brief summary of all these measures is included in this subsequent section.

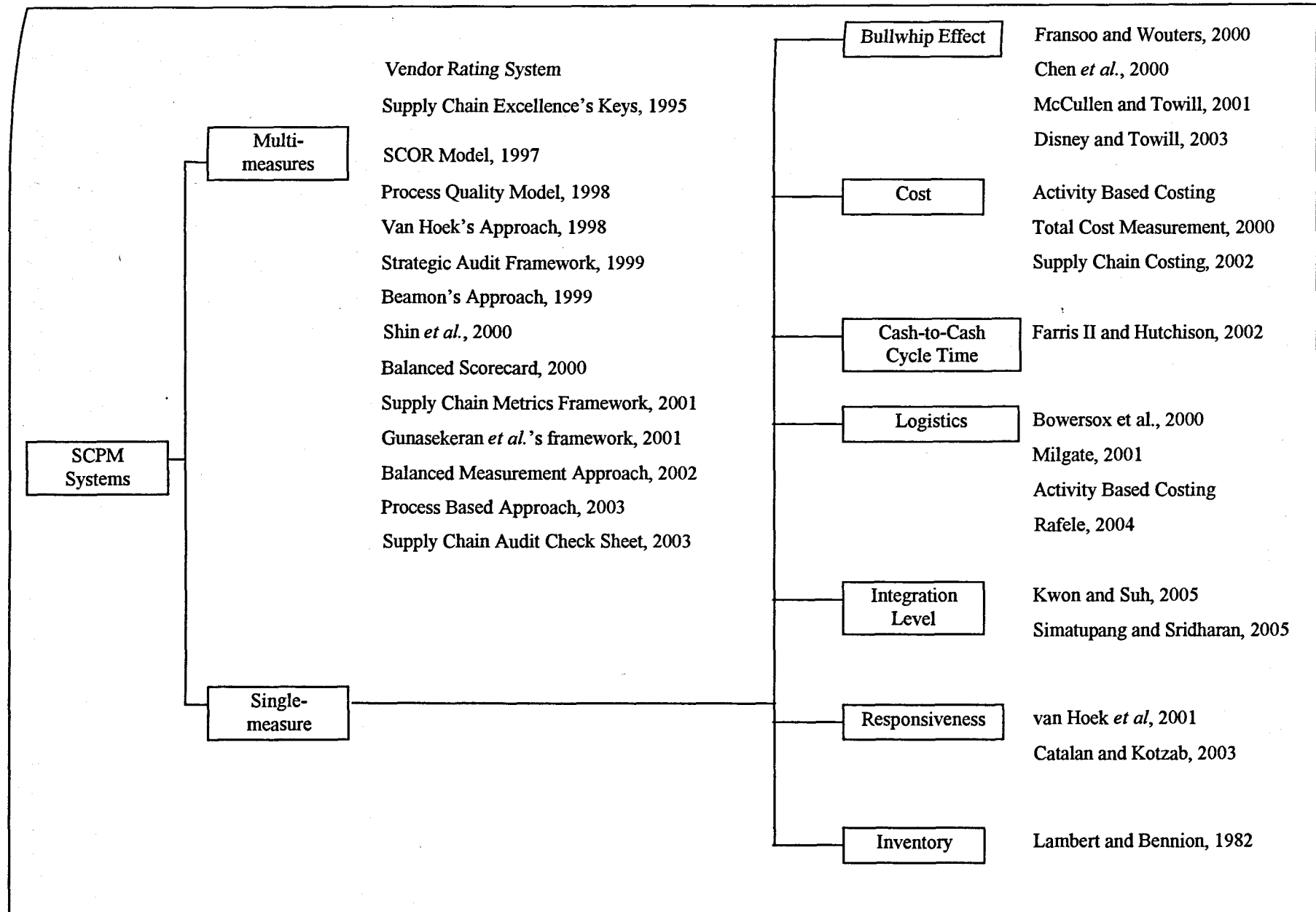


Figure 2.4: Supply Chain Performance Measurement Methods Categorisation

### **2.3.5.1 Vendor Rating System/Supplier Performance Measurement**

Before the business environment developed into today's sophisticated structure, vendor rating systems were good enough to assess and monitor the procurement structure. Many researchers and practitioners focused on vendor's performance measurement since 1960 (Muralidharan *et al.*, 2001). However, as the business environment evolves with all the new business concepts and technology advancement such as globalisation and the internet, SC structures have experienced great changes to cope with today's business requirements (Rafele, 2004). The concept of SCM emerges in response to these business revolutions and the competition platform has shifted from inter-company to inter-supply-chain (Cox, 1999; Cokins, 1999; Duclos *et al.*, 2003).

Vendor rating systems are considered as non-holistic measures for SC assessment because they only measure the performance of immediate suppliers. Nevertheless, they are the most common form of SCPM system and are used dyadic by some big name companies like Microsoft for their simplicity in comparison to a multi-tier SC measurement system (Avery, 2003). According to Schmitz and Platts's observations (2003, a), supplier performance measurement appears to be an important tool in the automotive industry, as a communication tool and to control and monitor suppliers' performance.

There are many factors to be considered when assessing suppliers' performance. Kemp (2003) summarised 32 widely used metrics in supplier performance

measurement, as shown in Table 2.2. Both Dickson (1966) and Kemp (2003) conclude that cost, quality and delivery performance are the three most common and important criteria in supplier performance measurement.

Quality performance	Service performance
Delivery performance	Flexibility
Total all in cost, i.e. price	Quality improvement capability
Willingness to create and share data and information	Lean thinking status and ability for lean operations
Dedication to cost analysis and cost control processes	Facilities, equipment and overall capabilities
Technical assistance capability	Labor situation
Electronic communication capabilities	National vis-à-vis regional or local status
Response time to communication	Managerial team, size, capabilities, age
Financial situation/strengths/weaknesses	Model considerations
Margins	Fit to our operations
Inventories	Fit to our style
Location vis-à-vis our sites	Willingness to locate in-house
Ability to innovate	Participation in early supplier programs
Willingness to do supplier managed inventories	Relationships with their SC and base
Consistency of performance	Sufficient size and ability to meet our needs
Demonstrated interest in our needs	Warranties

Table 2.2: Common Metrics in Supplier Performance Measurement (Kemp, 2003)

Different techniques have been utilised for measuring a vendor's performance (Ohdar and Ray, 2004). Table 2.3 provides a list of vendor rating techniques.

Even though some of these are multi-measures systems, the dyadic nature of the vendor-rating systems means that the measurement results are limited to one SC level. In other words, these measurement systems only measure the performance of the immediate upstream SC member. Therefore, they fail to meet the multi-tier measure characteristic that this research seeks for.



Techniques	Author(s)
Categorical method	NAPA, 1950s
Weighted point method	NAPA, 1950s Schmitz and Platts, 2003(a) CIPS, 2005
Cost ratio method	NAPA, 1950s
Analytic hierarchy process	Narasimhan <i>et al.</i> , 1983 Ghodsypour and Brien, 1998 Tam and Tummala, 2001 Muralidharan <i>et al.</i> , 2001
Principal component analysis	Petroni and Braglia, 2000
Total cost of ownership	Carr and Ittner, 1992 Ellram, 1995
Human judgement model	Patton, 1996
Interpretive structural modelling	Mandal and Deshmukh, 1994
Discrete choice analysis	Verma and Pullmn, 1998
Neural network	Siying <i>et al.</i> , 1997
Activity based costing (ABC)	Roodhooft and Konings, 1996
Importance/Performance Matrix	Bommer <i>et al.</i> , 2001
Fuzzy Logic	Lau <i>et al.</i> , 2002 Ohdar and Ray, 2004
Dimensional analysis method	Willis <i>et al.</i> , 1983 Humphreys <i>et al.</i> , 1998

Table 2.3: Summary of Vendor Rating System Literature

### 2.3.5.2 The Supply Chain Excellence's Keys proposed by Stewart (1995)

Stewart regards benchmarking as a front-end tool to initiate significant change. He uses a benchmarking method to carry out the study, with objectives to help companies break free of re-engineering paralysis and initiate fact driven implementation (Stewart, 1995). The first part of this method is to identify nine key metrics and quantitative data were collected and evaluated from the 1994 ISC Benchmark Survey. The data was segmented by five industry groups (systems, semiconductors, commodities, software and telecommunications). Then the leading companies in each of the nine metric areas were targeted by industry segment for telephone interviews. The data collected from telephone interviews were analysed to identify common practices. Finally, each metric was related to specific SCM areas

and documented affiliated practices. According to Stewart (1995), this is the first known study, which objectively links practices employed with relative quantitative performance achievements.

The nine metrics were again grouped according to the four key SCM focus areas:

- Delivery performance: Delivery to request date; Delivery to commit date; Order fill lead time.
- Flexibility and responsiveness: Production flexibility; Re-plan cycle; Cumulative source/make cycle time
- Logistics cost: Total logistics cost; Order management costs.
- Asset management: Inventory days of supply; Days of sale outstanding.

The finding from this study shows that companies that have historically outperformed the industry in these four areas have realised vastly superior revenue growth and stock appreciation (Stewart, 1995). Stewart also claims that this study has established a valid database of quantitative benchmarking measures. However, it is a dyadic measurement system that comes with a fixed set of metrics. Therefore, it fails to meet the two core SCPM success factors described in Section 2.3.3, i.e. multi-tiers measurement and strategy alignment. Nevertheless, some of the metrics from this system were adopted into the scorecard:

- Delivery to request date: represented by the “stockout level” in the scorecard
- Total logistics cost: similar to the “transportation cost” in the scorecard
- Inventory days of supply: same as the “inventory level” in the scorecard

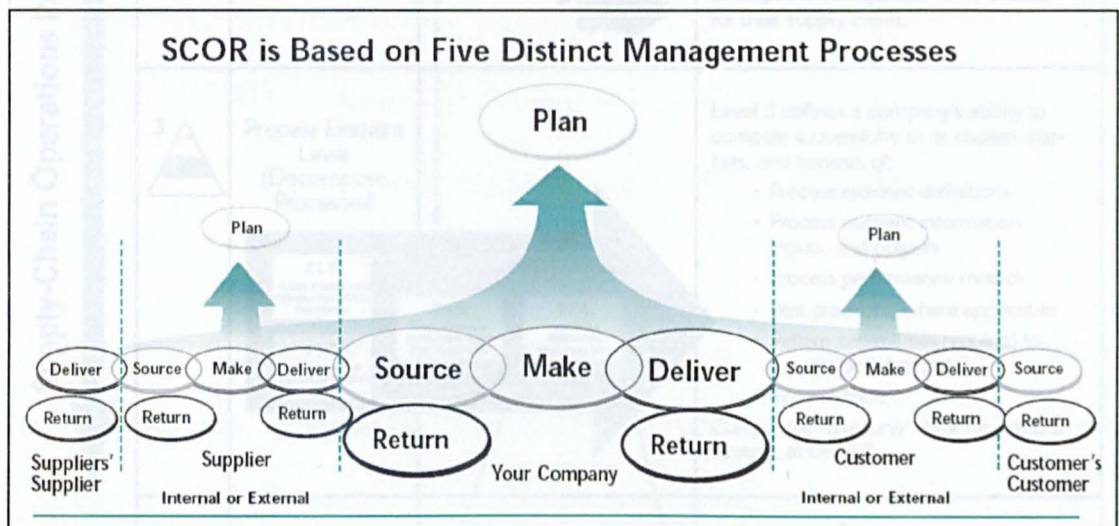
### **2.3.5.3 SCOR Model (Supply Chain Council)**

The SCOR (Supply Chain Operations Reference) model is the product of the Supply Chain Council (SCC), an independent, not-for-profit trade association open to all types of organizations. According to a statement made by the Logistics Management Institute in June 1999 – *“The SCOR model is the only supply chain framework that we found that links performance measures, best practices and software requirements to a detailed business process model”*. The model is specific to a product or family of products. It is a process reference model designed for effective communication among SC partners, as well as to describe, measure and evaluate SC configuration. The standard SCOR metrics enable measurement and benchmarking of supply-chain performance.

The SCOR is based on five management processes to describe SCs, as illustrated in Figure 2.5. The following are the descriptions of the five processes:

1. Plan:
  - Processes that balance aggregate demand and supply to develop a course of action which best meets sourcing, production and delivery requirements.
2. Source
  - Processes that procure goods and services to meet planned or actual demand.
3. Make
  - Processes that transform product to a finished state to meet planned or actual demand.
4. Deliver

- Processes that provide finished goods and services to meet planned or actual demand, typically including order management, transportation management, and distribution management.
5. Return
- Processes associated with returning or receiving products for any reason. These processes extend into post-delivery customer support.



**Figure 2.5: The five Management Processes in the SCOR Model (Supply Chain Council, 2004)**

These five management processes are decomposed into three levels of detail as shown in Figure 2.6. At the top level, SC performance can be directly tied to the business objectives of the organization. The configuration level and process element level are used to describe more and more detailed activities to provide greater insight into the operation of the SC. The model is further extended to implementation level because this is a cross-industry multi-tier model and each organisation's operation is unique (Stephens, 2001). The model also includes a process map to help users to evaluate and understand the SC. An example of the process map can be found in Appendix A.



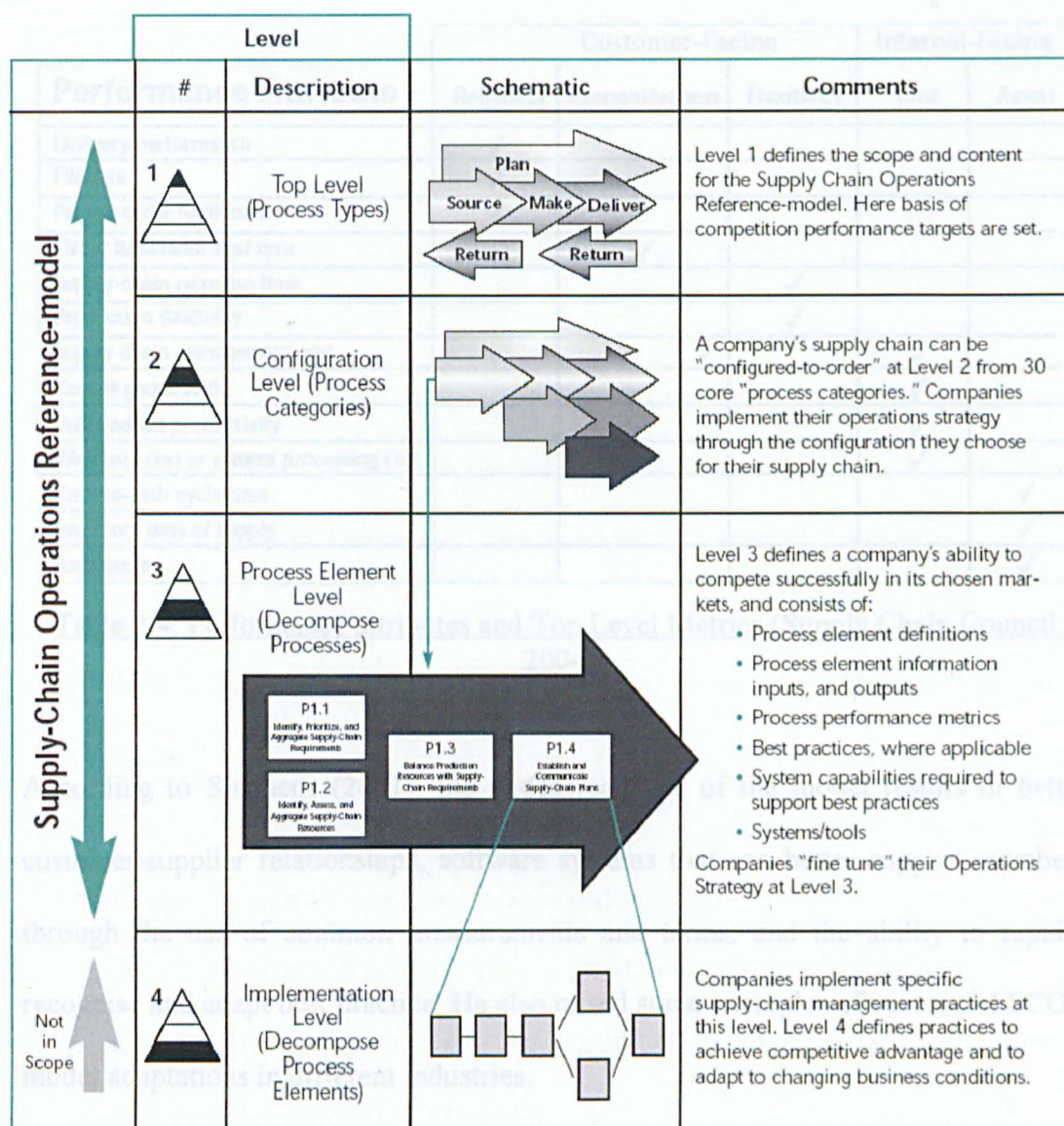


Figure 2.6: Three Level of Process Detail in SCOR Model (Supply Chain Council, 2004)

In the SCOR model, the SC is described and measured using five dimensions: reliability, responsiveness, flexibility, cost and assets. The first three performance attributes assess the interface between the organization and the customer (reliability, responsiveness and flexibility) while the other two (cost and assets) measure internal performance. Table 2.4 is the list of top-level metrics for each performance attribute.

Performance Attribute	Customer-Facing			Internal-Facing	
	Reliability	Responsiveness	Flexibility	Cost	Assets
Delivery performance	✓				
Fill Rate	✓				
Perfect order fulfillment	✓				
Order fulfillment lead time		✓			
Supply-chain response time			✓		
Production flexibility			✓		
Supply chain management cost				✓	
Cost of goods sold				✓	
Value-added productivity				✓	
Warranty cost or returns processing cost				✓	
Cash-to-cash cycle time					✓
Inventory days of supply					✓
Asset turns					✓

Table 2.4: Performance attributes and Top Level Metrics (Supply Chain Council, 2004)

According to Stephens (2001), the widespread use of the model results in better customer-supplier relationships, software systems that can better support members through the use of common measurements and terms, and the ability to rapidly recognise and adapt best practice. He also raised some examples of successful SCOR model adaptations in different industries.

There were three researchers from the US who recommended that change management should be included as an element in the “plan” SC process category of the SCOR model (Huan *et al.*, 2004). This is to equip the SCOR model with the ability to keep up with changes in terms of technology and business environment.

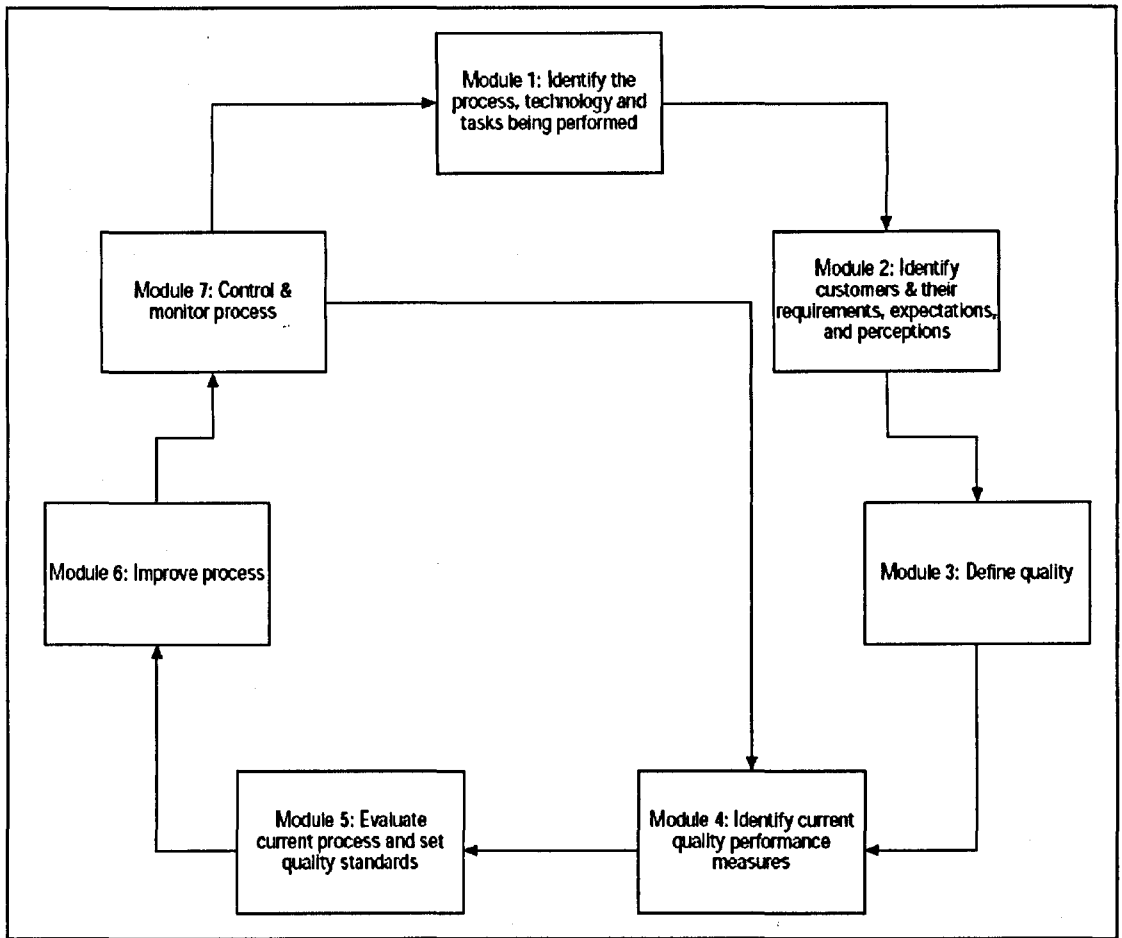
The SCOR model is the most significant SCPM system among all the reviewed measurement systems. It is an empirical tested multi-tier measurement system that allows its users to determine the metrics based on their SC strategy. However, the complexity arising from the five management processes and the four metrics level

has made it more difficult to be implemented. Nevertheless, the concept of multi-tier measure and distinctive metric levels were adopted into the scorecard.

#### **2.3.5.4 Process Quality Model (Beamon and Ware, 1998)**

In 1998, Beamon and Ware proposed a theoretical model to assess improve and control the quality of a SC system (Beamon and Ware, 1998). The basic framework of the model is given in Figure 2.7. There are seven modules in the model:

1. Module 1: To define the current system and all activities that are currently being performed.
2. Module 2: To identify customer requirements, expectations and perceptions to continuously improve customer service performance.
3. Module 3: To establish and refine the definition of quality in the SC system.
4. Module 4: To identify current cost, productivity and service measures and identify gaps in current measurements.
5. Module 5: To evaluate current performance and set standards for cost, productivity and service objectives.
6. Module 6: To identify and implement changes to improve overall SC process performance.
7. Module 7: To control and monitor productivity and service performance to ensure that the process meets standards. If it does not meet the standards, the user has to go back to module 4.



**Figure 2.7: The Process Quality Model (Beamon and Ware, 1998)**

This is a closed loop model that emphasises the importance of continuous improvement and process control throughout the entire SC. In module 2, the users have to identify the customers and their own requirements, expectation or perceptions to set the target of measurement. The development of the measurement system is based on the measurement target so that what has been measured can reflect the performance of the targeted area.

Although this method allows the users to develop their own measurement system based on their SC strategy, it is only a theoretical model thus no empirical evidence to support the method.



### **2.3.5.5 van Hoek's Approach (1998)**

Van Hoek developed a preliminary theoretical framework for SCPM, which he claims to *"provides a first indication of how, in a supply chain approach to performance measurement, the content of a measurement system may differ, depending on the supply chain operating format and the strategy approach or the evolution of strategies"* (van Hoek, 1998). The selection depends on the strategic context and operational contribution of different players to SC competitiveness.

Figure 2.8 shows the two-axis framework that van Hoek proposed. The vertical axis represents the possible contribution of organisation to SC competitiveness while the horizontal axis reflects the stage of development of logistics in an organisation. Van Hoek provided an example in a logistics context to illustrate the concept of this framework.

- Bottom left segment: Usually applicable to traditional suppliers where logistics is dominantly used as a cost saver and the organisation contribution is in the area of cost. The metrics may be part per minute, percentage of logistics cost as a share of total cost.
- Middle segment: Usually applicable to a retailer that focuses on market extension and uses logistics to deliver customer service. The suitable metrics may be fill rates and response times.

- Top right segment: The SMART car manufacturer is quoted as an example in this segment, where logistics is used to create new markets, and is focused on integrating the entire chain; relevant measures used by the SMART car manufacturer may be the level of commitment and percentage of customisation achieved.

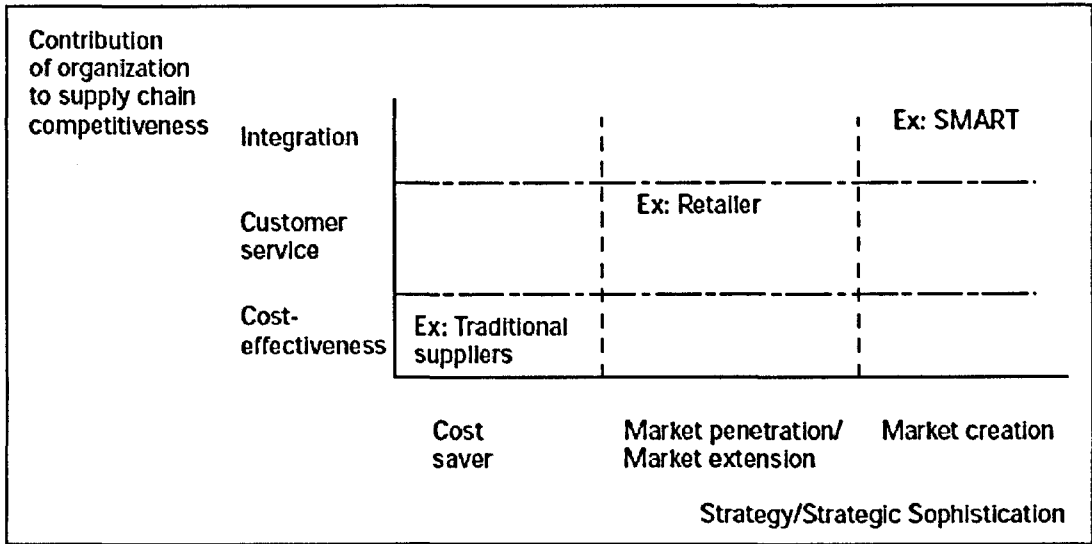


Figure 2.8: Preliminary Framework for Supply Chain Performance System (van Hoek, 1998)

According to the framework, the measurement system has to be established by taking the SC strategies and improvement target into consideration. However, the framework is quite basic and simple due to its preliminary status. Therefore is no empirical study to support this proposed framework.

### **2.3.5.6 Strategic Audit Framework (Gilmour, 1999)**

In 1999, Gilmour published a paper about an empirical study that explored the ways leading companies in the Pacific region manage their SC operations. The objective of the study was to establish a generic framework to evaluate the performance of SC activities. Figure 2.9 illustrates the framework that has been used in that study to audit the SC performance. The framework includes six functional process capabilities, two technology capabilities and three organisational capabilities. The description of these capabilities can be found in Table 2.5. Five dimensions for each of the eleven capabilities were established to determine the SC sophistication by area of managerial activity:

1. Strategy and organisation
2. Planning
3. Business process and information
4. Product flow
5. Measurement

In the study, the data was collected by sending questionnaires to the participating companies. For each capability component in each category, the respondents were asked to identify at what level they thought they were now and at what level they thought they would be in two years time. They were given a choice of four levels. A high score indicates a relatively high level of sophistication in the way the particular element is structured and managed.

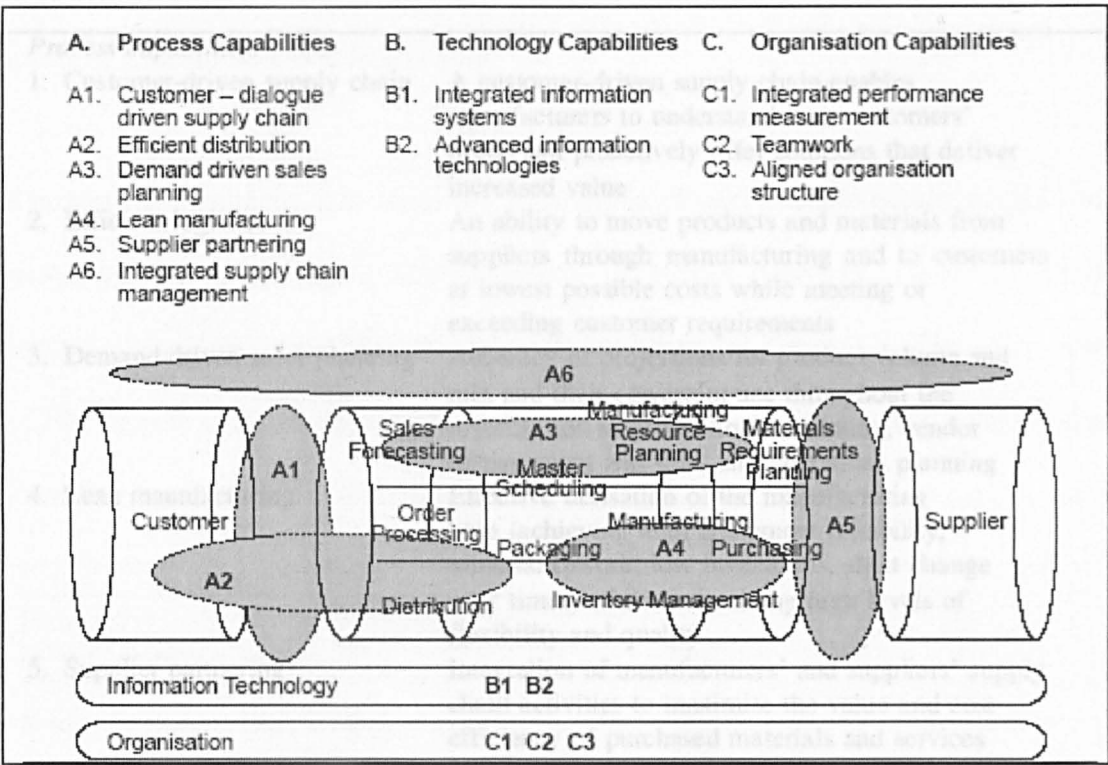


Figure 2.9: The Gilmour's Supply Chain Audit Framework (Gilmour, 1999)

This method is relatively simple and easy to use. It allows users to select their own metrics to examine the SC performance from different perspectives. Although the measures did extend beyond the focal company boundary, it is only limited to the immediate SC level. Despite that, the performance level is based on the respondents' judgement and perception. Therefore, it is a qualitative measurement, which is different from the quantitative measure targeted in this research.

Table 2.5: The Supply Chain Capability Components (Gilmour, 1999)

<i>Process capabilities</i>	
1. Customer-driven supply chain	A customer-driven supply chain enables manufacturers to understand their customers' needs and proactively offer solutions that deliver increased value
2. Efficient logistics	An ability to move products and materials from suppliers through manufacturing and to customers at lowest possible costs while meeting or exceeding customer requirements
3. Demand-driven sales planning	Accuracy of projections for product volume and mix and their consistent use throughout the organisation in production scheduling, vendor management and sales and operations planning
4. Lean manufacturing	Effective utilisation of the manufacturing base (achieving high equipment reliability, minimal rework, low inventories, short change over times) while maintaining high levels of flexibility and quality
5. Supplier partnering	Integration of manufacturers' and suppliers' supply chain activities to maximise the value and cost efficiency of purchased materials and services
6. Integrated supply chain management	Management of the supply chain at two levels: tactical management across functional and company boundaries; and strategic consideration of cost and performance options
<i>Information technology capabilities</i>	
1. Integrated information systems	Improved quality and timeliness of business data to drive supply chain planning, execution and performance monitoring from a common base, resulting in high integrity and consistency of decision making
2. Advanced technology	To improve the efficiency of workflows and to enable new ways to manage the supply chain
<i>Organisation capabilities</i>	
1. Integrated performance measurement	Enables the translation of business objectives into specific operational and financial targets for elements in the supply chain. Regular measurement and analysis of supply chain performance benefits suppliers and customers
2. Teamwork	A focus on building the knowledge base of individuals enhances the ability of employees to work together effectively in achieving broader business goals and improving performance
3. Aligned organisation structure	A cross-functional structure with the objective to support business processes

Table 2.5: The Supply Chain Capability Components (Gilmour, 1999)

**2.3.5.7 Beamon’s Approach (1999)**

Beamon recommended that there are three types of performance measures that are necessary components in any SCPM system – resources, output and flexibility. Each of these measures has different goals, as described in Table 2.6. Therefore, the SCPM system must contain at least one individual measure from each of the three identified types; coincide with the strategic goals (Beamon, 1999).

Performance measure type	Goal	Purpose
Resources	High level of efficiency	Efficient resource management is critical to profitability
Output	High level of customer service	Without acceptable output, customers will turn to other supply chains
Flexibility	Ability to respond to a changing environment	In an uncertain environment, supply chains must be able to respond to change

**Table 2.6: Goals of Performance Measure Types (Beamon, 1999)**

This approach emphasises balanced measurement by measuring three different aspects of SC performance (resources, output and flexibility) together with a selection of relevant metrics that correspond to the strategic goals. Even though Beamon provides example of metrics for each type of measure, there is no empirical case study using the approach. Beamon claims that his study is to establish a foundation toward the development of a universal framework for the selection of performance measures for SC systems.

**2.3.5.8 Shin *et al.*, 2000**

There was a research study conducted by Shin, Collier and Wilson aimed to test the impact of supply management orientation<sup>9</sup> (SMO) on the suppliers' operational performance and buyers' competitive priorities. In this study, they sent out a survey questionnaire, as shown in Table 2.7, to 800 companies in the automotive industry. The questionnaire contained three sections about SMO, supplier performance and buyer performance respectively. All questions were answered by the buyer and from the buyer's perspective. The survey respondents rated their company's position for the 22 questions in this questionnaire on a seven-point Likert scale.

<p><b>1. Buyer-Supplier Management Orientation</b></p> <p>Please indicate your level of agreement or disagreement with the following statement. (The seven-point Likert scale is anchored at one end with "Strongly Disagree" and the other end with "Strongly Agree")</p> <ul style="list-style-type: none"> <li>▪ We strive to establish long-term relationship with suppliers</li> <li>▪ Suppliers are actively involved in our new product development process</li> <li>▪ Quality is our number criterion in selecting suppliers</li> <li>▪ We rely on a small number of high quality suppliers</li> </ul>
<p><b>2. Supplier (Vendor) Performance</b></p> <p>Over the past two years, please indicate the change in each of the following measures for your suppliers. (The seven-point Likert scale is anchored at one end with "Significantly Decrease" and the other end with "Significantly Increase")</p> <ul style="list-style-type: none"> <li>▪ Lead times</li> <li>▪ On-time delivery</li> <li>▪ Delivery reliability</li> <li>▪ Quality</li> <li>▪ Cost</li> </ul>
<p><b>3. Buyer (Manufacturer) Performance</b></p>

<sup>9</sup> Supply Management Orientation is the management efforts or philosophy necessary for creating an operating environment where the buyer and supplier interact in a coordinated fashion (Shin *et al.*, 2000).

Over the past two years, please indicate the change in each of the following dimension of product quality.

(The seven-point Likert scale is anchored at one end with “Significantly Decrease” and the other end with “Significantly Increase”)

- Product quality
  - Performance
  - Features
  - Reliability
  - Conformance to specifications
  - Durability
  - Serviceability

Over the past two years, please indicate the change in each of the following operating measures.

(The seven-point Likert scale is anchored at one end with “Significantly Decrease” and the other end with “Significantly Increase”)

- Delivery
  - Delivery speed
  - Delivery reliability
  - Production lead time
- Costs
  - Production costs
  - Production lead time
- Flexibility
  - Process flexibility
  - Volume flexibility

Table 2.7: The SMO Survey Questionnaire (Shin *et al.*, 2000)

The measurement result from this method is based on the respondents’ judgement and perception on performance. It is a qualitative measure that is prone to high level of subjectivity and the results are significantly influenced by individual preferences and bias. Therefore, this research aims to develop a quantitative method to measure SC performance, which is less common in comparison to qualitative methods.



### 2.3.5.9 Balanced Scorecard (Brewer and Speh, 2000)

The balanced scorecard is a performance measurement method proposed by Kaplan and Norton (Kaplan and Norton, 1992). The scorecard examines a business from four perspectives: customer, internal, innovation and learning, and financial). Brewer and Speh (2000) proposed a theoretical concept to use the balanced scorecard for SCPM. They interrelated SCM and the balanced scorecard, by linking the SCM framework to the balanced scorecard, as shown in Figure 2.10.

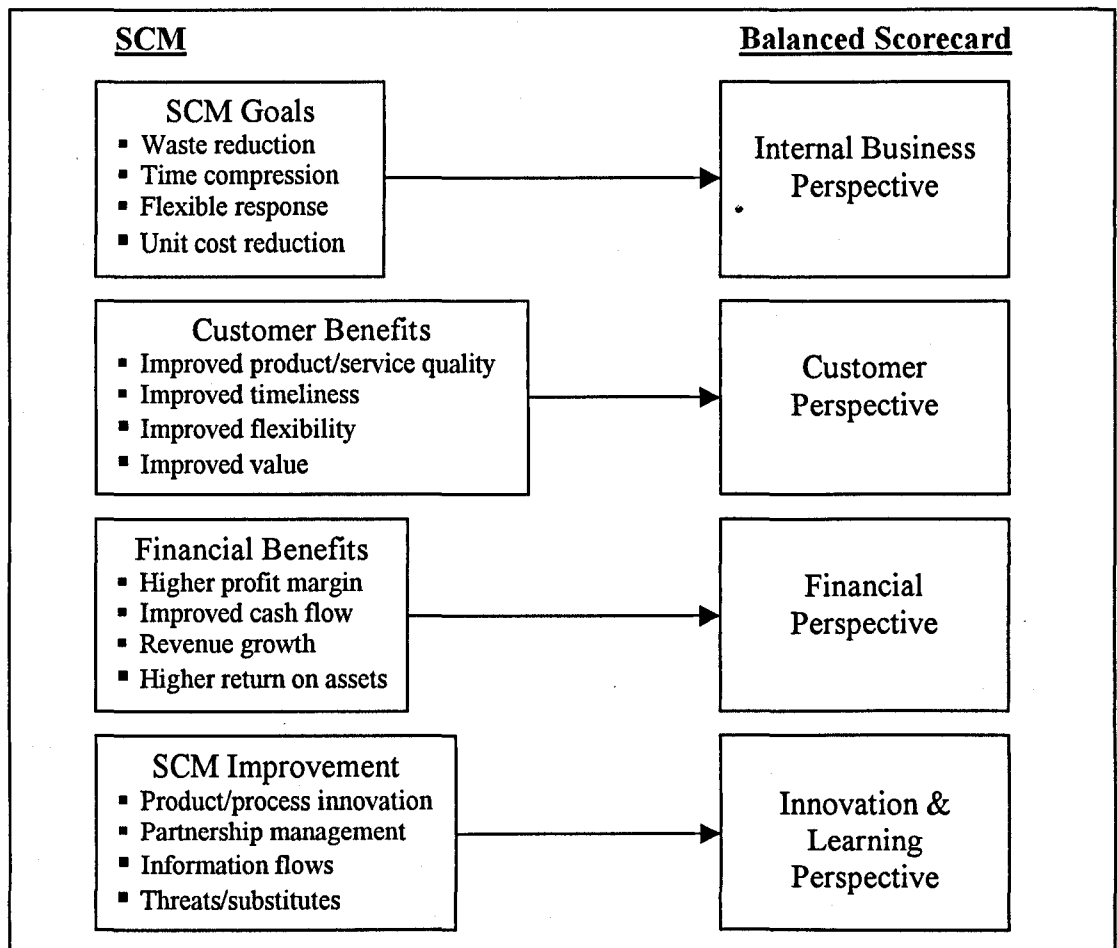


Figure 2.10: Links Between Supply Chain Management to the Balanced Scorecard (Brewer and Speh, 2000)

Supply Chain Management (SCM) is both a boundary spanning and function-spanning endeavour. Hence, in this scorecard, the four major SCM goals concern the

importance of both inter-functional and inter-firm coordination. This is comparable to the internal business perspective in the balanced scorecard, which is to measure what the organisation must do internally to meet its customers' expectations. The different demands and desires of customers all along the SC must be understood and managed effectively. Therefore, from the customer benefits perspective, it is very important to monitor the extent to which the customer is realising these important benefits and on assessing the factors that may impede their realisation. This matches with the customer perspective in the balanced scorecard. When the goals of the SC partners are achieved and the benefits are flowing through to customers, SC members should experience financial success. Hence, the performance has to be measured from financial benefits perspective as well. Hence, the balanced scorecard also includes measures from a financial perspective. SCM recognises that firms must continually learn and innovate to ensure future profitability. Brewer and Speh (2000) measure SC learning and innovations performance that is similar to the innovation and learning perspective in the balanced scorecard.

The balanced scorecard is a generic approach that allows users to define their own metrics based on their measurement target and business strategy. Brewer and Speh (2000) also classify the measures in the scorecard as integrated and non-integrated, with the non-integrated measures are applied across SC. Although there is very little evidence that firms have incorporated the balanced scorecard approach into their SCM practices (Brewer and Speh, 2000), the concept of balanced scorecard and multi-tier SC measure have been adopted into the scorecard developed in this research. This is because balanced and multi-tier measurements are two of the SCPM success factors identified in Section 2.3.3.

**2.3.5.10 Supply Chain Metrics Framework (Lambert and Pohlen, 2001)**

Lambert and Pohlen provided a framework for developing SC metrics that translate performance into shareholder value. The framework aligns performance at each link (supplier-customer pair) within the SC and it consists of seven steps (Lambert and Pohlen, 2001):

1. Map the SC from top to bottom to identify where the key linkages exist.
2. Use the customer relationship management and supplier relationship management processes to analyse each link (customer-supplier pair) and determine where additional value can be created for the SC.
3. Develop customer and supplier profit and loss (P&L) statements to assess the effect of the relationship on profitability and shareholder value of the two firms.
4. Realign SC processes and activities to achieve performance objectives.
5. Establish non-financial performance measures that align individual behaviour with SC process objectives and financial goals.
6. Compare shareholder value and market capitalisation across firms with SC objectives and financial goals.
7. Replicate steps at each link in the SC.

The translation of process improvements into supplier and customer profitability provides a method for developing metrics that identify opportunities for improved profitability and align objectives across all of the firms in the SC (Lambert and Pohlen, 2001). This framework concerns both financial and non-financial aspects, by translating the financial measures used at a management level into non-financial

measures that are usually applied at an operational level. However, this is a theoretical concept and more evidence is required to justify the feasibility of this measurement model.

#### **2.3.5.11 Gunasekeran *et al.*'s Framework (2001)**

Gunasekeran *et al.* (2001; 2003) proposed a framework for measuring the strategic, tactical and operational level performance of a SC. They carried out an importance rating survey to help in setting priorities and put the metrics within a framework so that a cohesive picture can easily be obtained to address what needs to be measured and how. The framework is shown in Table 2.8. The metrics are classified into strategic, tactical and operational levels so that each metric is assigned to an appropriate management level. At the same time, the metrics are also aligned to measure the performance of the four basic links in SC.

Although their framework provides the metrics, they recognise the variation of different supply chains as well as the measurement targets. Thus, they highlight that other measures can be added or use the framework as a starting point to develop an individual measurement system. They also suggest users develop their own measurement programme by adapting the approach that they used in this research (identify metrics, rate the metrics' importance, assign metrics to appropriate management level). The framework provides a balanced measurement by incorporating a variety of metrics to measure different aspects of performance. Although the importance rating survey is an empirical study, the framework is still a theoretical concept because there is no empirical application of the framework.

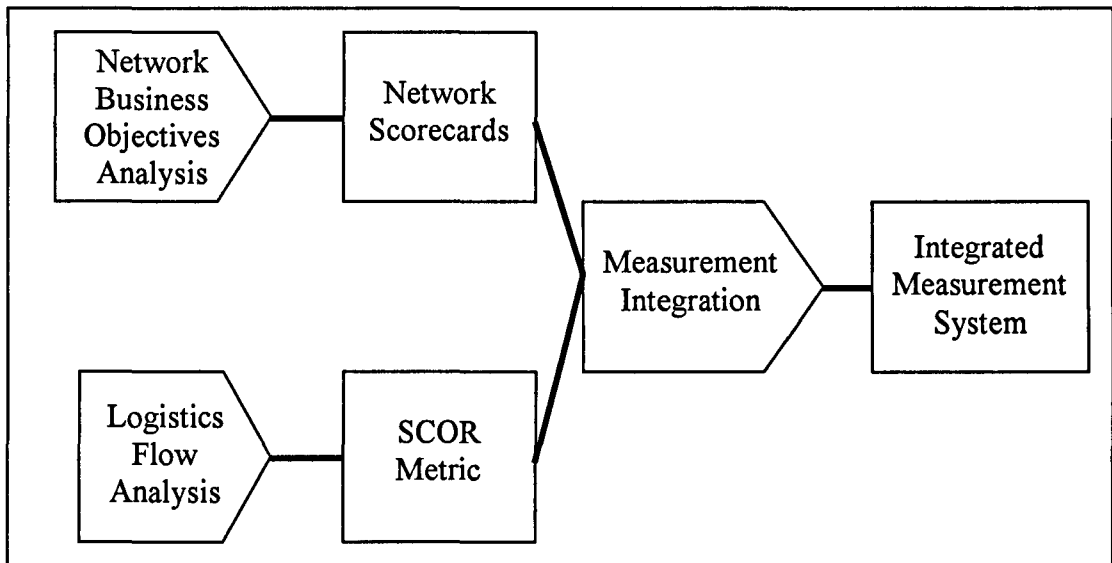
Supply chain activity/ process	Strategic	Tactical	Operational
Plan	Level of customer perceived value of product, Variances against budget, Order lead time, Information processing cost, Net profit Vs productivity ratio, Total cycle time, Total cash flow time, Product development cycle time	Customer query time, Product development cycle time, Accuracy of forecasting techniques, Planning process cycle time, Order entry methods, Human resource productivity	Order entry methods, Human resource productivity
Source		Supplier delivery performance, supplier leadtime against industry norm, supplier pricing against market, Efficiency of purchase order cycle time, Efficiency of cash flow method, Supplier booking in procedures	Efficiency of purchase order cycle time, Supplier pricing against market
Make/ Assemble	Range of products and services	Percentage of defects, Cost per operation hour, Capacity utilization, Utilization of economic order quantity	Percentage of Defects, Cost per operation hour, Human resource productivity index
Deliver	Flexibility of service system to meet customer needs, Effectiveness of enterprise distribution planning schedule	Flexibility of service system to meet customer needs, Effectiveness of enterprise distribution planning schedule, Effectiveness of delivery invoice methods, Percentage of finished goods in transit, Delivery reliability performance	Quality of delivered goods, On time delivery of goods, Effectiveness of delivery invoice methods, Number of faultless delivery notes invoiced, Percentage of urgent deliveries, Information richness in carrying out delivery, Delivery reliability performance

**Table 2.8: Supply Chain Performance Metrics Framework (Gunasekaran *et al.*, 2003)**

#### **2.3.5.12 Balanced Measurement Approach (Bullinger *et al.*, 2002)**

Bullinger *et al.* (2002) proposed a measurement methodology that integrates a bottom-up and top-down SCPM. It is a hybrid measurement approach, which integrates the SCOR model and the balanced scorecard, as seen in Figure 2.11. The SCOR model defines and controls material and product flow and the model's generic modelling characteristics provides a bottom-up measurement system. On the other hand, the SC network scorecards are developed by adapting the concept of balanced

scorecards from Kaplan and Norton (Bullinger *et al.*, 2002). This is the top-down controlling approach to keep the SC on track towards the goals and objectives. They include an example as shown in Table 2.9 to illustrate this approach. By integrating SCOR metrics and network scorecards, three types of relationships between bottom-up and top-down developed measures may occur (Bullinger *et al.*, 2002):



**Figure 2.11: The Balanced Measurement Methodology (Bullinger *et al.*, 2002)**

- The metrics are identical. The focus on strategic controlling objectives is equal to critical flow oriented measures. In this case, the metric is relevant for the (virtual) logistics network organisation as well as for all SC partners.
- The metrics are similar. They are not identical but have a certain relationship. In this case, the metrics focus on the same logistics target using different control methods or a relationship may be derived applying accounting targets. The most important decision is to achieve a common understanding of the derived identifiers. Metrics may be used in analogy with the network identifiers or by measurement of organisation-specific instruments with the liability to shift into network performance indicators.

- The metrics do not have any relationship. In this case, controlling measures for business objectives and key performance indicators for the control of material and product flows do not correspond. The network has to decide whether one or both have to be integrated.

	Financial Perspective	Customer Perspective	Organisational Perspective	Innovation Perspective
Supply Chain Perspective	<ul style="list-style-type: none"> <li>▪ Total supply chain costs</li> <li>▪ Total supply chain inventories</li> <li>▪ Total supply chain revenues</li> </ul>	<ul style="list-style-type: none"> <li>▪ Point of consumption product availability</li> <li>▪ Point of consumption product quality</li> </ul>	<ul style="list-style-type: none"> <li>▪ Supply chain relationship quality</li> <li>▪ Productivity loss</li> <li>▪ Perfect order fulfilment</li> </ul>	<ul style="list-style-type: none"> <li>▪ Market share</li> <li>▪ New product time-to-market</li> <li>▪ New product time-to-first-make</li> </ul>
Process Perspective	<ul style="list-style-type: none"> <li>▪ Return on investment</li> <li>▪ Return on capital employed</li> <li>▪ Cash-to-cash cycle</li> <li>▪ Revenues</li> </ul>	<ul style="list-style-type: none"> <li>▪ Customer satisfaction</li> <li>▪ Customer loyalty</li> <li>▪ Customer complaints</li> </ul>	<ul style="list-style-type: none"> <li>▪ Forecast accuracy</li> <li>▪ Planning process cycle</li> <li>▪ Schedule changes</li> </ul>	<ul style="list-style-type: none"> <li>▪ Percent sales from new product</li> <li>▪ Percent employees in cross-functional teams</li> </ul>
Function Perspective	<ul style="list-style-type: none"> <li>▪ Material acquisition cost</li> <li>▪ Inventory costs</li> <li>▪ Work in progress</li> <li>▪ Costs per unit produced</li> <li>▪ Freight costs</li> <li>▪ Picking costs</li> <li>▪ Transportation costs</li> <li>▪ Cash flow</li> </ul>	<ul style="list-style-type: none"> <li>▪ On-time delivery</li> <li>▪ Order fill rate</li> <li>▪ Order cycle time</li> <li>▪ Invoice accuracy</li> <li>▪ Number of back orders</li> <li>▪ Percent resolution on 1<sup>st</sup> customer call</li> <li>▪ Order track and trace performance</li> </ul>	<ul style="list-style-type: none"> <li>▪ Incoming material quality</li> <li>▪ Inventory count accuracy</li> <li>▪ Out of stocks</li> <li>▪ Line item fill</li> <li>▪ Inventory turns</li> <li>▪ EDI transactions</li> </ul>	<ul style="list-style-type: none"> <li>▪ Number of employee suggestions</li> </ul>

Table 2.9: Possible Supply Chain Performance Indicators (Bullinger *et al.*, 2002)

The SCOR model translates the top-level metrics into operational measures and aligns the metrics with business strategies and measurement targets, while the balanced scorecard ensures that measurements are taken from different perspectives.

Even though this approach integrates the strengths from the SCOR model and the balanced scorecard model, there is no empirical evidence provided to prove the feasibility of this approach. But nevertheless, the concept of balanced measurement and strategy alignment are recognised as two of the main factors that facilitate an effective SCPM. Therefore, these concepts are adopted into the scorecard in this research.

#### **2.3.4.13 Supply Chain Audit Check Sheets (Waller, 2003)**

In his book, Waller suggested that a global audit of SC could be done by analysing the costs relevant to revenues (Waller, 2003). There are two case studies included in the book to illustrate the measurement method. Table 2.10 provides an example of the financial measurement analysis in one of the case studies. In the first column are the revenues and costs, in the second column are the ratios of the financial data as a percent of revenues, and the third column the results either as a percent of the total distribution costs or as a percentage of the total production costs.

Monthly items	Results (\$)	As percent of revenues (%)	As percent of distribution costs (%)
Total sales revenue	40,906,939	100.00	
<b>Distribution costs</b>			
Special delivery costs	80,900	0.19	2.18
Stockout costs	1,431,960	3.50	38.54
Kilometres travelled	198,685	0.48	5.35
Normal truck hours	398,125	0.97	10.72
Overtime truck hours	48,110	0.12	1.30
Stocking costs at distribution site	298,158	0.73	8.03
External warehouse costs	1,258,324	3.08	33.88
Total distribution costs	3,714,262	9.08	100.00
<b>Margin distribution</b>	<b>37,192,677</b>	<b>90.92</b>	
<b>Production costs</b>			As percent of production costs (%)
Stocking costs at production site	3,799,118	9.29	11.50
Labour costs	8,540,277	20.88	25.85
Hiring and termination costs	372,600	0.91	1.13
Transfer costs	110,254	0.27	0.33



Raw material cost	20,145,587	49.25	60.99
Subcontracting costs	64,254	0.16	0.20
<b>Total production costs</b>	<b>33,032,090</b>	<b>80.75</b>	<b>100.00</b>
Operating income	4,160,587	10.17	

Table 2.10: Financial Measurement Analysis (Waller, 2003)

This measurement model has significant emphasis on financial measure and does not include other non-financial aspects. Hence, it is not a balanced measure. Furthermore, it is not a multi-tier measurement because the measure is confined to one SC level. Therefore, it is not adopted into the scorecard.

#### **2.3.5.14 Process Based Approach (Chan and Qi, 2003-a,b,c)**

Chan and Qi (2003-a) suggested a scientific mathematical model, using the process-based method and a fuzzy measurement algorithm to measure SC performance. According to the authors, in a SC context, a process consists of a series of activities from original suppliers and manufacturers to retailers that add value for the end customers. According to Chan and Qi (2003-a), the six core SC processes are supplier, inbound logistics, manufacturing, outbound logistics, marketing and sales, and end customers. This is similar to the value chain model by Michael Porter (1998). The key processes can be further decomposed into sub-processes and activities for more detailed performance analysis. For each process and sub-process, the corresponding performance measures are identified respectively. Then these measures are grouped into the hierarchy of the processes to form a process and performance measures hierarchy (PPMH) as shown by the example in Figure 2.12.

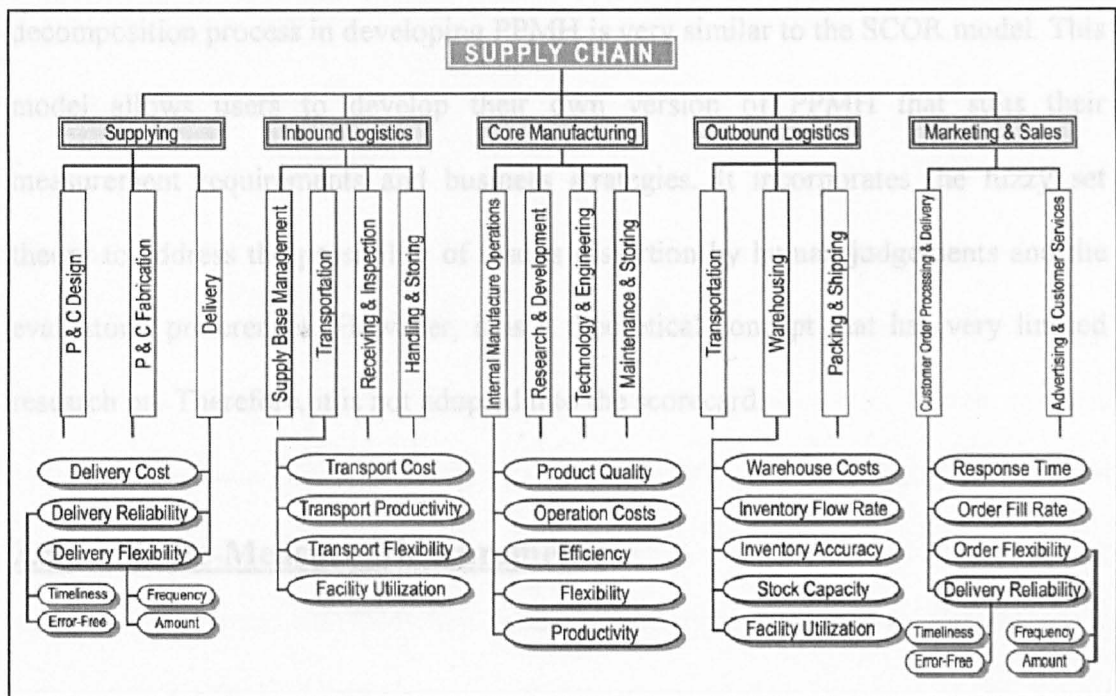


Figure 2.12: An Example of PPMH Chan and Qi (2003-a)

This method incorporates the fuzzy set theory in setting weights and measuring performance. It addresses the real situation of human judgement with fuzziness in measurement activity without losing the important information (Chan and Qi, 2003). Different weights are assigned for each metric, individual decomposed processes, as well as the evaluators' opinion (from the performance measurement team that composed of the representative from different management functions from each SC company). A geometric scale of triangular fuzzy numbers is employed to quantify the comparison ratios. The measurement scale is based on historical, current and target performance level (Chan *et al.*, 2003). The details of the calculation can be found from the following papers: Chan and Qi, 2003-a; Chan *et al.*, 2003; Chan and Qi, 2003-b.

Chan and Qi (2003-a) advocate that this process-based model helps to locate problems, facilitates process re-engineering and encourages SC integration. The

decomposition process in developing PPMH is very similar to the SCOR model. This model allows users to develop their own version of PPMH that suits their measurement requirements and business strategies. It incorporates the fuzzy set theory to address the possibility of results distortion by human judgements and the evaluators' preferences. However, it is a theoretical concept that has very limited research on. Therefore, it is not adopted into the scorecard.

### **2.3.6 Single-Measure Measurements**

Single-measure measurement is the opposite of multi-measure measurement. These are the measurement methods that are not included in the multi-measure measurement category. They only measure one particular SC characteristic, such as delivery performance, responsiveness, and flexibility.

There are **seven** types of single-measure measurements in this literature review:

- Bullwhip Effect
- Cost
- Cash-to-cash Cycle Time
- Logistics
- Integration Level
- Responsiveness
- Inventory

### **2.3.6.1 Bullwhip Effect**

#### **2.3.6.1.1 Introduction**

The bullwhip effect is one of the hot topics in SCM. It is also known as the whiplash effect (Lee et al., 1997a) (McCullen and Towill, 2001) or the Forrester effect (1961). Chen *et al.* (2000) define bullwhip effect as the phenomenon where demand variability increases further up a SC. Lee *et al.* (1997 a) describe bullwhip effect in greater detail by defining it in two parts: demand distortion (when the orders to supplier have larger variance than sales to the buyer) and variance amplification (when the distortion propagates upstream in an amplified form). Sterman (1989) reports evidence of bullwhip effect in the “Beer Game”. Companies like Procter & Gamble and Hewlett-Packard have been affected by this phenomenon (Lee *et al.*, 1997 b). In 1997, Holmstrom (1997) reported a SC where variability increases from 9 to 29 for two different product groups going from consumer demand to plant supply. All these evidences show that bullwhip effect is one of the major issues in SC.

According to Fransoo and Wouters (2000), Forrester was the first person to study the bullwhip effect. He did an extensive study on SC demand information amplification in his seminal book called “Industrial Dynamics” (Forrester, 1961). It included a series of case studies and advocated that industrial dynamics or organisational time varying behaviour is the main reason that causes bullwhip effect.

Another crucial study concerning the bullwhip effect is the “Beer Distribution Game” carried out by Sterman (1989). This experiment simulates the operation of a

SC. There are four players to represent four tiers of a SC: factory, distributor, wholesaler and retailer. Each player has to make independent inventory decisions without any IS among the SC members, except the orders placed by the downstream players. The experiment shows that the variances of orders amplify as one moves up in the SC.

#### 2.3.6.1.2 Causes

According to Lee *et al.* (1997 a, b), there are four causes of bullwhip effect:

- Demand signal processing: This refers to the situation where demand is non-stationary and past demand information is used to update forecasts.
- Rationing game: This refers to the strategic ordering behaviour of buyers when supply shortage is anticipated.
- Order batching: This happens when the fixed order cost is non-zero and ordering in every period would be uneconomical.
- Price variations: This refers to non-constant purchase prices of the product.

They also provide information on counter measures and state of practice that corresponds to each cause as shown in Table 2.11.

Causes	Contributing Factors	Counter-Measures	State of Practice
Demand signalling	<ul style="list-style-type: none"> <li>▪ No visibility of end demand</li> <li>▪ Multiple forecasts</li> <li>▪ Long lead time</li> </ul>	<ul style="list-style-type: none"> <li>▪ Access sell-thru or POS<sup>10</sup> data</li> <li>▪ Single control of replenishment</li> <li>▪ Lead time reduction</li> </ul>	<ul style="list-style-type: none"> <li>▪ Sell-thru data in contracts (e.g. HP, Apply, IBM)</li> <li>▪ VMI<sup>11</sup> (P&amp;G and Walmart)</li> <li>▪ Quick response mfg.<sup>12</sup> strategy</li> </ul>
Order batching	<ul style="list-style-type: none"> <li>▪ High order cause</li> <li>▪ FTL<sup>13</sup> economics</li> <li>▪ Random or correlated ordering</li> </ul>	<ul style="list-style-type: none"> <li>▪ EDI<sup>14</sup> &amp; CAO<sup>15</sup></li> <li>▪ Discount on assorted truckload, consolidation by 3<sup>rd</sup> party logistics</li> <li>▪ Regular delivery appointment</li> </ul>	<ul style="list-style-type: none"> <li>▪ McKesson, Nabisco</li> <li>▪ 3<sup>rd</sup> party logistics in Europe, emerging in the US</li> <li>▪ P&amp;G</li> </ul>
Fluctuating prices	<ul style="list-style-type: none"> <li>▪ High-low pricing</li> <li>▪ Delivery and purchase synchronised</li> </ul>	<ul style="list-style-type: none"> <li>▪ EDLP<sup>16</sup></li> <li>▪ Special purchase contract</li> </ul>	<ul style="list-style-type: none"> <li>▪ Procter &amp; Gambler (resisted by some retailers)</li> <li>▪ Under study</li> </ul>
Shortage game	<ul style="list-style-type: none"> <li>▪ Proportional rationing scheme</li> <li>▪ Ignorance of supply conditions</li> <li>▪ Unrestricted orders and free return policy</li> </ul>	<ul style="list-style-type: none"> <li>▪ Allocated based on past sales</li> <li>▪ Shared capacity &amp; supply information</li> <li>▪ Flexibility limited over time; capacity reservation</li> </ul>	<ul style="list-style-type: none"> <li>▪ Saturn, HP</li> <li>▪ Scheduling sharing (HP, Motorola)</li> <li>▪ HP, Sun, Seagate</li> </ul>

Table 2.11: The Causes and Counter-measures of the Bullwhip Effect (Lee *et al.*, 1997 a)

For each cause, Lee *et al.* have suggested three streams of solutions to tackle bullwhip effect – IS, channel alignment and improving operational efficiency, as shown in Table 2.12.

<sup>10</sup> POS = Point Of Sales

<sup>11</sup> VMI = Vendor Managed inventory

<sup>12</sup> mfg. = Manufacturing

<sup>13</sup> FTL = Full Truck Load

<sup>14</sup> EDI = Electronic Data Interchange

<sup>15</sup> CAO = Computer Assisted Ordering

<sup>16</sup> EDLP = Every Day Low Price

Causes	Information sharing	Channel alignment	Operational Efficiency
Demand signalling	<ul style="list-style-type: none"> <li>▪ Understanding system dynamics</li> <li>▪ Use POS<sup>17</sup> data</li> <li>▪ EDI<sup>18</sup></li> <li>▪ Internet</li> <li>▪ CAO<sup>19</sup></li> </ul>	<ul style="list-style-type: none"> <li>▪ VMI<sup>20</sup></li> <li>▪ Discount for information sharing</li> <li>▪ Consumer direct</li> </ul>	<ul style="list-style-type: none"> <li>▪ Lead-time reduction</li> <li>▪ Echelon-based inventory control</li> </ul>
Order batching	<ul style="list-style-type: none"> <li>▪ EDI</li> <li>▪ Internet ordering</li> </ul>	<ul style="list-style-type: none"> <li>▪ Discount for truckload assortment</li> <li>▪ Delivery appointments</li> <li>▪ Consolidation</li> <li>▪ Logistics outsourcing</li> </ul>	<ul style="list-style-type: none"> <li>▪ Reduction in fixed cost of ordering by EDI or electronic commerce</li> <li>▪ CAO</li> </ul>
Fluctuating prices		<ul style="list-style-type: none"> <li>▪ CRP<sup>21</sup></li> <li>▪ EDLP<sup>22</sup></li> </ul>	<ul style="list-style-type: none"> <li>▪ EDLP</li> </ul>
Shortage game	<ul style="list-style-type: none"> <li>▪ Sharing sales, capacity and inventory data</li> </ul>	<ul style="list-style-type: none"> <li>▪ Allocation based on past sales</li> </ul>	<ul style="list-style-type: none"> <li>▪ ABC<sup>23</sup></li> </ul>

Table 2.12: A Framework for SC Coordination Initiatives (Lee et al., 1997 b)

Svensson (2003) supports Lee *et al.*'s statement regarding the four causes of bullwhip effect, but he also added that companies' atomistic considerations in a SC (which creates sub-optimisation of business activities) is another factor that cause bullwhip effect. SCs with bullwhip problems will usually suffer deteriorating performance, such as excessive inventory, poor product forecasts, insufficient or excessive capacity, poor customer service, uncertain production planning and high correction costs (Lee *et al.*, 1997 a).

<sup>17</sup> POS = Point Of Sales

<sup>18</sup> EDI = Electronic Data Interchange

<sup>19</sup> CAO = Computer Assisted Ordering

<sup>20</sup> VMI = Vendor Managed inventory

<sup>21</sup> CRP = Continuous Replenishment Program

<sup>22</sup> EDLP = Every Day Low Price

<sup>23</sup> ABC = Activity-based Costing

On the other hand, McCullen and Towill (2001) recognise that there are three prime dimensions to the bullwhip problem:

- Replenishment dimension, which affects the flow of materials and information throughout
- Geographical dimension since activities take place in different locations
- Temporal dimension since activities take place at different times

#### 2.3.6.1.3 Measurement Methods

In 2000, Fransoo and Wouters published a paper about the conceptual measurement problems in quantifying bullwhip effect and their experiences in dealing with these problems (Fransoo and Wouters, 2000). They conducted their case studies in two food SCs - salads and ready-made pasteurised meals. They identified three conceptual measurement issues in assessing bullwhip effect (Fransoo and Wouters, 2000):

- First, there are different ways to aggregate the data. Some companies keep their sales data aggregated on a monthly basis while some might do it on a weekly basis. Problems will occur if the measurement requires daily or hourly data, which is quite common in measuring bullwhip effect.
- Second, measuring the total bullwhip effect does not tell which particular reason that contributes most to the effect and which solution is most effective and relevant.



- Any company in the SC to be analysed may be part of other SCs. For example, manufacturer A may be supplier for both retailer A and retailer B. In order to analyse the bullwhip effect between manufacturer A and retailer A, the influence from retailer B has to be removed. However, disaggregating the information to obtain insight into a particular SC might be a problem.

They measure bullwhip effect at a particular (set of) echelon(s) in the SC as the quotient of the coefficient of variation of demand generated by this (set of) echelon(s) and the coefficient of variation of demand received by this echelon:

$$\omega = \frac{c_{out}}{c_{in}} \dots \dots \dots (\text{Equation 2.1})$$

where

$$c_{out} = \frac{\sigma(D_{out}(t, t+T))}{\mu(D_{out}(t, t+T))} \dots \dots \dots (\text{Equation 2.2})$$

and

$$c_{in} = \frac{\sigma(D_{in}(t, t+T))}{\mu(D_{in}(t, t+T))} \dots \dots \dots (\text{Equation 2.3})$$

$\omega$  = bullwhip coefficient

$D$  = daily demand quantity

$t$  = first day of data period

$T$  = number of day during data period

$\sigma$  = standard deviation

$\mu$  = average

$D_{out}(t, t+T)$  and  $D_{in}(t, t+T)$  are the demands during the time interval  $(t, t+T)$ . The variability of upstream demand is divided by the variability of downstream demand. As mentioned before, there are different ways to aggregate the data, depending on the measurement targets and requirements. Fransoo and Wouters (2000) distinguish four levels of aggregation, assuming there are  $P$  product types and  $M$  outlets<sup>24</sup> in the SC:

<sup>24</sup> Outlet: SC members, e.g. distributions centre

- Product/Outlet ( $\omega_1$ ): this is the most detailed analysis, determining the standard deviation for all available demand series, resulting in  $P \times M$  standard deviations, and  $P \times M$  bullwhip measurements.
- Product ( $\omega_2$ ): demand per product type is aggregated over the outlets and this indicates the variability in demand of a product at the entire echelon, not distinguishing between individual outlets, and also assuming pooling between the outlets. This results in  $P$  bullwhip measurements.
- Outlet ( $\omega_3$ ): aggregated over the product types, this indicates the variability in demand of an outlet, not distinguishing between individual products. This requires that the product demands be added up, e.g. by using some kind of weighing factor. This results in  $M$  bullwhip measurements.
- Echelon<sup>25</sup> ( $\omega_4$ ): aggregated over the outlets and product types, the variability of total demand at the echelon can be determined. Different product demands can be added up using a weighing factor. This results in 1 bullwhip measurement.

Table 2.13 illustrates the different results from the four different aggregation level mentioned above. The demand data in this table are random, not an empirical study. From the study, they made three conclusions concerning bullwhip effect measurement (Fransoo and Wouters, 2000) correspond to the measurement issues:

- Make sure the data are aggregated in correct sequence. The sequence of data aggregation has to be based on the specific problem that is under investigation.
- It is important to distinguish the contribution of each echelon in the SC. Hence, the measurement has to be determined separately for each echelon.

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<sup>25</sup> Echelon: An echelon may consist of several parallel outlets

- The measurement needs to be filtered to identify which part of the overall effect is the result of different causes.

Day								
Aggregation Level	1	2	3	4	5	$\mu$	$\sigma/\mu$	$\omega$
Product/Outlet								
Outlet A:								
Product 1								
D <sub>in</sub>	5	4	6	4	6	5	0.200	2.449
D <sub>out</sub>	2	6	8	3	6	5	0.490	
Product 2								
D <sub>in</sub>	4	6	5	5	5	5	0.141	4.796
D <sub>out</sub>	1	9	2	6	7	5	0.678	
Outlet B:								
Product 1								
D <sub>in</sub>	14	15	14	13	14	14	0.051	4.796
D <sub>out</sub>	12	13	10	18	17	14	0.242	
Product 2								
D <sub>in</sub>	15	16	14	15	15	15	0.047	4.796
D <sub>out</sub>	16	17	11	19	12	15	0.226	
Average: 4.495 ( $\omega_1$ )								
Product								
Product 1								
D <sub>in</sub>	19	19	20	17	20	19	0.064	2.769
D <sub>out</sub>	14	19	18	21	23	19	0.178	
Product 2								
D <sub>in</sub>	19	22	19	20	20	20	0.061	4.472
D <sub>out</sub>	17	26	13	25	19	20	0.274	
Average: 3.642 ( $\omega_2$ )								
Outlet								
Outlet A								
D <sub>in</sub>	9	10	11	9	11	10	0.100	4.583
D <sub>out</sub>	3	15	10	9	13	10	0.458	
Outlet B								
D <sub>in</sub>	29	31	28	28	29	29	0.042	4.655
D <sub>out</sub>	28	30	21	37	29	29	0.197	
Average: 4.636 ( $\omega_3$ )								
Echelon								
D <sub>in</sub>	38	41	39	37	40	39	0.041	4.712
D <sub>out</sub>	31	45	31	46	42	39	0.191	
Average: 4.712 ( $\omega_4$ )								

**Table 2.13: Bullwhip Effect Measures at Different Aggregation Levels (Fransoo and Wouters, 2000)**

Another bullwhip effect measurement study was conducted by Chen, Drezner, Ryan and Simchi-Levi (2000). Their aims were to determine the impact of demand forecasting on the bullwhip effect, as well as to quantify the bullwhip effect (Chen *et al.*, 2000). It is a two-stage SC measurement model with only a retailer and a manufacturer. They compare the variance of the orders placed by the retailer to the manufacturer relative to the variance of the demand faced by the retailer. In the

study, they assume that all stages in the SC use the same demand data, the same inventory policy and the same forecasting technique. The details of this measurement model can be found in their paper (Chen *et al.*, 2000). From the study, they draw three conclusions:

- The smoother the demand forecast, the smaller the increase in variability.
- The longer the lead time, the retailer must use more demand data in order to reduce the bullwhip effect.
- With centralising demand information (to make customer demand information available to every stage of SC), bullwhip effect can be reduced but not completely eliminated.
- The difference of variability between the SCs with centralised and decentralised information system increases as we move up the SC.

In 2001, McCullen and Towill (2001) published a paper about a case study from the precision mechanical engineering sector. In their study, bullwhip effect was measured by using the average unsigned difference between the demand and production time series for replenishment demand on the central warehouse and actual production. The detailed bullwhip estimates for products 1-6 are shown in Table 2.14. The implementations of new distribution requirements planning based information systems and rapid response manufacturing systems in month 36 have reduced the bullwhip effect significantly.

Products	1	2	3	4	5	6
Months 1-35	62	84	59	84	35	37
Months 36-84	34	62	48	63	30	20
Change	-45%	-26%	-18%	-25%	-14%	-46%

Table 2.14: Bullwhip Across Two Observed Echelons Before and After the Improvement (McCullen and Towill, 2001)

Another paper published by Disney and Towill (2003) showed how the bullwhip sources are affected by the introduction of VMI, using a simulation model. In this study, they measure bullwhip effect using a similar equation:

$$Bullwhip = \frac{\sigma^2_{ORATE}}{\sigma^2_{CONS}} \dots\dots\dots (Equation 2.4)$$

where

$\sigma^2$  is the conditional variance of the orders (subscript ORATE) and consumption (CONS).

This is very similar to Fransoo and Wouters formula, except that the standard deviation is replaced by variance.

Among these three different approaches to measure bullwhip effect (Fransoo and Wouters, 2000; Chen *et al.*, 2000; Disney and Towill, 2003), Equation 2.1 proposed by Fransoo and Wouters (2000) was adopted into the scorecard for its simplicity and the strong empirical evidence that proven the approach feasibility and applicability.

### 2.3.6.2 Cost

#### 2.3.6.2.1 Introduction

Financial performance has been the primary measure of success in most organisations (Bullinger *et al.*, 2002; Tangen, 2003).

*“Maintaining minimal cost is one of the strategic imperatives at all”*

(Aquilano *et al.*, 1995).

Before the concept of balanced measurement emerged, most companies used traditional cost accounting information to evaluate performance (Beamon, 1999), some tended to over emphasise on financial measures (Beamon, 1999; Bullinger *et al.*, 2002; Olve *et al.*, 1999).

Many researchers have identified the shortcomings of using traditional accounting data to measure performance (Christopher, 1998):

- The assumptions that upon which a traditional accounting system is based were made 80 years ago (Johnson, 1983). Obviously the business environment has evolved in the last 60 years – higher product and process complexity, shorter product life cycles, higher quality standards and higher market competition (Jeans and Morrow, 1989). Most of these assumptions are outdated and are no longer suitable (Neely *et al.*, 1995). For example, the allocation of overhead costs according to direct labour cost might have diverted the cost saving efforts down the wrong track. This is due to manufacturing technology advancement, which

has changed the major contributor of the full product cost from direct labour cost to overhead cost (Neely *et al.*, 1995).

- Not forward-looking, short-term orientation, lack of predictive power and lack of strategic focus (Neely *et al.*, 1995; Bullinger, *et al.*, 2002).
- The overhead costs are less visible and hard to assign to activities (Mena *et al.*, 2002), due to the cost aggregation practice (Themido *et al.*, 2000). For example, many “tailored” logistics costs are incorporated in overhead cost (LaLonde and Pohlen, 1996).
- Inaccurate costing information due to the difficulty in tracking overhead cost (Themido *et al.*, 2000). This is because the changes in business environment have shifted the focus of cost structure from direct cost to indirect and overhead cost (Themido, 2000).
- Lacked a strategic focus (Bromwich and Bhimani, 1989). Every SC member was more focused on its internal benefits, which caused local optimisation (Cox *et al.*, 2000; Smith and Lockamy III, 2000)
- Most of the data provided by accounting systems are more suitable for external financial reporting rather than for business management (Neely *et al.*, 1995). This is because a management accounting system is designed to value stock rather than to provide meaningful data for business management, such as the product costs. The data shows only the result of yesterday’s actions rather than indicating tomorrow’s performance. It does not provide any forward-looking perspective and lacks predictive power (Bullinger *et al.*, 2002; Adebajo and Mann, 1999). Hence, it is unable to reflect contemporary value creating actions and it does not capture key business changes until it is too late (Bullinger *et al.*, 2002; Adebajo

and Mann, 1999; Chan *et al.*, 2003; Beamon, 1999; Holmberg, 2000; Olve *et al.*, 1999).

- Some performance attributes that cannot be measured in financial terms were ignored, like customer's perceptions of value and requirements (Smith and Lockamy III, 2000).

Since traditional cost accounting is no longer appropriate for current business environment, many studies have been carried to discover a perfect cost measurement method. However, most of these studies focus on measurement cost within an organisational boundary. There are very few cost measurement studies that measure across SCs (Lalonde and Pohlen, 1996). According to Todd and McGrath's study, leading companies (the best-in-class) have a lower SCM cost than their competitors (median), as illustrated by the chart in Figure 2.13. The median companies spent more of their revenue, between 3% to 7% on SCM than the leading companies. The SCM costs included in this chart are order management, material acquisition, inventory carrying and SC MIS<sup>26</sup>, planning and finance. Lambert and Bennis (1982) believe that the total cost of a SC can be reduced by allocating SC functions<sup>27</sup> to those members that can perform them most efficiently.

The following are the existing SC cost measurement methods:

- Activity based costing
- Total cost measurement by Viswanadham and Srinivasa Raghavan (2000)
- SC costing by Mena *et al.* (2002)

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<sup>26</sup> MIS: Management Information System

<sup>27</sup> The supply chain functions defined by Lambert and Bennis (1981) are buying, selling, transportation, storage, sorting, risk bearing, financing, order processing/communication.



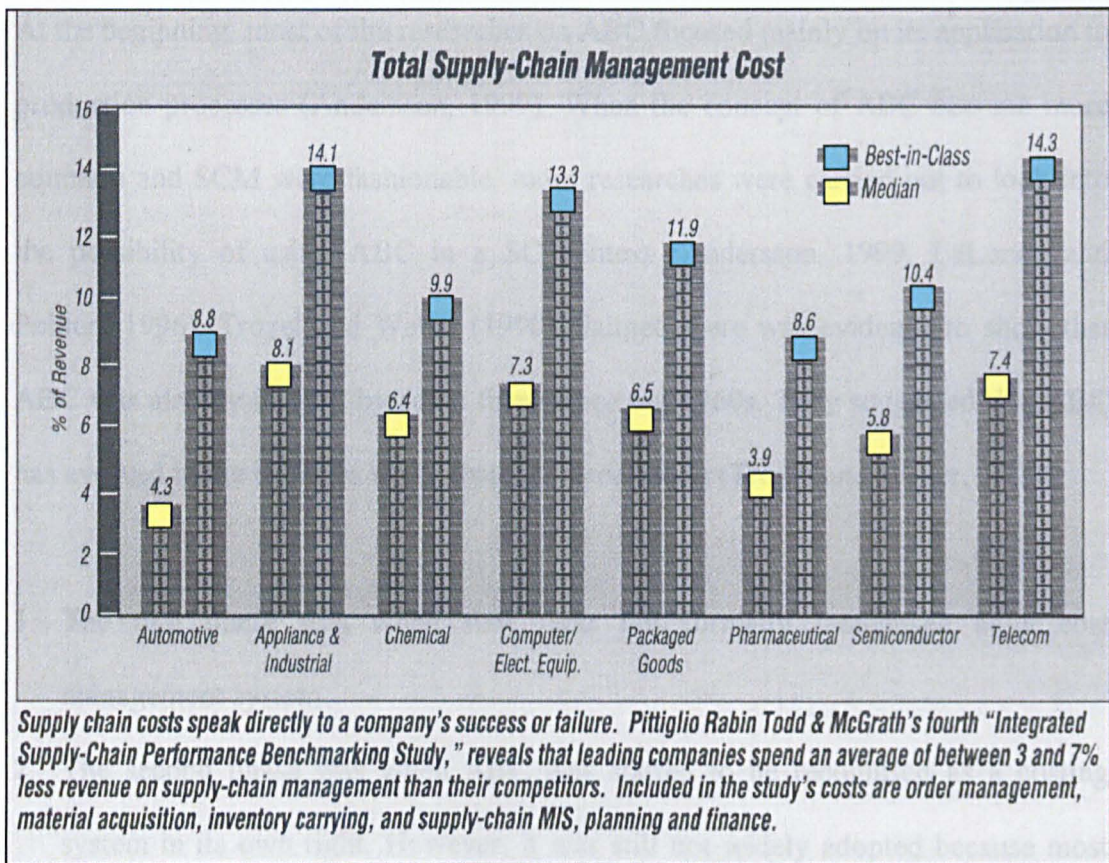


Figure 2.13: Supply Chain Management Costs (adapted from Morton, 1997)

#### 2.3.6.2.2 Activity Based Costing (ABC)

ABC has been recognised as a costing method that is able to tie financial measures to operational performance (Lapide, 2000), which is one of the shortcomings of traditional accounting methods. It has been applied to support new approaches to pricing decisions, profitability analysis, internal performance measurement and cost management (Roodhooft and Konings, 1996). ABC breaks down the activities into individual tasks or cost drivers, while estimating the resources (i.e. time and costs) needed for each cost centre (Lapide, 2000), including both direct and indirect costs (Cokins, 1999).

At the beginning, most of the researches on ABC focused mainly on its application to production processes (Andersson, 1999). When the concept of ABC become more common and SCM were fashionable, more researches were carried out to look into the possibility of using ABC in a SC context (Andersson, 1999; LaLonde and Pohlen, 1996). Troxel and Weber (1990) claimed there was evidence to show that ABC was already in used by some firms since the 1960s. They suggested that ABC has evolved in the business world through three stages (Troxel and Weber, 1990):

1. The first phase was when ABC was not formally recognised as a cost management system.
2. The second phase was when ABC was started to be recognised as a costing system in its own right. However, it was still not widely adopted because most practitioners thought that the original costing system had to be scrapped in order to implement ABC.
3. The third phase was when ABC was finally recognised as part of a strategic decision making process, which can coexist with incumbent cost management system.

Generally, activity based cost management is considered to be better than traditional cost management in terms of information accuracy, integration of customer requirements and support for SC strategy. Traditional cost accounting systems are often perceived to be incomplete, structurally deficient (costs are reported in a format that does not support decision making) and inaccurate (Cokins, 1999). ABC is able to translate the data from traditional cost accounting system into a more practical structure to facilitate business decisions and operations (Cokins, 1999; Pohlen,

2003). Generally, the advantages of using ABC in SC performance analysis can be summarised as follows:

- Enables firms to exploit linkages and perform trade-offs across the entire SC, as well as providing the means for assessing SC performance (Pohlen, 2003).
- Able to quantify unexpected costs, such as cost incurred by unplanned scheduling changes and cost to rectify the error at a customer's site (Barr, 1996).
- Allow users to identify loss-making products, which would have been hidden by traditional accounting techniques (Mena et al., 2002). Due to the fierce competition, the knowledge of the real cost of a product/service to a specific customer is becoming the key to company survival (Themido et al., 2000)
- Provides the ability to model the following SC elements (Andersson, 2001):
  - The cost of key processes within the SC
  - The cost of SCs relating to specific trading partners
  - The SC cost relating to particular categories of product
  - The resource and cost implications of changing activity volumes
  - The resource and cost implications of changing the way activities are performed

Andersson (1999) illustrated the method of applying ABC to two SC case studies to estimate costs and to optimise material flow. The case studies started with extensive mapping activities of the SCs. Then the maps were broken down in activities connected with the flow of goods. For each activity, a cost driver was identified and a cost calculation formula was developed. These formulae were developed with the

objective to be as general as possible to be able to use the same method for all members in the SC. A specially developed piece of software called SCOPTI was used to calculate the costs and to optimise the flow of goods. However, the detail of the cost calculation was not included in this particular paper.

In ABC, the practice of labelling activities as “non-value added” without customers’ input might not reflect customers’ true requirements. Also, it encourages companies to focus on current activities, which is not necessarily right, instead of searching for new opportunities for improvements (Smith and Lockamy III, 2000; Neely *et al.*, 1995). As a result, long term survival and profit is jeopardised.

Another disadvantage of ABC is the risk of subjectivity in the cost allocation to activities, and the complexity and cost involved in ABC system development and maintenance (Mena *et al.*, 2002). In some companies, the ABC system only covers a portion of SC activities and mainly focuses on the internal economics of activity costs. As a result, the system fails to capture market demand and changes (Johnson, 1992).

Due to these disadvantages and the complication associated with ABC, this method was not adopted into the scorecard.

#### 2.3.6.2.3 Total Cost Measurement (Viswanadham and Srinivasa Raghavan, 2000)

Viswanadham and Srinivasa Raghavan suggested a dynamic modelling technique for analysing SCs using Generalised Stochastic Petri Net (GSPN) (Viswanadham and Srinivasa Raghavan, 2000). This is a pictorial modelling technique that illustrates the physical flow and information flow in SC. They define a single objective function called total cost, which summarises all the following measures into one:

- Average work-in-progress
- Average finished goods inventories
- Order delivery lead time
- Materials replenishment cycle time

The total cost is the sum of the total inventory carrying cost ( $H_I$ ) and the cost incurred due to delayed deliveries per hour ( $H_D$ ). They also define the average net inventory as the total work-in-progress and the finished goods inventory present in the SC. The net delay in delivery is the sum of the average customer order lead times. They use these measures to assess the effect of end product arrival rates, targeted finished goods inventory and SC lead time.

The example in Table 2.15 shows the variation of total cost with arrival rates. The method aggregates the performance of SC members to give the overall performance of the whole SC. The study compares the performance of make-to-stock (MTS) and assemble-to-order (ATO) systems in terms of total cost.  $\lambda_D$  represents the end product arrival rates.

$\lambda_D$ units/h	Total cost			
	$H_D/H_I = 1.5$		$H_D/H_I = 40.0$	
	MTS system	ATO system	MTS system	ATO system
0.8	22.421	19.815	26.001	257.437
1.0	21.237	18.610	25.818	237.559
1.2	20.012	17.714	25.961	224.228
1.4	18.774	17.016	26.339	214.675

Table 2.15: The Total Cost Measurement (Viswanadham and Srinivasa Raghavan, 2000)

Although Viswanadham and Srinivasa Raghavan (2000) provide an example of how the measurement model can be used, there is no empirical evidence to justify its applicability in actual business situation. Therefore, it was not incorporated into the scorecard.

#### 2.3.6.2.4 Supply Chain Costing

There are two studies that fall under this category. Both of these costing methods employ many different costing techniques to measure SC costs – Direct Product Profitability, Activity Based Costing, Total Cost Ownership, Efficient Consumer Response, Throughput Accounting and Kaizen Costing. The first one was developed by Lalonde and Pohlen (1996) while the second one was derived by Carlos Mena, Linda Whicker, Simon Templar and Mike Bernon (Mena *et al.*, 2002).

There is another technique called SC costing, with six basic steps (Lalonde and Pohlen, 1996):

- Analysing SC processes
- Breaking the processes down into activities

- Identifying the resources required to perform an activities
- Costing the activities
- Tracing the activity costs to SC outputs
- Analysis and simulation

This method is very similar to ABC where both methods assign costs to activities, except for one aspect. ABC measures within an organisational boundary whereas SC costing might include costing of another firms. According to Lalonde and Pohlen (1996), this method increases cost visibility and it links activity costs to non-financial measures. They believe that the cost visibility and linkage between costs to non-financial measures have brought three advantages to the user. Firstly, the method facilitates the process to equitably allocate cost benefits and burdens between SC members. It also helps the users to identify the contribution of each supplier, in order to eliminate low value added relationship and to form alliances with high value added suppliers/customers. Thirdly, using SC costing, the users can identify and remove low value adding activities embedded within SC.

In 2002, Carlos Mena, Linda Whicker, Simon Templar and Mike Bernon proposed to measure SC cost by using four different costing methods in synergy across a SC (Mena *et al.*, 2002). Figure 2.14 summarises the scope and focus of the four costing approaches along a SC.

ABC helps individual organisations to assign costs to activities while throughput accounting facilitates optimum utilisation of the system's constraints. Both ABC and accounting throughput focus within an organisational boundary. Total cost of

ownership (TOC) is a tool to evaluate the costs of supplies and how they will impact on the organisation throughout the life cycle of a product. Finally, there is Kaizen costing, which is a technique for disciplining and managing cost by setting cost reduction targets for each of the components of the product.

Both ABC and throughput accounting concentrate on an individual organisation, as indicated by the lines in the diagram. In TOC and Kaizen costing, the measurement scope extends beyond organisational boundaries towards upstream suppliers. However, in Kaizen costing, it is possible to link the use of this technique between the different organisations in the SC, as indicated by the circles linking the lines.

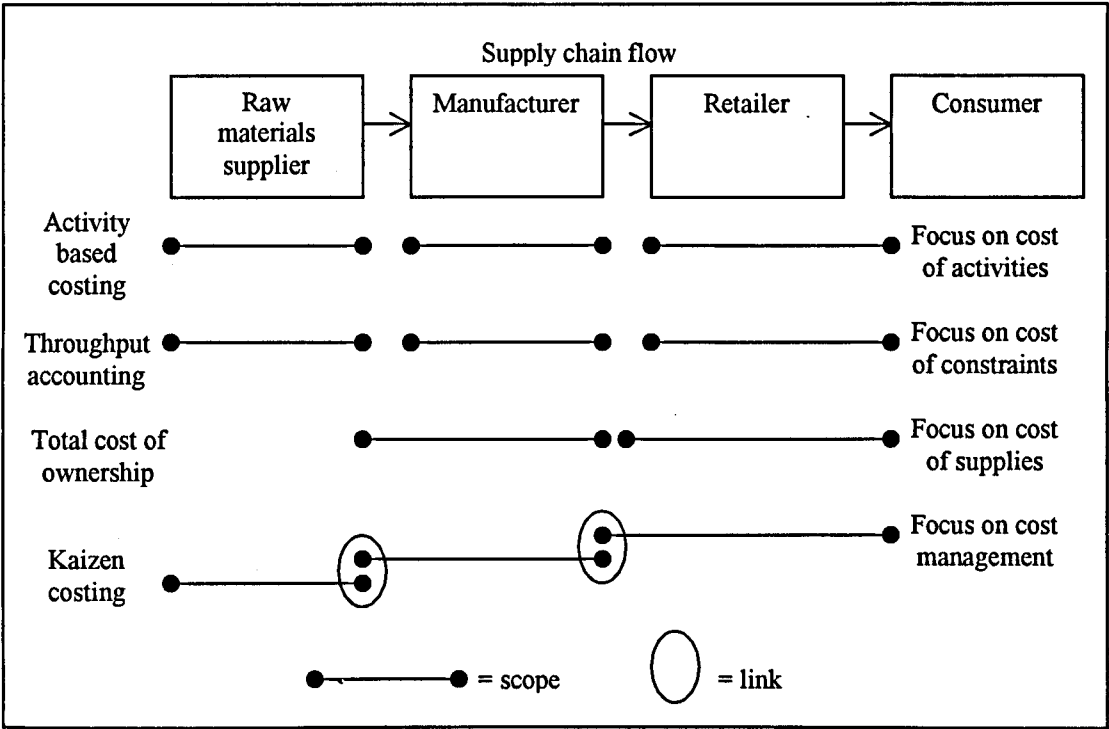


Figure 2.14: Supply Chain Costing Model by Mena *et al.* (2002)

However, the major downfalls of this costing model are the lack of empirical evidence and the complication of implementing four different costing methods into one. Therefore, it is not incorporated into the scorecard.



### 2.3.6.3 Cash-to-Cash (C2C) Cycle Time

The application of a cash-to-cash metric in SC context is proposed by Farris II and Hutchison in 2002. It is also known as the cash conversion cycle (Soenen, 1993; Moss & Stine, 1993). There are many different definitions for the C2C metric (Moss and Stine, 1993; Stewart, 1995; Gallinger, 1997). A more general description of C2C is “*a composite metric describing the average days required to turn a dollar invested in raw material into a dollar collected from a customer*” (Stewart, 1995).

C2C cycle time is measured in days. It is equal to “*the net of the average age of the inventory plus the average collection period minus the average age of accounts payable*” (Schilling, 1996). The length of a C2C cycle time of a company depends on four factors (Soenen, 1993):

1. The number of days’ credit it gets from its suppliers
2. The length of the production process
3. The number of finished products remaining in inventory before they are sold
4. The average collection period from the company’s customers

Different methods were proposed on how to calculate C2C, such as using weighted cash conversion cycle (Gentry *et al.*, 1990) or measuring inventories using weighted dollar-days (Farris, 1996).

However, Farris II and Hutchison (2002) think that there should be more researches to develop a more accurate measure for C2C. They believe that C2C cycle time can

play a significant role in measuring on-going SCM improvement (Farris II and Hutchison, 2002). From a SCM perspective, C2C cycle time measures across inbound material activities with suppliers, through manufacturing operations, and the outbound logistics and sales activities with customers (Farris II and Hutchison, 2002). Due to the preliminary stage of C2C application in SC context, it was not incorporated into the scorecard.

#### **2.3.6.4 Logistics**

##### **2.3.6.4.1 Introduction**

According to the Council of Logistics Management, the definition of logistics is “*a part of the supply chain process that plans, implements and controls efficient, effective flow and storage of goods, services, and related information from the point of origin to the point of consumption in order to meet customers’ requirements*” (CLM, 1998). Even though logistics is only part of a SC, quite often the term “supply chain” is used in place (Weber, 2002). According to Lambert and Pohlen (2001), this has been observed by many other researchers.

The role of logistics in business has been widely recognised in terms of scope and strategic importance (Rafele, 2004). It influences customer service level, product design, partnership building, and other core business processes (Caplice and Sheffi, 1995). A management consultancy firm found that there is a significant gap in overall performance level between companies that perform holistic logistics measurement and those that do not (Barr, 1996). The advantages from implementing an holistic logistics view are (Barr, 1996):

- Better delivery accuracy
- More responsive to customer demand
- Lower logistics costs
- Lower inventory cost

Caplice and Sheffi (1995) believe that a “good” logistic performance measurement system should be “*comprehensive, casually oriented, vertically and horizontally integrated, internally comparable and useful*”. However, it is not easy to adopt an integrated approach to logistics and distribution management (Themido *et al.*, 2000; Christopher, 1992). The selection of what to measure and the relevant targets can be complex due to the interdependence among SC members (Rafele, 2004). According to Rafele’s survey (2004), the most commonly used logistics performance indicators in manufacturing and shipment industries (downstream direction) are reliability, completeness, correctness, harmfulness, productivity, delivery lead time, delay, regularity, flexibility, availability and scrap level. However, the comprehension level and interpretation of these indicators are varied among the companies took part in this survey (Rafele, 2004).

There are four studies that measures SC logistical performance:

1. The SC 2000 Framework by Bowersox *et al.* (2000)
2. Milgate, 2001
3. Using Activity Based Costing (ABC), by Themido *et al.* (2000) and Dekker & Van Goor (2000)
4. The Reference Framework by Rafele (2004)

2.3.6.4.2 The Supply Chain 2000 Framework (Bowersox *et al.*, 2000)

This framework was developed by the researchers from Michigan State University (Bowersox *et al.*, 2000). They have conducted this research for more than 10 years and conclude that the leading logistical practices are generalisable across industries, along the SC and across cultural boundaries (Bowersox *et al.*, 2000). The main purpose of the framework is to identify the competencies essential to integrating SC logistics. The structure of the framework is shown in Figure 2.15. The details covering the Supply Chain 2000 framework can be found in this paper - Bowersox *et al.*, 2000. This framework has been used to analyse the SC performance of 306 North American companies.

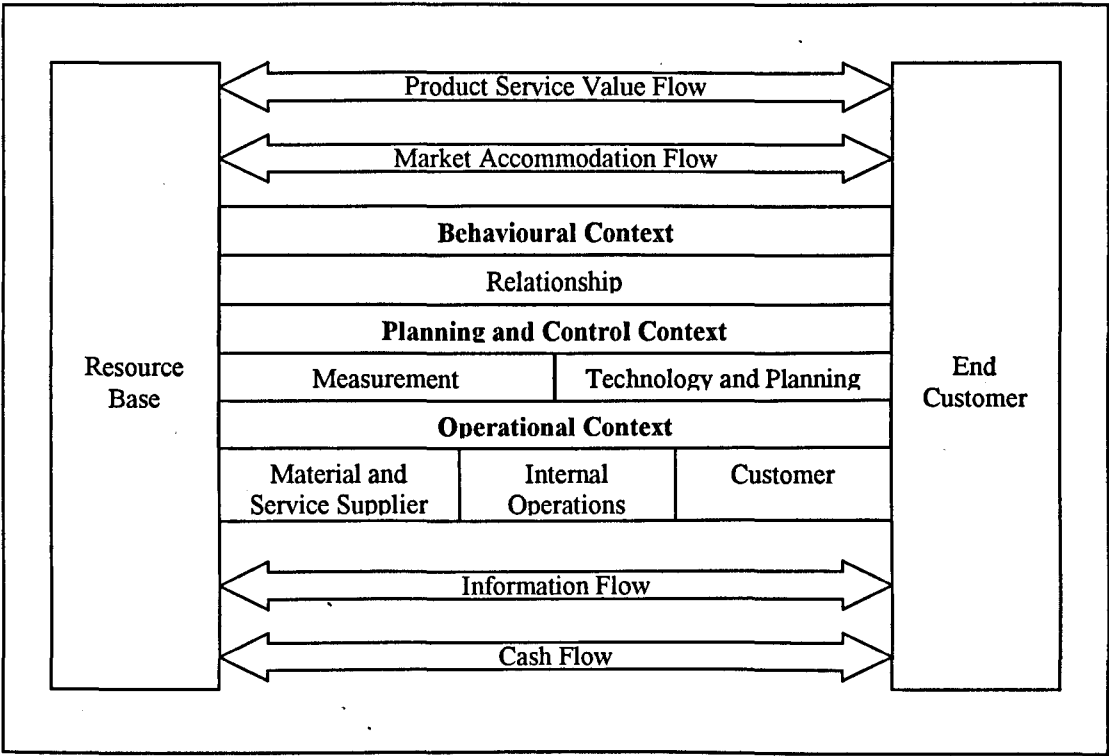


Figure 2.15: Supply Chain 2000 Framework (Bowersox *et al.*, 2000)

The research team identified five major dimensions of logistical assessment and also the performance metrics for each dimension, as seen in Table 2.16.

- Customer service measures the value important to customer.
- Cost management measures functional and integrated logistics expenditures related to SC operations.
- Quality measures service attributes designed to enhance customer loyalty.
- Productivity measures material and labour resource utilisation.
- Asset management measures the utilisation of fixed assets and working capital.

<b>Customer Service</b>	<b>Cost Management</b>	<b>Quality</b>	<b>Productivity</b>	<b>Asset Management</b>
<ul style="list-style-type: none"> <li>▪ Customer satisfaction</li> <li>▪ Product flexibility</li> <li>▪ Delivery speed</li> </ul>	<ul style="list-style-type: none"> <li>▪ Logistics cost</li> </ul>	<ul style="list-style-type: none"> <li>▪ Delivery dependability</li> <li>▪ Responsiveness</li> <li>▪ Order flexibility</li> <li>▪ Delivery flexibility</li> </ul>	<ul style="list-style-type: none"> <li>▪ Information systems support</li> <li>▪ Order fill capacity</li> <li>▪ Advance shipment notification</li> </ul>	<ul style="list-style-type: none"> <li>▪ Inventory turn</li> <li>▪ Return on assets</li> </ul>

Table 2.16: Performance Metrics used in Supply Chain 2000 Framework (Bowersox *et al.*, 2000)

Although this framework is supported by profound empirical study, it is impossible to incorporate the entire framework into the scorecard just to measure logistical performance. Apart from that, the details on each metric and the method to measure were not available.

#### 2.3.6.4.3 Supply Chain Delivery Performance (Milgate, 2001)

In Milgate's study (2001), he explores the impact of SC complexity on delivery performance. He used four measures to monitor delivery performance:

- Delivery lead time: the average actual time that elapses from the placement of an order until its shipment to the customer. Transportation time is not included.
- Throughput time: the time to complete an order from the start of its production to its completion.
- Percentage of late delivery: the percentage of customer orders delivered late.
- Average lateness: the average of the late orders.

The delivery lead-time and throughput time were incorporated into the *Dock-to-Dock Time*, while the percentage of late delivery and average lateness were adopted into *the reliability measure of the scorecard as the Stockout Level and Backorder Level* respectively.

#### 2.3.6.4.4 Activity Based Costing (ABC) in Logistic Costng

In logistics costing, the direct product profitability (DPP) and customer profitability analysis (CPA) are two commonly used techniques (Themido *et al.*, 2000). However these methods will not be discussed in this section as they are organisational measures rather than SC measures.

Bendiner (1993) believes that the main obstacle in integrating a SC's logistics and distribution management is the lack of cost visibility along the pipeline. Most traditional cost accounting systems do not address logistics activities. For example, a retail company identified almost \$200 million in costs that had previously been transparent to the company because the inbound transportation costs were embedded in the purchase price (Barr, 1996). Therefore, many researchers advocated that using ABC to measure logistics costs is the most effective option because it provides the cost visibility that traditional accounting lack (Themido *et al.*, 2000).

Themido *et al.* (2000) have implemented an ABC approach to assess the logistics cost of a third-party logistic operator. The resources, activity and cost objects are identified. Then the logistics costs are broken down according to these three elements. The end result from this model helps the user to identify the logistics cost per unit and per line, either by product or by region, or even both.

Another study conducted by Dekker and Van Goor (2000) looked into the use of ABC models to support SCM by extracting data from management accounting. They provide a case study to show the application of ABC to calculate the costs of a

pharmaceutical SC's logistic activity (Dekker and Van Goor, 2000). The ABC model that they used in this case study aggregates logistics costs at four levels, as shown in Figure 2.16.

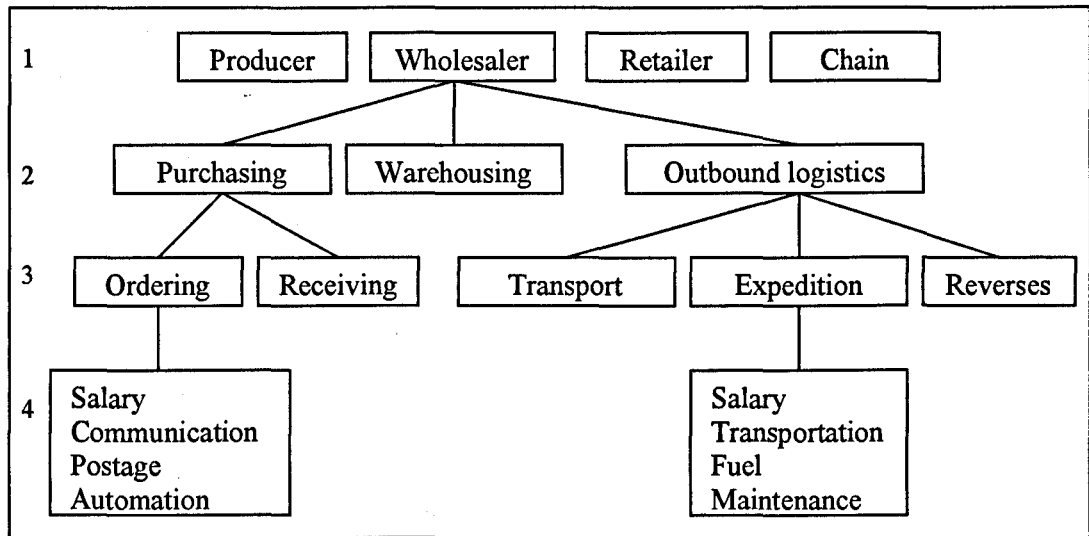


Figure 2.16: Structure Of Dekker and Van Goor Model (2000)

- Level 1: This is the highest level of aggregation. It shows the sum of each firm's costs.
- Level 2: There are three logistic processes for each firm: purchasing, warehousing and outbound logistics.
- Level 3: The processes in level 2 are further divided into similar activities for each firm.
- Level 4: This level presents the cost accounts of each activity in detail.

As mentioned in Section 2.3.6.2.2, ABC method tends to suffer from subjectivity in cost allocation, as well as the complexity and cost to implement the system (Mena *et al.*, 2002). Therefore, it is not adopted into the scorecard.



#### 2.3.6.4.5 Rafele's Reference Framework (2004)

This logistic service measurement model is proposed by Rafele (2004). The model incorporates two references to measure logistic performance – the “seven right conditions” and the PZB (Parasuraman, Zeithaml and Berry) model. The reference framework is shown in Figure 2.17.

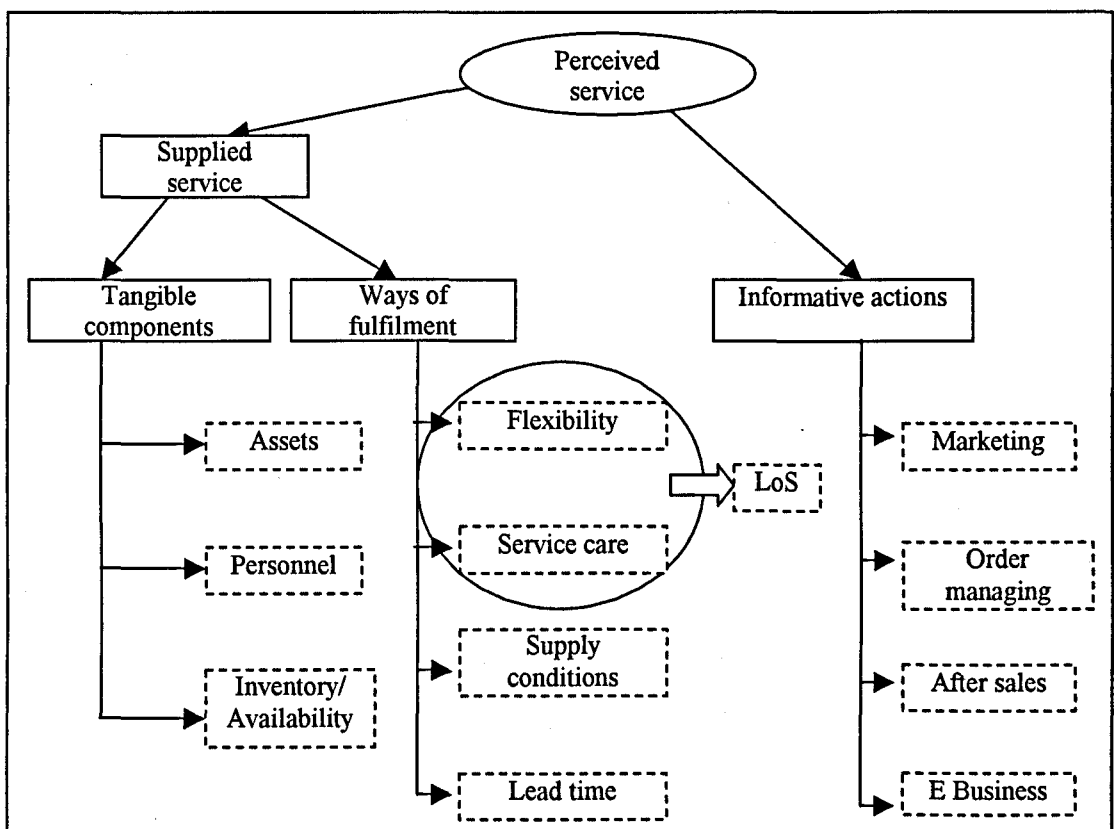


Figure 2.17: Rafele's Reference Framework (2004)

The 12 measurement aspects for logistics performance (in dotted line boxes) shown in Figure 2.17 are derived based on the three PZB model's service dimension:

- Tangible components: The resources to perform the service.
- Ways of fulfilment: The parameters of carrying out the service.
- Informative actions: The communications with customers regarding the service.

Then the users have to identify the metrics for each of these measurement aspects. Although Rafele has provided some examples of metrics for each measurement aspects, he believes that every industry is unique. Therefore, the users have to select the metrics that they think are best suited to their needs (Rafele, 2004). Some of the examples suggested by Rafele are shown in Table 2.17.

Tangible Components	
Internal Asset	<ul style="list-style-type: none"> <li>• Equipment productivity = Number of orders (or UL<sup>(*)</sup>, or quantity) delivered/produced divided by the period of time considered</li> <li>• Surface utilisation = Used surface of warehouse divided by the total surface of warehouse</li> <li>• Volume utilisation = Used volume of warehouse divided by the total volume of warehouse</li> </ul>
External Asset	<ul style="list-style-type: none"> <li>• Trucks fill rate = Number of UL(*) or quantity loaded divided by the number of UK(*) or quantity available in the same period of time</li> <li>• Accident impact = Number of accidents divided by the number of journeys in a certain period of time</li> </ul>
Personnel	<ul style="list-style-type: none"> <li>• Personnel efficiency = Number of orders (or UL(*), or quantity) delivered/handled divided by the number of persons working or hours worked in the same period of time</li> <li>• Accident severity rate = Number of accidents divided by the number of persons working or hours worked</li> </ul>
Inventory/Availability	<ul style="list-style-type: none"> <li>• Slow/medium/fast moving = Number of orders (or UL(*), or quantity) included in slow/medium/fast moving class divided by the total number of orders (or UL(*), or quantity) in the warehouse in the same period of time</li> <li>• Physical and accounting correspondence = Number of orders (or UL(*), or quantity) with mistakes divided by the total number of orders (or UL(*), or quantity) in the warehouse in the same period of time</li> <li>• Stock turnover = Number UL(*) or quantity delivered or shipped divided by the average stock in the warehouse in the same period of time</li> <li>• Stockout = Number of orders (or UL(*), or quantity) out of order divided by the total number of orders (or UL(*), or quantity) ordered during the same period of time</li> </ul>
Ways of Fulfilment	
Flexibility	<ul style="list-style-type: none"> <li>• Flexibility = Number of special/urgent/unexpected orders (or UL(*), or quantity) confirmed to the customer divided by the total number of special/urgent/unexpected orders (or UL(*), or quantity) required by the customer multiplied by 100 in the same period of time</li> </ul>
Service Care	<ul style="list-style-type: none"> <li>• Punctuality = Number of orders (or UL(*), or quantity) delivered on time divided by the total number of orders (or UL(*), or quantity) delivered multiplied by 100 in the same period of time</li> <li>• Regularity = Number of orders (or UL(*), or quantity) delivered with a <math>\Delta t</math> of delay/advance divided by the total number of orders (or UL(*), or quantity) delivered multiplied by 100 in the same period of time</li> </ul>

	<ul style="list-style-type: none"> <li>• Completeness = Number of full orders (or UL(*), or quantity) delivered divided by the total number of orders (or UL(*), or quantity) delivered multiplied by 100 in the same period of time</li> <li>Correctness = Number of mistake orders dispatched divided by the total number of orders dispatched multiplied by 100 in the same period of time or Number of codes/articles sent back divided by the total number of codes/articles sent multiplies by 100 in the same period of time</li> <li>• Harmfulness = Number of “damaged” orders dispatched in a period divided by the total number of orders dispatched in the same period multiplied by 100</li> <li>• Delay = number of days of delay or (number of days of delay divided by the number of days promised) multiplied by 100</li> </ul>
Supply Conditions	<ul style="list-style-type: none"> <li>• Delivery frequency = Number of orders (or UL(*), or quantity) delivered in a certain period of time</li> <li>• Shipped quantity = Quantity shipped in a certain period of time or quantity dispatched for each shipment</li> <li>• Way of packaging and way of shipment etc...</li> </ul>
Lead Time	<ul style="list-style-type: none"> <li>• Total order cycle time occurring from the arrival of a customer order to receiving of goods or cycle of the single activities (order transmission, order processing, order composition, order transfer to the production plant, article production, warehouse delivery, final delivery to the customer)</li> </ul>
<b>Informative Actions</b>	
Marketing	<ul style="list-style-type: none"> <li>• Range completeness, information on products and sell assistance, etc...</li> </ul>
Order Management	<ul style="list-style-type: none"> <li>• Documents management (invoices and orders), client and order advancement state, etc...</li> </ul>
After Sales	<ul style="list-style-type: none"> <li>• Back orders, claims management, use assistant and payment management, warranty conditions, etc...</li> </ul>
E information	<ul style="list-style-type: none"> <li>• Website completeness, ease of making orders by network and data transmission security, etc...</li> </ul>
NOTE: UL <sup>(*)</sup> = unit loads	

Table 2.17: The Example Metrics for Logistics Performance (Adapted from Rafele, 2004)

However, it is impractical to adopt all the 12 logistical measurement aspects because it will overcrowd the entire scorecard and significantly increases the data collection process. Apart from that, the metrics shown in Table 2.17 were also not incorporated because the metrics were only examples provided by Rafele (2004) without any empirical study to support them.

### **2.3.6.5 Integration Level**

#### **2.3.6.5.1 Introduction**

Since a SC is formed by a series of individual business entities, its success is mostly dependent on how well these business entities are integrated (Simatupang and Sridharan, 2005). The recent shift of focus in SCM has increased the significance of integrating SC processes (Towill, 1996). SC integration is not just integrating logistics across SC, it is to integrate all key business operations across the SC (Lambert *et al.*, 1998). A well-integrated SC can enhance revenue, reduce costs and improve operational flexibility (Simatupang and Sridharan, 2005). These benefits are recognised and proved by major organisations such as Hewlett Packard, IBM, Dell, Procter & Gamble (Simatupang and Sridharan, 2005).

SC integration can exist in many ways – information sharing and physical assets sharing for example (Kwon and Suh, 2005). To achieve the integration level that will benefit SC members, a high degree of trust and commitment among the members is required (Kwon and Suh, 2005), as well as a fair share of profit and cost (Schmitz and Platts, 2003-a).

There are two studies that have been carried out on measuring the integration level of SCs by using:

- Path analysis by Kwon and Suh (2005)
- Collaboration index by Simatupang and Sridharan (2005)

### 2.3.6.5.2 Path Analysis (Kwon and Suh, 2005)

Four organisations have sponsored a study to examine the relationship between six different factors in information sharing – partner's asset specificity, information technology share, potential opportunism, behavioural uncertainty, trust and commitment. This study is carried out by Kwon and Suh, using path analysis to estimate parameters and relationships between these factors (Kwon and Suh, 2005). The study hypothesises that *"Information sharing among supply chain participants mitigates a partner's behavioural uncertainty and even blocks a partner's temptation for opportunistic behaviour toward other trading partners, which, in turn, improves the level of trust, and eventually the level of commitment"* (Kwon and Suh, 2005). It is assumed that there is a sequential relationship between these factors.

A seven-point Likert scale questionnaire is sent to the members of the four organisations. The scale is from 1 (strongly disagree) to 7 (strongly agree). The questions within the questionnaire are listed as follow:

1. Trust: a willingness to take risk and believe that the partner will act to benefit our interest (Kwon and Suh, 2005).
  - Even when the partner gives us a rather unlikely explanation, we are confident that it is telling the truth.
  - The partner has often provided us information that has later proven to be inaccurate.
  - The partner usually keeps the promises that it makes to our firm.

- Whenever the partner gives us advice on our business operations, we know that it is sharing its best judgment.
  - Our organisation can count on the partner to be sincere.
2. Commitment: *“an exchange partner believing that an ongoing relationship with another is so important as to warrant maximum efforts at maintaining it; that is, the committed party believes the relationship endures indefinitely”* (Kwon and Suh, 2005).
- Even if we could, we would not drop the partner because we like being associated with it.
  - We want to remain a member of the partner’s network because we genuinely enjoy our relationship with it.
  - Our positive feelings towards the partner are a major reason we continue working with it.
3. Partner’s Asset Specificity: Investments in physical or human assets that are dedicated to a particular business partner and whose redeployment entails considerable switching costs (Heide, 1994).
- This partner firm has made significant investments in resources dedicated to their relationship with us.
  - This partner firm’s operating process has been tailored to meet the requirements of our organization.
4. Behavioural Uncertainty: *“the inability to predict partner behavior or changes in the external environment”* (Joshi and Trump, 1999).

- We can accurately predict the performance of this partner for our next business cycle.
  - We know that this partner will adapt quickly, should we have change our specifications at short notice.
5. Potential Opportunism of Partner: the expectation that a transaction partner will not undertake opportunistic behavior or increasing one's vulnerability to the risk of opportunistic behavior of the partner (Chiles and McMackin, 1996).
- There are other firms that could provide the partner firm with comparable business.
  - The partner would incur minimal costs in replacing our firms with another firm.
  - It would be difficult for the partner to replace the sales and profits generated from the business with us. (Reversed.)
6. Information Sharing:
- We share a common information technology (software) to facilitate communication with the partner.

This questionnaire is designed to extract data to measure the six relationship factors mentioned. Table 2.18 contains a brief description of the measure used for these factors. The reliability of these measures is determined by calculating their reliability coefficient.

Factors	Measures Details	Source
Trust	<ul style="list-style-type: none"> <li>▪ 5 items to assess the extent to which the partner is honest, truthful and reliable</li> <li>▪ 5 items to assess the firm's belief that the partner considers the firm's interests or welfare</li> <li>▪ Reliability coefficient = 0.94</li> </ul>	Kumar <i>et al.</i> , 1995
Commitment	<ul style="list-style-type: none"> <li>▪ Based on a 3-item construct on reseller performance scale</li> <li>▪ Reliability coefficient = 0.83</li> </ul>	
Partner's Asset Specificity	<ul style="list-style-type: none"> <li>▪ Measured by the specific asset investments in resources, procedures and people made by the partner</li> <li>▪ Reliability coefficient = 0.74</li> </ul>	Joshi and Strump, 1999 Heide, 1994
Behavioural Uncertainty	<ul style="list-style-type: none"> <li>▪ Measure the degree of predictability of a partner's behaviour</li> <li>▪ Reliability coefficient = 0.67</li> </ul>	Noordewier et al. (1990) Zaheer and Venkatraman (1995) Joshi and Stump (1999)
Potential Opportunism	<ul style="list-style-type: none"> <li>▪ Measured by a 3-item measures</li> <li>▪ Assess the degree to which the partner has other potential partners</li> <li>▪ Reliability coefficient = 0.67</li> </ul>	Heide and John, 1990
Information Sharing	<ul style="list-style-type: none"> <li>▪ Single item measure</li> <li>▪ Assess the degree to which the firm shares information technology in critical issues</li> </ul>	

Table 2.18: The Measure in Path Analysis (Kwon and Suh, 2005)

There are five hypotheses that were investigated in this study, using the questionnaire and the measures in Table 2.18. The results from the study prove that:

- SC partners' specific asset investments will increase the level of trust on the partners.
- Behavioural uncertainty perceived in relationships with SC partners will decrease the level of trust in the partners.
- The potential opportunism by both SC partners is not statistically related to the level of trust.



- Information sharing will lower the degree of behavioural uncertainty<sup>28</sup> and potential opportunism<sup>29</sup> and indirectly will improve the level of trust among SC partners.
- There is a positive relationship between the level of trust and the level of commitment.

The final conclusion from this study confirmed that a positive and significant relationship exists between the degree of commitment and the level of trust. However, the metrics are not applicable in the scorecard because they are qualitative measures based on the questionnaire respondents' judgement to define the performance.

#### 2.3.6.5.3 Collaboration Index (Simatupang and Sridharan, 2005)

Simatupang and Sridharan (2005) recognised that the adoption of SC collaboration requires a scientific means to assess the collaboration among SC members. Hence they proposed a measurement system that examined the interaction between collaboration index and performance index. The collaboration index is the average score across three dimensions of SC collaboration:

- Information Sharing (IS): *"the act of capturing and disseminating timely and relevant information for decision makers to plan and control supply chain operations"* (Simatupang and Sridharan, 2005).

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<sup>28</sup> Behavioural uncertainty: *the inability to predict partner behaviour or changes in the external environment* (Kwon and Suh, 2005)

<sup>29</sup> Potential opportunism: *assumes that some probability exists that any given actor will behave opportunistically some of the time* (Kwon and Suh, 2005)

- Decision Synchronisation (DS): *“to joint decision-making in planning and operational contexts”* (Simatupang and Sridharan, 2005).
- *“The planning context integrates decisions about long-term planning and measures such facets as selecting target markets, product assortments, customer service level, promotion, and forecasting”*
- *“The operational context integrates order generation and delivery processes that can be in the forms of shipping schedules and replenishment of the products in the stores”*
- Incentive Alignment (IA): *“the degree to which chain members share costs, risks, and benefits”* (Simatupang and Sridharan, 2005)

On the other hand, a performance index is a composite of operational measures that includes fulfilment, inventory and responsiveness.

They hypothesised that the collaboration index is positively associated with operational performance, which is represented by performance index. The measures were developed and sent out to a sample of New Zealand companies. The feedback from these companies is used as data to calculate the validity and reliability of this measurement method. Intensive statistical methods were used to analyse the data collected from the survey. The following were the conclusions from the study:

- The correlation analysis proves that there was a strong relationship between the collaboration and operational performance.
- The analysis of variance showed that each of the three dimensions affected some aspects of operational performance.

- DS<sup>30</sup> and IA<sup>31</sup> consistently influence all three operational performances. Basically, the higher the DS and IA, the better the operational performance.
- The interaction of DS and IA also affects the fulfilment performance positively.
- IS is found to positively influence fulfilment and inventory, but has very a moderate effect on responsiveness.

The SC members that have higher levels of collaboration practices were able to achieve better operational performance. Again, due to the qualitative nature of the measures, the metrics are not applicable in the scorecard.

#### **2.3.6.6 Responsiveness**

##### **2.3.6.6.1 Introduction**

According to Ramakrishnan's (2002) definition, SC responsiveness is "*the ability to respond and adapt time effectively based on the ability to read and understand actual market*". Please note that literatures on measurement of SC agility and SC flexibility are also grouped under this category. This is because basically these three topics have one common purpose – to meet market demands more efficiently and effectively (van Hoek *et al.*, 2001; Duclos *et al.*, 2003).

Improving responsiveness has emerged as one of the strategic imperatives as a result of increased global competition in the 1970s (Aquilano *et al.*, 1995). The ever increasing and changing consumer requirements have forced most businesses to

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<sup>30</sup> DS: Decision Synchronisation

<sup>31</sup> IA: Incentive Alignment

provide more customised products, shorten product life cycles, reduce costs and improve product quality levels (Duclos *et al.*, 2003; Mason-Jones *et al.*, 2000).

Initially, most of the literature on responsiveness focused on internal operations and process. By 1990s, the necessity to look beyond the borders of individual organisations has been widely recognised (Duclos *et al.*, 2003). This is due to the shift of business competition from an organisation level to an individual SC level (Duclos *et al.*, 2003). Therefore, not only the firm itself, but also the entire SC has to be responsive (Duclos *et al.*, 2003). Many researchers advocate that SC members should work together to achieve a level of agility beyond the reach of the individual company (van Hoek *et al.*, 2001). Also, the performance of each SC member affects the overall performance of a SC (Duclos *et al.*, 2003).

Based on current existing literature, there are nine categories of SC responsiveness (Vickery *et al.*, 1999; Duclos *et al.*, 2003):

1. Product: The ability to customise product to meet specific customer demand.
2. New Product: The ability to launch new or revise products.
3. Distributions: The ability to provide widespread access to products.
4. Operations system: The ability to configure assets and operations to react to emerging customer trends like product changes, volume or mix.
5. Market: The ability to mass customise and build close relationships with customers, including designing and modifying new and existing products.
6. Logistics: The ability to cost effectively receive and deliver product as the source of supply or customers change.

7. Supply: Ability to reconfigure the SC and alter the supply of product in line with customer demand.
8. Organisational: The ability to align labour force skills to the needs of SC to meet customer requirements.
9. Information System: The ability to align information system architectures and systems with the changing information needs of the organisation as it responds to changing customer demand.

There are two responsiveness measure studies that have been undertaken in a SC context. The first one is by van Hoek *et al.* (2001) and the other one is by Catalan & Kotzab (2003).

#### 2.3.6.6.2 van Hoek *et al.*'s Method (2001)

Most of the existing researches on agility focus on manufacturing agility. However, there was a study that suggested the relevance of explicit link between agility and SCs (Naylor *et al.*, 1999). They believed that the focus of agility research should be extended to SCs. Therefore, van Hoek, Harrison and Christopher have carried out a study on assessing SC agility (van Hoek *et al.*, 2001). According to their definition, agility is concerned with customer responsiveness and mastering turbulence.

During the study, they developed an agile SC audit to assess the status of agile capabilities of a sample of companies in the UK and the Benelux. First they identified the four dimensions of agility:

- Customer Sensitivity: market understanding, customisation, postponement and rapid response.
- Virtual Integration: leveraging information at a SC context.
- Process Integration: manage SC as a whole and master change across organisations.
- Network Integration: make sure all SC members cooperate to compete as a whole.

Then they integrate these agility dimensions into a SC approach. SC agility is measured based on these agility dimensions.

The respondents received a questionnaire that contained three to ten questions for each agility dimension. The respondents were asked to rate each criterion on a 1-5 Likert scale, followed by a telephone interview. The average agile performance is shown in Figure 2.18, as the mean score on the audit items within that category. This audit concludes that customer sensitivity is a key concern in SC agility.

However, due to the qualitative nature of the measures, the metrics are not applicable in the scorecard.

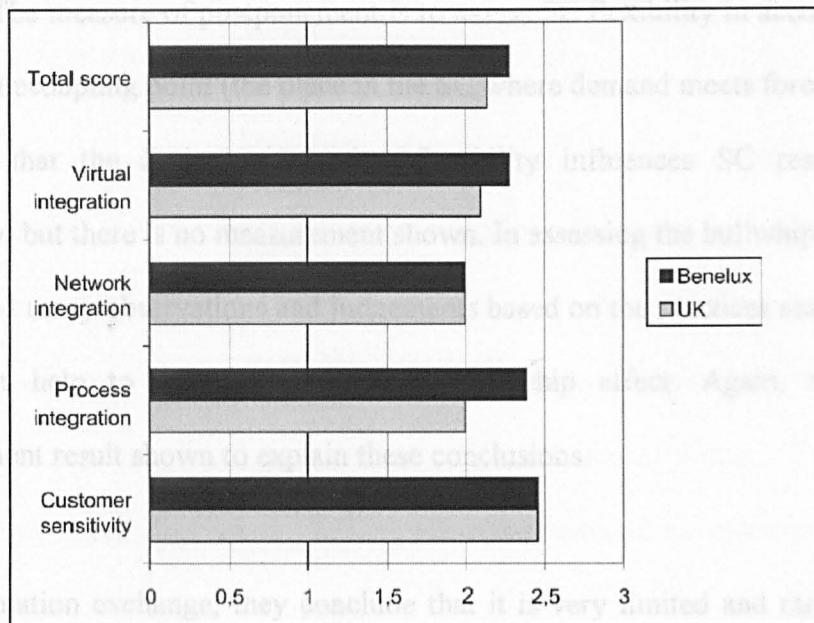


Figure 2.18: Supply Chain Agility Audit Result (Adapted from van Hoek *et al.*, 2001)

#### 2.3.6.6.3 Catalan and Kotzab's Method (2003)

#### 2.3.6.7 Inventory

Catalan and Kotzab (2003) have carried out a study in assessing the responsiveness of mobile phone SCs. They studied 17 Danish mobile phone related companies, which included components suppliers, contract developers, logistics service providers, distributors, retailers and after sales service providers. They use four variables to measure SC responsiveness, namely lead time, postponement, bullwhip effect and information exchange.

The lead time measure is the total throughput time for goods to travel from a component supplier to the end user. They use SC process mapping to calculate the lead time. The total response time for this case study is approximately 200 days, which is concluded as too long compared to its very short product life cycle and revenue opportunity. However, there is detail provided on how this conclusion is

reached. The measure of postponement is to assess SC flexibility in accordance with the order decoupling point (the place in the SC where demand meets forecasts). They conclude that the limited production flexibility influences SC responsiveness negatively, but there is no measurement shown. In assessing the bullwhip effect, they have stated many observations and judgements based on the practices and systems in place that help to reduce or encourage bullwhip effect. Again, there is no measurement result shown to explain these conclusions.

For information exchange, they conclude that it is very limited and rated as rather poor. However, no measurement result was shown to explain these conclusions and there is no detail description on how the measurement was performed.

#### **2.3.6.7 Inventory**

According to Waller (2003), *“supply chain inventory includes a vast spectrum of materials that is being transferred, stored, consumed, produced, packaged, or sold in one way or another during a firm’s normal course of business”*. Inventory exists in different forms throughout a SC pipeline – raw materials, work-in-progress, finished goods, goods in transit and spare parts. It is an insurance against uncertainty that might arise from poor production and delivery reliability, and changes in customer demands (Waller, 2003). One of the key principles for maintaining a lean SC in the automotive industry is to reduce the inventory level along the SC pipeline (Coia, 2003).



Inventory measurement across a SC has been suggested by different researchers (Lee and Corey, 1992; Lambert and Pohlen, 2001). An effective inventory management helps to improve customer service level and reduce costs (Lee and Corey, 1992). There are many studies and measurement systems that claim to be SC inventory measurement. However, most of them are actually measures of inventory performance within an organisational boundary, such as Talluri *et al.*'s inventory model (Talluri *et al.*, 2004) and Waller's SC audit sheet (Waller, 2003). This is because the words "supply chain" are often used to represent the material flow within an organisation.

"Inventory turns" is one of the most commonly used metrics to measure inventory performance. However, it is not appropriate in a SC context as it cannot capture key differences in product cost, form and risk within the SC (Lambert and Pohlen, 2001). By referring to Figure 2.19, it is obvious that a decrease of 5% inventory level at the retailer level will reduce more cost than at a suppliers level (Lambert and Bennion, 1982). Therefore, the more members within the chain, or the closer the inventory is held to the customer, the higher the inventory cost will be (Sachan *et al.*, 2005; Lambert and Bennion, 1982).

As depicted in Figure 2.19, Lambert and Bennion (1982) use a SC mapping process to illustrate inventory cost throughout a SC. Their method covers both the financial value of inventory, as well the cost to carry inventory. A similar method was also used by Sachan *et al.* (2005) to examine Indian grain SC cost. This concept of measuring inventory cost was captured within the *Inventory Carrying Cost* metric in the scorecard.

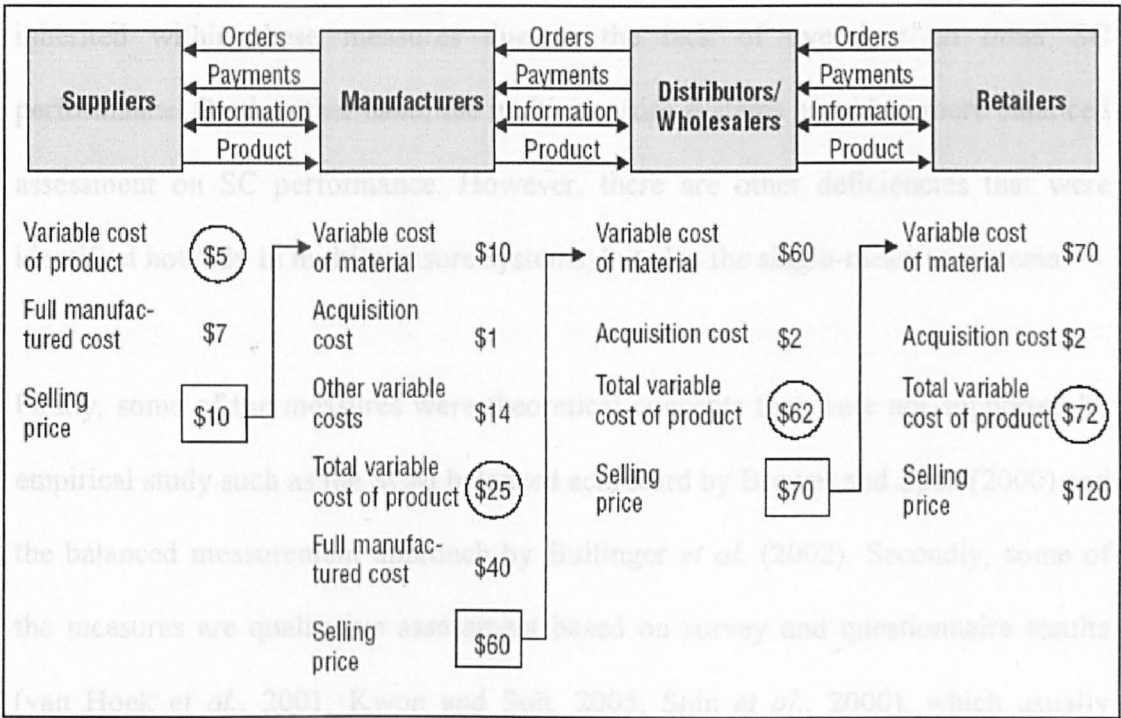


Figure 2.19: Supply Chain Inventory (Lambert and Bennion, 1982)

2.3.7 Literature Review Summary

This section is to summarise the strengths and weaknesses of all the SCPM systems and measures that have been reviewed in this chapter, as well as the influence of some of these measures on the scorecard developed in this research. The reviewed measurement systems were grouped into two categories: multi-measure (contain more than one metrics and measure more than one aspect of SC performance) and single-measure (only measure one aspect of SC performance), as shown in Figure 2.4.

Single-measure systems are not balanced measures because they only provide performance indication on a specific SC characteristic, such as responsiveness (van Hoek *et al.*, 2001) or logistics (Rafele, 2004). The risk of local optimisation is

inherited within these measures due to the lack of overview on other SC performance. On the other hand, the multi-measure systems provide a more balanced assessment on SC performance. However, there are other deficiencies that were identified not only in multi-measure systems, but also the single-measure systems.

Firstly, some of the measures were theoretical concepts that were not supported by empirical study such as the SCM balanced scorecard by Brewer and Speh (2000) and the balanced measurement approach by Bullinger *et al.* (2002). Secondly, some of the measures are qualitative assessment based on survey and questionnaire results (van Hoek *et al.*, 2001; Kwon and Suh, 2005; Shin *et al.*, 2000), which usually depends on respondents' subjective judgement on performance. Thirdly, the lengthy and complicated procedure in some measurement systems was not practical to be applied to SC in commercial environment, such as using ABC to assess logistical performance proposed by Themido *et al.* (2000) and the SC costing model by Lalonde and Pohlen, (1996).

During the literature review, the author observed that many researchers used the term "supply chain measure" on dyadic measures such as vendor rating systems or the Supply Chain Excellence's Keys approach by Stewart (1995). However, by definition, a SC measure should measure more than one SC level. Therefore, these dyadic measure should not be classed as SC measures.

In conclusion, none of the reviewed measures can provide a balanced quantitative multi-tier SCPM system, which is not only feasible in commercial environment but also justified by empirical studies and evidence. Therefore, this research is instigated

to develop an original SCPM system that meet these criteria, as well as all the SCPM success factors identified in Section 2.3.3.

However, even though these multi- and single-measure systems were not suitable for the purpose of this research and fail to meet all the SCPM success factors, nonetheless, some of the measures and concepts were taken into consideration and incorporated into the scorecard, as follow:

1. Three of the metrics from the Supply Chain Excellence Keys proposed by Stewart (1995):
  - Delivery to request date: represented by the “stockout level” in the scorecard
  - Total logistics cost: similar to the “transportation cost” in the scorecard
  - Inventory days of supply: same as the “inventory level” in the scorecard
2. The concept of multi-tier measure across the entire SC from:
  - SCOR model
  - Brewer and Speh (2000)
3. The concept of balanced measurement from:
  - Brewer and Speh (2000)
  - Bullinger *et al.*, 2002
4. The concept of strategy alignment:
  - Bullinger *et al.*, 2002

5. The concept of distinctive metric levels from:
  - SCOR model
6. Equation 2.1 proposed by Fransoo and Wouters (2000) to measure bullwhip effect.
7. The delivery lead-time and throughput time from Milgate's study were incorporated into the Dock-to-Dock Time, while the percentage of late delivery was adopted into the reliability measure of the scorecard as the Stockout Level (Milgate, 2001).

## **2.4 Information Sharing**

### **2.4.1 Introduction**

Simatupang and Sridharan (2005) define IS as an act of capturing and disseminating timely and relevant information for decision makers to plan and control SC operations. It plays a significance role in SCM (Lyons *et al.*, 2005) and measurement (Zeng and Pathak, 2003; Lee and Whang, 2000). According to a survey carried out by AMR Research Inc, nearly \$15 billion of SCM softwares have been purchased since 1999 (Ruppel, 2004). One of the distinct lead-time pipelines in SC is the sales/order information transfer (Mason-Jones and Towill, 1997). In SC relationship management defined by Cox *et al.* (2000), IS is one of the variables in the way of working: collaborative (high info sharing level) or arm's-length (low info sharing level).

There are many different ways to classify IS level. Li *et al.* (2005) categorise IS level as partial sharing and complete sharing, based on the type of the information shared. The share of basic operational information is classed as partial share while sharing strategic information is considered as complete share. Yu *et al.* (2001) split IS into three levels: decentralised control, coordinated control and centralised control.

Since IS usually requires disclosure of sensitive information, like operational data (e.g. production schedule), financial data (e.g. cost of goods), strategic information (e.g. forecasting, new product design) (Kwan and Suh, 2005), a high degree of interdependency and trust between SC members is very crucial for the success of SCM (Lalonde, 2002; Handfield, 2002). Trust is a vital ingredient to form strategic alliance and partnership for mutual SC benefits (Sherman, 1992; Spekman, 1988). It is to believe that the SC member will perform actions that will result in positive outcomes for the firm and will not take unexpected actions that may result in negative outcomes (Anderson and Narus, 1990).

In most SC, IS only occurs between immediate SC members, rather than throughout the SC. This information transmission bottleneck leaves the magnitude of bullwhip effect open (Zeng and Pathak, 2003). 86% of SC professionals believe that current SC techniques available are not meeting the needs of SC IS requirements (Ruppel, 2004). To achieve optimum performance, the IS system has to be optimised both internally and externally (Ruppel, 2004). The quality of information shared can be assessed based on its accuracy, timeliness and format (Closs *et al.*, 1997).

### **2.4.2 Benefits of Information Sharing**

Zeng and Pathak (2003) advocate that information integration is one of the core aspects of SCM. IS plays a significance role in SCM and measurement:

*“A SC that makes decisions based on global information would clearly dominate one with disjoint decisions by separate and independent entities in the supply chain”* (Lee and Whang, 2000).

This statement is advocated by both researchers and practitioners (Dennis and Kamal, 2003; CGI Group Inc., 2002; Lyons *et al.*, 2005). 71% of US manufacturers believe that improving IT project performance is the top priority (Radjou, 2004). High information visibility in SC facilitates better management of SC as a whole (Golicic *et al.*, 2002). According to Dennis and Kambil (2003), the success of Saturn’s service-to-profit supply chain model is attributed to the practice of IS among SC members. CGI Group Inc., which is an independent information technology service company, also believes that one of the success factors for SCPM is the ability to collect data needed as quickly as possible (CGI Group Inc., 2002). A research study that uses 12 different models to examine the value of IS indicates that IS has significant value for SCM (Li *et al.*, 2005). An information enriched SC can offer significant performance improvements without undermining the autonomy of individual business at various SC level (Mason-Jones and Towill, 1997). Some even believe that information technology is the key enabler for business process re-engineering (Hammer and Champy, 1993).

Generally, the importance and benefits of IS in SC can be categorised into seven groups:

1. Facilitate SC integration
2. Reduce bullwhip effect
3. Reduce inventory level
4. Reduce costs
5. Improve responsiveness
6. Higher sales
7. Improve capacity utilisation

1. Facilitate SC integration

IS is the basis of SC integration (Lee and Whang, 2000) and collaboration (Kwan and Suh, 2005; Simatupang and Sridharan, 2005). In order to create a seamless SC corresponding to system thinking, a free flow of relevant information is needed (Mason-Jones and Towill, 1997) because partnership and alliances are highly dependent on information support (Gustin *et al.*, 1995). Trust<sup>32</sup> plays a vital role in SC integration (Kwan and Suh, 2005; Simatupang and Sridharan, 2005). By having an open and efficient IS system, it allows the SC members to share projection of their requirements and facilitates the communication among the SC members (Lewis and Talalayevsky, 2004). This helps organisations to synchronise SC activities (Rudberg *et al.*, 2002; Lapiedra *et al.*, 2004; Lyons *et al.*, 2004), enhances the decision making process (Lewis and Talalayevsky, 2004) and facilitates SC integration (Lewis and Talalayevsky, 2004; Childerhouse *et al.*, 2003). It allows buyers to coordinate with

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<sup>32</sup> According to Kwan and Suh (2005) definition, trust is “continuous and open communication between and among supply chain partners will minimise, if not eliminate, any degree of uncertainty and misunderstanding”.



suppliers without requiring ownership, as a means to reduce risk (Lewis and Talalayevsky, 2004), thus improving SC performance without deteriorating the autonomy of SC members (Childerhouse *et al.*, 2003). The investment in IS will also increase interdependence between SC members (Lewis and Talalayevsky, 2004) and promotes SC members commitment towards the SC, which will contribute to SC integration (Kwan and Suh, 2005).

## 2. Reduce bullwhip effect

IS is a possible solution to counter bullwhip effect (Lyons *et al.*, 2005) because it is caused by delay and distortion during demand information transfer (Mason Jones and Towill, 1997; Kian *et al.*, 2003). Information quality, including the validity and timeliness, is significantly and positively related to strategic information exchange (Mober *et al.*, 2002). The success of IS is highly influenced by the information accuracy (Smaros *et al.*, 2003). In automotive industry, pace synchronisation of production and delivery between suppliers and the vehicle manufacturer is heavily relied on information transparency (Lyons *et al.*, 2004). One way to guarantee minimum delay in information transfer is to feed each level of the SC with the market sales data directly (Lyons *et al.*, 2005). The business link between Wal-Mart Stores and Procter & Gamble in US is the best example to demonstrate this idea (Mober *et al.*, 2002). When the SC is fully integrated with information connections, the transparent information flow throughout the SC will provide full, if not better, visibility of SC demand, reduce uncertainty (Rudberg *et al.*, 2002; Lewis and Talalayevsky, 2004) and schedule instability (Childerhouse *et al.*, 2003). Companies are able to monitor the trends of end customer demands like seasonality (Mason-Jones and Towill, 1997), and improve demand forecast accuracy (Flidner, 2003).

This helps every SC member to reduce or eliminate bullwhip effect (Mason-Jones and Towill, 1997; Rudberg *et al.*, 2002; Smaros *et al.*, 2003; Yu *et al.*, 2001) like information distortion, schedule instability and prevent these problems propagate throughout the SC (Childerhouse *et al.*, 2003).

### 3. Reduce inventory level

As the phenomenon of bullwhip effect is reduced or eliminated, this means that the inventory level will be lowered as well. The sharing of production planning information (Cokins, 1999; Bourland *et al.*, 1996) and inventory level information (Lee and Whang, 2000) has help to reduce SC inventory. IS provide greater stock control and demand visibility, which in turns reduces uncertainty. SC members can identify and eliminate excessive and duplicate safety inventories (Mason-Jones and Towill, 1997; Lee and Whang, 2000, Rudberg *et al.*, 2002). According to AMR research, a lack of SC synchronisation and demand visibility can cause excessive costs of up to 65 days of inventory into the SC (Martin, 2001). The benefits of sharing demand information are actually greater for upstream SC members than the downstream SC members due to the demand amplification caused by bullwhip effect (Lee *et al.*, 2000; Yu *et al.*, 2000). The reduction of uncertainty can also reduce the risk of holding obsolete stock by providing latest demand information to every SC members (Mason-Jones and Towill, 1997; Smaros, 2003; Fliedner, 2003). A well-known UK machine tool manufacturer went bankrupt because they had to scrap four years' stock (Mason-Jones and Towill, 1997). Although there was a study showing that retailers might not benefit from sharing the customer ordering information with the manufacturer in terms of inventory performance (Yu *et al.*, 2001). Many still believe that IS has positive influence to reduce SC inventory (Smaros *et al.*, 2003;

Lewis and Talalayevsky, 2004; Rudberg *et al.*, 2002; Yu *et al.*, 2001; Simatupang and Sridharan, 2005).

#### 4. Reduce costs

IS can also help to lower total SC costs (Lambert and Bunnion, 1982). Poor information flow will increase factory costs (Childerhouse *et al.*, 2003), transaction cost (Mason-Jones and Towill, 1997), inventory cost, warehousing cost and transportation cost (Lambert and Bunnion, 1982). Therefore, by reducing demand uncertainty and removing unnecessary stock buffers along the SC, these costs can be reduced. According to one of the articles in Automotive News Europe, if a car is manufactured on make-to-order basis, there will be a cost saving of 96 Euros per vehicle sold in Europe (Cifferré, 2002). IS helps suppliers to achieve the balance between flexibility and cost reduction, especially in automotive industry (Childerhouse *et al.*, 2003).

#### 5. Improve responsiveness

Another advantage is the improvement on SC responsiveness by exposing the areas that need to be improved to match consumer demand (Lambert and Pohlen, 2001). In Cooper and Yoshikawa's (1994) study, a Japanese automotive SC shares many information among the SC members, such as production, quality control, research and development findings and the new technologies. The increase of SC visibility helps to shorten the speed of replenishment (Rudberg *et al.*, 2002) and allows the SC to become more flexible and adaptable to changes and emergency. By speeding up the flow of information, it will also improve the SC efficiency (Persson and Olhager, 2002).

## 6. Higher sales

Since not every SC members have direct contact with end users, by sharing real time sales data, the SC members can identify which product line is the best seller and react to market demand quicker (Birtwistle *et al.*, 2003; Mason-Jones and Towill, 1997). This can lead to higher sales (Fliedner, 2003). A study in automotive SC has shown that sharing of production planning information between the OEM and the suppliers has resulted in higher customer service levels (Fliedner, 2003).

## 7. Improve capacity utilisation

Some researchers believe that poor and flawed IS will also lead to inefficient capacity utilisation (Smaros *et al.*, 2003). In automotive SC, the sharing of production planning information between the OEM and the suppliers has improved capacity utilisation for both parties (Fliedner, 2003). By providing direct access to demand information, it helps SC members to remove redundant inventories within the pipeline and accelerates cycle time (Fliedner, 2003). With the shorter cycle time, more products can be produced in shorter period and the capacity requirement can be reduced (Fliedner, 2003).

### **2.4.3 Factors that Affect Information Sharing**

Creating a cross-organisational IS system is not an easy task. Although many researches and studies have proven that IS can bring so much benefit to the entire SC, many companies are still reluctant to share information with SC partners. There are five factors that the success of a SC IS system:

1. Trust
2. Commitment
3. Incentive alignment
4. Type of information to share
5. Costs

#### **1. Trust**

Trust is defined as *“The extent to which a customer believe that the supplier is honest, benevolent and competent”* (Ryssel *et al.*, 2004). Some researchers actually propose measuring IS by *“assessing the degree to which a respondent firm shares information technology in critical issues to maintain open and honest communication”* (Kwan and Suh, 2005), which proves the critical role of trust in IS. However, one of the most common barrier in IS is still the lack of trust between SC members (Lee and Whang, 2000; Parker, 1997; Fliedner, 2003). A survey in fashion industry shows that many retailers do not realise how SC members can affect their business. Most of these retailers are only looking for short-term deals and do not trust their suppliers. Therefore, they refuse to share information (Birtwistle *et al.*, 2003). In automotive industry, there is problem of low information transparency due to the

lack of trust among the SC member (Childerhouse *et al.*, 2003). This is because they fear exposing their strengths and weakness, not just to their rivals, but also towards their suppliers or customers (Cox *et al.*, 2000; Cokins, 1999). This is particularly pertinent to industries where a year-on-year cost-down approach to supply chain contract negotiations prevails, like the automotive industry (Childerhouse *et al.*, 2003). Without trust, most companies worry that sharing sensitive strategic information might put them in the risk of losing the dominance power. This is best illustrated by the shift of dominance power between IBM and Microsoft, where Microsoft took over a big share of personal computer's (PC) operating system market from IBM after a temporary outsource contract of PC's operating system (Cox *et al.*, 2000). It is also proven that IS can heavily influence the level of trust and help SC members to build trust to each other (Kwan and Suh, 2005). Childerhouse *et al.* (2003) highlighted that the three typical information flow problem encountered in industrial SC are information withheld<sup>33</sup>, information masked<sup>34</sup> or information distorted<sup>35</sup>.

## 2. Commitment

Apart from trust, the commitment of all the involved parties is also very important, especially from the top management (Weber and Kantamneni, 2002). According to Ryssel *et al.* (2004), commitment is defined as "*the customer's durable intention to develop and sustain the relationship with the supplier in the long term*". It is proven that relationship commitment is significantly and positively related to strategic

<sup>33</sup> E.g.: Supplier wins a year's contract to supply 10,000 widgets to OEM, but customer refuses to forecast a weekly breakdown - customer says "just deliver what we want, when we want it"

<sup>34</sup> E.g.: Supplier of finished goods has no direct view of market and delivers blindly on demand to an intermediary, who "badges" before passing on to retailer, hence supplier has little opportunity for forward planning

<sup>35</sup> E.g.: OEM provides detailed forecast throughout the chain but an intermediate player places cyclical demands on his upstream supplier even though OEM forecast proves to be reasonably accurate

information exchange (Mober *et al.*, 2002). Without commitment, the effort will not be long term even if the members fully trust each other.

### 3. Incentive alignment

Sometimes the interest of each SC members might not be the same, or even contradicting with each other (Flidner, 2003). Therefore the best way to gain SC members' trust and commitment is by equally sharing the benefits or providing incentives to all the SC members to participate the IS efforts (Lee and Whang, 2000; Yu *et al.*, 2001, Birtwistle *et al.*, 2003). A financial reward that outweighs the risks might encourage the SC members to share the information (Ruppel, 2004). Companies may not trust their SC members, but still willing to share information with them as long as their benefits can be guaranteed, e.g. through contracts (Mober *et al.*, 2002).

### 4. Type of information to share

The success of IS in SC depends on information availabilities and completeness (Smaros *et al.*, 2003), but not all information. Hence, the SC members need to decide what type of information to share. Generally, the information circulates within or across organisations are inventory level, sales data, order status, sales forecast, production/delivery schedule, performance metrics and capacity information (Lee and Whang, 1999; Lee and Whang, 2000). This can be categorised as operational and strategic information (Mober *et al.*, 2002). Operational information is the short-term quantitative information like daily sales activities, cost of goods, scheduling and inventory level. Strategic information is usually regarding long-term qualitative issues like business strategies and demand forecasting. Some researchers recommend

that both operational and strategic information should be shared in SC (Henderson, 2002). However, sometimes too much information circulating within the SC might cause uncertainty and confusion due to information overload (Golicic *et al.*, 2002). Therefore, an IS system should not contain excessive data that does not contribute to the objectives of IS.

## 5. Costs

The fifth issue to be considered is the costs to implement and operate IS system (Ruppel, 2004; Lee and Whang, 2000). The investments of cross-organisational IS technology are usually expensive and time consuming (Weber and Kantamneni, 2002). Most companies think that they will have to bear the costs to implement and run the system while the dominant SC members gain all the benefits (Birtwistle *et al.*, 2003). Therefore, companies that initiate the implementation should always provide some incentives to SC members to encourage participation, trust and commitment (Lee and Whang, 2000). The incentives can be a guarantee on fair share of the benefits brought by the system, or to subsidise, or even to pay for the system installation.

### **2.4.4 Development of Information Sharing**

A survey result shows that one of the top three “pains” in the automotive industry is the lack of information (Childerhouse *et al.*, 2003). Although many alerts have been raised to warn vehicle manufacturers to move towards “lean production” and “pull” philosophy, most of them are still operating based on “push” philosophy. The fixed allocation system obliges the dealers to place a set number of orders each month,



even before they have real customers for these orders. Thus the suppliers of automotive manufacturers suffer extremely volatile demand changes. Also, the information shared in automotive SC are usually masked, withheld or distorted, which exacerbate the problem (Childerhouse *et al.*, 2003). One of the General Motors units called Saturn has implemented a integrated information system with all its suppliers, customers and other support units for seamless and real time linkage (Teresko, 2000). Although the end customer demand is increasingly being made visible within automotive SCs, it is only limited to 1<sup>st</sup> tier suppliers and the speed of communication is still low (Griffiths and Margetts, 2000).

The most significant development that has revolutionised SC IS is the advancement of information technology (Ryssel *et al.*, 2004). Information technology refers to all kinds of technology used to create, capture, manipulate, communicate, exchange, present and use information in its various form (e.g. business data, conversation), which includes hardware, software and even the personnel that are dedicated to support these capabilities (Ryssel, 2004). The initial role of information technology was originally limited to the automation of clerical functions. However, as the information technology advanced, it becomes a strategic enabler for competitive success (Lapiedra *et al.*, 2004). Many new electronic information-sharing systems were developed, like "Quick Response" in retail SC (Birtwistle *et al.*, 2003), EDI (Lee and Whang, 2000), POS (Lee and Whang, 2000), CPFR (Fliedner, 2004), VMI (Smaros *et al.*, 2003) e-hubs (Zeng and Pathak, 2003) and ERP (Lee and Whang, 2000). The studies carried out by Lewis and Talalayevsky (2004) showed that information technology enabled information system is more efficient in terms of cost and time than traditional paper based information system. It provides better access,

reduces the number of decision points, improves decision-making process and reduces duplication. Some researchers propose to use IS systems in conjunction with some other systems like CRM and SCM, in order to extend the capability of current information technology level (Zeng and Pathak, 2003).

Among all the information technology advancement, the Internet has the most significant impact on IS. It facilitates global interconnectivity, which shifts the power from sellers to buyers by broadening buyers' reach of supply choices (Chou *et al.*, 2004), in both business-to-consumer and business-to-business type (The Economist Intelligence Unit and Meritus Consulting Services, 2000). Apart from sourcing and market reach, the Internet also provides a platform to virtually integrate SC members and functions (Lyons *et al.*, 2005). The web-based IS systems are cheaper, faster and easier to implement. Unlike EDI, there is no specific hardware connection required (Bartezzaghi and Ronchi, 2003; Rudberg *et al.*, 2002). It reduces time and cost associated with installing or matching various software packages (Zeng and Pathak, 2003). It is also more flexible than traditional IS systems because it can be integrated with SC members' existing EDI or ERP system (Rudberg *et al.*, 2002). The data transfer process has also become faster (McIvor and Humphreys, 2004; Bartezzaghi and Ronchi, 2003) and more accessible (Rudberg *et al.*, 2002; Lyons *et al.*, 2004) than most traditional IS systems. Many companies are actively seeking the best way to share information within the supply chain (Rudberg *et al.*, 2002) and the Internet appears to be the best solution. Many big name companies like Dell (Chou *et al.*, 2004), Ford Motor Company, General Motors and DaimlerChrysler (The Economist Intelligence Unit and Meritus Consulting Services, 2000) have successfully or intend to utilise Internet technology in SC information sharing. In addition there are

innovative examples of business-to-business (B2B) exchange of schedule information (Lyons and Kehoe, 2000) and Enterprise Resource Planning (ERP) systems are being developed to communicate more effectively with each other using a common protocol (Murillo, 2001).

One of the most sophisticated applications of e-commerce to supply chain operations is envisaged by many within the worlds automobile industry:

*... "A few quick clicks on the website, and the customer has chosen his perfect model, with the right engine, personalised in-car options, colour and trim. His order information has been instantaneously transmitted from the manufacturers website to suppliers, logistics partners and the assembly plant. Commodity deals are struck in an electronic market place, and components, assemblies and systems very quickly processed directly in-line with end customer demand. Just two weeks (reducing to 3 days?) after the order has been placed, the vehicle is delivered to the customer's door"*  
(Automotive News Europe, 2000)

This is not quite reality, but a dream that is gradually being realised as vehicle manufacturers work out their e-business strategies. A well-publicised trial system known as ConsumerConnect allowed Ford Focus, Taurus and Windstar customers in Canada to order from a limited range. General Motors has established a network integrating the customer to the supply chain. This involves building cars and trucks to customer preferences (Pepper, 2000). One of the Ford's industrial park has built the Vitria's Business Ware platform park to transmit various information, such as

transactions, production errors/changes, from Ford to its suppliers in real time (Automotive Logistics, 2004).

## **2.5 Chapter Summary**

This chapter has reviewed most of the major existing literature in SCPM, including SC and SCM. The history of SCPM was initiated with vendor rating systems or supplier performance measurement in the 1960s. However, strictly speaking, a vendor rating system is not SC measurement because it is a dyadic measure. The research on multi tier SCPM only started after SCM became popular (Holmberg, 2000; Bechtel and Jayaram, 1997; Gunasekeran *et al.*, 2001). Generally, the existing SCPM models can be divided into two categories: those that measure SC performance from different perspectives and those that only measure certain SC characteristics. During the literature review, there were 11 factors that were identified as the SCPM success factors.

Although there are many SC performance measures available, there is no generic solution that can suit all SCs. Every SC is unique in terms of its structure, operations, business environment and business strategies. Therefore, some of the measurement systems included in this literature review are actually frameworks or guidelines that help users to build their own SC measures according to their own supply chain characteristics and requirements. On the other spectrum, there are measurement systems that have a fixed set of metrics. These metrics are usually very specific to a certain type of SC.

Apparently, the frameworks and guidelines are more generic and able to provide customised SC measures. The metrics are more suitable than the measurement systems that come with a fixed set of metrics. However, the main drawback of these frameworks and guidelines is that there is a possibility where the users might interpret the guidance differently. As a result, the developed measures might not serve the purpose properly. Also, if given a choice, most industrial users would actually prefer to use a “ready made” measurement system, which is designed specifically for their SC for obvious reasons: time saving, less effort and more reliable.

This literature review concludes that none of the reviewed measures can provide a balanced quantitative measurement system, which is not only feasible in commercial environment but also justified by empirical studies and evidence. Therefore, this research is instigated to develop an original SCPM system that meet these criteria, as well as all the SCPM success factors identified in Section 2.3.3.

The review on IS has clearly illustrated the significance role of IS in SC performance because it facilitates SC integration, reduces bullwhip effect, reduces inventory level, reduce costs, improve responsiveness, increases sales and improves capacity utilisation. The review has also included a summary on factors that affect the success of a IS initiative: trust and commitment among SC members, incentive alignment to encourage SC members' participations, the type of information to share and the costs involved.

## **CHAPTER 3: DEVELOPMENT OF SUPPLY CHAIN PERFORMANCE MEASUREMENT FRAMEWORK**

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### **3.1 Introduction**

This chapter is to propose the SCPM scorecard that was developed in this research. As mentioned in Section 2.3.7, existing SCPM systems and measures are not suitable for the FUSION research for the following reasons:

1. Some of the measurement systems are not multi-tier measures.
2. Some of these are single-measure systems that focus on one specific SC performance. In other words, these measurement systems are not balanced approach.
3. Some of these measurement systems are based on theoretical concepts that have not been verified by empirical study.
4. Some of the measures are qualitative assessment like survey and questionnaire, which solely depend on individual' subjective judgement to assess performance.
5. Some of the measures have very lengthy and complicated procedure, thus are not practical to be applied in commercial environment.
6. None of these measurement systems can fulfil all the 11 SCPM success factors described in Section 2.3.3.

Due to these reasons, the author has developed a scorecard that possesses the characteristics stated in these six reasons. The scorecard measures SC performance across four SC levels - OEM, 1<sup>st</sup> tier supplier, 2<sup>nd</sup> tier supplier and 3<sup>rd</sup> tier supplier. It provides quantitative measures from four different perspectives (demand

synchronisation, responsiveness, reliability and cost) to provide a balanced performance indication. The metrics were selected based on the industry strategies – cost reduction and responsiveness enhancement to ensure that the measures are aligned with the SC strategies. The feasibility and applicability of the scorecard has been verified by three case studies on automotive SCs. In each of the four measurement perspectives, there are only two metrics. This is to keep the scorecard within a manageable scale and to ensure that it is not too lengthy or complicated for industrial users. The 11 success factors identified in Chapter Two were also taken into account during the development process. The relations between these success factors with the scorecard, and the details of the scorecard can be found in section 3.3.

## **3.2 The Scorecard**

### **3.2.1 Introduction**

The main objective of developing this scorecard is to provide a unique balanced quantitative multi-tier SC performance measurement system for automotive SCs, which at the same time fulfils the SCPM success factors.

There are 8 metrics in this scorecard, which are divided into four categories, as shown in Table 3.1: demand synchronisation measures, responsiveness measures, reliability measures and cost measures. These metrics measure both intra-firm (internal to the firm) and inter-firm (external, ties together supplier and buyer) aspects of SC performance. The metrics span the OEM to 3<sup>rd</sup> tier supplier. The aggregation or cumulative results from each tier represent the entire SC performance

level. This scorecard is based upon an analysis that is upstream of the OEM. Therefore, the metric and the case studies only include business-to-business (b2b) links, i.e. the OEM, 1<sup>st</sup> tier supplier, 2<sup>nd</sup> tier supplier and 3<sup>rd</sup> tier supplier. The business-to-consumer (b2c) link, which is the interface between the vehicle manufacturer and the buyer, is not included. This is because in the case studies, the SC demand originated from the OEM level not the consumer level due to the order commitment policy with the car dealers.

<u>Demand Synchronisation Measures</u>  <i>Demand MAD</i> <i>Bullwhip Coefficient</i>	<u>Responsiveness Measures</u>  <i>Inventory level</i> <i>Dock-to-Dock Time</i>
<u>Reliability Measures</u>  <i>Stockout Level</i> <i>Backorder Level</i>	<u>Cost Measures</u>  <i>Transportation Cost</i> <i>Inventory Carrying Cost</i>

Table 3.1: The Scorecard

The next section describes the four measurement categories and the metrics within these categories. Then the subsequent section elaborates on how this scorecard fulfils the SCPM success factors. A toolkit on how to develop the scorecard is also included in Appendix M.



### 3.2.2 Demand Synchronisation Measures

The demand synchronisation measures assess the discrepancy of demand information between SC levels. There are two metrics in this group – *demand MAD* and *bullwhip coefficient*. The *demand MAD* measures the difference of demand quantity between the vehicle manufacturer and its suppliers (1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> tier). The *bullwhip coefficient* compares the demand quantity perceived by the two ends of the SC, i.e. the OEM and the 3<sup>rd</sup> tier supplier.

The author proposed to mean absolute deviation, which is a common statistical formula, to measure the difference of demand quantity between SC levels (Kenney and Keeping, 1962). The *demand MAD*, as shown in Equation 3.1, calculates the mean absolute deviation of demand between the OEM and the suppliers. It measures the gap of demand quantity between the OEM and each supply level. A high *demand MAD* percentage means that the difference between the original demand and the demand perceived by the SC members is also high. The mathematical expression of this metric is as follow:

$$\text{Demand MAD} = \frac{\left( \frac{\sum_{i=1}^n |OD_i - SD_i|}{n} \right)}{\mu} \times 100\% \dots\dots\dots (\text{Equation 3.1})$$

Where:  $OD_i$  = OEM daily demand quantity  
 $SD_i$  = Supplier daily demand quantity  
 $n$  = Sample size  
 $\mu$  = Average daily demand

The measure of *bullwhip coefficient* in this scorecard is adopted from the mathematical expression proposed by Fransoo and Wouters (2000), which is Equation 2.1 reviewed in Section 2.3.6.1.3. The metric measures the bullwhip effect by comparing the OEM's demand quantity (i.e. the vehicle manufacturer) against the demand quantity of each SC level, as shown in Equation 3.2.

$$\text{Bullwhip Coefficient} = \frac{\frac{\sigma_{\text{upstream}}}{\mu}}{\frac{\sigma_{\text{downstream}}}{\mu}} \dots\dots\dots (\text{Equation 3.2})$$

Where:  $\sigma$  = Standard deviation of demand pattern

$\mu$  = Mean of demand pattern

- A *bullwhip coefficient*  $> 1$  means that the variance of the demand registered at the upstream tier is higher than that registered at the point of origin. Situations where a *bullwhip coefficient*  $> 1$  can be registered include having one weekly delivery of goods from lower tiers in the SC.
- A *bullwhip coefficient*  $< 1$  means that the variance of the demand registered at the upstream tier is lower than that registered at the point of origin. Situations where a *bullwhip coefficient*  $< 1$  might be registered include daily deliveries of goods from lower tiers in the SC.
- A *bullwhip coefficient*  $\doteq 1$  means a perfect SC that the upstream and downstream demands are exactly the same.

### 3.2.3 Responsiveness Measures

According to Ramakrishnan's definition (2002), responsiveness is "*the ability to respond and adapt time-effectively based on the ability to read and understand actual market signals in real-time according to changes in end-user demand*". The two metrics chosen to assess SC responsiveness in this research are *Inventory Level* and *Dock-to-Dock Time*.

According to Stewart (1995), one of the Supply Chain Excellence Keys is to measure the inventory days of supply. Two types of inventory are taken into consideration in this scorecard: raw material (RM) and finished goods (FG). Other inventories like work-in-progress and goods-in-transit are not included. In this scorecard, the *inventory level* is calculated by taking the average daily stock quantity and dividing it by the average daily usage quantity. Hence, the *inventory level* is presented in days of stock format. An *inventory level* of 2.6 days indicates that the amount of inventory can support 2.6 days of production. The overall SC inventory level is the sum of RM inventory level and FG inventory level from every SC level. The mathematical formula for inventory level is shown in Equation 3.3 as follows:

$$\text{Inventory Level} = \frac{\sum_{i=1}^n I_i}{\sum_{i=1}^n U_i} \dots\dots\dots (\text{Equation 3.3})$$

Where:  $I_i$  = Daily inventory quantity  
 $U_i$  = Daily usage quantity of OEM, i.e. the actual demand  
 $n$  = Sample size

This equation is defined by the author to measure the inventory level held by the studied companies and SCs. The measure is based on daily quantity rather than every hour or minute because it is the most common measurement unit to record inventory quantity, especially among the companies in the case studies.

The second metric is to measure SC lead time performance by defining SC *dock-to-dock time*. *Dock-to-dock time* is defined as the elapsed time between unloading raw materials and releasing finished product for shipment (Trotman, 1998). The delivery lead-time and throughput time from Milgate's study were incorporated into this metric (2001). In this scorecard, the *SC dock-to-dock time* indicates the length of SC pipeline. For each SC level, the *dock-to-dock time* includes material wait time, process time, transportation time, waiting time in between process, and finished goods wait time.

### **3.2.4 Reliability Measures**

Reliability is the ability to operate under prescribed conditions without failure or stopping, in order to achieve the predetermined output to meet customers' demand or to perform according to the defined specifications (Waller, 2003). The two metrics used to measure reliability are *stockout level* and *backorder level*.

The *Stockout level* indicates the inability of each SC level to meet demand at the right time (Waller, 2003). It assesses the frequency of stockout incidents in raw material supply, by looking at the average number of days on which a stockout incident occurred per month. This is similar to the late delivery measure in

Milgates’s study (2001). A higher *stockout level* means more disruptions in material availability. This metric is similar to one of the Supply Chain Excellence Keys proposed by Stewart (1995), which is “delivery to request date”. However, the details on how to measure “delivery to request date” is not shown. In this scorecard, the mathematical formula to measure *Stockout Level* is proposed by the author as follow:

$$SL = \frac{\sum_{i=1}^n S_i}{n} \dots\dots\dots \text{(Equation 3.4)}$$

- Where:
- $SL$  = Stockout Level
  - $S_i$  = Number of stockout incident on day  $i$
  - $n$  = Number of day / Sample size

The second reliability metric - *backorder level* is referred to as the portion of orders that are not delivered on time. It measures the intensity of material availability disruption by calculating the average quantities of materials that have been delayed in stockout incidents, which were sampled in the *stockout level* metric. The mathematical formula to measure *Backorder Level* is as follow:

$$BL = \frac{\sum_{i=1}^n B_i}{\sum_{i=1}^n S_i} \dots\dots\dots \text{(Equation 3.5)}$$

- Where:
- $BL$  = Backorder Level
  - $B_i$  = Backordered material quantity on day  $i$
  - $S_i$  = Number of stockout incident on day  $i$
  - $n$  = Number of day / Sample size

**3.2.5 Cost Measures**

There are two metrics within this category – *transportation cost* and *inventory carrying cost*.

According to Stewart (1995), one of the Supply Chain Excellence Keys is “total logistics cost”. The *transportation cost* measures regular logistics cost of each SC member. It measures the cost to transport the finished goods to the next downstream SC member with two equations - Equation 3.6 shows the transportation cost per unit of material while Equation 3.7 shows the total transportation cost per month. The mathematical expression of these two equations was proposed by the author as follow:

$$T_u = \frac{C}{U} \dots\dots\dots \text{(Equation 3.6)}$$

- Where:       $T_u$       = Average transportation cost per unit  
                  $C$         = Cost per delivery  
                  $U$         = Delivery batch size

$$T_m = C \times Q \dots\dots\dots \text{(Equation 3.7)}$$

- Where:       $T_m$       = Average transportation cost per month  
                  $C$         = Cost per delivery  
                  $Q$         = Number of delivery per month

The *inventory carrying cost* is calculated based on the value of the total SC inventories level. The inventory value is determined using Equation 3.8:

$$V = IL \times DV \times C \dots\dots\dots \text{(Equation 3.8)}$$

- Where:
- $V$  = Inventory value
- $IL$  = Inventory level identified in Equation 3.3
- $DV$  = Average daily volume
- $C$  = Cost per unit

Only two types of inventories are taken into consideration in this scorecard – the raw material inventories and the finished goods inventories. There are four aspects that constitute the total inventory carrying cost:

- **Loss of interest:** This measures the interest that would be earned if the capital were not invested in the inventories. The average daily inventory value is multiplied by the interest rate, and then divided by 12, which gives the monthly interest amount. The mathematical expression is as follow:

$$LI = \frac{I \times V}{12} \dots\dots\dots \text{(Equation 3.9)}$$

- Where:
- $LI$  = Loss of interest
- $I$  = Annual interest rate on capital cost
- $V$  = Inventory value identified in Equation 3.8

- **Storage cost:** This is the cost spent on premises to keep the inventories. It is calculated by multiplying the total inventory value by annual storage rate and then divided by 12. The mathematical expression is as follow:

$$SC = \frac{S \times V}{12} \dots\dots\dots \text{(Equation 3.10)}$$

- Where:
- $SC$  = Storage cost

$S$  = Annual storage rate

$V$  = Inventory value identified in Equation 3.8

- **Obsolescence cost:** This measures the losses incurred due to the reduced usefulness or desirability of the inventories. In this scorecard, the obsolescence cost is determined by multiplying the total inventory value by the annual obsolescence rate and then divided by 12. The mathematical expression is as follow:

$$OC = \frac{O \times V}{12} \dots\dots\dots (\text{Equation 3.11})$$

Where:  $OC$  = Obsolescence cost

$O$  = Annual obsolescence rate

$V$  = Inventory value identified in Equation 3.8

- **Opportunity cost:** This is the cost associated with opportunities that are foregone by not putting the capital (which has been invested to the inventories) to another alternative investment. It is calculated by multiplying the average daily inventory value by the opportunity cost rate and then divided by 12. The mathematical expression is as follow:

$$PC = \frac{P \times V}{12} \dots\dots\dots (\text{Equation 3.12})$$

Where:  $PC$  = Opportunity cost

$P$  = Annual opportunity rate

$V$  = Inventory value identified in Equation 3.8



### **3.2.6 Summary Scorecard**

The results from these individual metrics are summarised and presented in a scorecard format, as shown in Table M.8 in Appendix M. This enables the user to compare SCs' performance at both the SC level as well as individual supplier level.

### **3.3 The SCPM Success Factors**

During the literature review, the author has identified 11 factors that contribute to a successful SCPM system. These factors were taken into account when the scorecard was developed:

- 4.3.1 Strategy alignment
- 4.3.2 Balanced measurement
- 4.3.3 Appropriate quantity of metrics
- 4.3.4 Quantifiable metrics
- 4.3.5 Compatible metrics
- 4.3.6 System thinking
- 4.3.7 Universality
- 4.3.8 Involvement
- 4.3.9 Understanding of the existing measurement systems
- 4.3.10 Corporate culture
- 4.3.11 Distinction between metrics level

The following section elaborates the influence these factors on the scorecard, as well as how these factors are taken into account during the development process.

### **3.3.1 Strategy Alignment**

#### **3.3.1.1 SC Strategies in Automotive Industry**

A successful measurement system has to be derived from strategy (Holmberg, 2000; Globerson, 1985; Beamon, 1999; Neely *et al.*, 1995; Lapide *et al.*, 2000; Tangen, 2003; Walke 1998) in order to achieve the benefits summarised in Section 2.3.3.

The automotive industry has always been highly competitive, but is especially so in today's business environment where globalisation and technology advancement have raised the rivalry among vehicle manufacturers (Mara and Wilson, 1999). In order to maintain market share, or just merely to survive, many vehicle manufacturers have to adopt new management techniques or new technologies.

Due to the volatile competition, the automotive industry has been operating a year-on-year cost-down approach to SC contract negotiations (Childerhouse *et al.*, 2003). Cost reduction has become one of the organisational or SC strategies in automotive SC (Childerhouse *et al.*, 2003). Apart from cost reduction, it is also vital to engineer SCs to match customers' requirements (Fisher, 1997). The main problems in the automotive industry are the high product variety and the volatile OEM schedule or demand changes (Childerhouse *et al.*, 2003). As a result, vehicle manufacturers tend to impose very high demands on their suppliers in terms of product quality, in addition to the service level, to achieve the required responsiveness. Therefore, the

industry is torn between coping with extreme flexibility on the one hand and making products much cheaper on the other (Childerhouse *et al.*, 2003).

Hence, the measures of this scorecard revolved around these two SC strategies - cost reduction and responsiveness enhancement. The next four sections (3.3.1.2 to 3.3.1.5) explain the relation between the scorecard and these two automotive SC strategies.

### **3.3.1.2 Demand Synchronisation Measures**

There are many different information flows that circulate within SCs - inventory levels, sales data, order status, sales forecasts, production/delivery schedules, performance metrics and capacity information (Lee and Whang, 1999; Lee and Whang, 2000). Demand information is one of the most important and strategic pieces of information that facilitates most business decisions (Mober *et al.*, 2002), especially in the automotive industry, where production often still relies upon demand forecasts. The vehicle manufacturers operate some form of fixed allocation system and the car dealers are obliged to place a set number of orders each month before they have real customers for these orders (Childerhouse *et al.*, 2003). Hence, quite often the vehicle manufacturers have to change the production quantity at very last minutes if the orders placed are not sold. Many studies have proven that the variation of demand information elevates SC inventory levels (Lee *et al.*, 1997-b; Svensson, 2003). Most of these inventories are carried along the SC pipeline due to demand uncertainty and it is one of the seven wastes recognised by the Toyota Production System (Shingo, 1989).

Since demand uncertainty is one of the reasons that contribute to SC cost, the demand synchronisation metrics are included in this scorecard to assess the parity of demand information shared among the SC members. The *Demand MAD* measures the difference of demand quantity between the OEM with each SC level. If demand uncertainty exists within the SC, the demand quantity perceived by each SC level will be different (Lee *et al.*, 1997-b). As a result, more inventories will be needed to compensate the uncertainty. Therefore, by measuring the variance in demand quantity at each SC level, the demand synchronisation metrics expose the demand uncertainty within the SC, which directly affects inventory level and cost.

The *Bullwhip Coefficient* measures the difference of demand quantity between both ends of the SC. Forrester (1961) defines bullwhip effect as an increase of demand variability along a SC. According to Chen *et al.* (2000), two factors that are commonly assumed to cause bullwhip effect are demand forecast and order lead time. A SC that suffers from bullwhip effect usually encounters problems of excessive inventory (Lee *et al.*, 1997 b; Svensson, 2003), poor demand forecast, insufficient or excessive capacity, poor customer service, uncertain production planning, high correction costs, and a deterioration of the SC's demand synchronisation level (Lee *et al.*, 1997a; Martin, 2001).

### **3.3.1.3 Responsiveness Measures**

The responsiveness measure is to assess the SC ability to react to changes, which is one of the common strategies use in automotive industry. The future success of any

manufacturing industry is not only dependent on a manufacturer's ability to respond to customers' needs that are ever changing rapidly, but also the entire SC responsiveness (Lyons and Kehoe, 2000). According to Ramakrishnan's definition (2002), responsiveness is "*the ability to respond and adapt time-effectively based on the ability to read and understand actual market signals in real-time according to changes in end-user demand*". It is one of the crucial aspects to gain or maintain market share because it helps OEMs to meet customers' demand exact requirements as timely as possible, at an economically competitive price (Holweg, 2005). Catalan and Kotzab (2003) advocate that responsiveness will increase when SC members cooperate and build close relationships, holding higher inventories or shorten the cycle times.

However, many companies are still failing to respond to their customers within a satisfactory timeframe, especially when it is a customised product (Holweg, 2005). The automotive industry has been recognised to have low responsiveness in comparison to other mass customisation industries. The average order lead time for the car industry in Europe is 48 days while for the computer industry it is just 7 days (Holweg, 2005). Also many studies that have been carried out to study responsiveness are mainly conceptual and use qualitative descriptions (Rohr and Correa, 1998; Fisher, 1994), or are in a manufacturing context (Suarez *et al.*, 1995; Slack, 1983). Therefore, the responsiveness measure is included in this scorecard.

The first metric to measure SC responsiveness is the *SC inventory level*. It is widely admitted by many researchers that inventory management is one of the key factors to achieve an effective SCM (Waller, 2003; Lee and Corey, 1992) and an inventory

metric that can measures across a SC is needed (Lee and Corey, 1992). It will help to achieve the following benefits:

- Reduce costs and expenses by keeping inventory level as low as possible because all inventories have financial value (Waller, 2003). Some companies are locking up to 65 days of inventories into the business due to a lack of SC synchronisation and demand visibility (Martin, 2001). It will also incur higher obsolescence and depreciation cost, especially when the goods have short product life cycle (Waller, 2003). More inventories will become obsolete if the demand change requires brand new components. Many major vehicle manufacturers such as GM, Ford and Chrysler have tried to reduce inventory level by cutting production and offering retails and sales incentives (FoxNews, 2005). An effective inventory management can reduce costs of goods by 4%, and reduce inventory carrying costs by 2% (Waller, 2003).
- Keep the inventories flow through SC pipeline continuously and quickly to minimise process disruption (Waller, 2003). SC has to be able to responsively react to market demand without holding inventory (Martin, 2001). A SC with higher inventory levels will take longer to react to changes because there are more goods within the pipeline. This means that higher inventory levels will impede product innovation and new product introduction (Martin, 2001), i.e. SC responsiveness.
- Improve customer service level by maintaining enough finished goods level to meet customer demand on time (Waller, 2003). According to Waller's (2003) observation, an effective inventory management system can increase sales by 3.25% (Waller, 2003).

Usually, most users identified inventory turns as a SC performance measure (Lapide, 1999; Langdon, 2001; Anderson *et al*, 1997). However, as a SC metrics, it is not an effective measure because it fails to capture key differences in product cost, form, and risk within the supply chain (Lambert and Pohlen, 2001). Therefore, the author uses inventory level to assess SC inventory performance. The *SC inventory level* measurement as a The *SC inventory level* in this scorecard is the sum of RM inventory level and FG inventory level from the OEM to the 3<sup>rd</sup> tier supplier, not including other types of inventories like work-in-progress. This is because this scorecard focuses on performance measurement in a SC context, and RM inventory and FG inventory are located between the interfaces of SC levels.

Time is another important aspect in responsiveness assessment. In order to expedite SC responsiveness towards changes, the lead time for information and materials to travel through the SC pipeline should be kept as short as possible (Persson and Olhager, 2002). A SC with long lead time means that there are more inventories throughout the SC pipeline, in form of raw material, work in progress, finished goods and goods-in-transit. This directly affects SC inventory levels. Ballantyne's (2004) study shows that a reduction in lead time will bring a reduction in inventory level, and vice versa. Another study (Chen et al., 2000) indicates that lead time also affects bullwhip effect. One of the observations in this study is that the longer the lead time, the more demand data are required to reduce bullwhip effect. A SC with short dock-to-dock time can usually respond to demand or environmental changes more quickly because the time for the rectification to take effect throughout the SC will be shorter.

Therefore, the second metric in this category – *dock-to-dock time* is a representation of SC order lead time. It is directly related to *SC inventory level* because it will take longer for an order to travel through a SC pipeline if the inventory level is higher.

#### **3.3.1.4 Reliability Measures**

Reliability is the ability to operate under prescribed conditions without failure or stopping, in order to achieve the predetermined output to meet customers' demand or to perform according to the defined specifications (Waller, 2003). A SC is a series of different business entities that are interrelated to each other. Therefore, the reliability of the entire SC depends on the synchronisation level, efficiency and effectiveness of SC members. Any disruption at any part of a SC will affect the overall performance of the SC (Waller, 2003). The following example is taken from an interview in a case study regarding Nissan's SC:

*"When you're looking at the number of supplied parts that go into a final vehicle assembly, if the production line starts getting disrupted because of poor quality parts from the supplier base then that build will come into severe jeopardy, so 50 PPM is a business need based on the low stocks that we'll be carrying and the complexity of the build. That is the message we're sending out to every supplier we have."* (Adapted from Doran 2001)

An unreliable SC will affect customer service level, profitability, product quality, production process (Waller, 2003) and competitiveness (Olhager, 2002). There are many ways to assess reliability performance, such as delivery accuracy, fill rate,



perfect order fulfilment, the percentage of schedule changes and the percentage of delivery to request and commit date (Supply Chain Council, 2004; Stewart, 1995). Some vehicle manufacturers first-tier suppliers are subject to a “parts per million” (PPM) reject rate of below 50, which is critical to the success of a synchronous supply system (Doran, 2001).

Reliability has a great influence on cost. A low reliability means there will be more errors and most errors incur extra costs in terms of compensation, lost sales, rectification action, down time etc. The operations of synchronous supply in the automotive industry require absolute precision in materials delivery. Any missed delivery will cause excessive costs from down time, production disruptions, premium freight, rectification actions and compensation. This can cause a severe impact on cost and responsiveness. Furthermore, if one of the SC members fails to deliver according to schedule, it affects the material availability of the downstream SC member. The knock on effect will ripple through the SC and this means that these costs and disruptions will be multiplied and replicate through the SC pipeline.

Therefore, the *stockout level* and *backorder level* are selected as the reliability metrics in this scorecard. The *stockout level* provides a simple way to monitor the major cause of disruption in synchronous supply, i.e. miss deliveries. Beamon (1999) suggests some stockout measures to assess product availability performance, such as stockout probability and the number of stockout incidents. On the other hand, the *backorder level* shows the intensity of the miss delivery by quantifying the number of parts/components involved in the backlog.

### 3.3.1.5 Cost Measures

In order to maintain SC competitiveness, the SC members must be efficient with respect to cost (Olhager, 2002). According to Todd and McGrath's study, some companies spent from 3% to 7% of annual expenses on SCM than the leading companies in the same industry (Morton, 1997). Cost visibility helps to plan and control SC operations and decision-making activities (Mena *et al.*, 2002; Johnson, 1992). For most vehicle manufacturers, cost reduction has become one of the organisational or SC strategies due to the fierce competition brought on by over capacity, increased customer demands, expansion of product requirements and globalisation. However, there is a lack of cost measurement technique that measure across the entire SC (LaLonde and Pohlen, 1996). According to Robert Sabath, most companies are unable to track their costs all the way through the SC (Barr, 1996). He recommended a holistic cost measurement approach and recognised that having accurate costing methods from one end of the SC to the other is vital. Therefore, cost measure is included in this scorecard to fill this gap and also as a direct measure on cost reduction efforts.

Transportation is the activity of moving materials or finished goods from one place to the other. In a SC context, it is the movement of goods throughout the SC pipeline. It reflects the efficiency and effectiveness of SC operations. The Ford's European manager of inbound material flow and logistics, Micheal Kulger said that the automotive industry needs to eliminate excessive transportation in international SCs to create a better total cost (Kluger, 2004). According to a survey in France (L'Usine Nouvelle, 1994), transportation cost makes up 44% of SC cost. Therefore, *transportation cost* is one of the metrics selected as cost measure.

Inventory holding is another factor that contributes to SC cost. Apart from the financial value of inventories (Waller, 2003), there are also money spent on maintaining and keeping the goods while they are in the company's possession. These expenses are classified as *inventory carrying cost* or inventory holding cost. It includes costs associated with keeping inventory over time, for example storage cost, overhead costs, loss of interest, opportunity costs, depreciation and deterioration. The benefits of measuring inventory carrying cost is that it considers both the cash value of the inventory and the varying opportunity costs at different SC level (Lambert and Pohlen, 2001; Stock and Lambert, 2001) The more inventories that a SC carries, the higher the inventory carrying cost will be.

### **3.3.2 Balanced Measurement**

In order to assess SC performance, a measurement system is required rather than a single measure (Beamon, 1999). A balanced measurement system assesses an entity from different perspectives to obtain an overall view on how well the entity has performed. In this research, the author has chosen to measure automotive SC performance from four perspectives (i.e. demand synchronisation, responsiveness, reliability and cost), which cover both financial and non-financial measures, based on the automotive SC strategies - cost reduction and responsiveness enhancement. Despite that, the metrics are also carefully selected to assess both the causes and effects of the strategies, as shown in Table 3.2.

Metrics	SC Strategy			
	Cost Reduction		Responsiveness Enhancement	
	Cause	Effect	Cause	Effect
Demand MAD	√			
Bullwhip Coefficient	√		√	
Inventory Level	√		√	
Dock-to-dock Time			√	
Stockout Level				√
Backorder Level				√
Transportation Cost		√		
Inventory Carrying Cost		√		

Table 3.2: The Scorecard Balance Measurement

### 3.3.3 Appropriate Quantity Metrics

The third design criterion is that a good performance measurement system should have the right amount of metrics (CGI, 2002). This is to make sure that the measurement system is kept within a manageable size and easy to use. The best way to narrow the metric quantity down is by referring to the business or SC strategy. By exploring the rationale underlying the measures, only the relevant and crucial metrics will be included in the measurement set (Neely *et al.*, 1995). Hence, there are only eight metrics in this scorecard and these metrics provide an objective indication of the SC performance level towards the SC strategies.

### 3.3.4 Quantifiable Metrics

A good performance measurement system should have quantifiable metrics (CGI, 2002). All metrics have to be clearly defined and illustrated (Globerson, 1985). The metrics in the scorecard are quantifiable and can be easily understood and used. Most

of the data required by the measurement system are readily measurable. The procedures on how to collect the data and how to perform the measure calculation were clearly defined as well.

### **3.3.5 Compatible Metrics**

It is also very important to make sure that all the metrics are compatible with the current circumstances (Maskell, 1989), especially in a fast moving business, where changes take place frequently in terms of technology, business practices and production processes. It has to be able to react and change according to environmental variation, either within or outside the organisational boundary in order to achieve dynamism (Bititci *et al.*, 2000). In this scorecard, all the metrics were selected based on the SC strategies (i.e. cost reduction and responsiveness enhancement), as well as the type of information available within the studied SCs. The author acknowledges that the measures should change as circumstances do, therefore it should be reviewed regularly.

### **3.3.6 System Thinking**

The concept of system thinking promotes that each component in the measurement system (i.e. performance model, measurement methods and metrics) must be considered throughout the entire SC, across the SC levels (Holmberg, 2000). It reduces the possibility where the measurement outcomes bias towards certain SC members and prevent local optimisation. It allows SC members to work together to tackle the weaknesses at any SC level that will benefit the entire SC. Having

recognised the significance and importance of system thinking, the study scope of this scorecard includes four SC levels – OEM, 1<sup>st</sup> tier supplier, 2<sup>nd</sup> tier supplier and 3<sup>rd</sup> tier supplier. With cross boundary measurement, the distribution of costs and benefits among the SC members can be monitored and the problem of local optimisation can be avoided (Lambert and Bennion, 1982).

### **3.3.7 Universality**

This scorecard was designed to be applied on any automotive SC with strategy focuses on cost reduction and responsiveness enhancement. This enables the users to compare SC performance, as well as individual companies performance that constitute the SC. An effective SCPM model should have high level of universality to allow for comparison of competing organisations or SCs (Beamon, 1999; Globerson, 1985). This is especially important nowadays because businesses are competing with each other on SC basis (Cox, 1999; Cokins, 1999; Duclos *et al.*, 2003).

### **3.3.8 Involvement**

The involved parties and individuals should be consulted during the metrics selection process (Neely *et al.*, 1995) and fully committed to the measurement efforts (Blenkinsop and Davis, 1991). Measures should be understandable by all SC members (Schroeder *et al.*, 1986). In order to perform the measurement, the project stakeholders were informed to make sure that they were aware of and agreed with the measurement initiative, and they were consulted to obtain the information needed.

The main project stakeholders include the production managers, supply chain manager, logistics managers, buyers and senior management personnel who were interested in the measurement results.

### **3.3.9 Understanding of Existing SCPM Systems**

An effective SCPM system must take into account the difference of corporate culture between SC members (Blenkinsop and Davis, 1991), especially if it has influence over the measurement process and results. This includes the company beliefs, values, business principles, traditions, ways of operating and internal working environment (Thompson and Strickland III, 2005). All the existing SCPM methods were reviewed in Section 2.3 in order to understand the existing SCPM systems, especially in automotive industry. The literature review shows that there was no cross-organisational measurement system that measures automotive SC performance as a whole.

### **3.3.10 Corporate Culture**

A successfully SCPM system must take the difference of corporate culture among the SC members into consideration during the development process and the measurement process (Blenkinsop and Davis, 1991). All the metrics within the scorecard were carefully selected so that the studied SCs can be measured and compared on the same ground. Apart from that, the author has also ensured that all SC members are willing to release the information required to complete the measurement.

### **3.3.11 Distinction Between Metrics Level**

Gunasekaran *et al.* (2001) stated that there should be a clear distinction between metrics at strategic, tactical, and operational levels. The measures in this scorecard were designed to evaluate the performance of the entire SC (strategic level) based on the collective performance of each SC member (tactical and operational level). Therefore, this scorecard contains both strategic and operational metrics. These metrics were divided according to the measurement level, i.e. the OEM, 1<sup>st</sup> tier supplier, 2<sup>nd</sup> tier supplier, 3<sup>rd</sup> tier supplier and finally the SC level (which is the collective performance from the OEM, 1<sup>st</sup> tier supplier, 2<sup>nd</sup> tier supplier and 3<sup>rd</sup> tier supplier).

## **3.4 Chapter Summary**

The main purpose of this chapter is to elaborate the scorecard developed in this research, in terms of the scorecard structure, how the 11 success factors were adopted into the scorecard, and also how the scorecard prevails over the drawbacks of current SCPM system reviewed in Chapter Two.

The scorecard has eight metrics that are divided into four groups: demand synchronisation measures, responsiveness measures, reliability measures and cost measures. It measures SC performance across four SC levels - OEM, 1<sup>st</sup> tier supplier, 2<sup>nd</sup> tier supplier and 3<sup>rd</sup> tier supplier. It provides quantitative measures from four different perspectives (demand synchronisation, responsiveness, reliability and cost)



to provide a balanced performance indication. The metrics were selected based on the industry strategies – cost reduction and responsiveness enhancement to ensure that the measures are aligned with the SC strategies. The feasibility and applicability of the scorecard has been verified by three case studies on automotive SCs. In each of the four measurement perspectives, there are only two metrics. This is to keep the scorecard within a manageable scale and to ensure that it is not too lengthy or complicated for industrial users. The 11 success factors identified in Chapter Two were taken into account during the development process.

The next chapter is the case studies chapter, which illustrate how this scorecard was applied on three different automotive SCs to measure their performance.

## CHAPTER 4: CASE STUDIES

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### 4.1 Introduction

This chapter is to explain how the scorecard was applied in three different case studies in order to validate the feasibility and applicability of the scorecard on automotive SC in actual industry environment.

The automotive industry is the leading industry in the business world and it is seen as a flagship sector that epitomises the health of the economy and an exemplar for other industries (Childerhouse *et al.*, 2003; Helper, 1991). Before the 1980s, supply chains in the automotive industry were managed in a very traditional manner. The vehicle manufacturers chose their suppliers by price, through market-based auctions and had multiple supply sources for any one component. Both the vehicle manufacturers and the suppliers kept information exchanges to a minimum due to lack of trust and commitment, even when the suppliers struggled to comply with the service agreement (Lapiedra *et al.*, 2004). Needless to say, this types of business relationship were short-term, arms-length and there was not much collaboration within the chain.

Due to the pressure from globalisation and technology advancement, the automotive industry has become highly competitive and raised the rivalry among vehicle manufacturers (Mara and Wilson, 1999; Lapiedra *et al.*, 2004). The increase in competition in the industry has changed the interaction of automotive supply chains (SCs). The industry is torn between coping with extreme flexibility on the one hand and making products much cheaper on the other (Childerhouse *et al.*, 2003).

Therefore, most automotive SCs are trying to achieve cost reduction while improving responsiveness. Price is no longer the sole selection criterion. A more collaborative and long-term relationship is developed with suppliers (Lapiedra *et al.*, 2004). There is more information sharing among the SC members, contributing to joint problem solving. The practice of single source supply has become common in the industry. Vehicle manufacturers develop trust towards their suppliers in order to transfer the responsibility of component development to the supplier, so that they can free up and redeploy their resources on core competencies.

## **4.2 Case Study Methodology**

As mentioned in Chapter One, the main objective of this research is to develop a multi-tier SCPM system for the automotive industry. The author proposes a holistic scorecard that contains eight metrics in four different measurement groups. Once the scorecard was established, the feasibility and applicability of the scorecard was verified through empirical studies. The performance of three automotive SCs were measured using the scorecard:

Case study 1:

- SC A
- The OEM is a mid-volume, high customisation vehicle manufacturer
- The OEM, 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> tier suppliers are located in the UK

Case study 2:

- SC B

- The OEM is a high-volume, low customisation vehicle manufacturer
- The OEM, 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> tier suppliers are located in Spain

Case study 3:

- SC C
- The OEM is a high-volumes low customisation vehicle manufacturer
- The OEM, 1<sup>st</sup> and 2<sup>nd</sup> tier suppliers are located in the UK. However, the 3<sup>rd</sup> tier supplier was not included because the supplier is located in the Far East and therefore unable to take part in the case study.

The case study methodology used in this thesis is as depicted in Figure 1.3 and explained in Section 1.5.3. The SC background information was assimilated through questionnaires, meetings, interview and historical data. However, throughout the case studies, some of the information was obtained via informal methods such as observations and consultation with the relevant personnel when queries arose. All the data and results from the case studies were validated with the companies involved through reports, presentations and meetings throughout the case study period.

Using case study method not only helps the author to prove the feasibility and applicability of the scorecard in actual commercial environment, the results and outcomes of the studies have also provided those companies involved in the case studies an insight on their companies' performance as well as their SC performance. This is very useful information for them because the rivalry between businesses has expanded from between individual companies to a competition between SC (Duclos *et al.*, 2003; Christopher, 1992).

### **4.3 Sequenced In Line Supply (SILS)**

Much has been written about Just In Time (JIT) manufacture, a concept where products and components are pulled in line with customer demand (Womack, Jones 1990). This concept is significant in the automotive industry and has been further developed to the extent where vehicle assemblies (e.g. seats, cockpits, front-end systems) are produced by suppliers JIT to be assembled into the vehicle. This is known as Sequenced-in-line-supply (SILS). It has a significant influence on the material supply and handling process in the automotive industry (Coleman *et al.*, 2002) and it is a very common practice in the automotive industry. Vehicle manufacturers such as Nissan (Doran, 2001), BMW (Buss, 2004), Ford (Coleman *et al.*, 2002) and Saab (Automotive Logistics, 2004) are all handling their core material supply using sequenced supply systems. Sequenced supply, which is also known as synchronous supply, is defined as (Doran, 2001):

*“A controlled and integrated approach to the supply of goods which matches the exact requirements of the customer reflecting vehicle, rather than model, variations. Synchronous supply necessitates close proximity to the customer, efficient supply chain management skills and an integrated information system which can accommodate the time critical transfer of data and activate the synchronous manufacturing process to deliver zero defect goods, at the right time, at the right place and the right cost.”*

It is very different from conventional supply mechanism where the parts are delivered in batch with no specific sequence adherence. SILS is similar to JIT (Just

In Time) in that the materials are only delivered at the time when the buyer needs them. However, sequenced supply requires higher precision and efficiency because the materials delivery sequence has to be vehicle specific and according to the OEM assembly sequence, whereas for JIT it is only model specific (Doran, 2001). In order to give suppliers sufficient time to build the required materials, the OEM usually provides demand forecasts to suppliers in advance (Coleman *et al.*, 2002).

Sequenced supply requires a high level of collaboration between suppliers and vehicle manufacturers. The primary difficulty associated with synchronous supply is the issue of ensuring that upstream suppliers can develop their own systems and processes to the standards needed (Doran, 2001). Suppliers have to make sure that the components meet the specifications, quality requirements and delivered on time in the right sequence to the vehicle manufacturer. Every downstream supplier has to manage and control its supplier efficiently and effectively to cope with the demands (Doran, 2001). Every SC level should know where the product is going and the role of the product throughout the SC (Doran, 2001). However, some 2<sup>nd</sup> tier suppliers have not risen to the challenge yet (Doran, 2001). On the other hand, vehicle manufacturers must be able to produce according to production schedules. BMW defines the ability to build the cars in exactly the order that the plant announces to suppliers six days before assembly begins as sequence adherence (Buss, 2004). Any failure or error within sequenced supply will cause disruption in a supplier's delivery process or an OEM's production process, which will incur extra cost. Also, there is a possibility that this disruption might have a knock-on effect on other supply chain members' production routine.

Another element that might affect sequenced supply is the quality of information that an OEM transmits to its sequenced suppliers. A sequenced supply mechanism is usually facilitated by a real time information broadcast system. This system continuously transmits the OEM's production information to suppliers in real time. It contains information about the material specifications, delivery sequence and the time when the material is needed for production. However, this information usually comes in very short notice (between 8 to 12 hours in advance from the required time). Therefore, there is another source of forecast that provides the demand information with a longer horizon, usually one or two weeks before the production day. The accuracy of this demand information is very important to help the supplier to produce the right components at the right time, thus preventing delivery failure and avoiding rectification and compensation cost.

All the three vehicle manufacturers in the case studies are operating sequenced supply (i.e. the SILS) with their 1<sup>st</sup> tier suppliers. Sequenced supply is applied to all core materials with high variety and high consumption rate (such as seat modules and instrument panels). It is a common practice in the automotive sector and it brings the following advantages (Doran, 2001; Dwyer, 1998):

- Guarantee short and reliable lines of supply
- Reduces stocks; It is practically impossible to hold that level of stock on site to match all the variants
- Reduces lead times
- Promotes lean organisation
- Maintain a proactive environment within the SC

- Encourages continuous improvement

**4.4 Seat Module Supply Chain**

Based on the fact that SILS plays a significant role in automotive SCs the author decided to choose a sequenced supplied component/module to be the measurement subject in this research.

Three types of seat modules were selected, based on Childershouse et al’s (2003) product categorisation in the automotive industry, to generate a composite scorecard to ensure that the results were representative: runner (high usage rate), repeater (medium usage rate) and stranger (low usage rate). Table 4.1 shows the average demand volume of each sample type per day. The data collected from these three was samples weighted according to their demand volume and combined together to provide the overall supply chain performance.

	SC A OEM (Production volume = 380/day)	SC B OEM (Production volume = 1000/day)	SC C OEM (Production volume = 1250/day)
Runner	81	484	207
Repeater	40	34	N/A
Stranger	23	5	41

Table 4.1: Average Demand Volume of Seat Modules



4.5 Case Study 1 – SC A

4.5.1 Background Information

The first case study was started in November 2002. It is a medium-volume and high customisation vehicle manufacturer situated in the UK. Its daily production volume is about 380 vehicles and there are more than 1 million end product varieties. For each type of seat, there are two basic styles (classic and sport), two kinds of materials (cloth and leather) and six colours to choose from (sand, ivory, heritage tan, warm charcoal, dove and red), power adjustment and safety. As shown in Figure 4.1, there are 19 seat modules variety available based on styles, materials and colours.

<u>Style</u>	<u>Material</u>	<u>Colour</u>	<u>Variety</u>
Classic	Cloth:	Sand, Heritage, Charcoal, Dove	4
	Leather:	Sand, Heritage, Charcoal, Dove, Ivory	5
Sport	Cloth:	Sand, Heritage, Red, Charcoal	4
	Leather:	Sand, Heritage, Red, Charcoal, Dove, Ivory	6
			Total = 19

Figure 4.1: SC A Seat Module Variety

The three seat modules chosen in the case studies are shown in Table 4.2:

Seat Modules	Typical Daily Demand
Sand leather	81 (Runner)
Char leather	40 (Repeater)
Heritage leather	4 (Stranger)

Table 4.2: SC A Case Study Seat Modules

The case study incorporates four levels of the seat supply chain – the vehicle manufacturer (OEM), the seat manufacturer (1<sup>st</sup> tier supplier), the headrest manufacturer (2<sup>nd</sup> tier supplier) and the headrest fabric manufacturer (3<sup>rd</sup> tier supplier). All of them are located within the UK. As shown in Figure 4.2, it is a conventional, one-to-one interaction between consecutive SC levels for both information and material flow.

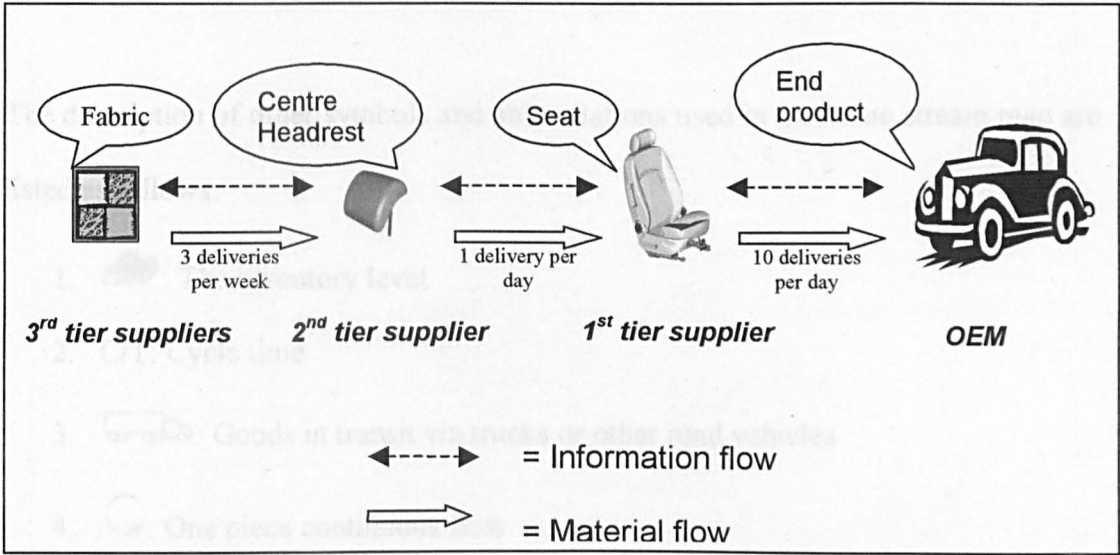


Figure 4.2: Seat Module SC A (Khoo *et al.*, 2004)

A more detailed graphical illustration of this SC is shown in Figure 4.3 using value stream mapping. It shows the process to produce seat modules, from the supply of headrest fabric to the complete seat module fitted to the vehicle. The processes are represented by the box symbols and colour coded according to supply chain level:

1. OEM (Vehicle manufacturer): Brown
2. 1<sup>st</sup> tier supplier (Seat module manufacturer): Grey
3. 2<sup>nd</sup> tier supplier (Headrest manufacturer): Light Pink

#### 4. 3<sup>rd</sup> tier supplier (Fabric manufacturer): Red

These boxes represent the major processes in this supply chain. The first row shows the name of the process. The second row shows the cycle time of the process. The third row is the number of working hours available per day. The fourth row is the product or material that goes through the process.

The description of other symbols and abbreviations used in the value stream map are listed as follows:





1. : The inventory level
2. C/T: Cycle time
3. : Goods in transit via trucks or other road vehicles
4. : One piece continuous flow
5. : Batch flow

Figure 4.2: SC A Value Stream Map (Khoo et al., 2003)



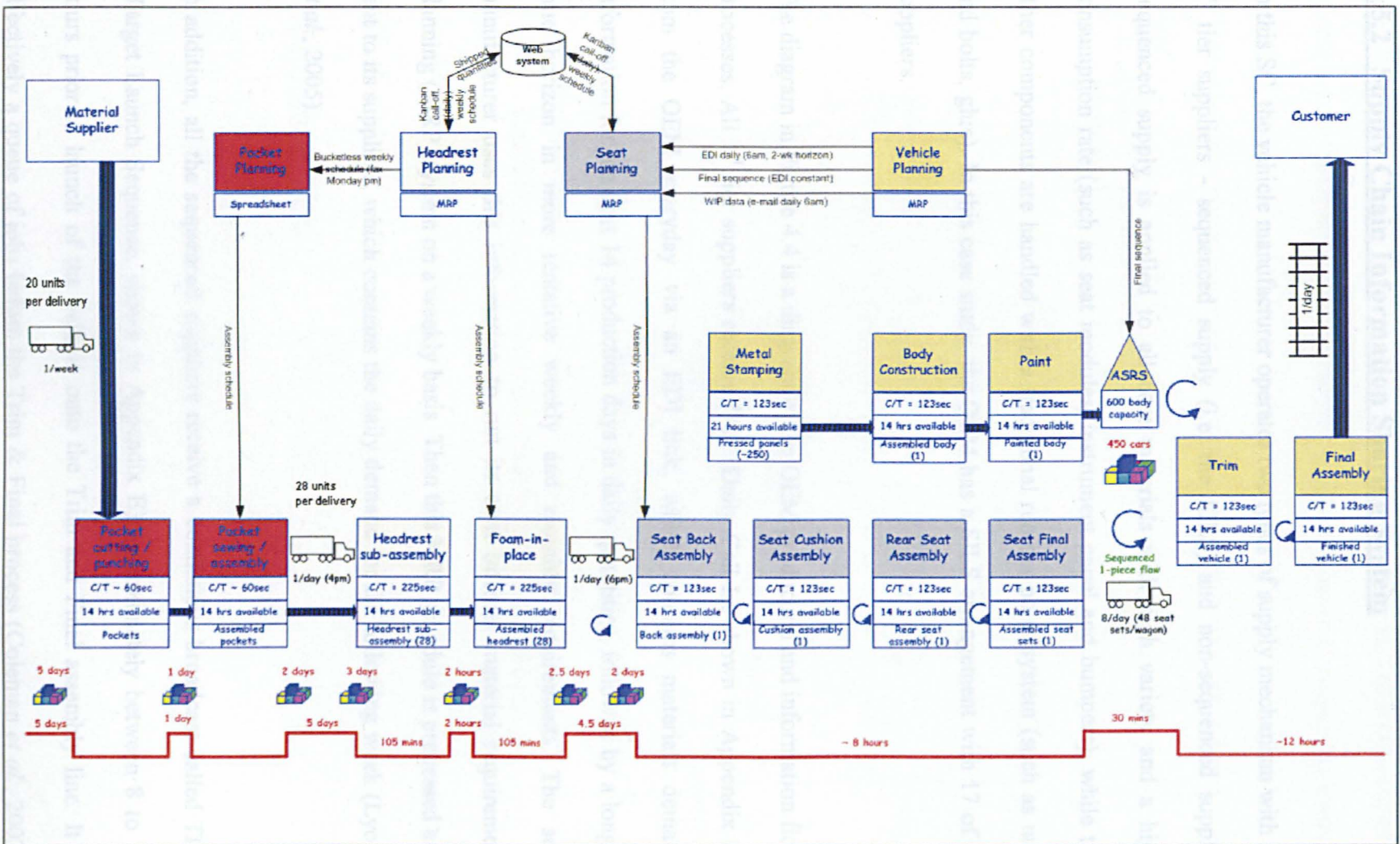


Figure 4.3: SC A Value Stream Map (Khoo *et al.*, 2003)

### **4.5.2 Supply Chain Information Sharing System**

In this SC, the vehicle manufacturer operates two types of supply mechanism with its 1<sup>st</sup> tier suppliers - sequenced supply (i.e. the SILS) and non-sequenced supply. Sequenced supply is applied to all core materials with high variety and a high consumption rate (such as seat modules, instrument panel and bumpers), while the other components are handled with a traditional reorder point system (such as nuts and bolts, glue). In this case study, the OEM has a SILS arrangement with 17 of its suppliers.

The diagram in Figure 4.4 is a diagram of the OEM production and information flow processes. All 1<sup>st</sup> tier suppliers receive DCI (Daily Call In, shown in Appendix D) from the OEM everyday via an EDI link, which contains materials demand information for the next 14 production days in daily quantities, followed by a longer time horizon in more tentative weekly and monthly requirements. The seat manufacturer uses this information to run its own internal material requirement planning (MRP) system on a weekly basis. Then this MRP schedule is processed and sent to its suppliers, which contains the daily demand for the following week (Lyons *et al.*, 2005).

In addition, all the sequenced suppliers receive a continuous broadcast called TLS (Target Launch Sequence, shown in Appendix E) approximately between 8 to 12 hours prior to launch of the vehicle onto the Trim and Final assembly line. It is effectively a queue of jobs before the Trim & Final process (Coleman *et al.*, 2002). The sequenced suppliers deliver the materials to the Trim and Final assembly line

according to TLS, which includes the material specifications as well as the sequence of delivery so that it matches the assembly line job sequence to reduce the material handling process.

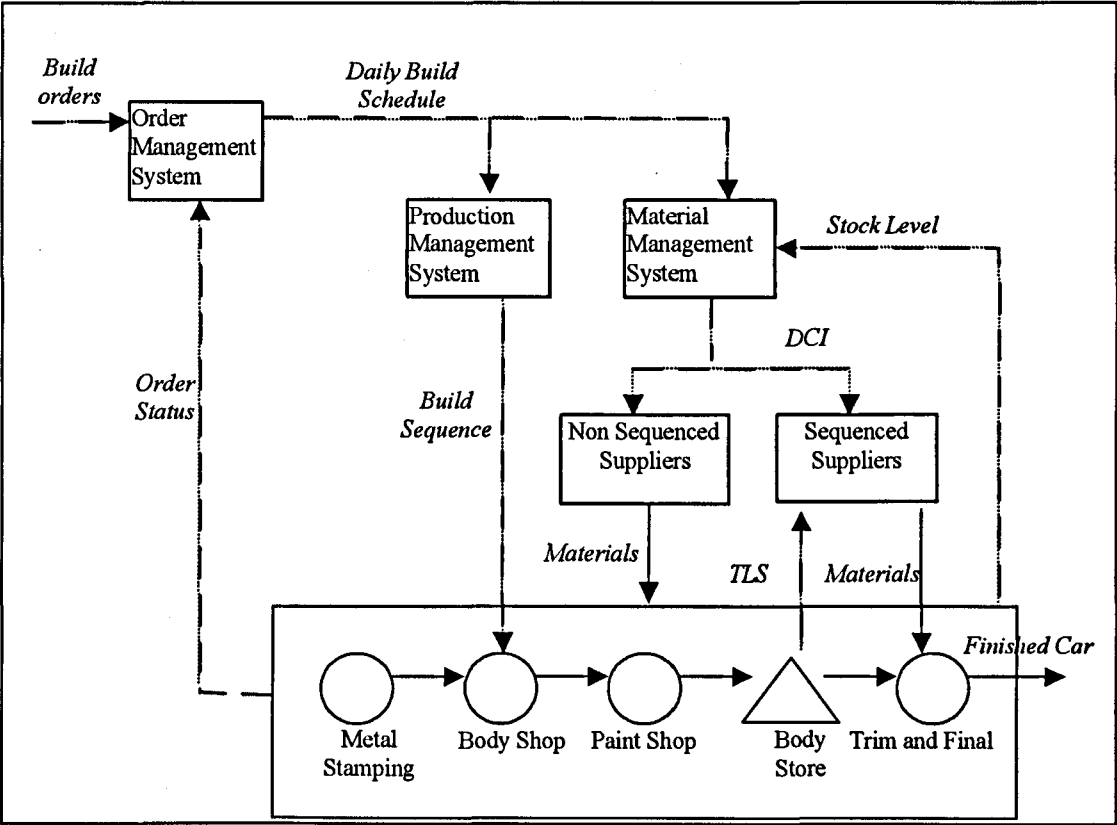


Figure 4.4: The SILS Material and Information Flows in SC A

4.5.3 Results

4.5.3.1 Demand MAD

Table 4.3 is the measurement result of SC A *Demand MAD* using Equation 3.1 and Table M.1 (in Appendix M).

The *OEM – 1<sup>st</sup> tier supplier* (0%) is the average of *Demand MAD* between the OEM (vehicle manufacturer) and the 1<sup>st</sup> tier supplier (seat module manufacturer), from

three different product types (runner, repeater and stranger). The 0% *Demand MAD* indicates that there is no difference in demand quantity between the vehicle manufacturer and the seat module supplier.

The *OEM – 2<sup>nd</sup> tier supplier* (118.24%) is the average of *Demand MAD* between the OEM and the 2<sup>nd</sup> tier supplier (headrest manufacturer), from three different product types (runner, repeater and stranger). The 118.24% figure means the 2<sup>nd</sup> tier supplier demand quantity is 118.24% higher or lower than the OEM average demand quantity.

The *OEM – 3<sup>rd</sup> tier supplier* (114.45%) is the average of *Demand MAD* between the OEM and the 3<sup>rd</sup> tier supplier (headrest fabric supplier), from three different product types (runner, repeater and stranger). The 114.45% means that the 3<sup>rd</sup> tier supplier demand quantity is 114.45% higher or lower than the OEM average demand quantity.

The *SC Demand MAD* (77.56%) is the average of the above three. The 77.56% indicates that the average demand quantity between 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> tier supplier is 77.56% higher or lower than the OEM's average demand quantity.



**SC A Demand MAD**

SC Demand MAD =	77.56%
OEM - 1st tier supplier =	0.00%
OEM - 2nd tier supplier =	118.24%
OEM - 3rd tier supplier =	114.45%

**Runner: Sand Leather (ADX)**

Analysis Days	02-Sep	03-Sep	04-Sep	05-Sep	06-Sep	09-Sep	10-Sep	11-Sep	12-Sep	13-Sep	16-Sep	17-Sep	18-Sep	19-Sep	20-Sep	23-Sep	24-Sep	25-Sep	26-Sep	30-Sep	Sum	Demand MAD
OEM demand	106	84	85	98	43	104	91	89	123	0	131	98	88	75	0	90	92	66	58	91	1613	
1st tier supplier demand	106	84	85	98	43	104	91	89	123	0	131	98	88	75	0	90	92	66	58	91	1613	
OEM - 1st tier supplier	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2nd tier supplier demand	56	112	84	0	168	0	224	0	84	140	112	0	112	112	140	0	0	140	0	196	1680	
OEM - 2nd tier supplier	50	28	2	98	125	104	133	89	44	140	19	98	24	37	140	90	92	74	58	105	1550	95.80%
3rd tier supplier demand	0	200	0	140	0	80	200	0	320	0	0	240	0	240	0	0	80	0	0	0	1500	
OEM - 3rd tier supplier	106	116	86	42	43	24	109	89	192	0	131	142	88	165	0	90	12	66	58	91	1650	101.98%

Sample size (n) = 20  
Average actual demand ( $\mu$ ) = 80.90

**Repeater: Char Leather (LEG)**

Analysis Days	02-Sep	03-Sep	04-Sep	05-Sep	06-Sep	09-Sep	10-Sep	11-Sep	12-Sep	13-Sep	16-Sep	17-Sep	18-Sep	19-Sep	20-Sep	23-Sep	24-Sep	25-Sep	26-Sep	30-Sep	Sum	Demand MAD
OEM demand	46	40	65	54	31	64	65	57	43	25	39	33	36	40	0	37	34	28	32	33	802	
1st tier supplier demand	46	40	65	54	31	64	65	57	43	25	39	33	36	40	0	37	34	28	32	33	802	
OEM - 1st tier supplier	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2nd tier supplier demand	56	84	56	0	0	0	84	0	84	0	56	0	0	56	84	0	0	84	0	112	756	
OEM - 2nd tier supplier	10	44	9	54	31	64	19	57	41	25	17	33	36	16	84	37	34	56	32	79	778	97.01%
3rd tier supplier demand	0	90	0	100	0	200	0	100	0	0	0	140	0	0	0	0	60	100	0	0	780	
OEM - 3rd tier supplier	46	40	65	46	31	136	65	43	43	25	39	107	36	40	0	37	26	72	32	33	962	119.95%

Sample size (n) = 20  
Average actual demand ( $\mu$ ) = 40.10

**Stranger: Heritage Leather (ADY)**

Analysis Days	02-Sep	03-Sep	04-Sep	05-Sep	06-Sep	09-Sep	10-Sep	11-Sep	12-Sep	13-Sep	16-Sep	17-Sep	18-Sep	19-Sep	20-Sep	23-Sep	24-Sep	25-Sep	26-Sep	30-Sep	Sum	Demand MAD
OEM demand	5	11	3	4	0	6	9	3	0	15	8	7	1	2	0	3	5	1	1	0	84	
1st tier supplier demand	5	11	3	4	0	6	9	3	0	15	8	7	1	2	0	3	5	1	1	0	84	
OEM - 1st tier supplier	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2nd tier supplier demand	0	0	0	0	0	0	0	0	28	0	0	0	0	28	0	0	0	0	0	0	56	
OEM - 2nd tier supplier	5	11	3	4	0	6	9	3	28	15	8	7	1	26	0	3	5	1	1	0	136	161.90%
3rd tier supplier demand	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	20	
OEM - 3rd tier supplier	5	11	3	4	0	6	9	3	0	15	8	7	19	2	0	3	5	1	1	0	102	121.43%

Sample size (n) = 20  
Average actual demand ( $\mu$ ) = 4.20

Table 4.3: Demand MAD Results for SC A



#### 4.5.3.2 Bullwhip Coefficient

Table 4.4 displays the measurement results of SC A seat module bullwhip effect using Equation 3.2 and Table 3.3.

The *OEM – 3<sup>rd</sup> tier supplier* is the average of *Bullwhip Coefficient* between the OEM (vehicle manufacturer) and the 3<sup>rd</sup> tier supplier (headrest fabric supplier), from three different product types (runner, repeater and stranger). It shows the demand amplification between two ends of the supply chain. A 3.96 *Bullwhip Coefficient* indicates that the original demand, i.e. the OEM's demand, has been amplified by the factor of 3.96 when the demand reaches the 3<sup>rd</sup> tier supplier.

The *OEM – 1<sup>st</sup> tier supplier* is the average of *Bullwhip Coefficient* between the OEM (vehicle manufacturer) and the 1<sup>st</sup> tier supplier (seat module manufacturer), from three different product types (runner, repeater and stranger). The *bullwhip coefficient* of 1 indicates that there is no demand amplification between the vehicle manufacturer and the seat module supplier.

The *1<sup>st</sup> tier supplier – 2<sup>nd</sup> tier supplier* is the average of *Bullwhip Coefficient* between the 1<sup>st</sup> tier supplier (seat module manufacturer) and the 2<sup>nd</sup> tier supplier (headrest manufacturer), from three different product types (runner, repeater and stranger). The *bullwhip coefficient* of 2.66 indicates that there is demand amplification from the seat module manufacturer to the headrest manufacturer.

### SC A Bullwhip Coefficient

**Runner: Sand Leather (ADX)**

Repeater: Char Leather (LEG)

**Stranger: Heritage Leather (ADY)**

OEM - 3rd Tier Bullwhip Coefficient =	4.55
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The *2<sup>nd</sup> tier supplier – 3<sup>rd</sup> tier supplier* is the average of *Bullwhip Coefficient* between the 2<sup>nd</sup> tier supplier (headrest manufacturer) and the 3<sup>rd</sup> tier supplier (headrest fabric supplier), from three different product types (runner, repeater and stranger). The *bullwhip coefficient* of 1.51 indicates that there is also demand amplification of 1.51 from the headrest manufacturer to the headrest fabric supplier.

#### 4.5.3.3 Inventory Level

Table 4.5 is the inventory measurement results of SC A seat module using Equation 3.3 and Table M.3 (in Appendix M). The average inventory level for this SC is 18.22 days worth of inventory, by taking the average of inventory level from the three samples (Runner: 7.03, Repeater: 12.31, Stranger: 35.33). The average inventory levels of RM and FG inventories within each SC level are also listed in the tables. There are three limitations to this measure:

1. The results do not include the 3<sup>rd</sup> tier supplier (headrest fabric supplier) RM inventories because it is not within the research scope.
2. The FG inventory level of 2<sup>nd</sup> tier supplier is an estimated figure because the day-to-day data is not available.
3. The OEM's FG inventories is excluded from this measure because it is not within the research scope.



**SC A Inventory Level**

Avrg SC inv level =	18.22 days of stock
Avrg OEM RM inv level =	0.00 days of stock
Avrg 1st tier FG inv level =	0.00 days of stock
Avrg 1st tier RM inv level =	5.06 days of stock
Avrg 2nd tier FG inv level =	1.50 days of stock
Avrg 2nd tier RM inv level =	1.86 days of stock
Avrg 3rd tier FG inv level =	6.45 days of stock

**Runner: Sand Leather (ADX)**

Analysis Days	02-Sep	03-Sep	04-Sep	05-Sep	06-Sep	09-Sep	10-Sep	11-Sep	12-Sep	13-Sep	16-Sep	17-Sep	18-Sep	19-Sep	20-Sep	23-Sep	24-Sep	25-Sep	26-Sep	30-Sep	Σ	Inv Level in days
OEM daily usage	106	84	86	98	43	104	91	89	128	0	131	98	83	75	0	90	92	66	58	91	1618	
OEM RM stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier FG stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier RM stock level	137	165	163	65	190	86	219	130	88	228	209	111	107	116	256	166	74	148	89	194	2941	1.82
2nd tier FG stock level	Data not available																				N/A	1.50
2nd tier RM stock level	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	2000	1.24
3rd tier FG stock level	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	4000	2.47
																					8941.00	7.03

**Repeater: Char Leather (LEG)**

Analysis Days	02-Sep	03-Sep	04-Sep	05-Sep	06-Sep	09-Sep	10-Sep	11-Sep	12-Sep	13-Sep	16-Sep	17-Sep	18-Sep	19-Sep	20-Sep	23-Sep	24-Sep	25-Sep	26-Sep	30-Sep	Σ	Inv Level in days
OEM daily usage	46	40	65	54	31	64	65	57	43	25	39	33	36	40	0	37	34	28	32	33	802	
OEM RM stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier FG stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier RM stock level	143	171	94	40	177	113	132	75	116	144	131	128	92	108	191	154	120	176	143	222	2670	3.33
2nd tier FG stock level	Data not available																				N/A	1.50
2nd tier RM stock level	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	2000	2.49
3rd tier FG stock level	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	4000	4.99
																					8670.00	12.31

**Stranger: Heritage Leather (ADY)**

Analysis Days	02-Sep	03-Sep	04-Sep	05-Sep	06-Sep	09-Sep	10-Sep	11-Sep	12-Sep	13-Sep	16-Sep	17-Sep	18-Sep	19-Sep	20-Sep	23-Sep	24-Sep	25-Sep	26-Sep	30-Sep	Σ	Inv Level in days
OEM daily usage	5	11	3	4	0	6	9	3	0	15	8	7	1	2	0	3	5	1	1	0	84	
OEM RM stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier FG stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier RM stock level	61	50	47	43	43	37	28	25	53	38	30	23	29	55	55	50	45	44	43	43	842	10.02
2nd tier FG stock level	Data not available																				N/A	1.50
2nd tier RM stock level	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	1000	11.90
3rd tier FG stock level	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	1000	11.90
																					2842.00	35.33

Table 4.5: Inventory Level Results for SC A



#### 4.5.3.4 Dock-to-Dock Time

The *SC dock-to-dock time* was calculated using Table M.4 (in Appendix M). Table 4.6 illustrates the breakdown of the *SC Dock-to-Dock Time* according to these activities. The transit time and process time are based on an estimation provided by the companies while the FG buffer time and RM buffer time is based on the inventory level obtained in Section 4.5.3.3.

<b>SC A Dock-to-Dock Time</b>			
<b>SC D2D Time (in working hours) = 302.47</b>			
<b>Value Adding Time (in working hours) = 4.60</b>			
<b>Value Adding Ratio (vs SC D2D Time) = 1.52%</b>			
Process	Time (hours)		
	Runner	Repeater	Stranger
	Sand Leather (ADX)	Char Leather (LEG)	Heritage Leather (ADY)
Transit from 1st Tier to OEM	0.30	0.30	0.30
1st Tier FG Buffer	0.00	0.00	0.00
1st Tier Process Time	0.60	0.60	0.60
1st Tier RM Buffer	29.08	53.27	160.38
Transit from 2nd Tier to 1st Tier	3.00	3.00	3.00
2nd Tier FG Buffer	24.00	24.00	24.00
2nd Tier Process Time	1.50	1.50	1.50
2nd Tier RM Buffer	19.78	39.90	190.48
Transit from 3rd Tier to 2nd Tier	3.00	3.00	3.00
3rd Tier FG Buffer	39.56	79.80	190.48
3rd Tier Process Time	2.50	2.50	2.50
<b>Total (in hours)</b>	<b>123.32</b>	<b>207.87</b>	<b>576.23</b>

Table 4.6: Dock-to-Dock Time Results for SC A

The process time in this table is different from the cycle time shown in the value stream map in Section 4.5.1. This is because the value stream map only shows the cycle time of major production processes in the SC. The process times in Table 4.6 refers to the time elapsed when a product enters and leaves the production system. Therefore, it includes other minor processes that are not shown in the value stream map.

The *Dock-to-Dock Time* for this SC is 302.47 hours, based on the average *Dock-to-Dock Time* from three different samples (Runner: 123.32 hours, Repeater: 207.87 hours, Stranger: 576.23 hours). Only 1.52% of these 302.47 working hours, which is 4.60 hours, are value-adding activities, i.e. the *process time*. Other elements like transit time and waiting time as inventory are classed as non value adding activities.

#### **4.5.3.5 Stockout and Backorder Level**

The *Stockout level* was measured using Equation 3.4 and the *Backorder level* was measured using Equation 3.5, both using Table M.5 (in Appendix M). However, in this case study, there is no stockout incident throughout the SC during the case study period, thus the stockout level and backorder level are both zero.

#### **4.5.3.6 Transportation Cost**

The *transportation cost* was measured using Equation 3.6 and 3.7 as shown in Table M.6 (in Appendix M). The breakdown of transportation cost is shown in Table 4.7. The *Cost Per Delivery* is provided by the Road Haulage Association in the UK based on the travel distance, weight and volume.

The *Average SC Transportation Cost* for this supply chain is £3.63 per unit based on the average *Cost Per Unit*, and £27,672 per month based on the sum of *Delivery Cost Per Month*. The *Cost Per Unit* is obtained by dividing the *Cost Per Delivery* with the *Delivery Batch Size* (i.e. number of unit in each delivery). The *Delivery Cost Per Month* is calculated by multiplying the *Cost Per Delivery* by *Delivery Per Month*.

<b>SC A Transportation Cost</b>						
<b>SC Transportation Cost (Per Unit) =</b>				<b>£3.63</b>		
<b>SC Transportation Cost (Per Month) =</b>				<b>£27,672.00</b>		
<b>SC Level</b>	<b>Distance (miles)</b>	<b>Cost Per Delivery *</b>	<b>Delivery Batch Size</b>	<b>Cost per Unit (T<sub>u</sub>)</b>	<b>Delivery Per Month *</b>	<b>Delivery Cost Per Month (T<sub>m</sub>)</b>
<b>1st Tier - OEM</b>	1.00	£150.00	48	£3.13	160	£24,000.00
<b>2nd Tier - 1st Tier</b>	34.00	£98.50	28	£3.52	20	£1,970.00
<b>3rd Tier - 2nd Tier</b>	15.00	£85.10	20	£4.26	20	£1,702.00
* The cost per trip is based on the rates provided by Road Haulage Association						
* Assumption of 20 working days per month						

Table 4.7: Transportation Cost for SC A

Although the travel distance between the 1<sup>st</sup> tier supplier and the OEM (i.e. 1<sup>st</sup> tier – OEM) is closer than the other two SC interfaces (i.e. 2<sup>nd</sup> tier – 1<sup>st</sup> tier; 3<sup>rd</sup> tier – 2<sup>nd</sup> tier), the transportation of 1<sup>st</sup> tier – OEM is significantly higher. This is mainly due to the technology and process complication involved in the delivery process. The 1<sup>st</sup> tier supplier has to carefully arrange the parts in each delivery to ensure that the parts can be unloaded according to the OEM production sequence, i.e. SILS. Apart from the sequence arrangement, the parts also have to be mounted on bespoke fixtures so that the parts can be unloaded straight into the OEM production lines with minimal man-handling process. Both the sequence arrangement and the bespoke fixtures have increased the transportation cost, in comparison to the other two SC interfaces that deliver in conventional method, i.e. batch delivery.

#### 4.5.3.7 Inventory Carrying Cost

The *inventory carrying cost* is measured using Equation 3.8, 3.9, 3.10, 3.11 and 3.12 in Table M.7 (in Appendix M). The annual rate for the four cost centres was an estimated rate based on the average of annual rates used by each SC members and



validated by the SC members. The measurement results can be found in Table 4.8.

The average of the *Total Inventory Carrying Cost* from the three samples provides the *Average SC Inventory Carrying Cost Per Month*, which is £114.18. In order to be

able to compare the cost performance between the case studies, the summary table also shows the *Average SC Inventory Carrying Cost Per Unit*, which is £0.02.

SC A Inventory Carrying Cost					
SC Inventory Carrying Cost Per Month = £114.18					
SC Inventory Carrying Cost Per Unit = £0.02					
		Inventory Carrying Cost			
Cost Centre:	% of Inventory Value		Runner Sand Leather (ADX)	Repeater Char Leather (LEG)	Stranger Heritage Leather (ADY)
Interest on capital cost	7.00%	per year	£45.31	£36.59	£10.31
Storage	3.00%	per year	£19.42	£15.68	£4.42
Obsolescence and depreciation	6.00%	per year	£38.84	£31.37	£8.84
Opportunity cost	10.00%	per year	£64.73	£52.28	£14.73
Total Inventory Carrying Cost Per Month=			£168.31	£135.92	£38.31
Inventory Qty Per Month =			8,941	8,670	2,842
Inventory Carrying Cost Per Unit =			£0.02	£0.02	£0.01
Inventory Type	Runner: Sand Leather (ADX)			Inventory Value	
	Inventory Level	Avrg Daily Volume	Cost Per Unit		
OEM RM stock level	0.00	80.90	£750.00	£0.00	
1st tier FG stock level	0.00		£750.00	£0.00	
1st tier RM stock level	1.82		£20.00	£2,941.00	
2nd tier FG stock level	1.50		£20.00	£2,427.00	
2nd tier RM stock level	1.24		£8.00	£800.00	
3rd tier FG stock level	2.47		£8.00	£1,600.00	
	7.03			Total Inventory Value =	
				£7,768.00	
Inventory Type	Repeater: Char Leather (LEG)			Inventory Value	
	Inventory Level	Avrg Daily Volume	Cost Per Unit		
OEM RM stock level	0.00	40.10	£750.00	£0.00	
1st tier FG stock level	0.00		£750.00	£0.00	
1st tier RM stock level	3.33		£20.00	£2,670.00	
2nd tier FG stock level	1.50		£20.00	£1,203.00	
2nd tier RM stock level	2.49		£8.00	£800.00	
3rd tier FG stock level	4.99		£8.00	£1,600.00	
	12.31			Total Inventory Value =	
				£6,273.00	
Inventory Type	Stranger: Heritage Leather (ADY)			Inventory Value	
	Inventory Level	Avrg Daily Volume	Cost Per Unit		
OEM RM stock level	0.00	4.20	£750.00	£0.00	
1st tier FG stock level	0.00		£750.00	£0.00	
1st tier RM stock level	10.02		£20.00	£842.00	
2nd tier FG stock level	1.50		£20.00	£126.00	
2nd tier RM stock level	11.90		£8.00	£400.00	
3rd tier FG stock level	11.90		£8.00	£400.00	
	35.33			Total Inventory Value =	
				£1,768.00	

Table 4.8: Inventory Carrying Cost for SC A



## **4.6 Case Study 2 – SC B**

### **4.6.1 Background Information**

This case study started in January 2003. It is a high-volume and low customisation vehicle manufacturer. Its daily production volume is approximately 1000 vehicles (three different vehicle models) and there are about 1 million end product varieties. There is only one type of seat covering that comes with five different colours: kimono white, cascade indigo, charisma black, generic spice and cascade truffle. The three seat modules chosen in the case studies are shown in Table 4.9:

Seat Modules	Typical Daily Demand
Kimono white	484 (Runner)
Charisma black	34 (Repeater)
Generic spice	6 (Stranger)

**Table 4.9: SC B Case Study Seat Modules**

The case study incorporates four levels of the seat module supply chain – the vehicle manufacturer (the OEM), the seat manufacturer (1<sup>st</sup> tier supplier), the headrest manufacturer (2<sup>nd</sup> tier supplier) and the headrest foam supplier (3<sup>rd</sup> tier supplier). All of them located in Spain. As shown in Figure 4.5, it is quite different from the conventional one-to-one interaction in the first case study. Some of the information is also transmitted between non-immediate SC levels:

1. The 1st tier supplier sends the demand information from its MRP system to the 3rd tier supplier weekly. It is a spreadsheet that contains the firm orders for that

- particular week. Indeed, the 1st tier supplier orders headrest foam from the 3rd tier supplier to the 2nd tier supplier.
2. The 2nd tier supplier has access to the OEM's demand forecast called DCI. However, it is used only as a reference when the OEM is terminating a particular seat colour.

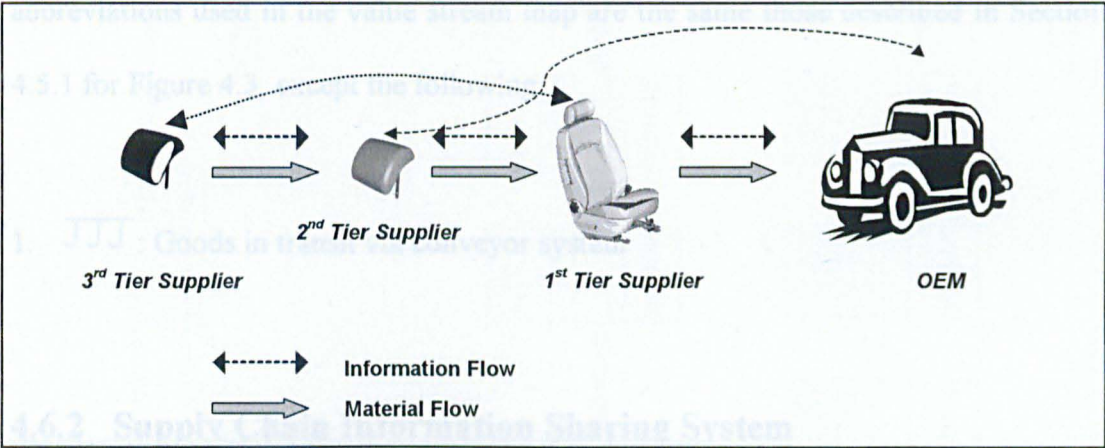


Figure 4.5: Seat Module SC B (Khoo *et al.*, 2004)

A more detailed graphical illustration of this supply chain is shown in Figure 4.6 using value stream mapping. It shows the process to produce a seat module, from the supply of foam for a headrest to the complete seat module fitted on the vehicle. The processes are represented by the box symbols and colour coded according to supply chain levels:

1. OEM (Vehicle manufacturer): Beige 

Final Assembly
CT= 880
FTT %
Avg/lot 14 hrs
Finished vehicle (1)
2. 1<sup>st</sup> tier supplier (Seat module manufacturer): Blue 

Seat Final Assembly
CT= 74 880
FTT %
Avg/lot 4 hrs
Painted body (1)
3. 2<sup>nd</sup> tier supplier (Headrest manufacturer): Red 

Headrest module Assembly
CT= 30 880
FTT %
Avg/lot 24 hrs
Cut material
4. 3<sup>rd</sup> tier supplier (Foam supplier): Grey 

Materials supplier
--------------------

These boxes represent the major processes in this supply chain. The first row shows the name of the process. The second row shows the cycle time of the process. The forth row is the number of working hours per day. The fifth row is the product or material that goes through the process. The description of other symbols and abbreviations used in the value stream map are the same those described in Section 4.5.1 for Figure 4.3, except the following:

1.  $\overline{\text{JJJ}}$ : Goods in transit via conveyor system

#### **4.6.2 Supply Chain Information Sharing System**

The information flow in SC B is similar to SC A because both the OEMs use the same technology and system for materials management and production management. However, the TLS in SC B was broadcast four to five hours prior to launch of the vehicle onto the Trim & Final process, which is shorter than SC A.

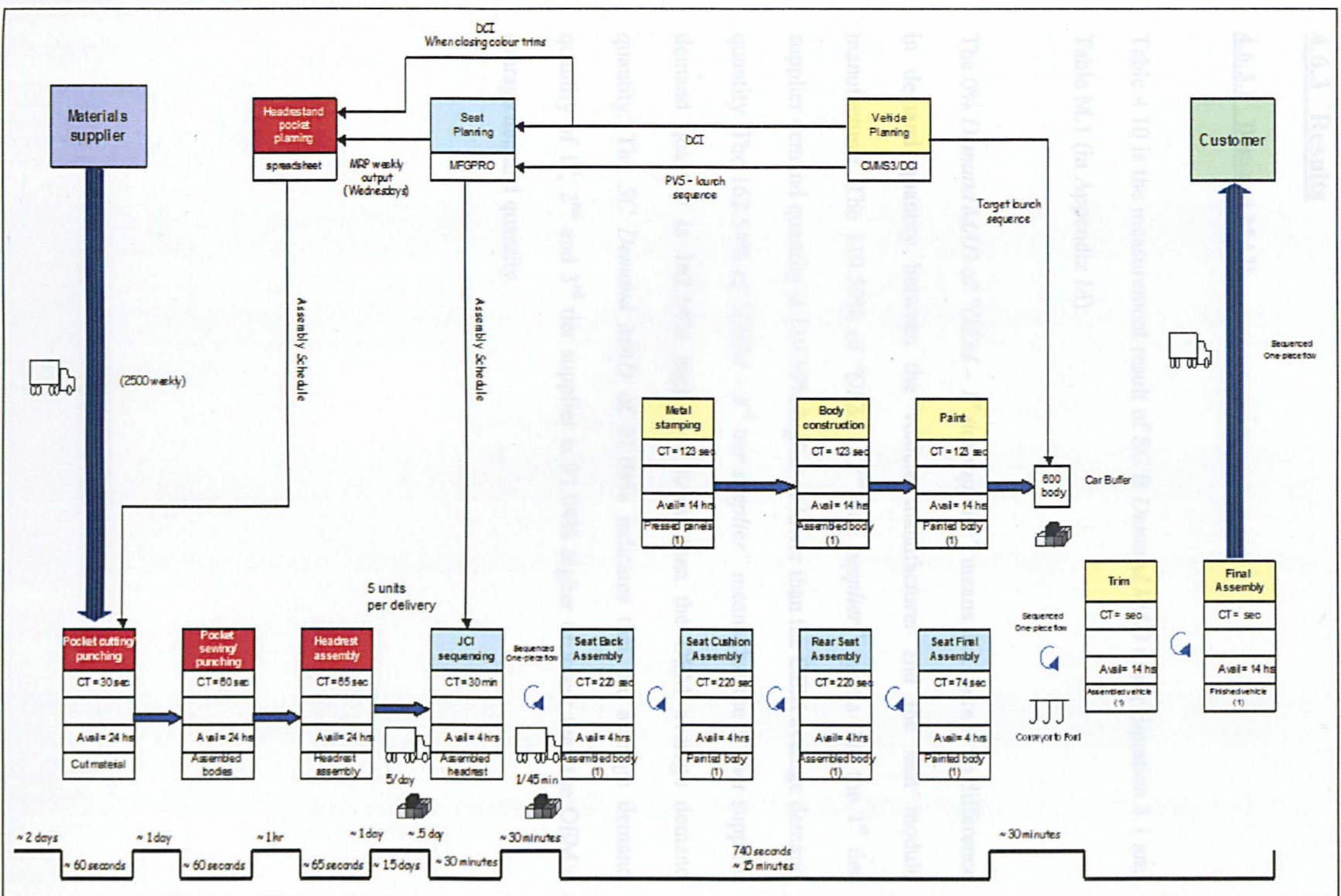


Figure 4.6: SC B Value Stream Map



### **4.6.3 Results**

#### **4.6.3.1 Demand MAD**

Table 4.10 is the measurement result of SC B *Demand MAD* using Equation 3.1 and Table M.1 (in Appendix M).

The 0% *Demand MAD* of “OEM – 1<sup>st</sup> tier supplier” means that there is no difference in demand quantity between the vehicle manufacturer and the seat module manufacturer. The 110.59% of “OEM – 2<sup>nd</sup> tier supplier” means that the 1<sup>st</sup> tier supplier demand quantity is 110.59% higher or lower than the OEM average demand quantity. The 162.54% of “OEM – 3<sup>rd</sup> tier supplier” means that the 3<sup>rd</sup> tier supplier demand quantity is 162.54% higher or lower than the OEM average demand quantity. The *SC Demand MAD* of 91.04% indicates that the average demand quantity of 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> tier supplier is 91.04% higher or lower than the OEM’s average demand quantity.

**SC B Demand MAD**

SC Demand MAD =	91.04%
OEM - 1st tier supplier =	0.00%
OEM - 2nd tier supplier =	110.69%
OEM - 3rd tier supplier =	162.64%

**Runner: Kimono White (KW)**

Analysis Days	17-Feb	18-Feb	19-Feb	20-Feb	21-Feb	24-Feb	25-Feb	26-Feb	27-Feb	28-Feb	03-Mar	04-Mar	05-Mar	06-Mar	07-Mar	10-Mar	11-Mar	12-Mar	13-Mar	14-Mar	17-Mar	Sum	Demand MAD
OEM demand	504	534	578	572	574	244	298	348	366	318	416	510	612	700	418	470	790	522	534	554	318	10170	
1st tier supplier demand	504	534	578	572	574	244	298	348	366	318	416	510	612	700	418	470	790	522	534	554	318	10170	
OEM - 1st tier supplier	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2nd tier supplier demand	504	504	504	504	504	280	336	336	280	448	448	448	448	448	504	560	504	560	560	560	336	9576	
OEM - 2nd tier supplier	0	30	74	68	70	36	38	12	86	130	32	62	164	252	86	90	276	38	26	6	18	1594	15.67%
3rd tier supplier demand	2200	0	0	0	0	2200	0	0	0	0	2200	0	0	0	0	2200	0	0	0	0	0	8800	
OEM - 3rd tier supplier	1696	534	578	572	574	1956	298	348	366	318	1784	510	612	700	418	1730	780	522	534	554	318	15702	154.40%

Sample size (n) =	21
Average actual demand ( $\mu$ ) =	484.29

**Repeater: Charisma Black (CB)**

Analysis Days	17-Feb	18-Feb	19-Feb	20-Feb	21-Feb	24-Feb	25-Feb	26-Feb	27-Feb	28-Feb	03-Mar	04-Mar	05-Mar	06-Mar	07-Mar	10-Mar	11-Mar	12-Mar	13-Mar	14-Mar	17-Mar	Sum	Demand MAD
OEM demand	36	30	26	31	44	56	81	68	50	42	38	42	51	60	38	7	10	5	2	3	5	725	
1st tier supplier demand	36	30	26	31	44	56	81	68	50	42	38	42	51	60	38	7	10	5	2	3	5	725	
OEM - 1st tier supplier	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2nd tier supplier demand	56	56	56	56	112	56	56	56	56	56	56	56	0	56	56	56	0	0	56	56	0	1008	
OEM - 2nd tier supplier	20	26	30	25	68	0	25	12	6	14	18	14	51	4	18	49	10	5	54	53	5	507	69.93%
3rd tier supplier demand	181	0	0	0	0	181	0	0	0	0	181	0	0	0	0	181	0	0	0	0	0	724	
OEM - 3rd tier supplier	145	30	26	31	44	125	81	68	50	42	143	42	51	60	38	174	10	5	2	3	5	1175	162.07%

Sample size (n) =	21
Average actual demand ( $\mu$ ) =	34.52

**Stranger: Generic Spice (GS)**

Analysis Days	17-Feb	18-Feb	19-Feb	20-Feb	21-Feb	24-Feb	25-Feb	26-Feb	27-Feb	28-Feb	03-Mar	04-Mar	05-Mar	06-Mar	07-Mar	10-Mar	11-Mar	12-Mar	13-Mar	14-Mar	17-Mar	Sum	Demand MAD
OEM demand	3	10	10	4	8	7	9	5	10	0	3	3	6	8	9	4	4	0	0	0	1	104	
1st tier supplier demand	3	10	10	4	8	7	9	5	10	0	3	3	6	8	9	4	4	0	0	0	1	104	
OEM - 1st tier supplier	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2nd tier supplier demand	0	0	0	0	0	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56	168	
OEM - 2nd tier supplier	3	10	10	4	8	105	9	5	10	0	3	3	6	8	9	4	4	0	0	0	55	256	246.15%
3rd tier supplier demand	27	0	0	0	0	27	0	0	0	0	27	0	0	0	0	27	0	0	0	0	0	108	
OEM - 3rd tier supplier	24	10	10	4	8	20	9	5	10	0	24	3	6	8	9	23	4	0	0	0	1	178	171.15%

Sample size (n) =	21
Average actual demand ( $\mu$ ) =	4.95

Table 4.10: Demand MAD Results for SC B

#### **4.6.3.2 Bullwhip Coefficient**

Table 4.11 displays the measurement results of SC B seat module bullwhip effect using Equation 3.2 and Table M.2 (in Appendix M).

A *Bullwhip Coefficient* of 4.52 indicates that the original demand, i.e. the OEM's demand, have been amplified by the factor of 4.52 when the demand reaches the 3<sup>rd</sup> tier supplier. The *bullwhip coefficient* of 1 indicates that there is no demand amplification between the vehicle manufacturer and the seat module manufacturer. The *bullwhip coefficient* of 2.05 indicates that there is demand amplification from the seat module manufacturer to the headrest manufacturer. The *bullwhip coefficient* of 5.01 indicates that there is also demand amplification from the headrest manufacturer and the headrest foam supplier.



**SC B Bullwhip Coefficient**

OEM - 3rd tier supplier =	4.52
OEM - 1st tier supplier =	1.00
1st tier supplier - 2nd tier supplier =	2.05
2nd tier supplier - 3rd tier supplier =	5.01

**Runner: Kimono White (KW)**

Analysis Days	17-Feb	18-Feb	19-Feb	20-Feb	21-Feb	24-Feb	25-Feb	26-Feb	27-Feb	28-Feb	03-Mar	04-Mar	05-Mar	06-Mar	07-Mar	10-Mar	11-Mar	12-Mar	13-Mar	14-Mar	17-Mar	$\sigma$	$\mu$	$\sigma/\mu$	B.C.
OEM demand	504	534	578	572	574	244	298	348	366	318	416	510	612	700	418	470	780	522	534	554	318	137.23	484.29	0.28	
1st tier supplier demand	504	534	578	572	574	244	298	348	366	318	416	510	612	700	418	470	780	522	534	554	318	137.23	484.29	0.28	1.00
2nd tier supplier demand	504	504	504	504	504	280	336	336	280	448	448	448	448	448	504	560	504	560	560	560	336	90.79	456.00	0.20	0.70
3rd tier supplier demand	2200	0	0	0	0	2200	0	0	0	0	2200	0	0	0	0	2200	0	0	0	0	0	885.22	419.05	2.11	10.61

 $\mu$  = Average actual demand $\sigma$  = demand standard deviation

OEM - 3rd Tier Bullwhip Coefficient = 7.45

**Repeater: Charisma Black (CB)**

Analysis Days	17-Feb	18-Feb	19-Feb	20-Feb	21-Feb	24-Feb	25-Feb	26-Feb	27-Feb	28-Feb	03-Mar	04-Mar	05-Mar	06-Mar	07-Mar	10-Mar	11-Mar	12-Mar	13-Mar	14-Mar	17-Mar	$\sigma$	$\mu$	$\sigma/\mu$	B.C.
OEM demand	36	30	26	31	44	56	81	68	50	42	38	42	51	60	38	7	10	5	2	3	5	22.79	34.52	0.66	
1st tier supplier demand	36	30	26	31	44	56	81	68	50	42	38	42	51	60	38	7	10	5	2	3	5	22.79	34.52	0.66	1.00
2nd tier supplier demand	56	56	56	56	112	56	56	56	56	56	56	56	0	56	56	56	0	0	56	56	0	26.77	48.00	0.56	0.84
3rd tier supplier demand	181	0	0	0	0	181	0	0	0	0	181	0	0	0	0	181	0	0	0	0	0	72.83	34.48	2.11	3.79

 $\mu$  = Average actual demand $\sigma$  = demand standard deviation

OEM - 3rd Tier Bullwhip Coefficient = 3.20

**Stranger: Generic Spice (GS)**

Analysis Days	17-Feb	18-Feb	19-Feb	20-Feb	21-Feb	24-Feb	25-Feb	26-Feb	27-Feb	28-Feb	03-Mar	04-Mar	05-Mar	06-Mar	07-Mar	10-Mar	11-Mar	12-Mar	13-Mar	14-Mar	17-Mar	$\sigma$	$\mu$	$\sigma/\mu$	B.C.
OEM demand	3	10	10	4	8	7	9	5	10	0	3	3	6	8	9	4	4	0	0	0	1	3.61	4.95	0.73	
1st tier supplier demand	3	10	10	4	8	7	9	5	10	0	3	3	6	8	9	4	4	0	0	0	1	3.61	4.95	0.73	1.00
2nd tier supplier demand	0	0	0	0	0	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56	26.77	8.00	3.35	4.59
3rd tier supplier demand	27	0	0	0	0	27	0	0	0	0	27	0	0	0	0	27	0	0	0	0	0	10.86	5.14	2.11	0.63

 $\mu$  = Average actual demand $\sigma$  = demand standard deviation

OEM - 3rd Tier Bullwhip Coefficient = 2.90

Table 4.11: Bullwhip Coefficient Results for SC B



**4.6.3.3 Inventory Level**

Table 4.12 is the inventory measurement results of SC B seat module using Equation 3.3 and Table M.3 (in Appendix M). The average inventory level for this SC is 30.07 days worth of inventory, by taking the average of inventory levels from the three samples (Runner: 7.51, Repeater: 14.88, Stranger: 67.84). The average inventory levels of RM and FG inventories within each supply chain level are also listed in the tables. The three limitations stated in Section 4.5.3.3 are also applicable in this case study.

**SC B Inventory Level**

Avrg SC Inventory Level =	30.07 days of stock
Avrg OEM RM inv level =	0.00 days of stock
Avrg 1st tier FG inv level =	0.00 days of stock
Avrg 1st tier RM inv level =	19.14 days of stock
Avrg 2nd tier FG inv level =	2.03 days of stock
Avrg 2nd tier RM inv level =	6.91 days of stock
Avrg 3rd tier FG inv level =	2.00 days of stock

**Runner: Kimono White (KW)**

Analysis Days	17-Feb	18-Feb	19-Feb	20-Feb	21-Feb	24-Feb	25-Feb	26-Feb	27-Feb	28-Feb	03-Mar	04-Mar	05-Mar	06-Mar	07-Mar	10-Mar	11-Mar	12-Mar	13-Mar	14-Mar	17-Mar	Σ	Inv Level in days
OEM daily usage	504	534	578	572	574	244	298	348	366	318	416	510	612	700	418	470	780	522	534	554	318	10170	
OEM RM stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier FG stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier RM stock level	1298	1268	1194	1126	1056	1092	1130	1118	1032	1162	1194	1132	968	716	802	892	616	654	676	678	692	20496	2.02
2nd tier FG stock level	500	500	500	500	500	276	332	332	276	444	444	444	444	444	500	556	500	556	556	556	332	9492	0.93
2nd tier RM stock level	400	2096	1592	1088	584	304	2168	1832	1552	1104	656	2408	1960	1512	1008	448	2144	1584	1024	464	128	26056	2.56
3rd tier FG stock level	Data not available																				N/A	2.00	
																					56044	7.51	

**Repeater: Charisma Black (CB)**

Analysis Days	17-Feb	18-Feb	19-Feb	20-Feb	21-Feb	24-Feb	25-Feb	26-Feb	27-Feb	28-Feb	03-Mar	04-Mar	05-Mar	06-Mar	07-Mar	10-Mar	11-Mar	12-Mar	13-Mar	14-Mar	17-Mar	Σ	Inv Level in days
OEM daily usage	36	30	26	31	44	56	81	68	50	42	38	42	51	60	38	7	10	5	2	3	5	725	
OEM RM stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier FG stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier RM stock level	63	89	119	144	212	212	187	175	181	195	213	227	176	172	190	239	229	224	278	331	326	4182	5.77
2nd tier FG stock level	56	56	56	56	112	56	56	56	56	56	56	112	56	168	112	168	112	112	112	56	0	1680	2.32
2nd tier RM stock level	425	369	313	201	145	270	214	158	102	46	171	171	115	59	3	184	184	128	72	72	72	3474	4.79
3rd tier FG stock level	Data not available																				N/A	2.00	
																						9336	14.88

**Stranger: Generic Spice (GS)**

Analysis Days	17-Feb	18-Feb	19-Feb	20-Feb	21-Feb	24-Feb	25-Feb	26-Feb	27-Feb	28-Feb	03-Mar	04-Mar	05-Mar	06-Mar	07-Mar	10-Mar	11-Mar	12-Mar	13-Mar	14-Mar	17-Mar	Σ	Inv Level in days
OEM daily usage	3	10	10	4	8	7	9	5	10	0	3	3	6	8	9	4	4	0	0	0	1	104	
OEM RM stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier FG stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier RM stock level	222	212	202	198	190	295	286	281	271	271	268	265	259	251	242	238	234	230	230	230	286	5161	49.63
2nd tier FG stock level	6	6	6	6	118	6	6	6	6	6	6	6	6	6	6	6	6	6	6	62	6	294	2.83
2nd tier RM stock level	90	117	117	117	117	5	32	32	32	32	32	59	59	59	59	59	86	86	86	86	30	1392	13.38
3rd tier FG stock level	Data not available																				N/A	2.00	
																						6847	67.84

Table 4.12: Inventory Level Results for SC B



#### 4.6.3.4 Dock-to-Dock Time

Table 4.13 shows that the *Dock-to-Dock Time* for this SC is 661.29 hours. Only 0.70% of these 661.229 working hours, which is 4.60 hours, are value-adding activities. Other limitations and details are the same as described in SC A.

<b>SC B Dock-to-Dock Time</b>			
SC D2D Time (in working hours) = 661.29			
Value Adding Time (in working hours) = 4.60			
Value Adding Ratio (vs SC D2D Time) = 0.70%			
Process	Time (hours)		
	Runner	Repeater	Stranger
	Kimono White (KW)	Charisma Black (CB)	Generic Spice (GS)
Transit from 1st Tier to OEM	0.20	0.20	0.20
1st Tier FG Buffer	0.00	0.00	0.00
1st Tier Process Time	0.60	0.60	0.60
1st Tier RM Buffer	48.37	138.44	1191.00
Transit from 2nd Tier to 1st Tier	0.20	0.20	0.20
2nd Tier FG Buffer	14.93	37.08	45.23
2nd Tier Process Time	1.50	1.50	1.50
2nd Tier RM Buffer	40.99	76.67	214.15
Transit from 3rd Tier to 2nd Tier	6.00	6.00	6.00
3rd Tier FG Buffer	48.00	48.00	48.00
3rd Tier Process Time	2.50	2.50	2.50
<b>Total</b>	<b>163.29</b>	<b>311.18</b>	<b>1509.38</b>

Table 4.13: Dock-to-Dock Time Results for SC B

#### 4.6.3.5 Stockout and Backorder Level

The *Stockout level* was measured using Equation 3.4 and the *Backorder level* was measured using Equation 3.5, both using Table M.5 (in Appendix M). However, in this case study, there is no stockout incident throughout the SC during the case study period, thus the stockout level and backorder level are both zero.

**4.6.3.6 Transportation Cost**

The *transportation cost* was measured using Equation 3.6 and 3.7 as shown in Table M.6 (in Appendix M). The breakdown of transportation cost is shown in Table 4.14. The rates for each delivery, which is the *Cost Per Delivery*, are estimated costs provided by the companies.

<b>SC B Transportation Cost</b>						
SC Transportation Cost (Per Unit) =				£1.44		
SC Transportation Cost (Per Month) =				£34,828.18		
				(T <sub>u</sub> )		
				(T <sub>m</sub> )		
SC Level	Distance (miles)	Cost Per Delivery	Delivery Batch Size	Cost per Unit	Delivery Per Month *	Delivery Cost Per Month
1st Tier - OEM *	0.31	£663.39	1,000	£0.66	20	£13,267.88
2nd Tier - 1st Tier	0.16	£189.73	56	£3.39	100	£18,973.07
3rd Tier - 2nd Tier	235.50	£129.36	500	£0.26	20	£2,587.24
Euro		GBP	Exchange rate (Feb 03) = 1.5074			
€ 1,000		£663.39				
€ 286		£189.73	* Continuous supply flow by conveyor belt system			
€ 195		£129.36	* Assumption of 20 working days per month			

**Table 4.14: Transportation Cost for SC B**

The *Average SC Transportation Cost* for this supply chain is £1.44 per unit based on the average *Cost Per Unit* and £34,828 per month based on the sum of *Delivery Cost Per Month*. The *Cost Per Unit* is obtained by dividing the *Cost Per Delivery* with the *Delivery Batch Size* (i.e. number of unit in each delivery). The *Delivery Cost Per Month* is calculated by multiplying the *Cost Per Delivery* by *Delivery Per Month*.

Due to the location of the supply chain, the *Cost Per Delivery* was converted from Euros into British Pound Sterling according to the average exchange rate in February 2003, which is the data period. The exchange rate and the converted values are also shown in the table.

The delivery from the 1<sup>st</sup> tier supplier to the OEM is via a continuous conveyor system. Therefore, the *Cost Per Delivery* between these two supply chain levels is based on the daily operating cost of the conveyor system and the *Delivery Per Month* is assumed to be one delivery per day.

#### **4.6.3.7 Inventory Carrying Cost**

The *inventory carrying cost* is measured using Equation 3.8, 3.9, 3.10, 3.11 and 3.12 in Table M.7 (in Appendix M). The annual rate for the four cost centres was an estimated rate based on the average of annual rates used by each SC members and validated by the SC members. The measurement results can be found in Table 4.15. The average of the *Total Inventory Carrying Cost* from the three samples provided the *Average SC Inventory Carrying Cost Per Month*, which is £49.63. In order to be able to compare the cost performance between the case studies, the summary table also shows the *Average SC Inventory Carrying Cost Per Unit*, which is £0.0019 for this case study. Again, due to the location of the supply chain, the *Cost Per Unit* was converted from Euros into British Pounds according to the average exchange rate in February 2003, which is the data period. The exchange rate and the converted values are also shown in the table.



SC B Inventory Carrying Cost					
SC Inventory Carrying Cost Per Month = £49.63					
SC Inventory Carrying Cost Per Unit = £0.0019					
			Inventory Carrying Cost		
Cost Centre:	% of Inventory Value		Runner Kimono White (KW)	Repeater Charisma Black (CB)	Stranger Generic Spice (GS)
Interest on capital cost	9.00%	per year	£38.72	£5.51	£3.64
Storage	3.00%	per year	£12.91	£1.84	£1.21
Obsolescence and depreciation	6.00%	per year	£25.81	£3.67	£2.43
Opportunity cost	10.00%	per year	£43.02	£6.12	£4.04
Total Inventory Carrying Cost Per Month =			£120.45	£17.13	£11.32
Inventory Qty Per Month =			56,044	9,336	6,847
Inventory Carrying Cost Per Unit =			£0.00	£0.00	£0.00
Inventory Type	Runner: Kimono White (KW)			Inventory Value	
	Inventory Level	Avrg Daily Volume	Cost Per Unit		
OEM RM stock level	0.00	484.29	£36.70	£0.00	
1st tier FG stock level	0.00		£36.70	£0.00	
1st tier RM stock level	2.02		£1.46	£1,424.44	
2nd tier FG stock level	0.93		£1.46	£659.68	
2nd tier RM stock level	2.56		£1.39	£1,728.54	
3rd tier FG stock level	2.00		£1.39	£1,349.34	
	7.51		Total Inventory Value =	£5,162.00	
Inventory Type	Repeater: Charisma Black (CB)			Inventory Value	
	Inventory Level	Avrg Daily Volume	Cost Per Unit		
OEM RM stock level	0.00	34.52	£36.70	£0.00	
1st tier FG stock level	0.00		£36.70	£0.00	
1st tier RM stock level	5.77		£1.46	£290.64	
2nd tier FG stock level	2.32		£1.46	£116.76	
2nd tier RM stock level	4.79		£1.39	£230.46	
3rd tier FG stock level	2.00		£1.39	£96.19	
	14.88		Total Inventory Value =	£734.05	
Inventory Type	Stranger: Generic Spice (GS)			Inventory Value	
	Inventory Level	Avrg Daily Volume	Cost Per Unit		
OEM RM stock level	0.00	4.95	£36.70	£0.00	
1st tier FG stock level	0.00		£36.70	£0.00	
1st tier RM stock level	49.63		£1.46	£358.68	
2nd tier FG stock level	2.83		£1.46	£20.43	
2nd tier RM stock level	13.38		£1.39	£92.34	
3rd tier FG stock level	2.00		£1.39	£13.80	
	67.84		Total Inventory Value =	£485.26	
Xchange rate (Feb 03) =		1.5074			
Euro		GBP			
€ 55.32		£36.70			
€ 2.20		£1.46			
€ 2.10		£1.39			

Table 4.15: Inventory Carrying Cost for SC B

Initially, the case study was to incorporate four 'SC' levels - the vehicle manufacturer (the OEM), the seat manufacturer (2<sup>nd</sup> tier supplier), the headrest manufacturer (2<sup>nd</sup> tier supplier) and the headrest webbing manufacturer (3<sup>rd</sup> tier supplier). All of them are located within the UK, except the 3<sup>rd</sup> tier supplier, which is located in the Far East (Shanghai). Unfortunately, due to the pandemic, this 3<sup>rd</sup> tier supplier could not take part in this study. As shown in Figure 4.7, it is a conventional one-to-one interaction between consecutive SC levels for both information and material flow.

**4.7 Case Study 3 – SC C**

**4.7.1 Background Information**

This case study was started in August 2003. It is a high volume and low customisation vehicle manufacturer. Its daily production volume is about 1250 vehicles. There are two production lines within the OEM assembly plant and they build three different models. Only one of the car models is selected as the research subject. For this model, there are only three seat options with only one colour available (grey): comfort, sport and elegance.

For this case study, only two seat modules were chosen as shown in Table 4.16. This is because both Comfort and Elegance are runners.

Seat Modules	Typical Daily Demand
Comfort	207 (Runner)
Sport	41 (Stranger)

Table 4.16: SC C Case Study Seat Modules

Initially, the case study was to incorporate four SC levels – the vehicle manufacturer (the OEM), the seat manufacturer (1<sup>st</sup> tier supplier), the headrest manufacturer (2<sup>nd</sup> tier supplier) and the headrest fabric manufacturer (3<sup>rd</sup> tier supplier). All of them are located within the UK except the 3<sup>rd</sup> tier supplier, which is located in the Far East (Shanghai). Unfortunately, due to the distance, this 3<sup>rd</sup> tier supplier could not take part in this study. As shown in Figure 4.7, it is a conventional one-to-one interaction between consecutive SC levels for both information and material flow.

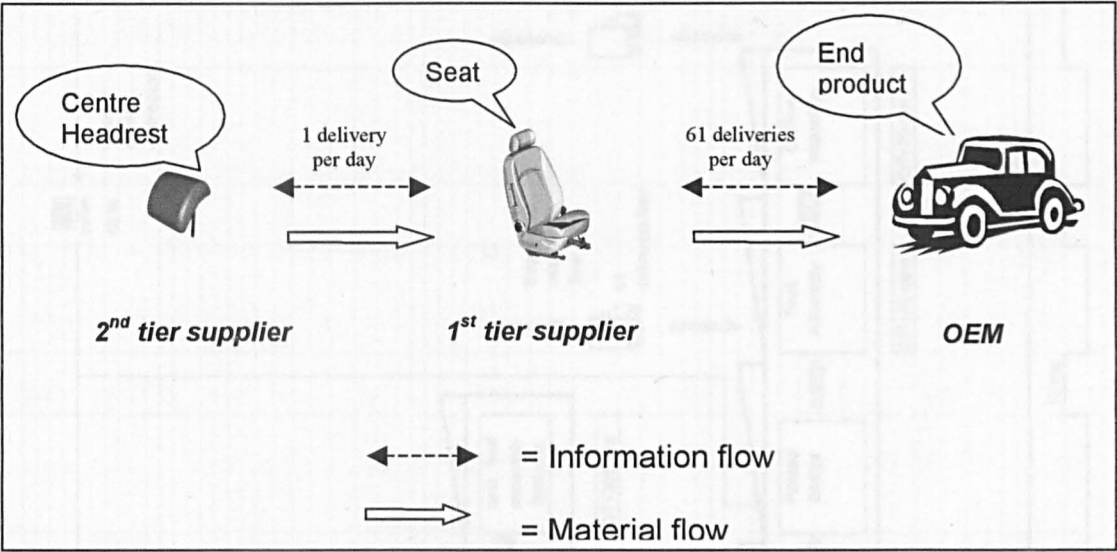


Figure 4.7: SC C Seat Module Supply Chain

A more detailed graphical illustration of this supply chain is shown in Figure 4.8 using value stream mapping. It shows the process to produce seat modules, from the supply of headrests to the complete seat module fitted on the vehicle. The description of symbols and abbreviations used in the value stream map are as described in Section 4.5.1.



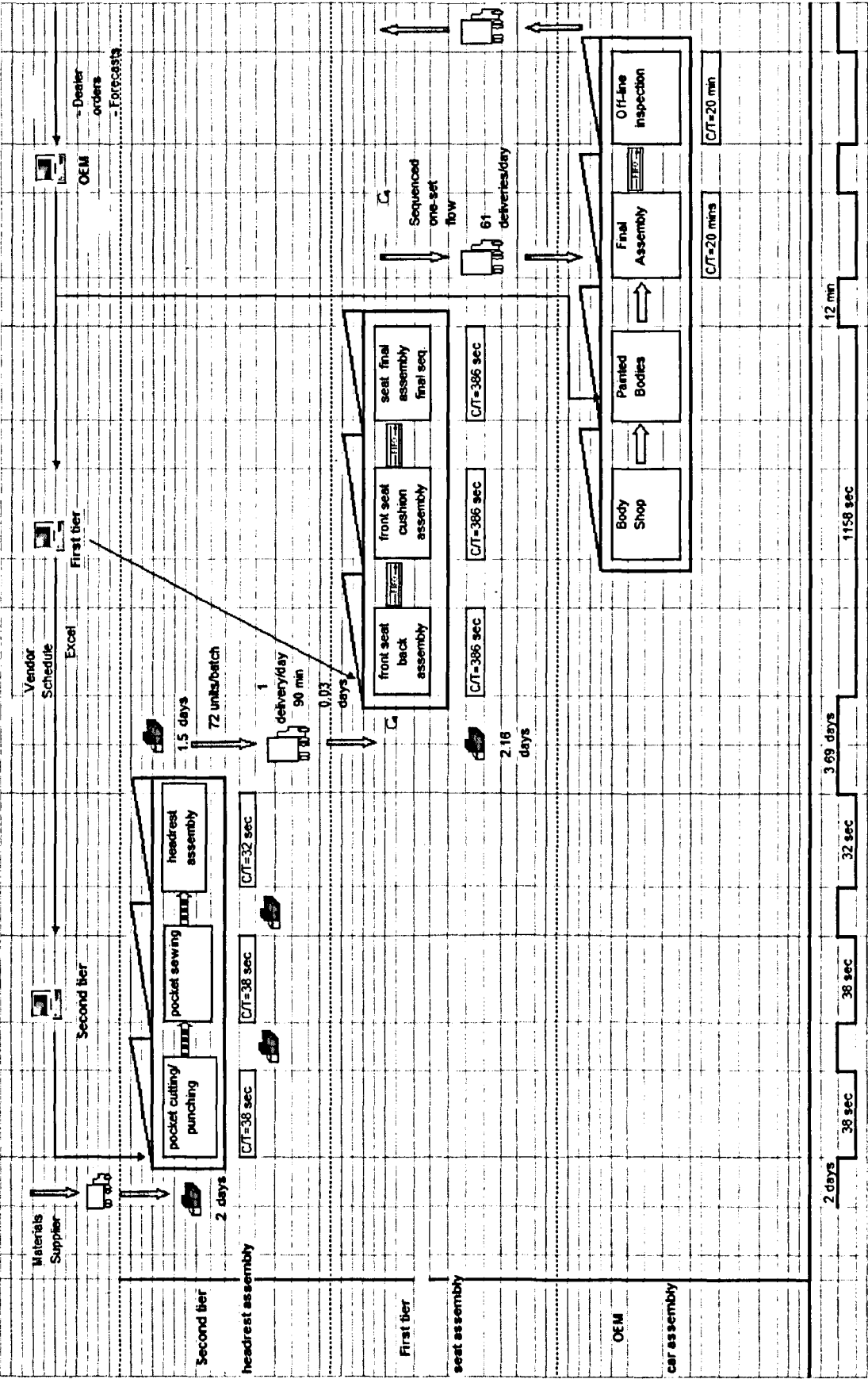


Figure 4.8: SC C Value Stream Map

### **4.7.2 Supply Chain Information Sharing System**

In this SC, the vehicle manufacturer operates two types of supply mechanism with its 1<sup>st</sup> tier suppliers - sequenced supply (i.e. the SILS) and non-sequenced supply. Sequenced supply is applied to all core materials with high variety and high consumption rate (such as seat modules, instrument panel), while the other components are handled with a traditional reorder point system (such as nuts and bolts, glue).

The synchronous supply system is activated when a painted body passes the start of the trim line at the vehicle assembly plant. An electronic message, similar to the TLS in the previous two case studies, is relayed to suppliers detailing the seating requirements for the particular model to be produced during that shift. This information is the “live” version of that day’s production. The supplier has a time window of around three hours to build, assemble and deliver the seat modules. Each order received by the supplier details the car identification number, whether the seats are for left or right-hand drive vehicles, the type and colour of material to be used and whether the seats require height adjusters, heaters, lumbar support or airbags. The flow of information observed in this SC is depicted in Figure 4.9.

A very special feature in this SC is that the OEM “freezes” its production schedule of the last six days. This means that no changes are allowed to be made on the jobs within the next six days production schedule. This eliminates most of the last minutes changes and maintains the production schedule stability.

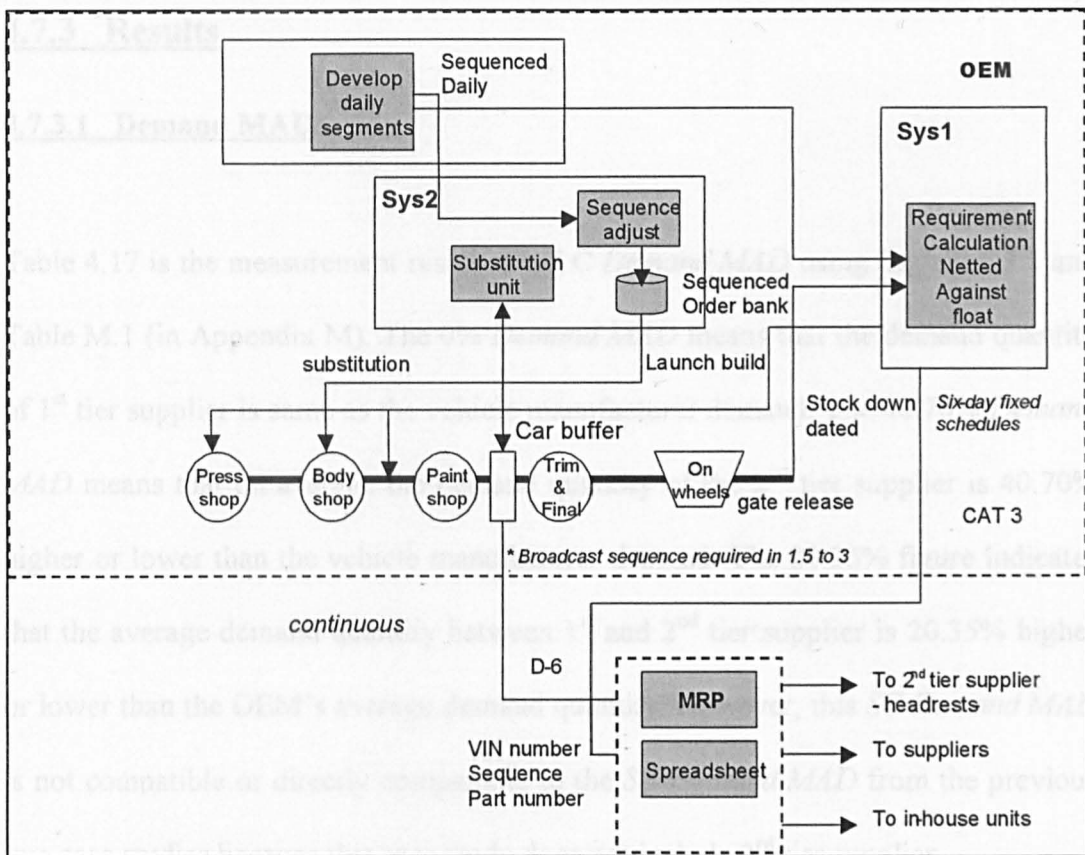


Figure 4.9: The SILS Information Flows in SC C

The “six days frozen schedule” is included in the CAT-3 files (shown in Appendix F), which are sent to all 1<sup>st</sup> tier suppliers on daily basis via URL. Each day the file provides the demand information for at least 12 days horizon, plus the coming weeks and months. The seat manufacturer uses this information to run its own internal material management system. Then it generates a spreadsheet that contains its demand requirements for the following weeks and months, and sent to its suppliers (i.e. 2<sup>nd</sup> tier supplier) via email (Lyons *et al.*, 2005).

Alongside CAT-3, the OEM also release a daily demand forecast called WRA (shown in Appendix G) to all 1<sup>st</sup> tier suppliers, which is a demand forecasts for the next three weeks.

### **4.7.3 Results**

#### **4.7.3.1 Demand MAD**

Table 4.17 is the measurement result of SC C *Demand MAD* using Equation 3.1 and Table M.1 (in Appendix M). The 0% *Demand MAD* means that the demand quantity of 1<sup>st</sup> tier supplier is same as the vehicle manufacturer demand. The 40.70% *Demand MAD* means that on average the demand quantity of the 2<sup>nd</sup> tier supplier is 40.70% higher or lower than the vehicle manufacturer demand. The 20.35% figure indicates that the average demand quantity between 1<sup>st</sup> and 2<sup>nd</sup> tier supplier is 20.35% higher or lower than the OEM's average demand quantity. However, this *SC Demand MAD* is not compatible or directly comparable to the *SC Demand MAD* from the previous two case studies because this case study does not include 3<sup>rd</sup> tier supplier.

**SC C Demand MAD**

SC Demand MAD = 20.35%

OEM - 1st tier supplier = 0.00%

OEM - 2nd tier supplier = 40.70%

OEM - 3rd tier supplier = N/A

**Runner: Comfort**

Analysis Days	18-Aug	19-Aug	20-Aug	21-Aug	22-Aug	25-Aug	26-Aug	27-Aug	28-Aug	29-Aug	30-Aug	01-Sep	02-Sep	03-Sep	04-Sep	05-Sep	06-Sep	08-Sep	09-Sep	10-Sep	11-Sep	12-Sep	13-Sep	Sum	Demand MAD
OEM demand	350	304	292	316	274	0	260	306	274	314	0	212	190	194	210	245	0	200	200	196	196	244	0	4778	
1st tier supplier demand	350	304	292	316	274	0	260	306	274	314	0	212	190	194	210	245	0	200	200	196	196	244	0	4778	
OEM - 1st tier supplier	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2nd tier supplier demand	360	288	288	288	216	0	288	288	360	216	0	216	216	216	216	216	0	144	216	216	216	216	0	4680	
OEM - 2nd tier supplier	10	16	4	28	58	0	28	18	86	98	0	4	26	22	6	30	0	56	16	20	20	28	0	574	12.01%

Sample size (n) = 23

Average actual demand ( $\mu$ ) = 207.74**Stranger: Sport**

Analysis Days	18-Aug	19-Aug	20-Aug	21-Aug	22-Aug	25-Aug	26-Aug	27-Aug	28-Aug	29-Aug	30-Aug	01-Sep	02-Sep	03-Sep	04-Sep	05-Sep	06-Sep	08-Sep	09-Sep	10-Sep	11-Sep	12-Sep	13-Sep	Sum	Demand MAD
OEM demand	58	46	70	66	54	0	56	54	50	68	0	46	54	40	60	46	0	38	30	38	38	42	0	954	
1st tier supplier demand	58	46	70	66	54	0	56	54	50	68	0	46	54	40	60	46	0	38	30	38	38	42	0	954	
OEM - 1st tier supplier	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%
2nd tier supplier demand	72	72	72	72	0	0	72	0	144	0	0	72	72	72	72	0	0	0	72	0	72	0	0	936	
OEM - 2nd tier supplier	14	26	2	6	54	0	16	54	94	68	0	26	18	32	12	46	0	38	42	38	34	42	0	662	69.39%

Sample size (n) = 23

Average actual demand ( $\mu$ ) = 41.48

Table 4.17: Demand MAD Results for SC C

#### **4.7.3.2 Bullwhip Coefficient**

Table 4.18 displays the measurement results of SC C seat module bullwhip effect using Equation 3.2 and Table M.2 (in Appendix M). 1.49 in *Bullwhip Coefficient* means that the original demand, i.e. the OEM's demand, has been amplified by the factor of 1.49 when the demand reaches the 2<sup>nd</sup> tier supplier. The *bullwhip coefficient* of 1 means that there is no demand amplification between the OEM's demand and the 1<sup>st</sup> tier supplier. The *bullwhip coefficient* of 1.49 means that the 1<sup>st</sup> tier supplier demand has been amplified by the factor of 1.49 when the demand reaches the 2<sup>nd</sup> tier supplier.



Table 4.18: Bullwhip Coefficient Results for SC C

SC C Bullwhip Coefficient

OEM - 2nd tier tier supplier =1.49

OEM - 1st tier supplier =1.00

1st tier supplier - 2nd tier supplier =1.49

Runner: Comfort

Analysis Days	18-Aug	19-Aug	20-Aug	21-Aug	22-Aug	25-Aug	26-Aug	27-Aug	28-Aug	29-Aug	30-Aug	01-Sep	02-Sep	03-Sep	04-Sep	05-Sep	06-Sep	08-Sep	09-Sep	10-Sep	11-Sep	12-Sep	13-Sep	$\sigma$	$\mu$	$\sigma/\mu$	B.C.
OEM demand	350	304	292	316	274	0	260	306	274	314	0	212	190	194	210	245	0	200	200	196	196	244	0	108.10	207.74	0.52	
1st tier supplier demand	350	304	292	316	274	0	260	306	274	314	0	212	190	194	210	245	0	200	200	196	196	244	0	108.10	207.74	0.52	1.00
2nd tier supplier demand	360	288	288	288	216	0	288	288	360	216	0	216	216	216	216	216	0	144	216	216	216	216	0	107.79	203.48	0.53	1.02

$\mu$  = Average actual demand

$\sigma$  = demand standard deviation

OEM - 2nd Tier Bullwhip Coefficient =1.02

Stranger: Sport

Analysis Days	18-Aug	19-Aug	20-Aug	21-Aug	22-Aug	25-Aug	26-Aug	27-Aug	28-Aug	29-Aug	30-Aug	01-Sep	02-Sep	03-Sep	04-Sep	05-Sep	06-Sep	08-Sep	09-Sep	10-Sep	11-Sep	12-Sep	13-Sep	$\sigma$	$\mu$	$\sigma/\mu$	B.C.	
OEM demand	58	46	70	66	54	0	56	54	50	68	0	46	54	40	60	46	0	38	30	38	38	42	0	21.95	41.48	0.53		
1st tier supplier demand	58	46	70	66	54	0	56	54	50	68	0	46	54	40	60	46	0	38	30	38	38	42	0	21.95	41.48	0.53	1.00	
2nd tier supplier demand	72	72	72	72	0	0	72	0	144	0	0	72	72	72	72	0	0	0	72	0	72	0	0	0	42.46	40.70	1.04	1.97

$\mu$  = Average actual demand

$\sigma$  = demand standard deviation

OEM - 2nd Tier Bullwhip Coefficient =1.97

**4.7.3.3 Inventory Level**

Table 4.19 is the inventory measurement results of SC C seat module using Equation 3.3 and Table M.3 (in Appendix M). The average inventory level for this SC is 5.49 days worth of inventory, by taking the average of the inventory level from the runner and stranger samples (Runner: 5.03, Stranger: 5.95). The *Average SC Inventory Level* is not comparable to the previous two case studies because it does not include the 3<sup>rd</sup> tier FG inventory level. The average inventory levels of RM and FG inventories within each supply chain level are also listed in the tables. The three limitations stated in Section 4.5.3.3 are also applicable in this case study.



**SC C Inventory Level**

Avrg SC inv level =	5.49 days of stock
Avrg OEM RM inv level =	0.00 days of stock
Avrg 1st tier FG inv level =	0.00 days of stock
Avrg 1st tier RM inv level =	1.99 days of stock
Avrg 2nd tier FG inv level =	1.50 days of stock
Avrg 2nd tier RM inv level =	2.00 days of stock

**Runner: Comfort**

Analysis Days	08-Jan	04-Jan	28-Jan	20-Jan	08-Jan	00-Jan	08-Jan	18-Jan	14-Jan	02-Mar	24-Mar	02-Jan	10-Jan	04-Jan	18-Jan	25-Feb	02-Mar	12-Jan	00-Jan	02-Jan	02-Jan	25-Feb	27-Feb	Σ	Inv Level in days
OEM daily usage	360	288	288	288	216	0	288	288	360	216	0	216	216	216	216	216	0	144	216	216	216	216	0	4580	
OEM RM stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier FG stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier RM stock level	409	389	357	349	283	268	288	288	360	324	240	271	287	313	337	363	301	254	270	288	306	334	276	7155	1.53
2nd tier FG stock level	Data Not Available																							N/A	1.50
2nd tier RM stock level	Data Not Available																							N/A	2.00
																								7155.00	5.03

**Stranger: Sport**

Analysis Days	00-Jan	02-Jan	12-Jan	00-Jan	12-Jan	00-Jan	00-Jan	02-Jan	06-Jan	10-Jan	12-Jan	02-Jan	00-Jan	04-Jan	10-Jan	14-Jan	08-Jan	02-Jan	00-Jan	02-Jan	00-Jan	04-Jan	08-Jan	Σ	Inv Level in days
OEM daily usage	72	72	72	72	0	0	72	0	144	0	0	72	72	72	72	0	0	0	72	0	72	0	0	936	
OEM RM stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier FG stock level	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
1st tier RM stock level	104	132	146	152	86	69	85	29	129	71	59	89	107	143	145	113	105	74	116	80	114	76	68	2292	2.45
2nd tier FG stock level	Data Not Available																							N/A	1.50
2nd tier RM stock level	Data Not Available																							N/A	2.00
																								2292.00	5.95

\* OEM's FG inventory level are not included

\* There is no FG inventory in 1st tier due to the sequenced supply operations

Table 4.19: Inventory Level Results for SCC



4.7.3.4 Dock-to-Dock Time

Table 4.20 shows that the *Dock-to-Dock Time* for this SC is 7.81 hours. About 7.95% of the *Dock-to-Dock Time*, which is 0.62 hours, is value-adding activities. Other limitations and details are the same as described in SC A. However, the *SC Dock-to-Dock Time* from this case study is not comparable to the previous two case studies because it does not include the 3<sup>rd</sup> tier supplier.

SC C Dock-to-Dock Time		
SC D2D Time (in working hours) = 7.81		
Value Adding Time (in working hours) = 0.62		
Value Adding Ratio (vs SC D2D Time) = 7.95%		
Process	Time (hours)	
	Runner Comfort	Stranger Sport
Transit from 1st Tier to OEM	0.20	0.20
1st Tier FG Buffer	0.00	0.00
1st Tier Process Time	0.32	0.32
1st Tier RM Buffer	1.53	2.45
Transit from 2nd Tier to 1st Tier	1.50	1.50
2nd Tier FG Buffer	1.50	1.50
2nd Tier Process Time	0.30	0.30
2nd Tier RM Buffer	2.00	2.00
Total (in hours)	7.35	8.27

Table 4.20 Dock-to-Dock Time Results for SC C

4.7.3.5 Stockout and Backorder Level

The *Stockout level* was measured using Equation 3.4 and the *Backorder level* was measured using Equation 3.5, both using Table M.5 (in Appendix M). However, in this case study, there is no stockout incident throughout the SC during the case study period, thus the stockout level and backorder level are both zero.

4.7.3.6 Transportation Cost

The *transportation cost* was measured using Equation 3.6 and 3.7 as shown in Table M.6 (in Appendix M). The breakdown of transportation cost is shown in Table 4.21. The *Cost Per Delivery* is provided by the Road Haulage Association in the UK based on the travel distance, weight and volume.

SC C Transportation Cost						
SC Transportation Cost (Per Unit) =				£0.99		
SC Transportation Cost (Per Month) =				£2,486.96		
SC Level	Distance (miles)	Cost Per Delivery *	Delivery Batch Size	Cost per Unit (T <sub>u</sub> )	Delivery Per Month *	Delivery Cost Per Month (T <sub>m</sub> )
1st Tier - OEM	1.00	£1.64	1	£1.64	1,220	£1,998.36
2nd Tier - 1st Tier	75.00	£24.43	72	£0.34	20	£488.60
* The cost per trip it based on the rates provided by Road Haulage Association						
* Assumption of 20 working days per month						

Table 4.21: Transportation Cost for SC C

The *Average SC Transportation Cost* for this SC is £0.99 per unit based on the average *Cost Per Unit*, and £2,486 per month based on the sum of *Delivery Cost Per Month*. The *Cost Per Unit* is obtained by dividing the *Cost Per Delivery* with the *Delivery Batch Size* (i.e. number of unit in each delivery). The *Delivery Cost Per Month* is calculated by multiplying the *Cost Per Delivery* by *Delivery Per Month*.

4.7.3.7 Inventory Carrying Cost

The *inventory carrying cost* is measured using Equation 3.8, 3.9, 3.10, 3.11 and 3.12 in Table M.7 (in Appendix M). The annual rate for the four cost centres was an estimated rate based on the average of annual rates used by each SC members and



validated by the SC members. The measurement results can be found in Table 4.22. The average of the *Total Inventory Carrying Cost* from the three samples provides the *Average SC Inventory Carrying Cost Per Month*, which is £52.64. In order to be able to compare the cost performance between the case studies, the summary table also shows the *Average SC Inventory Carrying Cost Per Unit*, which is £0.01.

SC C Inventory Carrying Cost				
SC Inventory Carrying Cost Per Month = £52.64				
SC Inventory Carrying Cost Per Unit = £0.01				
			Inventory Carrying Cost	
			Runner Comfort	Stranger Sport
Cost Centre:	% of Inventory Value			
Interest on capital cost	9.00%	per year	£26.85	£6.99
Storage	3.00%	per year	£8.95	£2.33
Obsolescence and depreciation	6.00%	per year	£17.90	£4.66
Opportunity cost	10.00%	per year	£29.84	£7.77
Total Inventory Carrying Cost Per Month=			£83.54	£21.75
Inventory Qty Per Month =			7,155	2,292
Inventory Carrying Cost Per Unit =			£0.01	£0.01
Inventory Type	Runner: Comfort		Cost Per Unit	Inventory Value
	Inventory Level	Avrg Daily Volume		
OEM RM stock level	0.00		£85.39	£0.00
1st tier FG stock level	0.00		£85.39	£0.00
1st tier RM stock level	1.53	207.74	£5.69	£1,807.15
2nd tier FG stock level	1.50		£5.69	£1,773.05
	3.03		Total Inventory Value =	£3,580.20
Inventory Type	Stranger: Sport		Cost Per Unit	Inventory Value
	Inventory Level	Avrg Daily Volume		
OEM RM stock level	0.00		£85.39	£0.00
1st tier FG stock level	0.00		£85.39	£0.00
1st tier RM stock level	2.45	41.48	£5.69	£577.93
2nd tier FG stock level	1.50		£5.69	£354.02
	3.95		Total Inventory Value =	£931.94

Table 4.22: Inventory Carrying Cost for SC C



## 4.8 Case Study Results Summary

Table 4.23 shows the scorecard with the summary of measurement results of all the eight metrics for the case studies. The metrics are colour coded according to its measurement group:

<b>Automotive Supply Chain Measurement Scorecard</b>				
<b>Metrics</b>	<b>Level</b>	<b>SC A</b>	<b>SC B</b>	<b>SC C</b>
Demand MAD	Supply Chain	77.56%	91.04%	20.35%
	OEM - 1st tier supplier	0.00%	0.00%	0.00%
	OEM - 2nd tier supplier	118.24%	110.59%	40.70%
	OEM - 3rd tier supplier	114.45%	162.54%	N/A
BullWhip Coefficient	Supply Chain	3.96	4.52	N/A
	OEM - 1st tier supplier	1.00	1.00	1.00
	1st tier supplier - 2nd tier supplier	2.66	2.05	1.49
	2nd tier supplier - 3rd tier supplier	1.51	5.01	N/A
Inventory Level (days of stock)	Supply Chain	18.22	30.07	N/A
	OEM RM inv level	0.00	0.00	0.00
	1st tier FG inv level	0.00	0.00	0.00
	1st tier RM inv level	5.06	19.14	1.99
	2nd tier FG inv level	1.50	2.03	1.50
	2nd tier RM inv level	1.86	6.91	2.00
	3rd tier FG inv level	6.45	2.00	N/A
Dock-to-Dock Time (hours)	Supply Chain	302.47	661.29	N/A
Stockout Level	Supply Chain	0	0	0
Backorder Level	Supply Chain	0	0	0
Transportation Cost (cost per unit)	Supply Chain	£3.63	£1.44	£0.99
	1st Tier - OEM	£3.13	£0.66	£1.64
	2nd Tier - 1st Tier	£3.52	£3.39	£0.34
	3rd Tier - 2nd Tier	£4.26	£0.26	N/A
Transportation Cost (cost per month)	Supply Chain	£27,672.00	£34,828.18	N/A
Inventory Carrying Cost (cost per unit)	Supply Chain	£0.02	£0.0019	£0.01
Inventory Carrying Cost (cost per month)	Supply Chain	£114.18	£49.63	N/A

Table 4.23: Case Studies Scorecard

1. Blue: Demand Synchronisation (*Demand MAD* and *Bullwhip Coefficient*)
2. Purple: Responsiveness (*Inventory Level* and *Dock-to-Dock Time*)
3. Yellow: Reliability (*Stockout Level* and *Backorder Level*)

#### 4. Pink: Cost (*Transportation Cost and Inventory Carrying Cost*)

A detailed discussion and analysis on the scorecard results and supply chains performance can be found in the next chapter (Chapter Five: Discussion).

### **4.9 Chapter Summary**

The main purpose of this chapter was to illustrate the application of the scorecard, developed through the current research, and formulated in Chapter Three. Using this scorecard, three case studies were undertaken to assess three different automotive seat module supply chains performance. SC A and SC C are both located within the UK while SC B is in Spain. SC B and C are both high-volume, low customisation vehicle manufacturers and SC A is a mid-volume, high customisation vehicle manufacturer. The background information of these SCs was also included, especially their SC material flow, as well as their information flow. Each SC was evaluated based on four measurement groups - demand synchronisation, responsiveness, reliability and cost. There were eight metrics in total with two from each measurement group. A detailed discussion and analysis on the scorecard results and SCs performance are included in Chapter Five: Discussion.

# CHAPTER 5: DISCUSSION

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## 5.1 Introduction

The aim of this chapter is to analyse and compare supply chain (SC) performance of the case studies in Chapter Four. This is based on the measurement results presented by the scorecard developed in Chapter Three. The analysis and comparison are presented according to the four measurement groups in the scorecard.

Based on the measurement results and observations made during the case studies, the chapter moves on to discuss the SC elements and design that help to achieve optimum SC performance. Then the novel aspects and the potential applications of the scorecard is discussed and explained.

## 5.2 Performance Analysis and Comparison

### 5.2.1 Introduction

The measurement results from the case studies were put together into a summary scorecard format, as shown in Table 5.1. The table shows the measurement result at both SC level (labelled as “*Supply Chain*” in the “*Level*” column) and individual SC level or interface. The metrics are colour coded according to the measurement group:

1. Blue: Demand Synchronisation (*Demand MAD* and *Bullwhip Coefficient*)
2. Purple: Responsiveness (*Inventory Level* and *Dock-to-Dock Time*)
3. Yellow: Reliability (*Stockout Level* and *Backorder Level*)



4. Pink: Cost (*Transportation Cost and Inventory Carrying Cost*)

<b>Automotive Supply Chain Measurement Scorecard</b>				
<b>Metrics</b>	<b>Level</b>	<b>SC A</b>	<b>SC B</b>	<b>SC C</b>
Demand MAD	Supply Chain	77.56%	91.04%	20.35%
	OEM - 1st tier supplier	0.00%	0.00%	0.00%
	OEM - 2nd tier supplier	118.24%	110.59%	40.70%
	OEM - 3rd tier supplier	114.45%	162.54%	N/A
BullWhip Coefficient	Supply Chain	3.96	4.52	N/A
	OEM - 1st tier supplier	1.00	1.00	1.00
	1st tier supplier - 2nd tier supplier	2.66	2.05	1.49
	2nd tier supplier - 3rd tier supplier	1.51	5.01	N/A
Inventory Level (days of stock)	Supply Chain	18.22	30.07	N/A
	OEM RM inv level	0.00	0.00	0.00
	1st tier FG inv level	0.00	0.00	0.00
	1st tier RM inv level	5.06	19.14	1.99
	2nd tier FG inv level	1.50	2.03	1.50
	2nd tier RM inv level	1.86	6.91	2.00
	3rd tier FG inv level	6.45	2.00	N/A
Dock-to-Dock Time (hours)	Supply Chain	302.47	661.29	N/A
Stockout Level	Supply Chain	0	0	0
Backorder Level	Supply Chain	0	0	0
Transportation Cost (cost per unit)	Supply Chain	£3.63	£1.44	£0.99
	1st Tier - OEM	£3.13	£0.66	£1.64
	2nd Tier - 1st Tier	£3.52	£3.39	£0.34
	3rd Tier - 2nd Tier	£4.26	£0.26	N/A
Transportation Cost (cost per month)	Supply Chain	£27,672.00	£34,828.18	N/A
Inventory Carrying Cost (cost per unit)	Supply Chain	£0.02	£0.0019	£0.01
Inventory Carrying Cost (cost per month)	Supply Chain	£114.18	£49.63	N/A

Table 5.1: Case Studies Scorecard

The analyses are presented in four different sections according to the measurement groups. This scorecard summarises and presents the measurement results from each of the eight metrics in a comprehensive and concise format.



### 5.2.2 Demand Synchronisation

Table 5.2 summarises the measurement results for *Demand MAD* (extracted from Table 4.3, Table 4.10 and Table 4.17) and *Bullwhip Coefficient* (extracted from Table 4.4, Table 4.11 and Table 4.18) according to individual SC measurement levels.

	Level	Demand MAD			Level	Bullwhip Coefficient		
		Runner	Repeater	Stranger		Runner	Repeater	Stranger
SC A	OEM – 1 <sup>st</sup> tier	0.00%	0.00%	0.00%	OEM - 1st tier	1.00	1.00	1.00
SC B		0.00%	0.00%	0.00%		1.00	1.00	1.00
SC C		0.00%	N/A	0.00%		1.00	N/A	1.00
SC A	OEM – 2 <sup>nd</sup> tier	95.80%	97.01%	161.90%	1st tier - 2nd tier	2.06	2.78	3.13
SC B		15.67%	69.93%	246.15%		0.70	0.84	4.59
SC C		12.01%	N/A	69.39%		1.02	N/A	1.97
SC A	OEM – 3 <sup>rd</sup> tier	101.98%	119.95%	121.43%	2nd tier - 3rd tier	1.64	1.43	1.45
SC B		154.40%	162.07%	171.15%		10.61	3.79	0.63
SC C		N/A	N/A	N/A		N/A	N/A	N/A

Table 5.2: Demand Synchronisation Performance Summary

The 0% in *Demand MAD* and *Bullwhip Coefficient* of 1 indicate that the demand synchronisation between the OEM and the 1<sup>st</sup> tier supplier performed extremely well in all three SCs. This was solely due to the SILS system in place where all the seat modules were assembled-to-order, with 4-12 hours advance production schedule broadcasted to the 1<sup>st</sup> tier suppliers by the OEMs. Therefore, the 1<sup>st</sup> tier suppliers were producing and delivering the exact quantity of OEMs demand and thus there was no demand amplification at all.

Demand variation appeared between 2<sup>nd</sup> and 3<sup>rd</sup> tier suppliers. This is indicated by the high percentage in *Demand MAD* and *Bullwhip Coefficient* figures that are more or less than 1. Most of the new technologies and concepts like SILS are implemented between the OEMs and 1<sup>st</sup> tier suppliers. However, the upstream SC members are

still operating on a make-to-stock policy, with limited information sharing and arms-length collaboration. Hence, the demand synchronisation performance declined upstream of the 1<sup>st</sup> tier supplier.

Overall, the scorecard shows that SC C has the best demand synchronisation level, indicated by the lowest *Demand MAD* and *Bullwhip Coefficient* figures that are closest to figure 1 at most of the measurement levels. Although the measurement of SC C does not include the 3<sup>rd</sup> tier supplier, the comparison based on individual SC measurement level performances still provides strong evidence that SC C has a lower *Demand MAD* and better *Bullwhip Coefficients*. This is mainly due to the frozen 6 days production schedule policy of SC C OEM. The frozen schedule eliminated most of the last minutes changes and maintained production schedule stability. This directly reduced demand uncertainty between the OEM and the 1<sup>st</sup> tier supplier, which subsequently decreased the magnitude of demand amplification further upstream the SC.

Overall, SC A has a better demand synchronisation performance than SC B, indicated by its lower *Demand MAD* and *Bullwhip Coefficient* closer to one. However, due to the similarity between these two SCs, in both materials and information flows, the performance gap between these two SC is actually quite small in comparison to SC C, as shown in Figure 5.1.

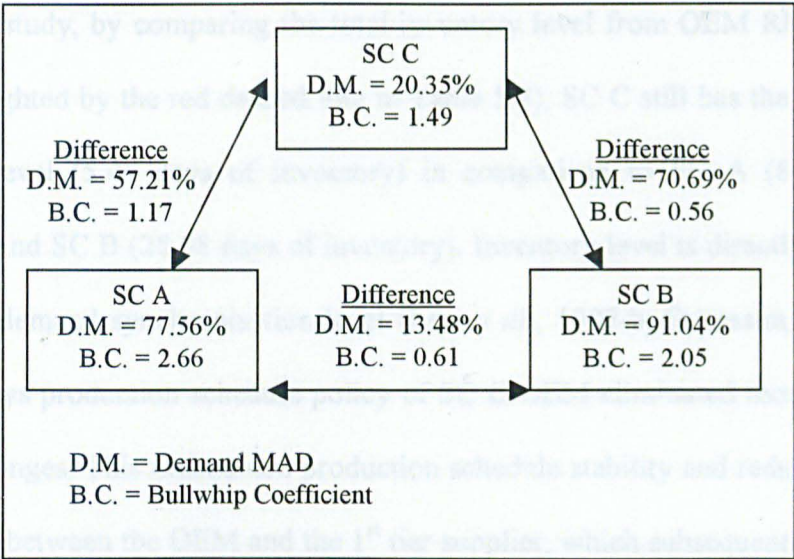


Figure 5.1: Demand Synchronisation Metrics Comparison

5.2.3 Responsiveness

Table 5.3 is an extract from the performance scorecard of the measurement results on SCs responsiveness from both metrics – *Inventory Level* (Table 4.5, Table 4.12 and Table 4.19) and *Dock-to-Dock Time* (Table 4.6, Table 4.13 and Table 4.20).

Metrics	Level	SC A	SC B	SC C
Inventory Level (days of stock)	Supply Chain	18.22	30.07	N/A
	OEM RM inv level	0.00	0.00	0.00
	1st tier FG inv level	0.00	0.00	0.00
	1st tier RM inv level	5.06	19.14	1.99
	2nd tier FG inv level	1.50	2.03	1.50
	2nd tier RM inv level	1.86	6.91	2.00
	3rd tier FG inv level	6.45	2.00	N/A
Dock-to-Dock Time (hours)	Supply Chain	302.47	661.29	N/A

Table 5.3: Responsiveness Performance Summary

Overall, SC C has the lowest *Inventory Level* at every inventory point, except at the 2<sup>nd</sup> tier raw material inventory where the inventory level is only slightly higher than SC A (0.14 days higher). Although the 3<sup>rd</sup> tier FG *Inventory Level* is not included in

SC C case study, by comparing the total inventory level from OEM RM to 2<sup>nd</sup> tier RM (highlighted by the red dashed line in Table 5.3), SC C still has the lowest total inventory level (5.49 days of inventory) in comparison to SC A (8.42 days of inventory) and SC B (28.08 days of inventory). Inventory level is directly influenced by the SC demand synchronisation level (Lee *et al.*, 1997-b; Svensson, 2003). The frozen 6 days production schedule policy of SC C OEM eliminated most of the last minutes changes. This maintained production schedule stability and reduced demand uncertainty between the OEM and the 1<sup>st</sup> tier supplier, which subsequently decreased the magnitude of demand amplification further upstream the SC. Therefore, SC C inventory levels is lower than the other two SCs. Without the frozen schedule policy, SC A and B have both suffered volatile production schedule instability from the possibility of last minutes changes. Hence, more inventories are needed to cope with the demand uncertainty.

The zero RM and FG inventory level between the OEM and the 1<sup>st</sup> tier supplier in all three SCs is mainly due to the implementation of SILS. The 1<sup>st</sup> tier supplier is able to assemble-to-order, thus there is no stock holding between the OEM and the 1<sup>st</sup> tier supplier. This observation is consistent with Cokins' (1999) finding where the sharing of production planning information between the OEM and the suppliers contributed to inventory reduction. However, this does not mean that the inventory has been reduced completely. Some of the inventories are actually consigned to the other upstream suppliers, as shown by the inventory levels carried by 2<sup>nd</sup> and 3<sup>rd</sup> tier suppliers.



The *Dock-to-Dock Time* represents the time for material to flow through the SC. In this research, the flow started from the 3<sup>rd</sup> tier supplier production process and ends after the receipt of material by the OEM. SC A (302.47 hours) has a lower *Dock-to-Dock Time* than SC B (661.29 hours). However, the *Dock-to-Dock Time* for SC C is not shown in Table 5.1 and Table 5.3 because it does not include the 3<sup>rd</sup> tier SC level due to the lack of information. In order to compare all three SCs, Table 5.4 is presented below, which shows the *Dock-to-Dock Time* for all three SCs, from 2<sup>nd</sup> tier RM inventory until the receipt of material by the OEM. The results from both the runner and stranger samples show that SC C has the shortest *Dock-to-Dock Time* (Runner: 7.35 hours; Stranger: 8.27 hours). The major differences come from the higher RM and FG inventory level (i.e. buffer) carried by both SC A and B (highlighted in yellow in Table 5.4). A lower inventory level means that the time for a material to flow through the SC pipeline is shorter. This is mainly due to the better demand synchronisation level in SC C. On the other hand, SC A has a shorter *Dock-to-Dock Time* than SC B, as shown in Table 5.1 and Table 5.4. Again, this is caused by the higher RM and FG inventory levels in SC B.

Activity	Runner			Stranger		
	SC A	SC B	SC C	SC A	SC B	SC C
Transit from 1st Tier to OEM	0.30	0.20	0.20	0.30	0.20	0.20
1st Tier FG Buffer	0.00	0.00	0.00	0.00	0.00	0.00
1st Tier Process Time	0.60	0.60	0.32	0.60	0.60	0.32
1st Tier RM Buffer	29.08	48.37	1.53	160.38	1191.00	2.45
Transit from 2nd Tier to 1st Tier	3.00	0.20	1.50	3.00	0.20	1.50
2nd Tier FG Buffer	24.00	14.93	1.50	24.00	45.23	1.50
2nd Tier Process Time	1.50	1.50	0.30	1.50	1.50	0.30
2nd Tier RM Buffer	19.78	40.99	2.00	190.48	214.15	2.00
Total time (in hours) =	78.26	106.79	7.35	380.26	1452.88	8.27

Table 5.4: *Dock-to-Dock Time* Summary Table

### **5.2.4 Reliability**

The two reliability metrics included in this scorecard are *Stockout Level* and *Backorder Level*. However, during the case study period, there was no stockout incident in all three SCs. Therefore, all three SCs were considered to have very reliable supply mechanism.

For the 1<sup>st</sup> tier suppliers, this is mainly due to the strict requirements of SILS and any stockout incident will bring costly consequences to both the OEMs and the suppliers. Hence the suppliers are highly committed to deliver on time with the right product every time. Despite that, the production schedule (TLS in SC A and B, CAT-3 in SC C) released in advance by the OEMs to the 1<sup>st</sup> tier suppliers reduced the possibility of stockout incident. This information enabled the suppliers to assemble-to-order and deliver the right product in the right quantity at the right time.

For the 2<sup>nd</sup> and 3<sup>rd</sup> tier suppliers, the zero stockout incidents are mainly due to the make-to-stock manufacturing policy. As shown in Section 5.2.3, the inventory levels held by 2<sup>nd</sup> and 3<sup>rd</sup> tier suppliers are higher than the OEM and 1<sup>st</sup> tier suppliers. These inventories absorbed most of the demand instability and uncertainty, thus guaranteeing a constant supply of materials.



### 5.2.5 Cost

Table 5.5 is an extract from the scorecard on SCs cost performance for both *Transportation Cost* (Table 4.7, Table 4.14 and Table 4.21) and *Inventory Carrying Cost* (Table 4.8, Table 4.15 and Table 4.22).

Metrics	Level	SC A	SC B	SC C
Transportation Cost (cost per unit)	Supply Chain	£3.63	£1.44	£0.99
	1st Tier - OEM	£3.13	£0.66	£1.64
	2nd Tier - 1st Tier	£3.52	£3.39	£0.34
	3rd Tier - 2nd Tier	£4.26	£0.26	N/A
Transportation Cost (cost per month)	Supply Chain	£27,672.00	£34,828.18	N/A
Inventory Carrying Cost (cost per unit)	Supply Chain	£0.02	£0.0019	£0.01
Inventory Carrying Cost (cost per month)	Supply Chain	£114.18	£49.63	N/A

Table 5.5: Cost performance Summary

Based on Table 5.5, SC C has the lowest *transportation cost per unit* (£0.99 per unit), SC B came second (£1.44 per unit) and SC C came third (£3.63 per unit). On the other hand, SC B has the lowest *inventory carrying cost per unit* (£0.0019), then it is SC C (£0.01) and SC A (£0.02). However, due to the lack of 3<sup>rd</sup> tier supplier cost information for SC C, the results for *transportation cost per month* and *inventory carrying cost per month* in Table 5.5 is not comparable to the other two SCs. Therefore, another summary table, Table 5.6 is included to compare the cost performance excluding the 3<sup>rd</sup> tier supplier. The information for *transportation costs* is extracted from the individual transportation cost table in the case studies (Table 4.7, Table 4.14 Table 4.21 for SC A, B and C respectively) and the recalculations of the *inventory carrying cost* for SC A and B are shown in Appendix H and Appendix I respectively.



SC Level	Transportation Cost per Month			Transportation Cost per Unit		
	SC A	SC B	SC C	SC A	SC B	SC C
1st Tier - OEM	£24,000.00	£13,267.88	£1,998.36	£3.13	£0.66	£1.64
2nd Tier - 1st Tier	£1,970.00	£18,973.07	£488.60	£3.52	£3.39	£0.34
	£25,970.00	£32,240.94	£2,486.96	£3.32	£2.03	£0.99
	Inv Carrying Cost per Month			Inv Carrying Cost per Unit		
	£73.73	£22.33	£52.64	£0.01	£0.0011	£0.01

Table 5.6: Cost Performance Summary without 3<sup>rd</sup> tier Supplier

The results from Table 5.6 show that SC C has the lowest *transportation cost* (£2,487 per month and £0.99 per unit), in comparison to SC A (£25,970 per month and £3.32 per unit) and SC B (£32,240 per month and £2.03 per unit). Based on the delivery rates provided by the UK Road Haulage Association, there are many factors that can affect transportation cost - delivery batch size, weight and other special delivery requirements such as temperature control. Hence, the transportation cost measurement results were unable to depict any consistent trend between transportation cost and the other performance aspects within the scorecard.

On the other hand, SC B has the lowest *inventory carrying cost* (£22.33 per month and £0.0011 per unit) in comparison to SC A (£73.73 per month and £0.01 per unit) and SC C (£52.64 per month and £0.01 per unit). The difference in inventory carrying cost is mainly due to the difference of product costs. Even though SC B has the highest inventory level, its cost per unit of product (i.e. seat modules and headrest) is much lower than the other two SCs, as shown in Table 5.7. The seat modules in SC A are more expensive because the seats are equipped with more luxury options, such as power seat adjustment and leather cover. Another reason is the location of suppliers. The seat modules and headrest suppliers in SC B are based in Spain while the suppliers for SC A and C are based in the UK. Due to the cheaper



overhead and material costs in Spain over in the UK, thus the product costs are lower for SC B.

	Seat modules	Headrest
SC A	£750.00	£20.00
SC B	£36.70	£1.46
SC C	£85.39	£5.69

Table 5.7: Cost Per Unit Material

5.2.6 Performance Summary

After the analysis of SCs performance for the four measurement groups, Table 5.8 provides a three-level ranking of the SCs based on their performance level for each metric:

- F: first, the best performed
- S: second best
- T: third

Measurement Group	Metrics	SC A	SC B	SC C
Demand Synchronisation	Demand MAD	S	T	F
	Bullwhip Coefficient	S	T	F
Responsiveness	Inventory Level	S	T	F
	Dock-to-dock Time	S	T	F
Reliability	Stockout Level	F	F	F
	Backorder Level	F	F	F
Costs	Transportation Cost per Unit	T	S	F
	Inventory Carrying Cost per Unit	T	F	S

Table 5.8: Performance Summary Table

Since SC C has the best performance in seven metrics out of eight, it is fair to conclude that SC C is the best performing SC among the three. One special feature that distinguished SC C from the other two is the “frozen 6-day production

schedule". The OEM "freezes" its production schedule for six days, which prevents changes to be made on production jobs within the next six days. This eliminates most of the last minutes changes, maintains the production schedule stability and helps the OEM to achieve the sequence adherence in SILS (Lyons *et al.*, 2005). Hence, SC C has a better demand synchronisation performance than the other two SCs.

Although SC A and B have both excelled in different areas, SC A has performed better in five metrics: *Demand MAD*, *Bullwhip Coefficient*, *Inventory Level*, *Dock-to-Dock Time* and *Transportation Cost per Month*. Therefore, SC A has better performance than SC B.

Throughout the results analysis, there is significant evidence measured to demonstrate that SILS has considerable influence on the four performance areas in the scorecard. In order to operate SILS, the OEMs have to work very closely with the 1<sup>st</sup> tier suppliers and it has to be supported by a reliable communication system and production technology (Doran, 2001). The assemble-to-order manufacturing policy and the sharing of production schedules have enabled the sequenced suppliers to deliver the exact quantity of seat modules needed at the right time. Hence, the demand synchronisation level is extremely high. This has lowered demand uncertainty and leads to lower *Inventory Levels*. Since *Dock-to-Dock Time* and *Inventory Carrying Costs* are constituted of *Inventory Level*, a lower *Inventory Level* has also contributed to a shorter *Dock-to-Dock Time* and a lower *Inventory Carrying Cost*. Despite that, the sharing of production schedules and demand forecasts provides an early warning to the suppliers, which help to reduce *Stockout Level* and

*Backorder Level.* In conclusion, SILS have affected the performance of seven metrics out of eight within the scorecard, as illustrated in Figure 5.2.

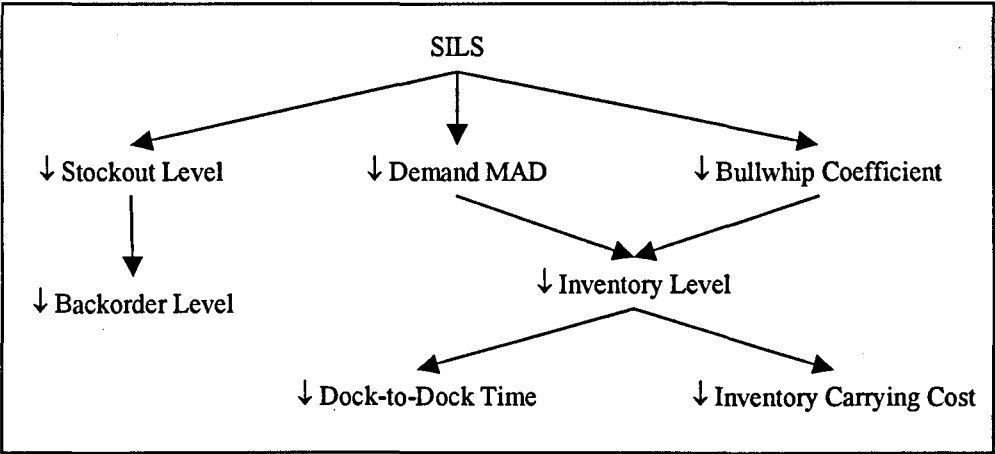


Figure 5.2: The Influence of SILS on Automotive SC Performance

However, not every SC member was benefited from SILS because it is only implemented between the OEMs and 1<sup>st</sup> tier sequenced suppliers. The information generated by the OEM usually is not visible to 2<sup>nd</sup> or 3<sup>rd</sup> tier suppliers and this contributes to the demand signal amplification to upstream SC levels (Lyons *et al.*, 2005) and pushes inefficiency upstream (Millington *et al.*, 1998). The results uncovered by the scorecard are consistent with this statement. The scorecard in Table 5.1 shows that the 2<sup>nd</sup> and 3<sup>rd</sup> tier suppliers have performed worse in *Demand MAD*, *Bullwhip Coefficient*, *Inventory Level* and *Dock-to-Dock Time* than OEMs and 1<sup>st</sup> tier suppliers. Apart from the effect of SILS, the make-to-stock manufacturing policy employed by the 2<sup>nd</sup> and 3<sup>rd</sup> tier suppliers is also part of the reason that caused the higher *Inventory Level* and *Dock-to-Dock Time*.

### **5.3 Supply Chain Elements for Optimum Performance**

Apart from comparing the SCs performance, the measurement results from the case studies have also provided some indications on three SC designs that can help the SC to achieve optimum performance. The three identified SC elements are:

#### **6.3.1 SILS**

#### **6.3.2 IS**

#### **6.3.3 SC proximity**

### **5.3.1 SILS**

Sequenced-in-line-supply (SILS) is one of the most significant developments in automotive SC where vehicle assemblies (e.g. seats, cockpits, front-end systems) are produced by suppliers JIT to be assembled into the vehicle. It is very similar to JIT (Just In Time) in that the materials are only delivered at the time when the buyer needs them. However, in SILS, the delivery sequence has to be vehicle specific (Doran, 2001). This is very different from conventional supply system, i.e. non-sequenced supply, where the parts are delivered in batch and delivery sequence is not predetermined.

The better performance shown by the OEMs and the 1<sup>st</sup> tier suppliers in all three SCs showed that SILS has considerable influence on the SC demand synchronisation, responsiveness, reliability and cost. The access to the OEMs production schedules allows the 1<sup>st</sup> tier suppliers to assemble-to-order and enables the sequenced suppliers

to deliver the exact quantity of seat modules needed at the right time. This has lowered demand uncertainty by synchronising the demand between the OEMs and the 1<sup>st</sup> tier suppliers, which lead to lower *Inventory Levels*, shorter *Dock-to-Dock Time*, lower *Inventory Carrying Cost*, lower *Stockout Level* and lower *Backorder Level*. The “knock-on” effect between these metrics has been illustrated in Figure 5.2. The benefits of SILS on automotive SCs is also recognised by other researcher (Doran, 2001).

### **5.3.2 Information Sharing**

Throughout the case studies and result discussions, IS has been identified as an important factor that affects SCs performance. All the SC members in the case studies shared demand forecasts with their consecutive SC member. However, only the 1<sup>st</sup> tier suppliers have access to the original demand information, i.e. the OEM demand. This is one of the main reasons that contributed to the highly efficient and effective performance between the OEMs and the 1<sup>st</sup> tier suppliers. Without the visibility to the original demand information, the 2<sup>nd</sup> and 3<sup>rd</sup> tier suppliers face higher demand uncertainty and amplification, which affects the SC demand synchronisation, responsiveness, reliability and cost.

Therefore, timely access to OEMs production schedule, which is the SC original demand information, enabled the suppliers from different SC levels to more closely align production and delivery with customer demand, and reduce inventory level and lead time (Bremang, 2004). There is already evidence showing that sharing OEM production schedule with the entire SC can improve automotive SCs performance in

terms of demand amplification, cost and inventory level (Bremang, 2004). The results uncovered by the scorecard are consistent with this observation. The scorecard in Table 5.1 shows that the 2<sup>nd</sup> and 3<sup>rd</sup> tier suppliers have performed worse in *Demand MAD*, *Bullwhip Coefficient*, *Inventory Level* and *Dock-to-Dock Time* than OEMs and 1<sup>st</sup> tier suppliers.

Since IS plays such a significance role in automotive SC performance (as discussed in Section 2.4.2 in Chapter 2: Literature Review), it is crucial to ensure that the SC members operate an optimum IS system to gain these benefits. In this research, the author has observed two factors that affect IS in SC:

- Schedule stability
- Trust and commitment

#### **5.3.2.1 Schedule Stability**

According to an article in Automotive News Europe, if a car is manufactured on a make-to-order or “pull” basis, there will be a cost saving of 96 Euros per vehicle sold in Europe (Cifferre, 2002). Even though some vehicle manufacturers claim that they run their production on “pull” mechanisms, in fact it is just a hybrid of a “pull” and “push” system. Usually, the vehicle manufacturers plan their production schedules at least two weeks ahead, some even one month before the production day, then the production schedule is sent to 1<sup>st</sup> tier suppliers as a demand forecast. However, the dealers are obliged to place a set number of orders every month. Which means that some of the orders are not committed customer orders. As a result, the vehicle

manufacturer has to change the production schedule regularly or more often at the last minute if the dealers fail to meet the sales target. This means that the suppliers are facing a volatile demand fluctuation and it affects their ability to cope with the vehicle manufacturer's demand (Childerhouse *et al.*, 2003). The disturbance is even greater if the delivery is based on sequenced supply because the demand fluctuation might be magnified and passed on to upstream in SC (Childerhouse *et al.*, 2003). Therefore many vehicle manufacturers monitor its 1<sup>st</sup> tier suppliers delivery schedules adherence on on-going basis (Doran, 2001; Coleman *et al.*, 2002).

The significance of schedule stability has been observed by other researchers and practitioners, such as the Toyota Production System (Monden, 1997) and Nissan UK (Doran, 2001). Shigeo Shingo (1988) showed how schedule stability allowed the concept of JIT to be embedded deeply into SCs and by keeping schedules fixed, reduced demand uncertainty within the SC and resulting in inventory reduction. Furthermore, there are many associated benefits of low inventory in terms of reducing storage costs, obsolescence costs and improving cash flow, which are well-documented (Schonberger, 1986. Womack and Jones, 1990).

During the research, it was recognised that one potential impact of schedule stability is the cost of premium freight. Figure 5.3 is a column chart that shows the premium freight cost incurred in the OEM at different schedule adherence levels in SC A (Coleman *et al.*, 2002). The schedule adherence level is defined by the percentage of vehicles built on the target date out of the total amount of vehicles built on that particular day. For example, if on the 20 Dec 2001, there are 459 cars that have been built and 200 of these cars that are scheduled to be built on this day, then the



schedule adherence for this day is the percentage of 200 against 459. Hence, the schedule adherence for this day is 43.57% (Coleman *et al.*, 2002).

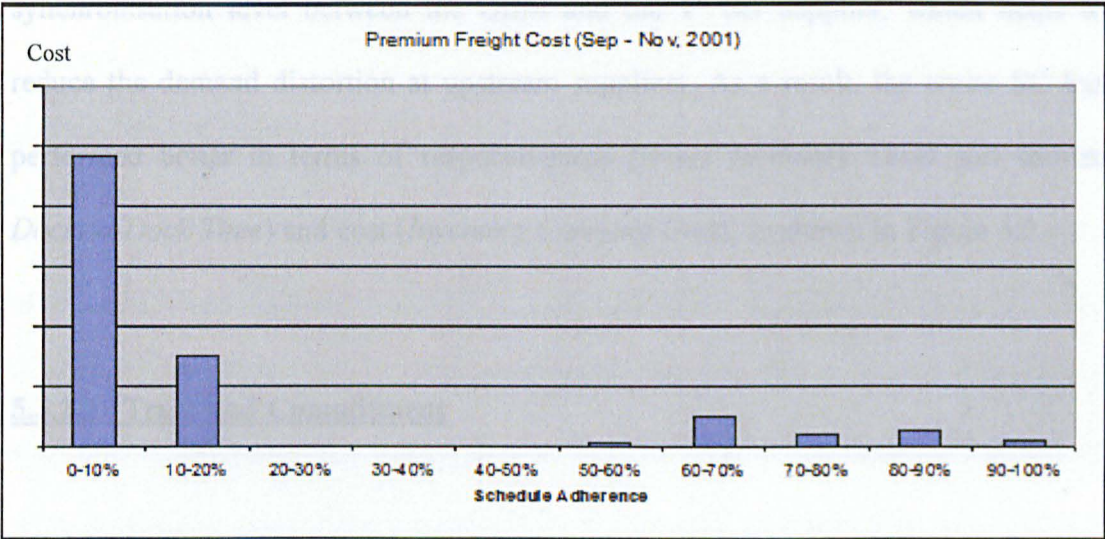


Figure 5.3: Premium Freight vs. Schedule Adherence (Coleman *et al.*, 2002)

The chart illustrates that there is a negative relationship between the premium freight and the schedule adherence. Almost 85% of the cost comes from the day where the schedule adherence falls below 20%. This is because when the production has fallen out of the planned schedule, it will incur premium freight to bring in the materials out of regular and scheduled deliveries. However, it was only possible to perform this study in SC A due to access restriction and limited information in SC B and C.

Apart from premium freight, another impact of schedule stability is the SC inventory level. Coleman *et al.*'s (2002) study has also shown that an unstable production schedule at the OEM will have a negative effect on suppliers inventory level. A SC with unstable OEM schedule tends to need more inventories to compensate for the volatile demand changes. This is also proven by the case studies in this research where SC C has a lower inventory level due to its more stable OEM production schedule from the 6 day fixed schedule. The 6-day fixed production schedule policy



in SC C OEM helped to maintain schedule stability by eliminating last minute changes and reducing the SC demand uncertainty. This enhanced the demand synchronisation level between the OEM and the 1<sup>st</sup> tier supplier, which helps to reduce the demand distortion at upstream suppliers. As a result, the entire SC has performed better in terms of responsiveness (lower *Inventory Level* and shorter *Dock-to-Dock Time*) and cost (*Inventory Carrying Cost*), as shown in Figure 5.2.

#### **5.3.2.2 Trust and Commitment**

All IS efforts need trust and commitment from all the involved parties. Trust is defined as “*The extent to which a customer believes that the supplier is honest, benevolent and competent*” and commitment is “*the customer’s durable intention to develop and sustain the relationship with the supplier in the long term*” (Ryssel *et al.*, 2004).

Before the 1980s, the automotive industry had low information transparency due to the lack of trust among the SC members (Childerhouse *et al.*, 2003). This is because they feared exposing their strengths and weaknesses, not just to their rivals, but also towards their suppliers or customers (Cox *et al.*, 2000; Cokins, 1999). Without trust, most companies worried that sharing sensitive strategic information might put them at the risk of losing power. The emphasis of possessing power within the SC can be seen in the following example:

*“Up to the 1980s, relationships between companies within the European automotive industry were based mainly on the dominant position of the*

*manufacturers compared with their suppliers. The process of a new car design at that time is a good example of the supremacy of the car manufacturers.” (Lapiedra et al., 2004)*

The relationships and interactions between SC members are partly dependent on power distribution. Usually, those most dominant tend to gain most of the benefits brought by a new implementation or changes, while the costs are borne by other SC members (Cox *et al.*, 2000). Hence, the value and benefits created is not equally shared by the SC members. This is one of the main reasons that causes the failure of western industry to replicate the success in Japanese SC practices (Cox *et al.*, 2000). SC integration can only be achieved if mutual benefits exist for all the SC members (Mena *et al.*, 2002). Full cooperation and trust among the SC members are vital and the profit and cost must be shared fairly among the members (Schmitz and Platts, 2003-a). However, these benefits will only be realised if for each member in the SC, this particular chain is of sufficient priority (Schmitz and Platts, 2003-a). With cross boundary measurement, the distribution of costs and benefits among the SC members can be monitored and the problem of local optimisation can be avoided (Lambert and Bennis, 1982).

Over the year, vehicle manufacturers have developed trust and commitment towards their suppliers and started to transfer the responsibility of component development to the supplier. This enabled the vehicle manufacturers to free up their resources and redeploy it on core competencies (Lapiedra et al., 2004). However, this also means that the vehicle manufacturers will have to share the technology and ideas with the suppliers. Therefore, the vehicle manufacturers believe that a long-term relationships

and mutual dependence with suppliers is essential to maintain production quality, including product development and innovations (Doran, 2001).

Despite the transfer of innovation and design responsibilities, another common SC IS initiative is the sharing of production schedules and demand forecasts. All the OEMs within the case studies share this information with their suppliers, but only limited to 1<sup>st</sup> tier suppliers. In order to achieve a holistic IS across SC and to achieve an optimum SC performance, it is necessary to break this IS boundary. As shown by the case study results, the sharing of demand forecast and production schedules from the OEM have enhanced the 1<sup>st</sup> tier supplier performance in comparison to the suppliers further upstream. A study carried out by Bremang (2004) has shown some clear empirical evidence that by sharing OEM's demand forecast with 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> tier suppliers, the performance of each SC level can be augmented by dampening the effect of demand amplification, allowing suppliers to align production and delivery closer to customer demand, achieving a more stable production schedules and reducing inventories.

However, it is not easy to ally all SC members to achieve the same SC goals because each SC member has its own constituencies, objectives and metrics (Simatupang and Sridharan, 2005). Inevitably, the SC members will put their own benefits at first priority (Childershouse *et al.*, 2003). When a SC member possesses resources that the other members want or need, this enables that SC member to exert some influence on the other SC members to create more favourable terms of trade for itself (Frazier *et al.*, 1989). This is the main obstacle to incorporate the concept of system thinking in SCM and measurement. Therefore, commitment is a key success factor in

achieving SC integration and trust is the root in fostering such commitment (Kwan and Suh, 2005).

### **5.3.3 SC proximity**

Supplier park is very common in today's automotive industry. There are at least 35 supplier parks around the world (Sako, 2003), including SC C in the case studies. In a supplier park, the suppliers are located adjacent to or close to the vehicle assembly plant (Sako, 2003). The distance proximity helps to reduce inventory carrying cost and delivery time, improve responsiveness, as well as facilitating SILS (Drickhamer, 2003). Although SC A and C do not have a comprehensive supplier park, both OEMs have some of their core suppliers located within 1 mile radius of their vehicle assembly plant.

However, most of the supplier parks only include 1<sup>st</sup> tier suppliers or 3<sup>rd</sup> party sequencing distribution centres. Which means the travel distance through the entire SC can still be quite lengthy because the 2<sup>nd</sup> and 3<sup>rd</sup> tier suppliers might be located in another city, country or continent. The SC proximity between SC members plays a significant role in SC performance in terms of cost and responsiveness (Drickhamer, 2003).

Based on the delivery rates provide by the UK Road Haulage Association, one of the factors that affect delivery cost is the travel distance. A further transportation distance incurs higher delivery cost. Therefore, by decreasing the SC proximity between the SC members, the total SC delivery cost can be reduced. However, there

are other factors that can affect delivery cost apart from delivery distance, such as delivery batch size, weight and special delivery requirements (e.g. temperature control, designated fixtures to hold the products during delivery). This is part of the reason why the delivery costs shown in the case studies measurement results were not directly proportionate to the travel distance. Apart from reducing delivery cost, the close proximity between the SC members' premises will also allows the SC members to have a more rapid response in emergency situation that required site visits and meetings.

#### **5.4 Novel Aspects and Applications of The Scorecard**

An extensive literature review has been carried out and all the current major SCPM systems and measures have been reviewed. The measurement models proposed by van Hoek (1998), Gilmour (1999), Brewer & Speh (2000) and Chan & Chi (2003) are frameworks that help users to develop or choose their own metrics to measure their SC. However, these models do not provide any guideline on how to extend the metrics to measure across the SC. Although the measurement methods proposed by Stewart (1995), Beamons (1999) and Gunasekeran *et al.* (2001) provide a set of metrics to measure different SC performance, there is still a lack of guidance on cross SC measurement. Many single-measure measurement methods in Section 2.3.6 also have similar downfall, such as the bullwhip effect measurement conducted by Chen, Drezner, Ryan and Simchi-Levi (2000) or the SC audit check sheet developed by Waller (2003). This means that the research on inter-organisational performance measurement is still rather rare (Schmitz and Platts, 2003-a).

The need for integrative and holistic measures on SC performance is vital (Schmitz and Platts, 2003-a). Each SC member has its business objectives and strategies. Most of the time, these objectives are different or even in direct conflict with each other (Schmitz and Platts, 2003-a). Since the performance of individual SC members affects the overall performance of the entire SC (Duclos *et al.*, 2003), the SC members have to understand the roles of other members to reduce conflict and achieve overall SC optimisation (Lambert and Bennion, 1982). All SC members should take ownership of SC metrics and be held responsible for the SC's performance (Lee and Corey, 1992; Waller, 2003). Therefore, the SC measures must be able to reflect the multi tiers characteristic of SCs (Lambert and Pohlen, 2001) to illustrate the overall competitiveness of a SC, thus helps SC members to determine what and where in the SC to improve for maximum benefits (van Hoek, 1998; Childerhouse *et al.*, 2003).

Many companies tried to measure their SC performance, but most of them are dyadic measure. These dyadic measurements were limited to evaluate the performance of tier one suppliers, customers, or third-party providers (Lambert and Pohlen, 2001; Lau *et al.*, 2002; Bommer *et al.*, 2001). In accordance with SC definition, a SC measure should include more than one tier of a SC (Handfield and Nichols, 1999; Caplice and Sheffi, 1995). The operations and performance of individual companies within the SC are actually affected and depend on the other SC members. A successful SCPM system must span the entire SC and across SC levels (Holmberg, 2000) because the outcome that counts is that of the entire SC, not that of single organisations (Anderson *et al.*, 1997; Lapide, 2000; Tagaras and Lee, 1992; Simatupang and Sridharan, 2005).

In summary, none of the reviewed measurement systems and measures is suitable for FUSION research purpose for the following reason:

1. Some of the measurement systems are not multi-tier measures, such as the vendor rating systems or the Supply Chain Excellence's Keys approach by Stewart (1995). Although the SCOR model is a multi-tier measure, the complexity arising from the five management processes and the four metrics level has made it more difficult to be implemented. Nevertheless, the concept of multi-tier measure and distinctive metric levels were adopted into the scorecard.
2. Some of these are single-measure systems that focus on one specific SC performance such as the measures proposed by van Hoek *et al.* (2001), Rafele (2004) and the other single-measure systems reviewed in Section 2.3.6. In other words, these measurement systems are not balanced approach.
3. Some of these measurement systems, such as the SCM balanced scorecard by Brewer and Speh (2000) and the balanced measurement approach by Bullinger *et al.* (2002), are based on theoretical concepts that have not been verified by empirical study.
4. Some of the measures are qualitative assessment like survey and questionnaire, which solely depend on individual's subjective judgement to assess performance, like van Hoek *et al.* (2001), Kwon and Suh (2005) and Shin *et al.* (2000).
5. Some of the measures have very lengthy and complicated procedure, thus are not practical to be applied in commercial environment, such as using ABC to assess logistical performance proposed by Themido *et al.* (2000) or the SC costing model by Lalonde and Pohlen, (1996).

6. None of these measurement systems can fulfil all the 11 SCPM success factors described in Section 2.3.3.

Therefore, the author has developed this unique multi-tier measurement scorecard that assesses SC performance across four SC levels - OEM, 1<sup>st</sup> tier supplier, 2<sup>nd</sup> tier supplier and 3<sup>rd</sup> tier supplier. It provides quantitative measures from four different perspectives (demand synchronisation, responsiveness, reliability and cost) to provide a balanced performance indication. The metrics were selected based on the industry strategies – cost reduction and responsiveness enhancement to ensure that the measures are aligned with the SC strategies. The feasibility and applicability of the scorecard has been verified by three case studies on automotive SCs. In each of the four measurement perspectives, there are only two metrics. This is to keep the scorecard within a manageable scale and to ensure that it is not too lengthy or complicated for industrial users. The 11 success factors identified in Chapter Two were also taken into account during the development process.

The scorecard contains eight metrics that focus on individual SC level performance. Then the collective performance of these individual SC level provides the performance indication for the entire SC. The multi-tier measure of this scorecard provides a complete evaluation on the entire SC and prevents local optimisation among SC members, where a SC member improves its own performance at the expense of others (Jayaram, 1997; Cox *et al.*, 2000; Smith and Lockamy III, 2000). The problem of local optimisation can also happen between different SC functionality. For example, a reduction in FG inventory level will have an impact on delivery reliability, especially if the demand uncertainty is volatile (Bremang, 2004).



The multi-perspectives measurement of the scorecard can prevent this problem and avoid improvement on a SC functionality at the expense of the other. With the holistic visibility on the entire SC, the SCPM system can help to improve SC performance by taking waste out of the SC rather than moving it somewhere else in the SC pipeline (Holmberg, 2000). The SC members can work together to tackle the weaknesses at any SC level that will benefit the entire SC (van Hoek, 1998). It also helps to monitor the distribution of costs and benefits among the SC members (Lambert and Bennis, 1982).

This scorecard will be very useful for both automotive and non-automotive parties. Automotive SC members can use the scorecard to obtain information to facilitate the decisions-making process at management level, for instance to evaluate the impact of a new implementation. The supply quality assurance team and third party logistics service providers that handle the logistics operations for multiple SC members within the same SC can also use this scorecard to monitor SC performance on a regular basis. For non-automotive external bodies such as researchers or consultants, the scorecard can be used as a SC performance assessment tool.

## **5.5 Research Limitations**

This section describes the limitations of the scorecard developed, as well as the research and the case studies undertaken. The limitations are listed as follow:

1. Exclusion of end consumer level

The measurement in the scorecard did not include the end consumer level, i.e. the vehicle buyers of the SCs. This research focused on business-to-business interface because business-to-consumer interface has different characteristics (e.g. flow volume, interaction method). Therefore, only the business-to-business interfaces within the SC were included to maintain measurement consistency. Hence, the end consumer level was excluded and the OEM is the lowest downstream SC level in the measurement. Apart from that, the OEMs in the case studies used “push” system to manage their sales order. Which means that the original demand of the SC is actually started from the OEM not the end consumer. Therefore, the OEM demands were used as the SC original demand in *Demand MAD* and *Bullwhip Coefficient* measures.

## 2. Lack of 3<sup>rd</sup> tier supplier information in SC C

Initially, the SC C case study was to incorporate four SC levels – from the OEM to the 3<sup>rd</sup> tier supplier. All of them are located within the UK except the 3<sup>rd</sup> tier supplier, which is located in the Far East (Shanghai). Unfortunately, due to the distance, this 3<sup>rd</sup> tier supplier could not take part in this study. Therefore, in the comparison of the entire SC performance, the 3<sup>rd</sup> tier supplier in SC A and B were excluded to make the SCs comparable to each other.

## 3. Exclusion of “Repeater” sample in SC C case study

In the SC A and B case studies, there were three seat modules samples (runner, repeater and stranger) in each metrics, except for SC C. This is because S C has only two types of seat module samples, which were runner and stranger.

## 4. Exclusion of FG inventory level

The OEM's FG inventories is excluded from this measure because it is not within the research scope and all the OEMs in the case studies did not hold any FG inventories.

5. Limit on *Inventory Level*, *Inventory Carrying Cost* and *Dock-to-Dock Time*

The measures on *inventory level* and *inventory carrying cost* in SC A and SC B did not include the 3<sup>rd</sup> tier supplier RM inventories because it is not within the research scope.

6. The estimated figures for certain inventory levels

Most of the inventory levels were derived from the day-to-day inventory data during the case study period. However, this inventory information was not always available at all inventory points. Therefore, some of the inventory levels in the case studies were based on estimated figures provided by the companies, usually based on their target safety stock level. The inventory levels that are based on estimated figures are the 2<sup>nd</sup> tier supplier FG inventory in SC A and C, 3<sup>rd</sup> tier supplier FG inventory in SC B and 2<sup>nd</sup> tier supplier RM inventory in SC C.

7. Exclusion of premium freight

As illustrated in Section 5.3.2.1, one of the impacts of schedule stability is the premium freight. However, due to access restriction and limited information in SC B and C, the measure on premium freight was only possible in SC A. Therefore, it is not included in the scorecard *transportation cost* measure.

## **5.6 Chapter Summary**

The case study results show that SC C is the best performing SC among the three. The second best is SC B and then it is SC A. A special feature that distinguished SC C from the other two is the “frozen 6-day production schedule” that eliminates most of the last minutes changes, maintains the production schedule stability and improve sequence adherence in SILS. The results have also shown that SILS plays a significance role in automotive SC performance. Both OEM and 1<sup>st</sup> tier suppliers in all three SCs have benefit from the better demand synchronisation due to SILS. It reduces demand uncertainty and leads to lower *Inventory Levels*. Since *Dock-to-Dock Time* and *Inventory Carrying Costs* are constituted of *Inventory Level*, a lower *Inventory Level* has also reduced *Dock-to-Dock Time* and lowered *Inventory Carrying Cost*. Despite that, the sharing of production schedule and demand forecast have provided an early warning to the suppliers, which then reduced *Stockout Level* and *Backorder Level*.

However, not every SC members get to share the benefits from SILS because it is only operated between the OEMs and 1<sup>st</sup> tier sequenced suppliers. The information generated by the OEM is not visible to 2<sup>nd</sup> or 3<sup>rd</sup> tier suppliers. This amplified the demand signal to upstream SC levels (Lyons *et al.*, 2005) and pushes inefficiency upstream (Millington *et al.*, 1998).

The measurement results from the case studies have also provided some indications on three SC designs that can help the SC to achieve optimum performance in terms

of demand synchronisation, responsiveness, reliability and cost - SILS, IS and the SC proximity between SC members.

The SCPM scorecard developed in this research has been applied in three real life automotive SCs to verify its feasibility and applicability. The scorecard provides a cross-organisational measurement system to evaluate automotive SC performance. The holistic measures provide a complete evaluation on the entire SC performance, which helps to:

- prevent local optimisation
- improve SC performance by taking waste out of the SC rather than moving it somewhere else in the SC pipeline
- monitor the distribution of costs and benefits among the SC members.

This scorecard will be useful for both automotive (e.g. SC members, third party logistics service providers) and non-automotive parties (e.g. researchers and consultants) as a “ready made” tool to measure automotive SC performance.

There were seven limitations on this research and scorecard:

1. Exclusion of end consumer level
2. Lack of 3<sup>rd</sup> tier supplier information in SC C
3. Exclusion of “Repeater” sample in SC C case study
4. Exclusion of FG inventory level
5. Limit on *Inventory Level*, *Inventory Carrying Cost* and *Dock-to-Dock Time*
6. The estimated figures for certain inventory levels
7. Exclusion of premium freight

## **CHAPTER SIX: CONCLUSIONS**

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### **6.1 Introduction**

The literature review concludes that the existing SCPM systems and measures are not suitable for the purpose of FUSION research for the following reasons:

1. Some of the measurement systems are not multi-tier measures.
2. Some of these are single-measure systems that focus on one specific SC performance. In other words, these measurement systems are not balanced approach.
3. Some of these measurement systems are based on theoretical concepts that have not been verified by empirical study.
4. Some of the measures are qualitative assessment like survey and questionnaire, which solely depend on individual' subjective judgement to assess performance.
5. Some of the measures have very lengthy and complicated procedure, thus are not practical to be applied in commercial environment.
6. None of these measurement systems can fulfil all the 11 SCPM success factors described in Section 2.3.3.

Therefore, the aim of this research is to develop a unique multi-tier SCPM system to provide a multi-tier balanced quantitative measurement system that is feasible in commercial environment, justified by empirical studies and also possesses the 11 success factors identified in Section 2.3.3.

This chapter summarises the findings of this thesis in order to provide answers to the research questions and objectives stated in Chapter One. Following on from this, the contribution to knowledge is discussed in order to reveal the true value of this research. Then the chapter moves on to consider the topics that need further investigation to expand and supplement the work undertaken in this thesis.

## **6.2 Research Questions (Response)**

The following is the response to each of the research questions presented in Chapter One:

### **Question 1**

*What are the SC strategies deployed in the automotive industry?*

The first criterion in developing a successful supply chain performance measurement (SCPM) system is to make sure that the measurement is aligned with the supply chain (SC) strategy and objectives (Walker, 1998). Like most of the automotive SCs, the three SCs in the case studies emphasise cost reduction and responsiveness enhancement. Due to the volatile competition, the automotive industry has been operating a year-on-year cost-down approach to SC contract negotiations (Childerhouse *et al.*, 2003). Cost reduction has become one of the organisational and SC strategies in automotive industry (Childerhouse *et al.*, 2003). At the same time, vehicle manufacturers tend to impose very high demands on their suppliers in terms of product quality, in addition to the service level, to achieve the required responsiveness. Therefore, the industry is torn between coping with extreme flexibility on the one hand and making products much cheaper on the other

(Childerhouse *et al.*, 2003). Therefore, apart from cost reduction, responsiveness enhancement is another SC strategy that is most commonly implemented in automotive SC.

#### Question 2

*What are the criteria that facilitate an effective SCPM for automotive SCs?*

In the literature review and during the case studies, the author has identified 11 criteria that need to be taken into consideration to achieve an effective SCPM system:

1. Strategy alignment
2. Balanced measurement
3. Appropriate quantity of metrics
4. Quantifiable metrics
5. Compatible metrics
6. System thinking
7. Universality
8. Involvement
9. Understanding of existing measurement systems
10. Corporate culture
11. Distinction between metrics level



## Question 3

*Is there any existing SCPM system that is suitable to measure automotive SCs?*

From the literature review, there is no evidence that there is any empirical, multi-tier, balanced and quantitative SCPM system for the automotive industry that is incorporated with all the 11 success factors.

## Question 4

*How to evaluate automotive SC performance?*

The SCPM scorecard developed in this research measures SC performance across four SC levels - OEM, 1<sup>st</sup> tier supplier, 2<sup>nd</sup> tier supplier and 3<sup>rd</sup> tier supplier. It provides quantitative measures from four different perspectives (demand synchronisation, responsiveness, reliability and cost) to provide a balanced performance indication. The metrics were selected based on the industry strategies – cost reduction and responsiveness enhancement to ensure that the measures are aligned with the SC strategies. The feasibility and applicability of the scorecard has been verified by three case studies on automotive SCs. In each of the four measurement perspectives, there are only two metrics. This is to keep the scorecard within a manageable scale and to ensure that it is not too lengthy or complicated for industrial users. The 11 success factors identified in Chapter Two were also taken into consideration in the measurement process.

## Question 5

*What are the design elements that affect automotive SC performance?*

The measurement results from the case studies have also provided some indications on three SC designs that can help automotive SCs to achieve optimum performance – Sequenced In Line Supply (SILS), information sharing (IS) and proximity between SC members.

The better performance shown by the original equipment manufacturers (OEM) and the 1<sup>st</sup> tier suppliers in the case studies showed that SILS has considerable influence on the SC demand synchronisation, responsiveness, reliability and cost. The access to the OEMs production schedules allows the 1<sup>st</sup> tier suppliers to assemble-to-order and deliver the exact quantity of seat modules needed at the right time. It has also lowered demand uncertainty by synchronising the demand between the OEMs and the 1<sup>st</sup> tier suppliers, which lead to lower *Inventory Levels*, shorter *Dock-to-Dock Time*, lower *Inventory Carrying Cost*, lower *Stockout Level* and lower *Backorder Level*.

Throughout the case studies and result discussions, IS has been identified as an important factor that can affect SCs performance. Timely access to OEMs accurate production information and demand forecasts can significantly improve the demand synchronisation level between the OEM and the 1<sup>st</sup> tier suppliers. This lowered demand uncertainty and leads to lower *Inventory Levels*. Since *Dock-to-Dock Time* and *Inventory Carrying Costs* are constituted of *Inventory Level*, a lower *Inventory Level* has also contributed to a shorter *Dock-to-Dock Time* and a lower *Inventory*

*Carrying Cost.* Despite that, the sharing of production schedule and demand forecast have provided an early warning to the suppliers that helps to reduce *Stockout Level* and *Backorder Level*.

The distance proximity between SC members helps to reduce inventory carrying cost and delivery time, improve responsiveness, as well as facilitating SILS, as shown by the case study results. By decreasing the distance between the SC members, the total SC delivery cost can also be reduced. However, there are other factors that can affect delivery cost apart from delivery distance, such as delivery batch size, weight and special delivery requirements (e.g. temperature control, designated fixtures to hold the products during delivery). This is part of the reason why the delivery costs shown in the case studies measurement results were not directly proportionate to the travel distance.

### **6.3 Contributions To Knowledge**

The contributions to knowledge brought by this research are concluded as follows:

- A unique SCPM scorecard that provides a systematic, multi-tier, balanced and empirically proven quantitative method to evaluate automotive SC performance, which fulfils the 11 SCPM success factors identified in Chapter Two. With all these advantages over conventional dyadic measures, this scorecard will be useful for both automotive (vehicle manufacturers, suppliers in the automotive industry, third party logistics service providers) and non-automotive parties (researchers, consultants).

- The 11 SCPM system success factors identified can be used as a concise guideline to facilitate SCPM design process, helping industrialists and researchers to build their own SC measures, or to improve an existing measurement system. Apart from that, it can also serve as a generic improvement guideline for companies from any industries that seek to enhance their SC performance.
- This research has also revealed that cost reduction and responsiveness enhancement are the accepted automotive SC strategies, and the scorecard provides an additional, sophisticated input.
- The case studies results has also provided empirical evidence on the design elements that affect an automotive SC performance in demand synchronisation, responsiveness, reliability and cost – SILS, IS and the proximity between SC members.

## **6.4 Further Work**

This research has achieved the objectives that it set out to accomplish in the Introduction. However, there were some areas that need further investigation to expand and supplement the work undertaken in this research.

1. The measurement system applied in this research spans four SC levels – 3<sup>rd</sup>, 2<sup>nd</sup>, 1<sup>st</sup> and OEM. In other words, only the business-to-business (b2b) interface and excluding the business-to-consumer (b2c) links. The OEM's demand was used to gauge the demand synchronisation along the SC. This is because the car dealers are obliged to meet the order quantity dictated by the OEM. Hence, the OEM demand is the original demand in the studied automotive SCs. However, for SC in other industries such as food supply, a SC measurement that includes the end consumer is necessary. Therefore, a new research in SCPM should look into the possibility to develop a new SCPM system or to extend this scorecard that can accommodate both business-to-business and business-to-consumer SC interface.
2. Although in case study C, one of the suppliers was located in the Far East. However, due to the distance, this supplier was unable to take part in the case study. Therefore, a potential research opportunity is to apply this scorecard on a cross-national or cross-continent SC to provide further evidence on the scorecard applicability.

3. The case studies in this research were based on stochastic data to evaluate SC performance. Further research can be carried out to investigate the possibility of using dynamic data in this scorecard.
4. The case studies in this research mainly focus on external SC. Further research can be performed to assess the possibility to implement the scorecard on internal SC.
5. Another prospect research opportunity is to adopt the scorecard on non-automotive SC.
6. SCM is a fast evolving knowledge area. Therefore, further research should be carried out continuously to update the scorecard so that it is always compatible with different new-emerging technology in SC area, such as m-commerce or mobile technology, RFID (Radio Frequency Identification) and telematics.
7. In the *Inventory Carrying Cost* measure, the annual rate used to determine the monetary value of *Loss of Interest* is an estimated rate based on the average of annual rates used by each SC members. Another prospect research opportunity is to use compound interest rate instead.
8. Although the SCPM scorecard developed in this research has been applied on three real automotive SCs, more studies should be carried out to investigate the practical implications of this multi-tier SCPM scorecard. This represents a research opportunity.

9. Another prospect research opportunity is to explore other SC design elements that can influence an automotive SC performance apart from SILS, IS and proximity between SC members.
10. Simplifying product variety is another potential research opportunity. A typical Japanese car has less than one million product varieties while a US car can have several million (Williams, 1994). Some of these vehicle manufacturers have tried to reduce their product variety down to 1-2 millions (Williams, 1994). More researches should be carried out to investigate how this can be achieved.

## **6.5 Chapter Summary**

This chapter summarised the main findings of this research and provided the responses and answers to the research questions and objectives. The SCPM scorecard developed in this research presents a systematic and empirical approach to evaluate the performance of automotive SCs that are focused on cost reduction and responsiveness enhancement. The scorecard provides a unique, balanced, multi-tier and quantitative SCPM system that provides a complete evaluation on the entire automotive SC, which is very rare in SCPM knowledge area. However, further investigations and studies should be carried out to extend the applicability of this scorecard to other industries and to explore the practical implications of this scorecard.

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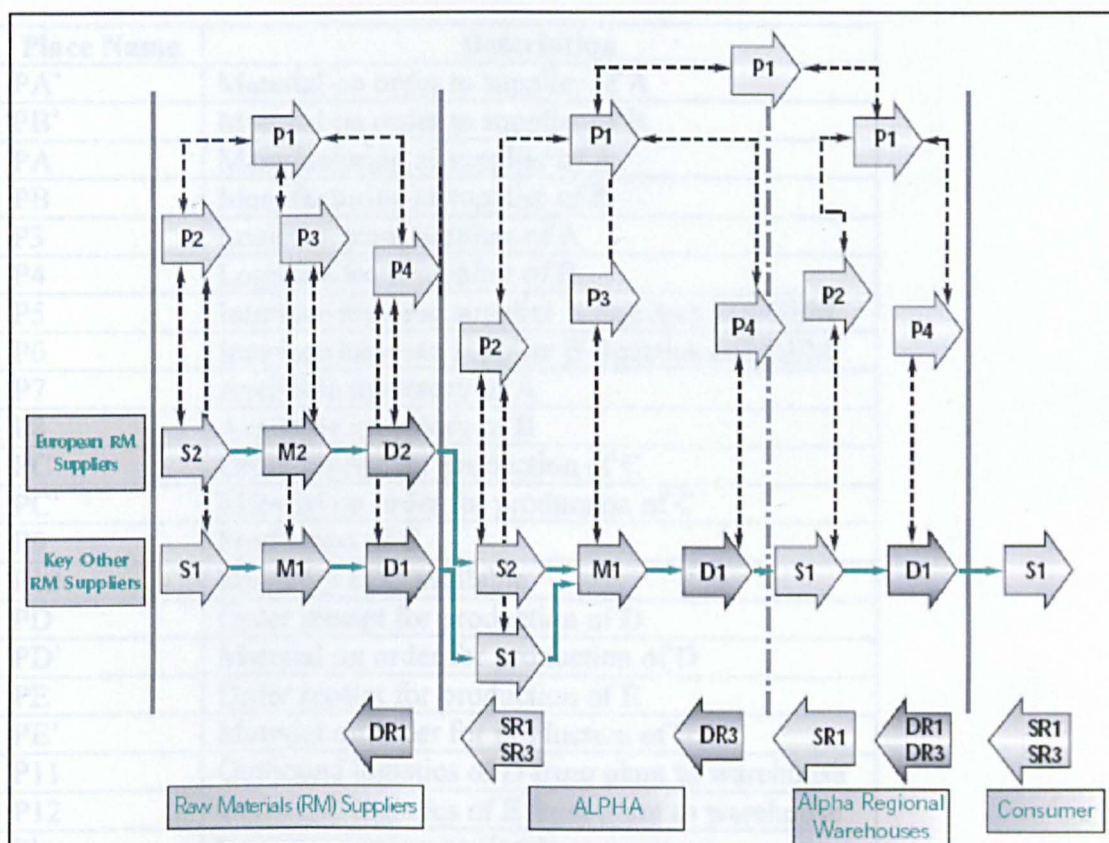


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## Appendix A: The SCOR Model Process Map



Transition Name	Description
1A	Start of manufacturing of A
1B	Start of manufacturing of B
1C	Triggering by supplier of A
1D	Triggering by supplier of B
2A	Ordering from supplier of A
2B	Ordering from supplier of B
2C	Replenish stock for interfaces with supplier of A
2D	Replenish stock for interfaces with supplier of B
3A	Triggering production of C
3B	Triggering production of C parts production
3C	Production of C
3D	Trigger for assembling of D

## **Appendix B: The Interpretation of Acronyms in the Petri net**

<b>Place Name</b>	<b>Description</b>
PA'	Material on order to supplier of A
PB'	Material on order to supplier of B
PA	Manufacturing at supplier of A
PB	Manufacturing at supplier of B
P3	Logistics from supplier of A
P4	Logistics from supplier of B
P5	Interface between supplier A logistics and OEM
P6	Interface between supplier B logistics and OEM
P7	Available inventory of A
P8	Available inventory of B
PC	Order receipt for production of C
PC'	Material on order for production of C
P9	Production of C
P10	Inventory of C available
PD	Order receipt for production of D
PD'	Material on order for production of D
PE	Order receipt for production of E
PE'	Material on order for production of E
P11	Outbound logistics of D from plant to warehouse
P12	Outbound logistics of E from plant to warehouse
Plog	Logistics carriers available
P13	Assembling of D from inventory of C
P14	Assembling of E from inventory of C
P16	Finished goods inventory of D at warehouse
P17	Finished goods inventory of E at warehouse
P15	Back order for D ready
P18	Back order for E ready
P19	Customer order for D ready
P20	Customer order for E ready

<b>Transition Name</b>	<b>Description</b>
tA	Start of manufacturing of A
tB	Start of manufacturing of B
t1	Processing by supplier of A
t2	Processing by supplier of B
t3	Transportation from supplier of A
t4	Transportation from supplier of B
t5	Paper work for interfaces with supplier of A
t6	Paper work for interfaces with supplier of B
tC	Trigger for production of C
t7	Manufacturer of C starts production
t8	Processing of C
tD	Trigger for assembling of D

tE	Trigger for assembling of E
t9	End of assembling of D from C
t10	End of assembling of E from C
t11	Outbound logistics of D
t12	Outbound logistics of E
t13	Assembling of D
t14	Assembling of E
t15	Customer order for D served
t16	Customer order for E served
t17	Arrival of order for D
t18	Arrival of order for E

## **Appendix C: Case Study Questionnaire**

The following is a summary of questions within the case study questionnaire:

### **Company Background:**

1. Company name
2. Location
3. Respondent name and job title
4. Annual turnover
5. Number of employees

### **Product:**

6. Product range
7. Daily production volume for each product and in total
8. Average price per product

### **Production and Scheduling:**

9. Production process
10. Process time
11. Quality system
12. Inventory level / Stock buffer within the production process
13. Cost per inventory unit
14. Approximate rate for inventory cost centre: interest on capital cost, storage, depreciation & obsolescence, opportunity cost
15. Order frequency
16. Production scheduling process
17. Production scheduling system
18. Demand forecast system
19. Material management system

### **Materials Supply:**

20. Number of main parts procure
21. Sourcing policy

22. Supplier(s)
23. Average price per part
24. Quality system
25. Order frequency
26. The supply mechanism(s)
27. Delivery batch size
28. Delivery frequency
29. Communication system(s) used to facilitate the supply process
30. Type of information used to facilitate the supply process, from and to suppliers;  
frequency of communication

Product Delivery:

31. Customers
32. Cost per delivery
33. Order frequency
34. Delivery distance
35. Transit time
36. Stockout incidents: frequency and number of backorders
37. Communication system(s) used to facilitate the delivery process
38. Type of information used to facilitate the delivery process, from and to  
customers; frequency of communication



## Appendix D: Daily Call In (DCI) Screenshot for SC A and B

CMMSAAIA		SUPPLIER RELEASE - 1		07/02/02 14:19:21		PLT 02641 JH	
==>							
PART: 1X43- 13W029-CJ		SUPP: M4EAA		830/862 (P/S): S			
PROG START DATE: 04/02/02		PROG NO. 661-34		Send (F,R): _		Process Status: S	
Date	TW % Adj	Quantity	Cum	Pend Amnd:	Amnd Ty	pe:	Strik Prot:
-----	- - -	-----	-----	Ship Freq:	11	Final Rlse:	
PRIOR		0	2969	Part Desc:	HD/LP ASY	W INTG FRT TRN	
70202		0	2969	Supplier:	HELLA MFG	LTD	
80202		0	2975	Issue Dte:	7/2/02	Thcknss:	0.0000
90202		0	2975	Pct Bus:	100	Width:	0.000
100202		0	2975	Part Stat:	C	Length:	0.00
110202		0	2980	R/F/G: RF	7 K02	T&G:	
120202		0	2986	Ship/Del:	S	Stl Comm:	
130202		0	2989	Trn Dy/Sr:	0.9	Thck Dsc:	
140202		0	2999	862 Code:	D	S/B:	
150202		0	3006	Last No:	6332	18 PO. No.:	HD5778
160202		0	3006	Last Date:	6/2/02	Rel Type:	A
170202		0	3006	Last Qty:	33	Buyer Name/Phone #	
180202		0	3011	Cum Rec+IT	3263	N D TAYLOR	
190202		0	3022			-204471	
200202		0	3064	Ship To:		Bill To:	02641

## Appendix E: An example of TLS Information for SC A and B

Location	CSO Vin	Seq. No.	CARIN	Engine	Country	Moonroof?	Colour	Hand of Drive	Model Year
TLS	1329042	7915	289726	2.0LT	FRANCE		QUART	LH	2002
TLS	1346359	7916	289944	2.5LT	AMERIC	M	TOPAZ	LH	2003
TLS	1334460	7917	289824	2.0LT	AUSTRA	M	CARNI	RH	2002
TLS	1339824	7918	289877	3.0LT	BRITAI		CARNI	RH	2002
TLS	1346389	7919	289862	2.5LT	AMERIC	M	BRITS	LH	2003
TLS	1345420	7920	289783	2.5LT	AMERIC	M	TOPAZ	LH	2003
TLS	1340731	7921	289937	2.5LT	BRITAI		PLATI	RH	2002
TLS	1346390	7922	289857	2.5LT	AMERIC	M	BRITS	LH	2003
TLS	1346391	7923	289927	2.5LT	AMERIC	M	BRITS	LH	2003
TLS	1329456	7924	289825	2.0LT	FRANCE		QUART	LH	2002
TLS	1351714	7925	289020	3.0LT	BRITAI	M	ANTHR	RH	2002
TLS	1346400	7926	289977	2.5LT	AMERIC	M	BRITS	LH	2003
TLS	1340752	7927	289835	2.5LT	BRITAI		ZIRCO	RH	2002
TLS	1346402	7928	289671	2.5LT	AMERIC	M	BRITS	LH	2003
TLS	1345421	7929	289844	2.5LT	AMERIC	M	TOPAZ	LH	2003
TLS	1330171	7930	290079	2.5LT	BELGIU		BRITS	LH	2002
TLS	1346403	7931	289909	2.5LT	AMERIC	M	BRITS	LH	2003
TLS	1345956	7932	289872	3.0LT	AMERIC	M	QUART	LH	2003
TLS	1340764	7933	289871	2.5LT	BRITAI		TOPAZ	RH	2002
TLS	1346404	7934	289979	2.5LT	AMERIC	M	BRITS	LH	2003
TLS	1346405	7935	289628	2.5LT	AMERIC	M	PH-RE	LH	2003
TLS	1340768	7936	289915	2.5LT	BRITAI		PLATI	RH	2002
TLS	1346410	7937	289935	2.5LT	AMERIC	M	PLATI	LH	2003
TLS	1346016	7938	289882	3.0LT	AMERIC	M	TOPAZ	LH	2003
TLS	1335583	7939	289815	3.0LT	ITALY		QUART	LH	2002
TLS	1346017	7940	289727	3.0LT	AMERIC	M	TOPAZ	LH	2003
TLS	1346418	7941	289740	2.5LT	AMERIC	M	PLATI	LH	2003
TLS	1340593	7942	289810	3.0LT	AUSTRI		BRITS	LH	2002
TLS	1346019	7943	289914	3.0LT	AMERIC	M	TOPAZ	LH	2003
TLS	1345422	7944	289897	2.5LT	AMERIC	M	TOPAZ	LH	2003

## Appendix F: An example of CAT-3 Information for SC C

Car Model	Nissan Line	Chassis Number	Forecast TNC	Production Time	Front WIC	Rear WIC	Trim Colour	JCA Line	Build Num	Build Seq
P121	1	133228	200309010002	01/09/2003 07:06	CA	CC	G	1	1	1
P121	1	133229	200309010004	01/09/2003 07:09	CA	CC	G	1	1	2
P121	1	133230	200309010006	01/09/2003 07:12	L4	LV	G	1	1	3
P121	1	133231	200309010008	01/09/2003 07:15	CG	CA	Z	1	1	4
P121	1	133232	200309010010	01/09/2003 07:18	CA	CC	G	1	1	5
P121	1	133233	200309010012	01/09/2003 07:21	S9	SQ	G	1	1	6
P121	1	133234	200309010014	01/09/2003 07:24	L4	LB	G	1	1	7
P121	1	133235	200309010016	01/09/2003 07:27	L4	LV	G	1	1	8
P121	1	133236	200309010018	01/09/2003 07:30	L3	LV	G	1	1	9
P121	1	133237	200309010020	01/09/2003 07:33	S5	SQ	G	1	1	10
P121	1	133238	200309010022	01/09/2003 07:36	CG	CC	G	1	1	11
P121	1	133239	200309010024	01/09/2003 07:38	L1	LV	Z	1	1	12
P121	1	133240	200309010027	01/09/2003 07:43	CH	CC	G	1	2	1
P121	1	133241	200309010029	01/09/2003 07:46	L3	LB	Z	1	2	2
P121	1	133242	200309010031	01/09/2003 07:49	L1	LV	Z	1	2	3
P121	1	133243	200309010033	01/09/2003 07:52	L4	LV	Z	1	2	4
P121	1	133244	200309010035	01/09/2003 07:55	L3	LB	Z	1	2	5
P121	1	133245	200309010037	01/09/2003 07:58	CG	CA	G	1	2	6
P121	1	133246	200309010039	01/09/2003 08:01	CG	CC	G	1	2	7
P121	1	133247	200309010041	01/09/2003 08:04	CA	CC	G	1	2	8
P121	1	133248	200309010043	01/09/2003 08:07	CA	CC	G	1	2	9
P121	1	133249	200309010045	01/09/2003 08:09	CA	CC	G	1	2	10
P121	1	133250	200309010047	01/09/2003 08:12	L3	LV	G	1	2	11
P121	1	133251	200309010049	01/09/2003 08:15	L3	LV	G	1	2	12
P121	1	133252	200309010052	01/09/2003 08:20	L3	LV	Z	1	3	1
P121	1	133253	200309010054	01/09/2003 08:23	LB	LP	G	1	3	2
P121	1	133254	200309010056	01/09/2003 08:26	CG	CC	G	1	3	3

**Appendix G: An example of WRA for SC C**

PartNumber	ForecastQuantity	StartDate	StartTime	StartShift	DurationDays	DurationHours	DurationShifts
370113LGCA	2	08/09/2003		1	0	0	1
370113LGCA	1	10/09/2003		1	0	0	1
370113LGCA	1	11/09/2003		2	0	0	1
370113LGCA	1	15/09/2003		1	0	0	1
370113LGCA	1	15/09/2003		1	0	0	1
370113LGCA	1	15/09/2003		2	0	0	1
370113LGCA	1	16/09/2003		2	0	0	1
370113LGCA	1	17/09/2003		2	0	0	1
370113LGCA	1	18/09/2003		2	0	0	1
370113LGCA	1	19/09/2003		1	0	0	1
370113LGCA	1	22/09/2003		2	0	0	1
370113LGCA	2	23/09/2003		2	0	0	1
370113LGCA	1	24/09/2003		1	0	0	1
370113LGCA	1	24/09/2003		2	0	0	1
370113LGCA	1	25/09/2003		2	0	0	1
370113LGCA	1	26/09/2003		2	0	0	1
370113LGCA	1	29/09/2003		2	0	0	1
370113LGCA	1	30/09/2003		2	0	0	1
370113LGCA	1	01/10/2003		1	0	0	1
370113LGCA	1	01/10/2003		2	0	0	1
370113LGCA	1	02/10/2003		2	0	0	1
370113LGCA	1	03/10/2003		1	0	0	1
370113LGCA	1	03/10/2003		2	0	0	1
370113LGCB	4	08/09/2003		1	0	0	1
370113LGCB	3	08/09/2003		2	0	0	1
370113LGCB	2	09/09/2003		1	0	0	1
370113LGCB	4	09/09/2003		2	0	0	1
370113LGCB	2	10/09/2003		1	0	0	1
370113LGCB	3	10/09/2003		2	0	0	1
370113LGCB	4	11/09/2003		1	0	0	1
370113LGCB	2	11/09/2003		2	0	0	1
370113LGCB	4	12/09/2003		1	0	0	1

## Appendix H: SC A Inventory Carrying Cost without 3rd tier Supplier

<b>SC A Inventory Carrying Cost (without 3rd tier supplier)</b>					
Average SC Inventory Carrying Cost Per Month = £73.73					
Average SC Inventory Carrying Cost Per Unit = £0.01					
		Inventory Carrying Cost			
Cost Centre:	% of Inventory Value	Runner	Repeater	Stranger	
		Sand Leather (ADX)	Char Leather (LEG)	Heritage Leather (ADY)	
Interest on capital cost	7.00%	per year	£31.31	£22.59	£5.65
Storage	3.00%	per year	£13.42	£9.68	£2.42
Obsolescence and depreciation	6.00%	per year	£26.84	£19.37	£4.84
Opportunity cost	10.00%	per year	£44.73	£32.28	£8.07
Total Inventory Carrying Cost Per Month =		£116.31	£83.92	£20.97	
Inventory Qty Per Month =		8,941	8,670	2,842	
Inventory Carrying Cost Per Unit =		£0.01	£0.01	£0.01	
Inventory Type	Runner: Sand Leather (ADX)			Inventory Value	
	Inventory Level	Avrg Daily Volume	Cost Per Unit		
OEM RM stock level	0.00		£750.00	£0.00	
1st tier FG stock level	0.00	80.90	£750.00	£0.00	
1st tier RM stock level	1.82		£20.00	£2,941.00	
2nd tier FG stock level	1.50		£20.00	£2,427.00	
	3.32		Total Inventory Value =	£5,368.00	
Inventory Type	Repeater: Char Leather (LEG)			Inventory Value	
	Inventory Level	Avrg Daily Volume	Cost Per Unit		
OEM RM stock level	0.00		£750.00	£0.00	
1st tier FG stock level	0.00	40.10	£750.00	£0.00	
1st tier RM stock level	3.33		£20.00	£2,670.00	
2nd tier FG stock level	1.50		£20.00	£1,203.00	
	4.83		Total Inventory Value =	£3,873.00	
Inventory Type	Stranger: Heritage Leather (ADY)			Inventory Value	
	Inventory Level	Avrg Daily Volume	Cost Per Unit		
OEM RM stock level	0.00		£750.00	£0.00	
1st tier FG stock level	0.00	4.20	£750.00	£0.00	
1st tier RM stock level	10.02		£20.00	£842.00	
2nd tier FG stock level	1.50		£20.00	£126.00	
	11.52		Total Inventory Value =	£968.00	



## Appendix I: SC B Inventory Carrying Cost without 3<sup>rd</sup> tier Supplier

SC B Inventory Carrying Cost (without 3rd tier supplier)					
Average SC Inventory Carrying Cost Per Month = £22.33					
Average SC Inventory Carrying Cost Per Unit = £0.0011					
Cost Centre:	% of Inventory Value		Inventory Carrying Cost		
			Runner Kimono White (KW)	Repeater Charisma Black (CB)	Stranger Generic Spice (GS)
Interest on capital cost	9.00%	per year	£15.63	£3.06	£2.84
Storage	3.00%	per year	£5.21	£1.02	£0.95
Obsolescence and depreciation	6.00%	per year	£10.42	£2.04	£1.90
Opportunity cost	10.00%	per year	£17.37	£3.39	£3.18
Total Inventory Carrying Cost Per Month =			£48.63	£9.51	£8.85
Inventory Qty Per Month =			56,044	9,336	6,847
Inventory Carrying Cost Per Unit =			£0.00	£0.00	£0.00
Inventory Type	Runner: Kimono White (KW)			Inventory Value	
	Inventory Level	Avrg Daily Volume	Cost Per Unit		
OEM RM stock level	0.00		£36.70	£0.00	
1st tier FG stock level	0.00	484.29	£36.70	£0.00	
1st tier RM stock level	2.02		£1.46	£1,424.44	
2nd tier FG stock level	0.93		£1.46	£659.68	
	2.95			Total Inventory Value =	
				£2,084.12	
Inventory Type	Repeater: Charisma Black (CB)			Inventory Value	
	Inventory Level	Avrg Daily Volume	Cost Per Unit		
OEM RM stock level	0.00		£36.70	£0.00	
1st tier FG stock level	0.00	34.52	£36.70	£0.00	
1st tier RM stock level	5.77		£1.46	£290.64	
2nd tier FG stock level	2.32		£1.46	£116.76	
	8.09			Total Inventory Value =	
				£407.40	
Inventory Type	Stranger: Generic Spice (GS)			Inventory Value	
	Inventory Level	Avrg Daily Volume	Cost Per Unit		
OEM RM stock level	0.00		£36.70	£0.00	
1st tier FG stock level	0.00	4.95	£36.70	£0.00	
1st tier RM stock level	49.63		£1.46	£358.68	
2nd tier FG stock level	2.83		£1.46	£20.43	
	52.45			Total Inventory Value =	
				£379.11	
Xchange rate (Feb 03) =	1.5074				
Euro	GBP				
€ 55.32	£36.70				
€ 2.20	£1.46				
€ 2.10	£1.39				

**Appendix J:**

Conference Paper

Coleman, J.; Khoo, C.; Lyons, A. and Kehoe, D. (2002) "The Significance of Schedule Stability in e-Enabled Supply Chains", *Proceedings of the Production and Operations Management Society Conference*, San Francisco, April 2002

Please refer to the next page

# **The Significance of Schedule Stability in e-Enabled Supply Chains**

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## ***Abstract***

In their work on the Future Supply Innovations (FUSION) project at the University of Liverpool, the authors have been engaged in action research at a mid-volume manufacturer of luxury cars and at several of its key component and module suppliers. The premise for the study was to identify and create the necessary pre-conditions to develop a prototype of an e-enabled supply chain. The prototype was to be used to assess the feasibility of providing web-enabled delivery triggers and final assembly schedules to first and second tier suppliers upstream of the vehicle assembly plant.

In this paper, the authors describe the FUSION project, suggest an operational design for the e-enablement of an automotive supply chain and explore the consequences of final assembly schedule stability on customer service and on plant and supply chain performance.

**Keywords:** Automobile Industry, E-commerce, Schedule stability, Supply Chain.



## Introduction

One of the most sophisticated applications of e-commerce to supply chain operations is envisaged by many within the world's automobile industry: -

**... "A few quick clicks on the website, and the customer has chosen his perfect model, with the right engine, personalised in-car options, colour and trim. His order information has been instantaneously transmitted from the manufacturer's web-site to suppliers, logistics partners and the assembly plant. Commodity deals are struck in an electronic market place, and components, assemblies and systems very quickly processed directly in-line with end customer demand. Just two weeks (reducing to 3 days?) after the order has been placed, the vehicle is delivered to the customer's door"...**

**(Automotive News Europe, 2000)**

This is not quite reality, but a dream that is gradually being realised as vehicle manufacturers work out their e-business strategies. A well-publicised trial system known as ConsumerConnect allowed Ford Focus, Taurus and Windstar customers in Canada to order from a limited range. General Motors has established a network integrating the customer to the supply chain. This involves building cars and trucks to customer preferences. (Pepper, 2000).

Electronic market places are also becoming more established. COVISINT took shape in late 1999, and is a vertical hub sponsored by the largest US vehicle manufacturers GM and Ford and the German-US conglomerate of Daimler-Chrysler. The dimensions of the project are impressive, and plans for the incorporation of Honda and Toyota are under way (Doherty, 2000).

In addition there are innovative examples of business-to-business (B2B) exchange of schedule information (Lyons and Kehoe 2001), and Enterprise Resource Planning

(ERP) systems are being developed to communicate more effectively with each other using a common protocol (Murillo, 2001).

Putting these pieces together still represents a significant challenge for the world's vehicle manufacturers, and is one whose potential rewards are considered too important to be ignored (Scheele, 1999).

Barriers are well founded: Product simplicity is one area that is being addressed. Ford targets a reduction in configurations for the average range of cars from several millions to approximately 1-2 millions. (This still compares with a typical Japanese car with fewer than 1 million) (Williams, 1994). Web transaction speed, computational capacity and standardisation of communication protocol are other issues.

However, one of the biggest hurdles at a case study company – a US owned, UK based luxury car maker - and the **issue to which this paper is primarily addressed**, is the change required in manufacturing policy. To explain, much has been written about Just In Time (JIT) manufacture, which pulls products and components in line with customer demand (Womack, Jones 1990). This concept is significant in the auto. industry, and has been developed to the extent where vehicle assemblies (e.g. seats, cockpits, front-end systems, powertrain) are produced by suppliers Just-In-Time to be assembled into the vehicle (Sequenced-in-line-supply (SILS) – the case study company currently have a SILS arrangement with 17 of its suppliers). However, once we leave the relative confines of vehicle assembly, and first tier final assembly satellite plants, the predominant manufacturing policy at play in the up-stream production process (where the majority of value is added) is Make-To-Stock (MTS). This paper explores how vehicle assembly schedule stability, and schedule adherence

at the case study company require suppliers to react to demand triggers from stock. It then explores a prototype e-business solution, which acts to provide open access to more reliable demand information at suppliers.

The following sections present the theoretical constructs that underpin this paper.

### **Schedule stability**

Successful production smoothing, along with schedule stability and high levels of schedule adherence are central to the Toyota Production System (Monden, 1997). Shigeo Shingo (1988) showed how schedule stability allowed the concept of JIT to be embedded deeply into the supply chain resulting in a net reduction in inventory. The associated benefits of 'non' or low stock production in terms of reducing storage and obsolescence costs and improving cash flow are well-documented (Schonberger, 1986. Womack and Jones, 1990)

### **Industrial Dynamics**

Insight into high inventory and the benefits of both schedule stability and e-enabled supply chains can be found in the laws of Industrial Dynamics. Originally defined by Forrester (1958) and since developed by Towill et al (Towill, 1992, 1994). the Forrester effect demonstrates that demand changes at source tend to be amplified as orders are fed between echelons of a supply chain. Hence suppliers further up the chain would feel relatively minor demand changes at a Vehicle Manufacturer much more severely. In order to reduce the chance of stock-outs, these suppliers tend to hold higher levels of safety stock (Towill, 1996). Hence, demand stability is important. The amplification effect can also be dampened by earlier receipt of accurate demand information. More accurate forecasting or faster transmission of

known demand information (via B2B links) can both achieve this. However, the most powerful offset of the Forrester effect occurs when raw market demand information is released simultaneously to all echelons in the supply chain. Using the Massachusetts Institute of Technology Beer Game as an example supply chain, Mason Jones and Towill (1997) conclude improvements of between 1.3:1 and 2.3:1 for demand amplification, stock depletion and demand response time.

### **Lean Vs Agile**

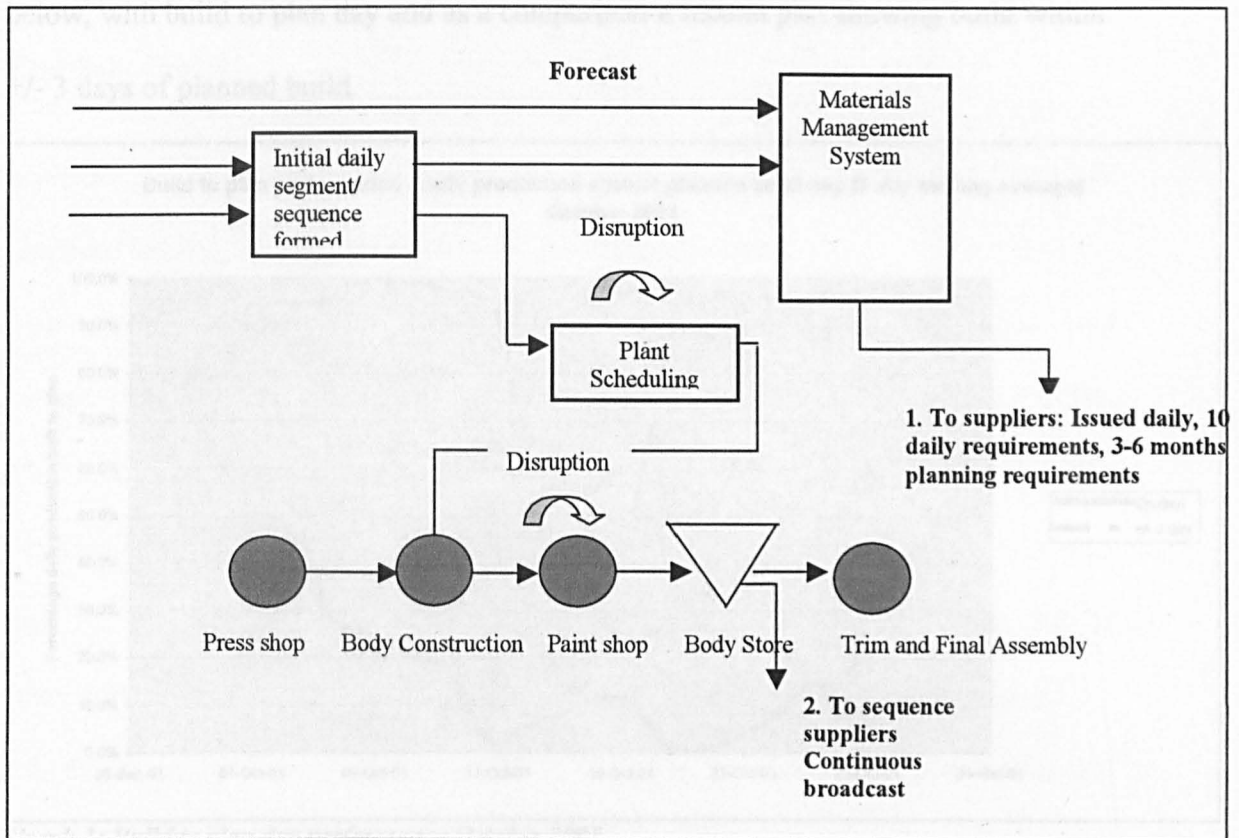
The Toyota Production System typifies what has become known as 'lean'. Keeping schedules fixed reduces uncertainty within the supply chain, helping to allow wasteful inventory to be reduced. Other significant cost savings follow on. More recently, authors have argued that the exemplary lean supply chains are those where all aspects of the business support the lean approach. Variety reduction, design-for-manufacture and increasing market volume are all quoted as examples that support Toyota's lean strategy (Womack and Jones, 1990). It has been argued (Christopher 2000) that lean concepts work well where demand is relatively stable and hence predictable, and variety is low. Conversely, in those contexts where demand is volatile and the customer requirement for variety is high, a much higher level of *agility* is required.

In the context of this paper and the case study company, the customer demand for variety is high. Whilst initial research indicates that scope for greater schedule stability exists, the nature of the way in which the products compete means greater uncertainty in the supply chain, and hence solutions that off-set this uncertainty are desirable.

## Schedule stability and Schedule adherence at the case study company.

The study began by modelling the existing scheduling system, and a simplified

Input/Output diagram is presented in figure 1.

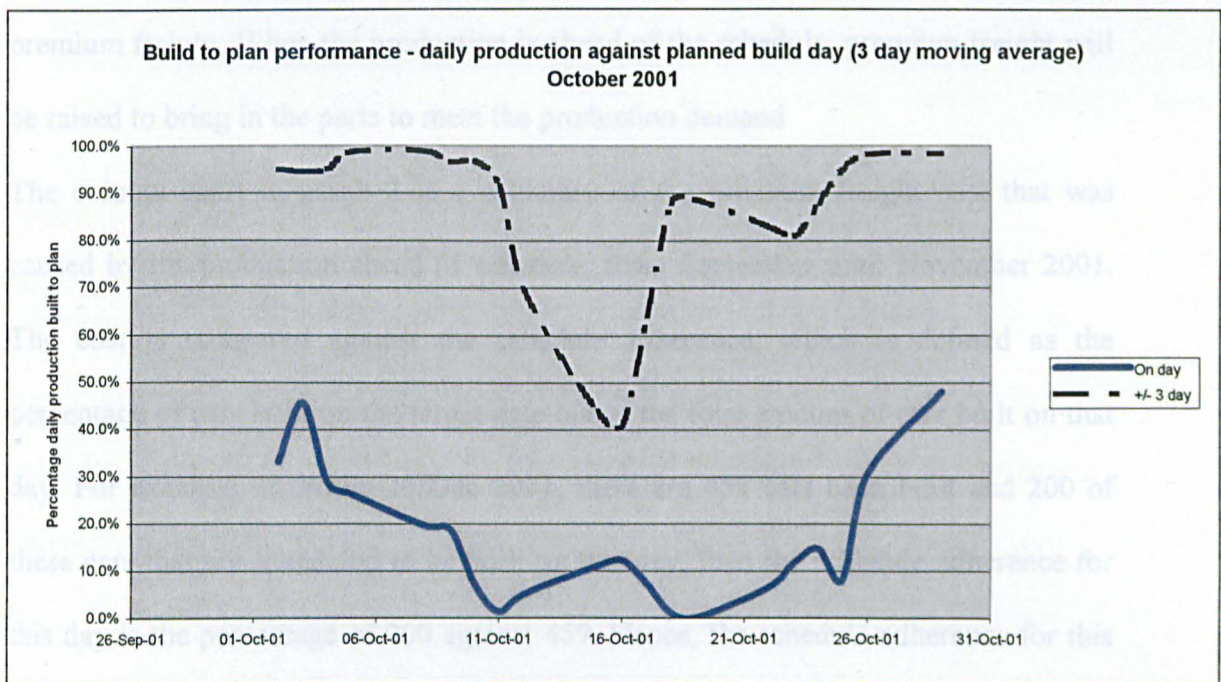


**Figure 1: Input/Output diagram of vehicle scheduling**

In figure 1 it can be seen that the two current demand triggers to suppliers are the daily schedule (1) that contains part demand for the next ten days in daily quantities, (followed by a longer time horizon in more tentative weekly and monthly requirements). In addition sequence suppliers receive a continuous broadcast (2) of requirements approximately 12 hours prior to launch of the vehicle onto the trim and final assembly line.



The next step in the study was to track the schedule adherence, and this was achieved with a three-month comparison of actual vehicle build day against planned build during the autumn of 2001. Because the majority of non-sequence suppliers deliver components with at least daily regularity, the main measure chosen with which to assess build accuracy was "Build to plan day". A sample graph for October is shown below, with build to plan day and as a comparison a second plot showing build within +/- 3 days of planned build.



**Graph 1: Build to plan day performance October 2001**

It can be seen that during this time period build to plan performance is low. It should be stated that there were peculiar circumstances during this time period that contributed to the performance and these factors have been accounted for in the analysis of the causes discussed below.

As may be expected, the supplier call-in schedules (based on planned build day) presented low levels of accuracy when compared to actual material requirements.

The study proceeded to attribute causes for the poor build to plan performance. Initial analysis shows that the most significant disruptions often occur before vehicles are released into body construction, and are related to unrealistic original segmentation and supply problems.

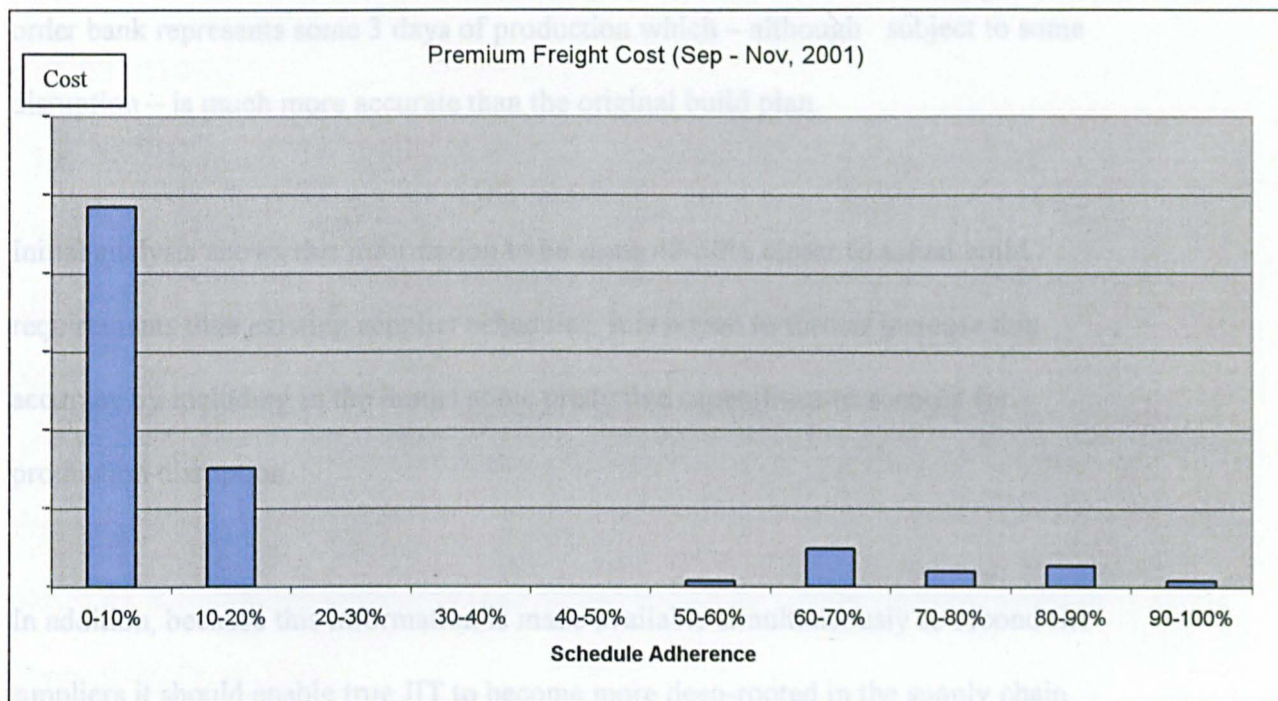
## **Study of effects of build to plan performance**

### **Premium Freight**

One of the effects of the schedule stability and schedule adherence is the cost of premium freight. When the production is ahead of the schedule, premium freight will be raised to bring in the parts to meet the production demand.

The column chart in graph 2 is a summary of the premium freight cost that was caused by the production ahead of schedule, from September until November 2001. The cost is compared against the schedule adherence, which is defined as the percentage of cars built on the target date out of the total amount of cars built on that day. For example, if on the 20 Dec 2001, there are 459 cars been built and 200 of these cars that are scheduled to be built on this day, then the schedule adherence for this day is the percentage of 200 against 459. Hence, the schedule adherence for this day is 43.57%. The chart illustrates that there is a negative relationship between the premium freight and the schedule adherence. Almost 85% of the cost comes from the day where the schedule adherence falls below 20%.





**Graph 2 : The Column Chart of Premium Freight v Schedule Adherence**

### **Inventory**

Another significant effect of build to plan performance is excess safety stock in the supply chain. Initial analysis at one key systems supplier indicates that within the environs of the vehicle assembly plant, and the final assembly plant of the systems supplier, inventory (including finished goods and supplier work-in-process) is very low - limited to approximately six hours production. However, analysis of the raw materials stock at the systems supplier shows between 5 and 10 days stock for the majority of components. The effects further up-stream at second and third tier suppliers will be investigated over the coming months.

### **B2B potential solutions**

The concept for prototype E-enabled supply chain is to release build information to suppliers and (as appropriate) second tier suppliers as soon as it becomes acceptably reliable. The system proposed gathers all orders already launched into build (i.e. between start of body construction and end of trim-and-final). (see figure 2) This



order bank represents some 3 days of production which – although subject to some disruption – is much more accurate than the original build plan.

Initial analysis shows this information to be some 40-50% closer to actual build requirements than existing supplier schedules. It is hoped to further increase this accuracy by including in the model some predictive capabilities to account for production disruption.

In addition, because this information is made available simultaneously to second tier suppliers it should enable true JIT to become more deep-rooted in the supply chain. Initial analysis is encouraging and it is hoped to develop the prototype further in the coming months.

## **Conclusions**

At a manufacturer of mid-volume luxury cars, the customer requirement for variety is high. Schedule adherence is currently low, and although great opportunities for improvement can and are being taken, instability and uncertainty are always likely to be more of an issue relative to a high volume low variety producer. It may be unrealistic to fix schedules as early, or to the degree of accuracy than those with a narrower product range. Cost may not be the overriding competitive criteria at a luxury car manufacturer but nevertheless the effects of such disruption have been shown to be considerable.

E-enabling the supply chain from the point at which the schedules become acceptably fixed seems, from initial analysis, to offer some very real business benefits to the case study company.

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**Appendix K:**

## Conference Paper

Khoo, C.W., Lyons, A.C. and Kehoe, D., "Supply Chain Performance Measurement",  
*Proceedings of the 18<sup>th</sup> International Conference on Computer-Aided Production  
Engineering*, Professional Engineering Publishing, March, 2003, pp. 279-288

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# Supply Chain Performance Measurement

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## SYNOPSIS

In the Future Supply Innovations (FUSION) project at the University of Liverpool, the authors have been engaged in action research at a luxury car assembly plant and several of its key components suppliers. The study is to identify and create the necessary pre-condition to develop a prototype of an e-enabled supply chain. One of the aims of this project is to develop a method to measure supply chain performance.

In this paper, the authors raise the interaction between the components and supply chain design, as well as the measurement metrics. A case study is included in this paper to illustrate the relationship between these three aspects.

## 1 INTRODUCTION

Measuring supply chain performance is no longer a new topic. There are many measurement approaches suggested by different researchers. There are three measures in Beamon's (1) approach: resource, output and flexibility. Gunasekeran et al (2) classified the measurement metrics into three levels (strategic, tactical and operational level), either financial or non financial, or both. Brewer and Speh (3) suggested using the balanced scorecard to measure supply chain performance. Even though there are so many different approaches to measure supply chain performance, one common fact is there is no one perfect measurement approach that can suit all supply chains.

The criteria to judge the success of a supply chain are varied. This paper seeks to explore a supply chain measurement approach suitable for the production of high volume, customised products such as cars and computers.

However, even within a mass-customised environment, it is impossible to have one single measurement method that will suit all the supply chains in this industry. The supply mechanisms of the components that built the end product are bound to be different. For example, the supply mechanism of the key components of a vehicle (e.g. seat and instrument panel) will be tighter and more sophisticated than the non-key components (e.g. label, coin holder). A different supply mechanism often means different measurement criteria are appropriate. The selection of measurement metrics for a specific supply chain design is discussed in this paper.

## **2 SUPPLY CHAIN DESIGNS AND MEASUREMENTS**

In the automotive industry, even though both the seat and the coin holder are components of the car, the supply chain structure for the seat is more complicated than the coin holder. In one of the UK luxury car assembly plants, the seats are supplied according to the final production sequence of the vehicle, an initiative sometimes called Sequenced In Line Supply (SILS), whereas, the coin holder is managed via a Kanban system. In SILS, the car assembly plant broadcasts the demand to the supplier, indicating the types of seats required and the sequence of fixing the seat onto the cars. There is a dedicated EDI system to broadcast the demand to the suppliers that supply sequenced components. Obviously, SILS is very different and more complicated than the Kanban system. This shows that the role of the component has to be taken into consideration when designing the supply mechanism.

Since there are different supply chain designs for different components, it is necessary to consider discrete performance measurement methods. The measurement should correspond to the supply chain structure. SILS is usually applied to key components, which have high variety and high cost. In SILS, the demand information broadcasted is to inform the suppliers about the type of component required and also the delivery sequence. Hence, it is very important to measure the OEM's production schedule adherence, which is the ability to produce according to schedule, as well as the delivery schedule adherence of the suppliers (i.e. the ability to deliver according to schedule). In order to make sure that the delivery sequence of components match with the production sequence, it is also important to measure the synchronisation level between the delivery sequence and the production sequence. The accuracy of demand information released by the OEM to the suppliers will also affect the performance of SILS. On the other hand, for the case under study, Kanban is normally applied to non-key components, with lower variety and value. Measuring schedule adherence and synchronisation accuracy are not as applicable to Kanban systems. Metrics like stockout level and delivery reliability are more suitable for measuring Kanban system performance.

However, differentiating the components according to their cost, importance and variety is a very basic classification method. There are other factors where the components can be further discriminated, such as the consumption rate, demand volatility and delivery distance. This also means that there will be more options of supply chain structure.

### 3 THE CASE STUDY

A case study has been carried out to examine the SILS supply mechanism of a UK-based luxury car assembly plant. As stated before, there are four elements that were considered to be important for suppliers in the performance of SILS - the production schedule adherence, the delivery schedule adherence, the synchronisation level and the material demand forecast accuracy. Measurements have been made on these metrics to assess the performance of SILS.

#### 3.1 The SILS Supply Chain Structure

Figure 1 illustrates the information flow between the car assembly plant and its suppliers. There are two EDI (Electronic Data Interchange) information flows – forecast A and forecast B. Forecast A contains materials demand information for the next ten days in daily quantities, (followed by a longer time horizon in more tentative weekly and monthly requirements). In addition, sequenced parts suppliers receive a continuous broadcast of forecast B approximately between 8 to 12 hours prior to launch of the vehicle onto the Trim and Final assembly line. Forecast B is effectively a queue of jobs before the Trim & Final process. The disruption of the job sequence in the Trim & Final process is very rare. Hence, the delivery sequence stated in forecast B always matches the actual material requirement in the Trim & Final process. The sequenced-part suppliers deliver the materials to the Trim and Final assembly line according to forecast B, which includes the parts required and the sequence of delivery.

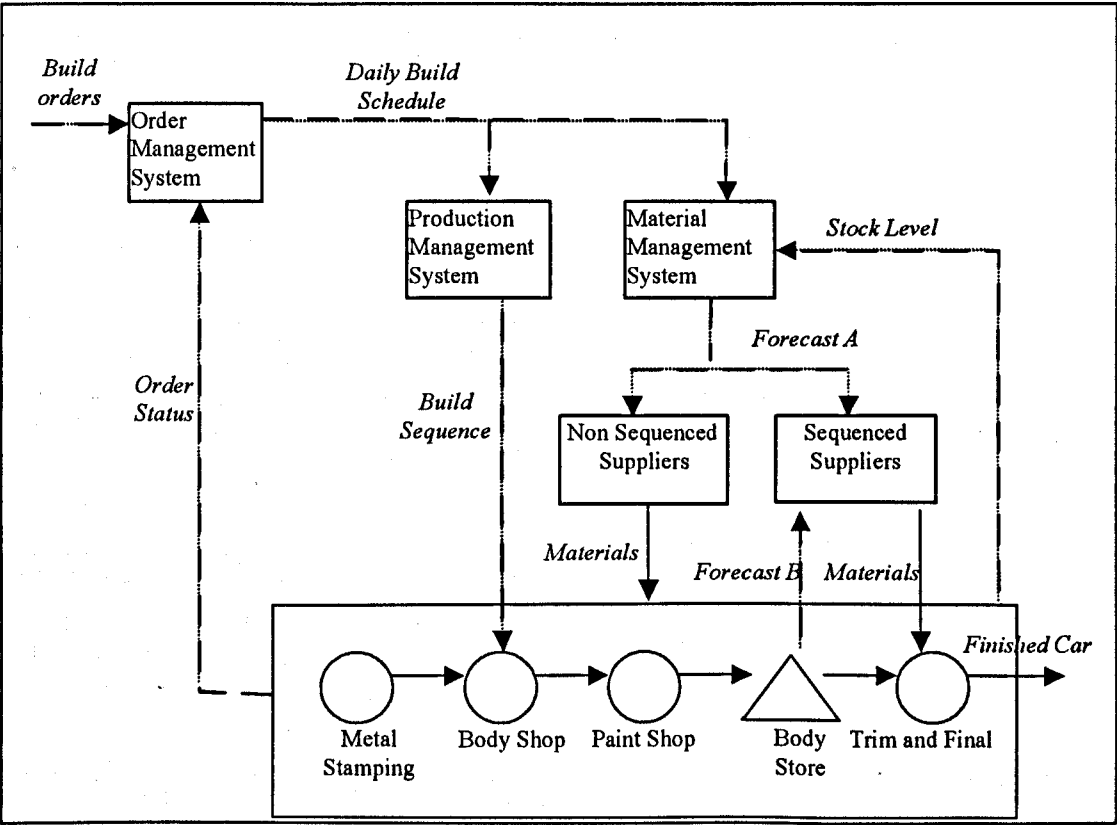


Figure1: The information flow between the car assembly plant and its suppliers

There is another information resource, which performs a similar task to forecast B (as a material demand forecast) and gives 7 days forecast of the production schedule – forecast C. It contains the specifications of the cars to be built. The receivers have to translate these specifications into material requirements, which they supply to the car manufacturer. For example, if forecast B indicates that 20 red-seat cars will be built on the 10 March 2002, then the seat supplier will be obliged to deliver 20 red seats on that day. Figure 2 illustrates how forecast B is generated. The production management system slices the WIP (Work in Progress) and committed orders within the production pipeline according to the daily build schedule. However, it is an informal material demand forecast. It is sent via email to a handful of sequenced-part suppliers, which were unable to operate with the demand uncertainty.

Table 1 provides a comparison of forecast A, B and C.

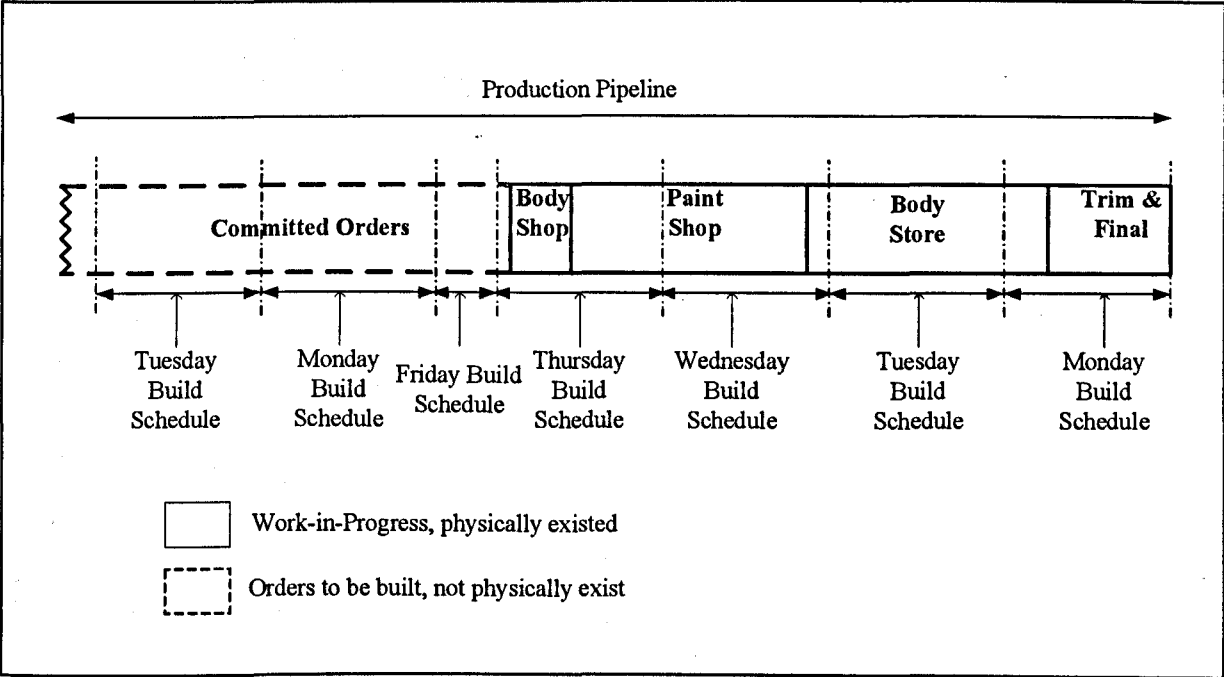


Figure 2: The slicing of WIP to generate forecast B

Features	Forecast A	Forecast B	Forecast C
Forecast Horizon	10 working days	8 – 12 hours, depends on the production rate and build schedule	5 – 7 days, depends on the WIP and committed orders
Generated by	Material Management System	Production Management System	Production Management System
Nature of information	Material demand forecast	Actual material demand in the Trim & Final process	Daily build schedule
Receiver	All suppliers	Sequenced-part suppliers	Some sequenced suppliers
Broadcast frequency	Daily (after production stops)	Continuous	Daily (after production stops)

Table 1: Comparison among the material demand forecasts



### 3.2 Material Demand Forecasts' Accuracy

In order to assess the accuracy of forecast A and C, graphs were constructed to compare the demand forecast of a type of front seat against the actual amount of cars fitted with that particular seat. The following are the explanations of the terms used in the graphs:

- "Actual" is the actual amount of cars that have been built with the monitored component fitted within that production day.
- "Day 1" is the forecast given 1 working day ahead. E.g. the "Day 1" forecast for 8 March is generated on 7th March evening.
- "Day 2" is the forecast given 2 working days ahead. E.g. the "Day 2" forecast for 8 March is generated on 6th March evening.
- "Day 3" is the forecast given 3 working days ahead. E.g. the "Day 3" forecast for 8 March is generated on 5th March evening.
- "Day 4" is the forecast given 4 working days ahead. E.g. the "Day 4" forecast for 8 March is generated on 4th March evening.
- "Day 5" is the forecast given 5 working days ahead. E.g. the "Day 5" forecast for 8 March is generated on 3rd March evening.

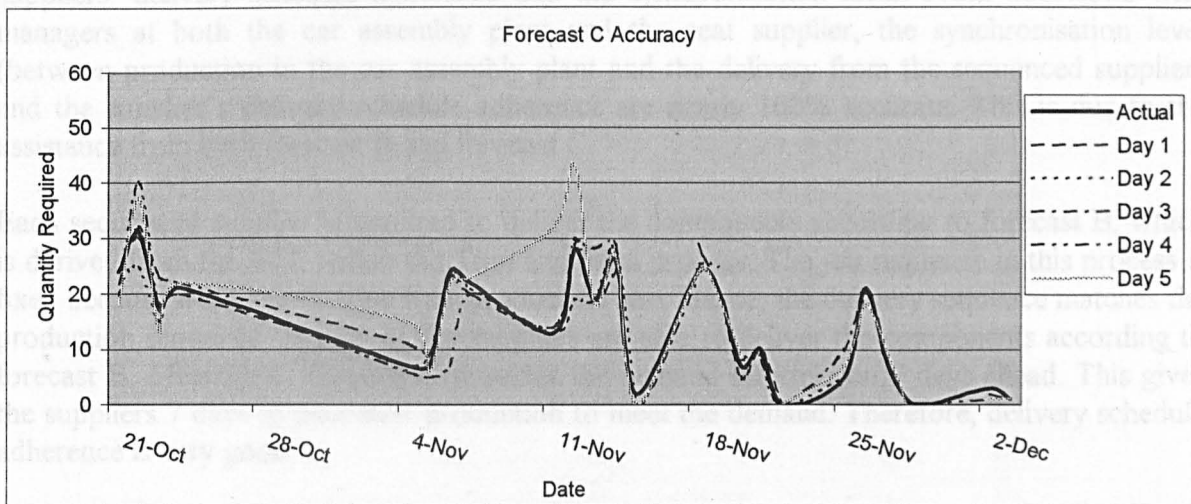


Figure 3: Forecast C analysis

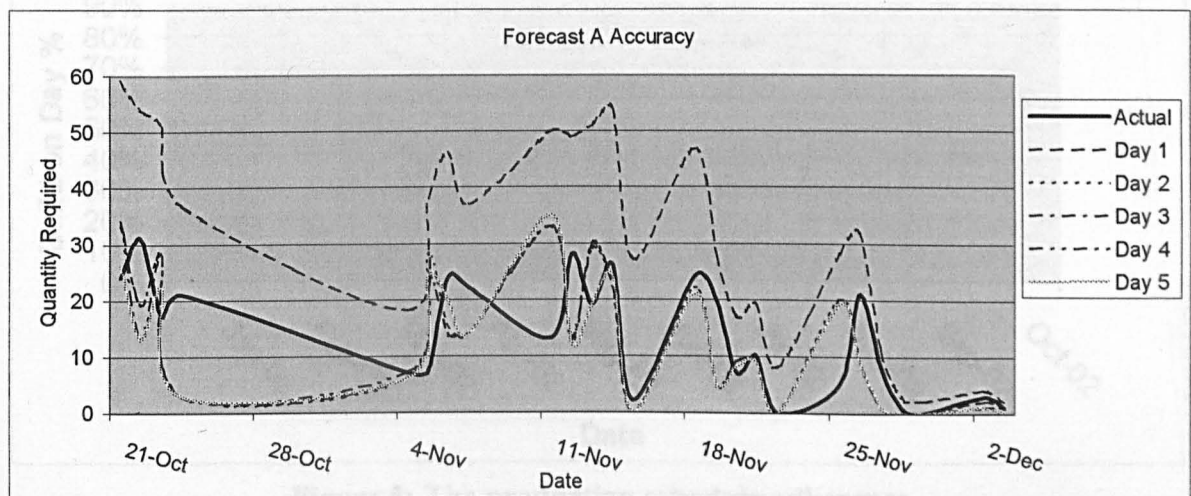


Figure 4: Forecast A analysis

By comparing the two graphs above, it can be seen that the demand forecast from C (the “Day 1” to “Day 7” lines) is closer to the actual consumption quantity. This shows that forecast C is more accurate than forecast A, even though A is the official demand forecast. The inaccuracy is due to the confusion and clashing of procedures between the material management system and the recording of production quantities.

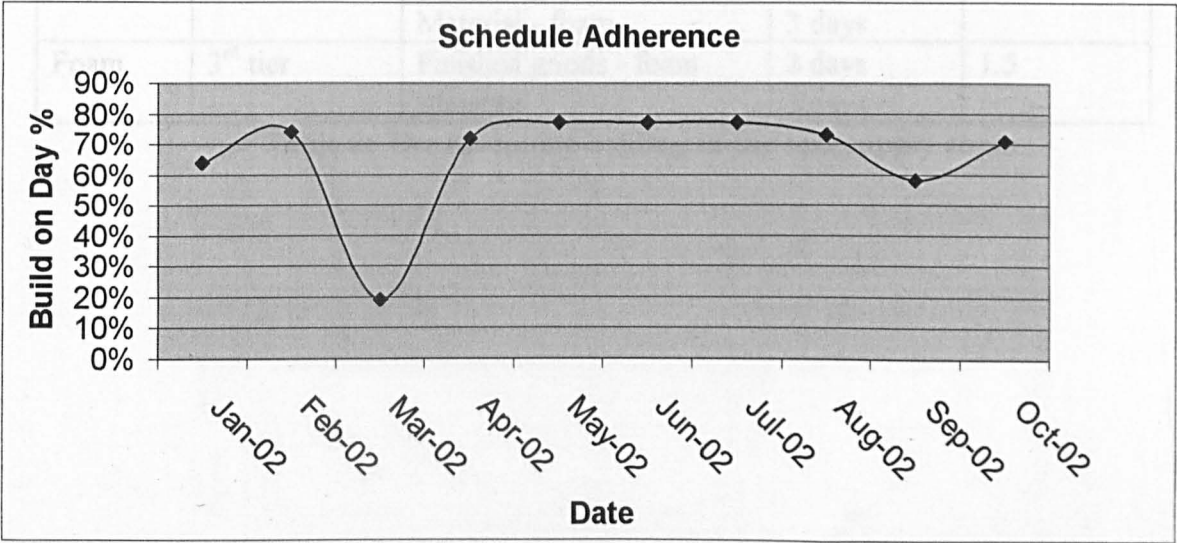
**3.3 Measuring the Production Schedule Adherence**

Figure 5 show the production schedule adherence of the car assembly plant. The “Build on Day %” measures the percentage of cars that are built according to the schedule in each month. The average Build On Day percentage is about 71% (exclude the Build on Day figure from March 02). This means that on average in each month, 71% of the cars are built on the same day to the planned schedule.

**3.4 The Delivery Schedule Adherence and the Synchronisation Level**

The volatile line pattern and the gaps between the forecast lines and the actual line in Figure 4 show that forecast A has a very low accuracy and reliability. However, this does not affect the suppliers’ delivery schedule adherence and the synchronisation level. From interviews with managers at both the car assembly plant and the seat supplier, the synchronisation level (between production in the car assembly plant and the delivery from the sequenced supplier) and the supplier’s delivery schedule adherence are nearly 100% accurate. This is due to the assistance from both forecast B and forecast C.

Each sequenced supplier is required to deliver the components according to forecast B, which is derived from the WIP within the Trim and Final process. The job sequence in this process is fixed because it is a continuous flow production line. Hence, the delivery sequence matches the production sequence, as long as the suppliers are able to deliver the components according to forecast B. Meanwhile, forecast C provides the demand information 7 days ahead. This gives the suppliers 7 days to plan their production to meet the demand. Therefore, delivery schedule adherence is very good.



**Figure 5: The production schedule adherence**

3.5 The Seat’s Supply Chain Performance

Figure 6 is the value stream map of the seat supply chain, from the 3<sup>rd</sup> tier supplier to the vehicle assembly plant. It shows the process to produce a seat, from the supply of foam for a headrest to the complete seat set fitted on the vehicle. The line drawn below the diagram is the throughput time for each process represented in the boxes above. The total supply chain throughput time is approximately 18 working days but the actual processing hour is about 28 hours, which is only 9.72% of the total throughput time. This is primarily due to the stock levels throughout the chain, as shown in Figure 6 and Table 2.

The suppliers are holding inventories, either in finished goods stocks or incoming material stock, as shown in Figure 3 and Table 2. Even though the vehicle assembly plant does not carry any sequenced components inventory, this does not means that the inventory has been reduced. In fact, the value stream mapping diagram and Table 2 show that the inventory has been consigned to suppliers. The seat manufacturer is able to assemble-to-order, according to forecast B. Therefore, there is no stock holding between the vehicle assembly plant and the seat manufacturer. However, there is inventory holding for the material, i.e. the headrests. The 2<sup>nd</sup> and 3<sup>rd</sup> tier suppliers also carry relatively high levels of both the material and finished goods inventories.

The demand amplification has been calculated and represented as the bullwhip coefficient (4) in Table 2. The seat manufacturer has the bullwhip coefficient of 1.0, which means there is no demand amplification. This is because the seats are assembled-to-order, according to forecast B. For the 2<sup>nd</sup> and 3<sup>rd</sup> tier suppliers, the demand has been amplified by 2.5 and 1.5 respectively. The bullwhip coefficient of 2.5 indicates that the output demand of the headrest supplier is 2.5 times more than the input demand.

Product	Supply Level	Stock Type	Stock Level	Bullwhip Coefficient
Seat	1 <sup>st</sup> tier	Material - headrest	1.5 days	1.0
Headrest	2 <sup>nd</sup> tier	Finished goods – headrest	2.5 days	2.5
		Material - foam	3 days	
Foam	3 <sup>rd</sup> tier	Finished goods - foam	2 days	1.5
		Material	5 days	

Table 2: The inventory holding in the seat supply chain

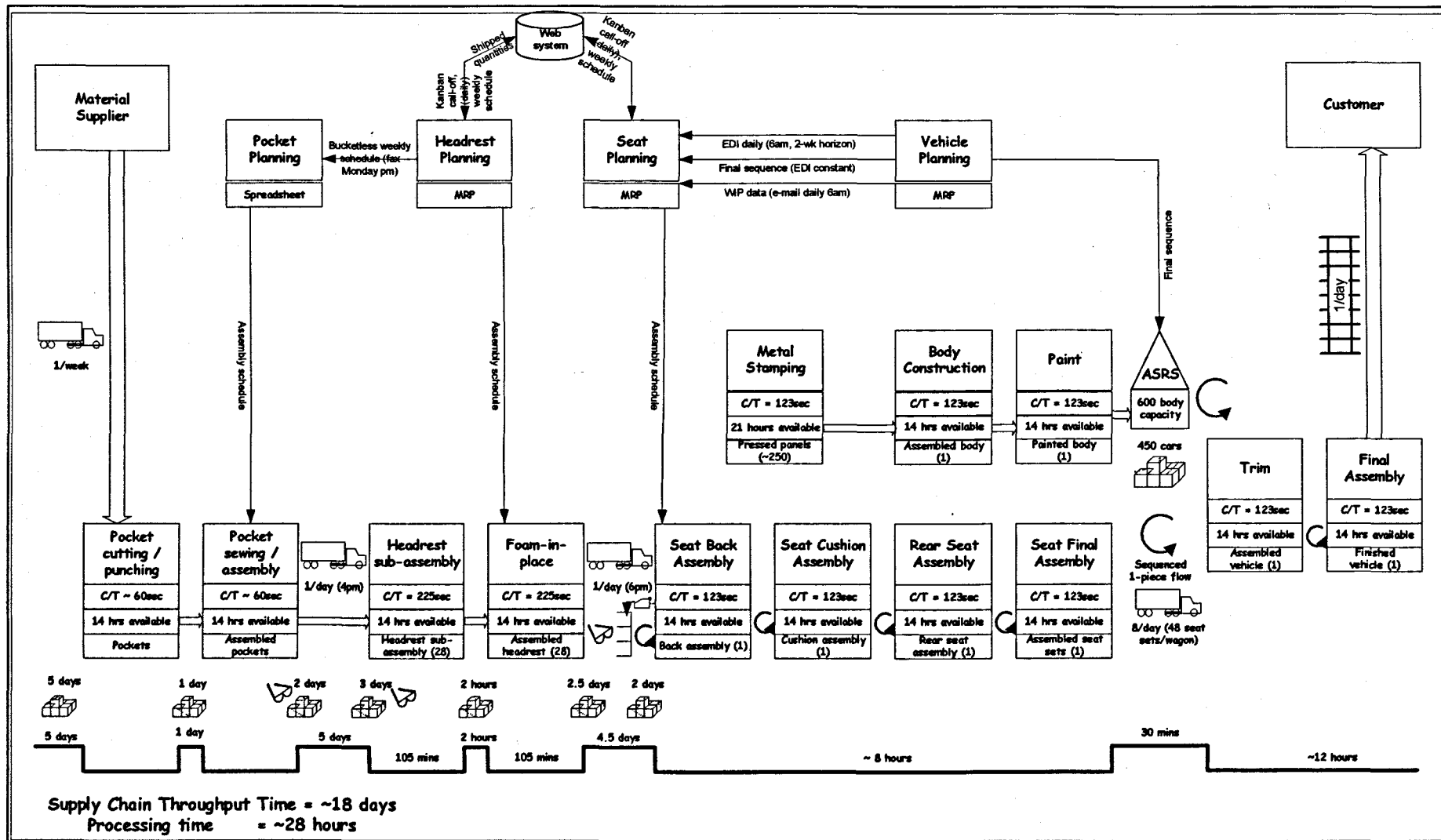


Figure 6: The seat supply chain value stream map

### **3.6 Case Study Conclusions**

Each of the production materials in this assembly plant are categorised into two types – sequenced and non-sequenced components. The sequenced components are those key components with high variety and order winning potential. Using the SILS method, the key components' stock level can be maintained at the minimum level. For instance, there are 384 types of front seats. The inventory cost will be very high if the car assembly plant has to keep material inventory for each seat type. Therefore, the management of the supply of those key components with SILS reduces the inventory cost.

In this case study, SILS is supported by three information systems – forecast A, B and C. The system that broadcasts forecast B is purpose built, just to transmit the demand information to sequenced suppliers. There are nearly 4000 part numbers used to build a car (5). It is impossible to supply all the components with SILS. Hence, the non-key components are managed by a Kanban system, which is cheaper and easier.

In lean thinking, costs tied up in inventory are considered as a waste. In order to reduce the inventory cost, one of the methods is to reduce demand uncertainty. In this case study, even though the official demand information (i.e. forecast A) has a low forecast reliability, forecast C manages to provide an alternative source of demand forecast with higher accuracy. However, the demand amplification through the supply chain still results in a higher stock of material and finished goods inventory. Sharing the raw demand data, with an emphasis on high accuracy and reliability, from the OEM throughout the supply chain is one of the solutions to eliminate demand uncertainty and amplification.

## **4 CONCLUSIONS**

Since there are different supply chain structures for different components, the metrics to assess supply chain performance have to be customised according to the design of the supply chain. A case study is included in this paper to illustrate the basic components classification in an automotive assembly plant, the supply chain structure for each component type, as well as the measurement of the supply chain for seat.

The case study shows how the nature and characteristics of components influence the supply chain structure. For economical and efficiency reasons, the design of a supply chain must take the component's importance, cost and variety into consideration. However, these are just the basic dimensions to classify the components. Further research is being carried out to investigate further classification dimensions.

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**Appendix L:**

## Conference Paper

Khoo, C.W., Lyons, A.C., Mondragon, A.C. and Kehoe, D.F. (2003) "Supply chain performance measurement for the automotive industry", *Proceedings of the 2<sup>nd</sup> International Workshop on Supply Chain Management and Information Systems*, Hong Kong, July 2004

Please refer to the next page

# SUPPLY CHAIN PERFORMANCE MEASUREMENT FOR THE AUTOMOTIVE INDUSTRY

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## Abstract

*The authors are from the FUSION (Future Supply Innovations) project at University of Liverpool. One of the project objectives is to develop a measurement approach to examine the performance of a supply chain, from top to bottom. There is a brief literature review on supply chain performance measurement methods. The paper also discusses some important issues in supply chain performance measurement. The measurement approach proposed by the FUSION team will also be included in the paper. This measurement approach is in scorecard format and it is specifically designed for the automotive industry. Following this will be an illustration of two case studies on supply chain performance measurement that have been carried out by the FUSION project team. The case studies involved a mid-volume luxury car manufacturer and a high volume car manufacturer, as well as their key component/module suppliers.*

**Keywords:** Performance Measurement, Supply Chain, Automotive Industry

## 1. Introduction

As Lapide [1] stated, there are a variety of adages that support performance measurements, such as "Anything measured improved", "What you measure is what you get", "You can't manage what you do not measure". In order to keep the supply chain performing according to the predetermined strategies and on track towards its improvement objectives, supply chain performance has to be assessed on a constant and consistent basis.

The FUSION (Future Supply Innovations) project at University of Liverpool aims to design and test information and materials flow architecture that will achieve total supply chain customisation and synchronous materials flow. This will involve the development of the means by which information can be relayed instantaneously to every participant within a multi-tier supply chain directly from the point of sale and the design of the physical system and ancillary architecture to rapidly transfer materials to

the point of manufacture and assembly. In order to achieve this aim, one of the objectives of this project is to develop a measurement approach that can examine the performance of supply chain, from top to bottom.

There are many different ways to define a supply chain. According to the Supply Chain Council, "It encompasses every effort involved in producing and delivering a final product or service, from the supplier's supplier to the customer's customer." while Franks (2000) [2] defines a supply chain as "the sequence of processes and activities involved in the complete manufacturing and distribution cycle; includes everything from product design through manufacturing and assembly and onto warehousing and distribution until the finished product is in the possession of the final owner." In this study, the definition of supply chain measurement is those methods that measure across organisational boundary. The available supply chain performance measurement methods can be grouped into two main categories:



- Overall measurement: This refers to measurement methods that measure different aspects of supply chain performance.
  - Holistic: The measurement approaches that measure supply chain from top to bottom. In this research, a holistic supply chain should include at least three layers of supply chain, e.g. the OEM, the 1<sup>st</sup> tier supplier and the 2<sup>nd</sup> tier supplier.
  - Non-holistic: The measurement approaches that measure only one layer of a supply chain.
- Partial measurement: This refers to measurement methods that only measure certain aspects of supply chain performance.

One cannot tell how good a supply chain is performing by looking at only one dimension of supply chain activity. All the elements in a supply chain are interrelated to each other. The success in one element might arise from or result in a sacrifice in another element [3]. Hence, it is vital to measure the performance from different perspectives. The overall measurement category can be further divided into two sub-categories: holistic and non-holistic. The "holistic" category is measurement methods that measure supply chain from top to bottom, e.g. from the Original Equipment Manufacturer (OEM) to the 2<sup>nd</sup> or 3<sup>rd</sup> tier supplier. The SCOR model and the supply chain process quality model [4] are examples for holistic measurement. Meanwhile, the "non-holistic" approaches measure only one layer of the supply chain interface, e.g. between the OEM and the 1<sup>st</sup> tier supplier, such as a vendor rating system or the supply chain management balanced scorecard [5].

Partial measurement is the opposite of overall measurement. It does not measure supply chain performance from varied perspectives. These methods measure only certain aspects of supply chain performance, such as bullwhip effect, cost or inventory level.

## 2. Supply Chain Measurement Issues

There are five major measurement issues that were identified and discussed by different researchers (Holmberg (2000), Chan *et al.* (2003), Adam *et al.* (1995), Gunasekaran *et al.* (2001), Beamon (1999) and Bullinger *et al.*, 2002). These are the factors that a company needs to be aware of before and during the performance measurement.

- Alignment between strategy and measurement
- Balanced measurement
- Excessive, isolated and incompatible metrics
- System thinking
- Information confidentiality

Holmberg [6], Adams *et al.* [8], Gunasekaran *et al.* [9] and Beamon [10] have all cited the need and importance to align measurement with supply chain strategy. Adams *et al.* [8] reported that the measurement initiatives that are not derived from strategy do not support the business. A missing connection between strategy and measurements may cause internal focus within each organisation, which becomes an obstacle to develop an overall supply chain strategy [6]. Gunasekaran *et al.* [9] and Beamon [10] agree that measurement goals must consider the overall supply chain strategy. Beamon also cites Maskell's finding, which states that *"by aligning the measurement methods to the overall strategy, the company can determine if its performance is meeting its strategic goals and people in the organisation will concentrate on what is measured; thus the performance measures will steer company direction"*. However, implementing a supply chain strategy requires metrics that align performance with the objectives of other members of the supply chain [11]. Aligned metrics direct management attention and effort to the areas requiring improvement leading to higher levels of supply chain performance [12].

Another measurement issue is to create a balanced supply chain measurement. The over emphasis on financial measures has always been a major issue in performance measurement [10] [13]. Before the idea of balanced measurement systems arose, most companies used accounting systems to measure performance. According to Bullinger *et al.* [13], Adebajo and Mann [14], Chan *et al.* [7], Beamon [10] and Holmberg [6], financial data shows only the result of yesterday's actions rather than

indicating tomorrow's performance. The measure does not provide any forward-looking perspective and lacks predictive power [13] [14]. Therefore, financial measurement can't capture key business changes until it is too late. Besides, the tracking of financial performance is insufficient to measure supply chain performance. Performance should be judged from different perspectives, not just solely from financial context [13]. There are some performance attributes that can't be measured in financial terms, such as responsiveness, customer satisfaction and product quality. Hence, it is very important to maintain a balanced measurement to ensure an overall performance appraisal.

Another measurement issue was brought up by Holmberg [6] is excessive, isolated and incompatible measures. The number of metrics used in organisations tends to increase over time. This is because metrics are seldom removed once introduced. Then these "old" metrics soon become obsolete as strategy and underlying activities continue to change. Baldwin and Clark [15] claim that a major cause of the USA's competitive decline is due directly to the managers' use of inappropriate performance measurement systems. Gunasekaran *et al.* [9] also place emphasis on having the right number of metrics because most companies fail to realise that performance measurement can be better addressed using a good few metrics. To resolve this problem, the most direct method is to keep constant review and update on the measurement methods and metrics [4] [1].

In 2001, Gunasekaran *et al.* [9] pointed out that some measurements did not incorporate system thinking in supply chain performance measurement. It is quite common to see some researchers and companies only measure their first tier suppliers when it comes to supply chain measurement, such as the process quality model proposed by Beamon and Ware [4] and Gilmour's strategic audit framework [16]. Some measures identified as supply chain metrics are actually measures of internal logistics operations [17]. Holmberg [6] defines system thinking as a concept in which the supply chain must be viewed as one whole entity. Thus each component in the measurement system must be considered throughout the entire supply chain, not just at any interface between customer and supplier. Lapide [1] also

comments that a company should measure performance of part of its supply chain that lies outside its own enterprise to ensure the effectiveness of supply chain processes. By looking at the overall performance of the entire supply chain, the problem of local optimisation can be avoided.

Information confidentiality is another issue in supply chain performance measurement. In order to measure supply chain performance, data has to be collected from supply chain members. Quite often the measurement approach requires access to sensitive or potentially sensitive financial and production data. Many companies are reluctant to make such information available to suppliers or customers for fear of exposing strengths or weaknesses. This is particularly pertinent to industries where a year-on-year cost-down approach to supply chain contract negotiations prevails. Trust among supply chain partners can be a key contributor to the success and effectiveness of supply chain performance measurement.

### 3. Research Methodology

Every supply chain is unique in terms of its structure and method of operation. Also, different companies will have different measurement targets. Hence, a performance measurement method should be custom made according to supply chain's characteristics and operation mechanism. Also, the measurement purpose has to be taken into consideration to ensure that the measurement method measures the right aspects of supply chain. In this study, the supply chain performance of Company A and Company B are compared using a scorecard designed specifically for the evaluation of automotive supply chain structures. The details about the scorecard can be found in the next section. The scorecard is first developed for individual seat sets over one-month analysis periods. Individual seat sets are then aggregated together to form a composite scorecard for the supply chain. Finally analysis months are aggregated together to form a set of measures.

Three types of seat modules were selected to generate a composite scorecard to ensure the outcome is representative: runner (high usage rate), repeater (medium usage rate) and stranger (low usage rate). Table 1 shows the average usage volume of



each sample type per day. The data collected from these three samples are weighted according to their usage volume and combined together to provide the overall performance.

	Company A (Production volume = 380/day)	Company B (Production volume = 1000/day)
Runner	81	484
Repeater	40, 23	34
Stranger	4	5

Table 1: Average Daily Usage Volume of Seat Modules

#### 4. Results

As mentioned before, every supply chain is unique in terms of its structure and operation mechanism. Also, different companies will have different measurement targets. Hence, a performance measurement method should be custom made according to supply chain's characteristics, mechanism as well as the measurement purpose. In this study, a performance measurement scorecard is designed specifically for automotive supply chain.

Table 2 shows the supply chain performance of two automotive companies in the scorecard designed specifically for automotive supply chain. The case studies involved a mid-volume luxury car manufacturer and a high volume car manufacturer. Figure 1 is a diagram that illustrates the seat supply chain structure of Company A. The daily production volume is about 380 cars. The seat set is a core module for car with high variety. For each type of seat, there are two basic styles (classic and sport), two kinds of materials (cloth and leather) and six colours to choose from. Four echelons of supply chain are covered in this case study – Company A (the OEM), the seat manufacturer (1<sup>st</sup> tier supplier), the headrest manufacturer (2<sup>nd</sup> tier supplier) and the headrest foam manufacturer (3<sup>rd</sup> tier supplier). All the companies are located within UK. As shown in Figure 1, it is a normal one-to-one interaction between the echelons. The downstream echelon conveys the demand information to the immediate upstream echelon.

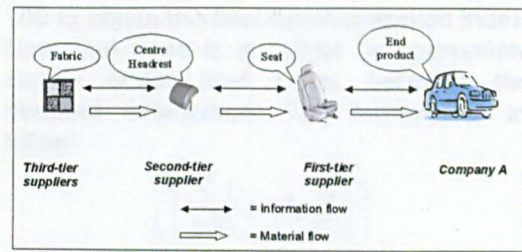


Figure 1: The Seat Supply Chain of Company A

Company B is a car manufacturer based in Spain. Averagely, the company makes 1000 cars per day. Figure 2 is a diagram that illustrates the seat supply chain structure of Company B. The variety of seat module in Company B is not as wide as Company A. There is only one type of seat that comes with five different colours. Four echelons of supply chain are covered in this case study – Company B (the OEM), the seat manufacturer (1<sup>st</sup> tier supplier), the headrest manufacturer (2<sup>nd</sup> tier supplier) and the headrest foam manufacturer (3<sup>rd</sup> tier supplier). All the companies are located within Spain. In Company B supply chain, apart from the traditional one-to-one interaction between the echelons, some of the information is also transmitted between non-immediate echelons:

- The 1<sup>st</sup> tier supplier sends the output of its MRP system to the 3<sup>rd</sup> tier supplier weekly. It is a spreadsheet that contains the firm orders for that particular week. Indeed, the 1<sup>st</sup> tier supplier orders headrest foam from the 3<sup>rd</sup> tier supplier to the 2<sup>nd</sup> tier supplier.
- The 2<sup>nd</sup> tier supplier has access to Company B's forecast A. However, it is used only as a reference when the Company B is terminating a particular colour trim.

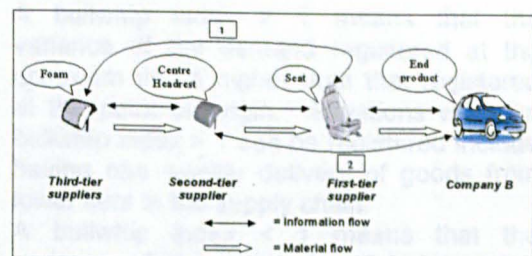


Figure 2: The Seat Supply Chain of Company B

The result shown in Table 2 is the performance measurement on both

companies' seat module supply chain, from the car manufacturer to the 3<sup>rd</sup> tier suppliers. There are nine metrics in the scorecard and these metrics are divided into four groups: Synchronisation measures, Responsiveness measures, Reliability measures and Cost measures.

	Supply Chain A	Supply Chain B
<b>SYNCHRONISATION MEASURES</b>		
<b>Synchronisation Index Overall (%)</b>	31.00	42.13
First tier	96.00	99.00
Second tier	6.20	73.67
Third tier	-9.40	-51.28
<b>Bullwhip measure (OEM - Tier 3)</b>	3.50	7.13
<b>RESPONSIVENESS MEASURES</b>		
<b>Supply chain cycle times Overall (days)</b>	10.00	11.22
First tier	3.00	5.52
Second tier	3.80	3.32
Third tier	3.10	2.38
<b>Pipeline Inventory Overall (days of stock)</b>	8.89	7.87
First tier RM	2.60	2.74
First tier FG	N/A	N/A
Second tier RM	2.00	1.53
Second tier FG	1.50	1.59
Third tier RM	N/A	N/A
Third tier FG	2.80	2.00
<b>Value adding ratio (%)</b>	12.20	38.95
<b>RELIABILITY MEASURES</b>		
<b>Stockout incidents - Overall</b>	0	0
First tier RM days stockout	0	0
Second tier RM days stockout	0	0
Third tier RM days stockout	N/A	N/A
<b>Backorders - Overall</b>	0	0
First tier RM backorders	0	0
Second tier RM backorders	0	0
Third tier RM days backorders	N/A	N/A
<b>COST MEASURES</b>		
<b>Transport - Overall</b>	£13,631	£411.67
First tier	£8,900	£142.82
Second tier	£2,928	£130.54
Third tier	£1,804	£138.30
<b>Inventory - Overall</b>	£2,361	£107.91
Interest on capital cost	£128	£34.69
Storage	£220	£11.56
Obsolescence & depreciation	£1,830	£23.13
Opportunity cost	£183	£38.54

Table 2: The Supply Chain Scorecard for Company A and Company B

### 3.1 Synchronisation Measures:

The **synchronisation index** calculated the Mean Absolute Deviation (MAD) for the period of study, between the offset demand and the actual demand. The resulting quantity is expressed as a percentage of the average usage. The total is subtracted from

100 to obtain the final synchronisation index. Note that there is an offset by appropriate supply chain lead times between the demand information. The formula is as follow:

$$Sync = 100 - \left( \frac{\left( \frac{\sum_{i=1}^p |a_i - b_{i-1}|}{p} \right)}{\mu} \right) * 100$$

Where:  $a$  = forecast quantities (daily demand)

$b$  = actual quantities (daily)

$p$  = days for the period examined

$\mu$  = mean demand for the period examined

The higher the percentage, the better the synchronisation. The "Overall Synchronisation Index" is the average of 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> tier synchronisation index.

The **bullwhip measure** is an amplified representation between tiers of the variability of the demand signal downstream in the supply chain and the variability of the demand signal upstream in the supply chain. It is calculated using the formula provided by Fransoo and Wouters [18] as follow:

$$Bullwhip \text{ Measure} = \frac{\frac{\sigma}{\mu} \text{ upstream}}{\frac{\sigma}{\mu} \text{ downstream}}$$

Where:  $\sigma$  = Standard deviation of demand pattern

$\mu$  = Mean of demand pattern

A bullwhip index  $> 1$  means that the variance of the demand registered at the upstream tier is higher than that registered at the point of origin. Situations where a bullwhip index  $> 1$  can be registered include having one weekly delivery of goods from lower tiers in the supply chain.

A bullwhip index  $< 1$  means that the variance of the demand registered at the upstream tier is lower than that registered at the point of origin. Situations where a bullwhip index  $< 1$  might be registered include daily deliveries of goods from lower tiers in the supply chain.

A bullwhip index = 1 means a perfect supply chain that the upstream and downstream demands are exactly the same.

In this study, the bullwhip measure is comparing the demand information at the OEM level with the demand information at 3<sup>rd</sup> tier supplier.

### 3.2 Responsiveness Measures:

**Supply chain cycle times** represent the combination of process, transport and waiting times. The "overall supply chain cycle time" is the sum of cycle time of 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> tier supply chain.

**Pipeline inventory** are calculated as the average on-hand stock, divided by average usage. There are two types of pipeline inventory: raw material (RM) and finished goods (FG). The "overall pipeline inventory" is the sum of RM and FG from every tier of supply chain.

**Value adding ratio** is expressed as the difference between supply chain cycle time and pipeline inventory, divided by pipeline inventory and multiplied by 100.

### 3.3 Reliability Measures:

The **stockout incident** measure gives the number of days on which a stockout occurred and the backorders measure shows the number of orders affected by the stockout. The "overall stockout level" is the sum of stockout incidents from every tier of supply chain.

**Backorders** totals the number of parts required on a stockout day. Again, the "overall backorders level" is the sum of backorder incidents from every tier of supply chain.

### 3.4 Cost Measures:

The **transportation costs** for Supply Chain A have been calculated using publicly available data from the Road Haulage Association (Acknowledgements to the RHA for providing this data free of charge). On the other hand, the haulage rates in Spain were used to calculate transportation costs of Supply Chain B. The "overall transportation cost" is the sum of stockout incidents from every tier of supply chain.

The **total inventory costs** were calculated as the sum of the following costs:

**Interest on capital cost** - It was calculated as the total inventory value multiplied by the suggested annual interest rate and divided by 12. The interest rate is 7% for Supply Chain A and 9% for Supply Chain B.

**Storage cost** - Calculated as the total inventory value multiplied by an annual storage cost rate. The storage cost rate is 1% for Supply Chain A and 9% for Supply Chain B.

**Obsolescence and depreciation cost** - For Supply Chain A, it is assume that 1 obsolescence incident per year (which means the inventories are scrapped once per year). For Supply Chain B, the rate is estimated to be 6% of the total inventory value.

**Opportunity cost** - Understood as the cost of passing up the next best choice when making a decision. This measure was calculated as total inventory value multiplied by an opportunity cost factor of 0.1 (10% for both Supply Chain A and B) divided by 12.

## 5. Case Study Discussions

In this scorecard, there are two supply chain synchronisation metrics. The first one is the "synchronisation index" that assesses the difference between the forecast demand and the actual demand. Supply Chain B has a higher overall synchronisation index than Supply Chain A, which means the demand forecast of Supply Chain B is more accurate. However, Supply Chain B's supply chain suffers higher demand amplification, as its bullwhip measure is 7.13 while for Supply Chain A it's only 3.50.

The results from the responsiveness measures shows that Supply Chain A has a shorter overall supply chain cycle time, but with more inventories throughout the supply chain pipeline. This is probably because Supply Chain A has a higher seat variety. There is no information available on the 1<sup>st</sup> tier finished goods inventory and the 3<sup>rd</sup> tier raw material inventory. Meanwhile, Supply Chain B has less waste (non value adding jobs) in the supply chain since its value adding index is higher.



The outcomes of reliability measures from both companies are the same – no backorder and stockout incident at all. The 3<sup>rd</sup> tier information is not available. As mentioned before, both companies use SILS to handle their seat supply chain and this requires high efficiency and effectiveness. The suppliers will have to pay a very high compensation cost if they are responsible for a stockout incident. Hence, zero stockout level is expected.

From financial perspective, Supply Chain A incurs higher transportation cost and inventory cost. This is mainly due to the higher overhead cost in UK compare to Spain, as well as the higher inventory level in Supply Chain A.

## 6. Conclusions

One of the ultimate objectives of the FUSION research is to develop a holistic supply chain performance measurement method for automotive industry. The performance of two automotive supply chain were assessed and compared in this paper. A scorecard was developed to measure the performance in qualitative format. It is specially designed for automotive supply chain. Overall, Company B's supply chain has performed better than Company A's supply chain since Company B's supply chain shows higher synchronisation index, lower bullwhip index, lower inventory level, higher value adding activities percentage, lower transportation cost and inventory cost.

Both companies in the case studies have very similar supply chain structure, using similar information system architecture and the information flow along both supply chains follows a similar pattern. However, the performances are still varies between these two supply chains, due to the location, information sharing level and material variety.

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## Appendix M: The Toolkit to Develop Scorecard

This toolkit illustrates the step-by-step instructions on how the scorecard is developed.

### Step 1

Analysis Days (i)	02-Sep	03-Sep	04-Sep	05-Sep	06-Sep	09-Sep	10-Sep	11-Sep	12-Sep	13-Sep	16-Sep	17-Sep	18-Sep	19-Sep	20-Sep	23-Sep	24-Sep	25-Sep	26-Sep	30-Sep	Sum	Demand MAD	Row No.
OEM demand (OD <sub>i</sub> )	105	84	86	98	43	104	91	89	128	0	131	98	88	75	0	90	92	65	58	91	1618		1
1st tier supplier demand (1stSD <sub>i</sub> )	105	84	86	98	43	104	91	89	128	0	131	98	88	75	0	90	92	65	58	91	1618		2
OD <sub>i</sub> - 1stSD <sub>i</sub>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00%	3
2nd tier supplier demand (2ndSD <sub>i</sub> )	56	112	84	0	168	0	224	0	84	140	112	0	112	112	140	0	0	140	0	196	1680		4
OD <sub>i</sub> - 2ndSD <sub>i</sub>	50	28	2	98	125	104	133	89	44	140	19	98	24	37	140	90	92	74	58	105	1550	95.80%	5
3rd tier supplier demand (3rdSD <sub>i</sub> )	0	200	0	140	0	80	200	0	320	0	0	240	0	240	0	0	80	0	0	0	1500		6
OD <sub>i</sub> - 3rdSD <sub>i</sub>	105	116	86	42	43	24	109	89	192	0	131	142	88	165	0	90	12	66	58	91	1650	101.98%	7
Sample size (n) =	20																				Avg Demand MAD =		65.93%
Average actual demand (μ) =	80.90																						

**Table M.1: Table for Demand MAD**

Table M.1 is to illustrate the structure and method to calculate Demand MAD. The step-by-step procedure is as follow:

1. Enter the date in the header row (coloured in grey).
2. Enter the sample size ( $n$ ), which is the total number of days ( $i$ ) (coloured in red).
3. Enter the daily OEM demand quantity ( $OD_i$ ) in Row No. 1 (coloured in green). The average of these daily OEM demand quantities is

calculate and shown in the “Average actual demand ( $\mu$ )”, i.e.  $\frac{\sum_{i=1}^n 1stSD_i}{n}$ .



4. Enter the daily 1<sup>st</sup> tier supplier demand quantity ( $1stSD_i$ ) in Row No. 2 (coloured in blue).
5. Enter the daily 2<sup>nd</sup> tier supplier demand quantity ( $2ndSD_i$ ) in Row No. 4 (coloured in yellow).
6. Enter the daily 3<sup>rd</sup> tier supplier demand quantity ( $3rdSD_i$ ) in Row No. 6 (coloured in purple).
7. Row No. 3, 5 and 7 calculate the absolute value of the difference between OEM daily demand quantity and individual supplier daily demand quantity, i.e.  $OD_i - SD_i$ .
8. The “Sum” column shows the total of the absolute value of difference in Row 3, 5 and 7, i.e.  $\sum_{i=1}^n (OD_i - SD_i)$
9. The “Demand MAD” column shows the *Demand MAD* of each SC level by dividing the “Sum” value in step 8 by the sample size ( $n$ ), further divide by the “Average Actual Demand” ( $\mu$ ), which is Equation 3.1. This gives the *Demand MAD* percentage for each SC level.
10. The average value of these individual SC Demand MAD is calculated as shown in “*Avrg Demand MAD*”, which provides *Demand MAD* for the entire SC.

## Step 2

Table M.2 is to illustrate the structure and method to calculate *Bullwhip Coefficient*. The coloured rows are where the user can input the following data for calculations. The step-by-step procedure is as follow:

Analysis Days	02-Sep	03-Sep	04-Sep	05-Sep	06-Sep	09-Sep	10-Sep	11-Sep	12-Sep	13-Sep	16-Sep	17-Sep	18-Sep	19-Sep	20-Sep	23-Sep	24-Sep	25-Sep	26-Sep	30-Sep	$\sigma$	$\mu$	$\sigma/\mu$	B.C.	Row No.
OEM demand ( $OD_i$ )	106	84	86	98	43	104	91	89	128	0	131	98	88	75	0	90	92	66	58	91	34.29	80.90	0.42		1
1st tier supplier demand (1stSD <sub>i</sub> )	106	84	86	98	43	104	91	89	128	0	131	98	88	75	0	90	92	66	58	91	34.29	80.90	0.42	1.00	2
2nd tier supplier demand (2ndSD <sub>i</sub> )	56	112	84	0	168	0	224	0	84	140	112	0	112	112	140	0	0	140	0	196	73.24	84.00	0.87	2.06	3
3rd tier supplier demand (3rdSD <sub>i</sub> )	0	200	0	140	0	80	200	0	320	0	0	240	0	240	0	0	80	0	0	0	106.99	75.00	1.43	1.64	4
$\mu$ = Average actual demand																									
$\sigma$ = demand standard deviation																									
OEM - 3rd Tier Bullwhip Coefficient =	3.37																								

**Table M.2: Table for Bullwhip Coefficient**

1. Enter the date in the header row (coloured in grey).
2. Enter the daily OEM demand quantity ( $OD_i$ ) in Row No. 1 (coloured in green).
3. Enter the daily 1<sup>st</sup> tier supplier demand quantity (1stSD<sub>i</sub>) in Row No. 2 (coloured in blue).
4. Enter the daily 2<sup>nd</sup> tier supplier demand quantity (2ndSD<sub>i</sub>) in Row No. 4 (coloured in yellow).
5. Enter the daily 3<sup>rd</sup> tier supplier demand quantity (3rdSD<sub>i</sub>) in Row No. 6 (coloured in purple).
6. The demand quantity standard deviation for each SC level is shown in the column labelled as " $\sigma$ ".
7. The demand quantity average for each SC level is shown in the column labelled as " $\mu$ ".
8. The standard deviation is divided by the average value and shown in the column labelled as " $\sigma/\mu$ ".
9. The "B.C." column shows the Bullwhip Coefficient for each SC level y dividing the upstream " $\sigma/\mu$ " value by the downstream " $\sigma/\mu$ " value, i.e. Equation 3.2.



10. The *Bullwhip Coefficient* for the entire SC is shown in “*OEM – 3<sup>rd</sup> Tier Bullwhip Coefficient*”, by dividing the 3<sup>rd</sup> tier “ $\sigma/\mu$ ” value by the OEM “ $\sigma/\mu$ ” value.

### Step 3

Analysis Days		02-Sep	03-Sep	04-Sep	05-Sep	06-Sep	09-Sep	10-Sep	11-Sep	12-Sep	13-Sep	16-Sep	17-Sep	18-Sep	19-Sep	20-Sep	23-Sep	24-Sep	25-Sep	26-Sep	30-Sep	Σ	Inv Level in days	Row No.	
OEM daily usage (U)		106	84	86	98	43	104	91	89	128	0	131	98	88	75	0	90	92	66	58	91	1618		1	
OEM RM inventory level (I)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	2	
1st tier FG inventory level (I)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	3	
1st tier RM inventory level (I)		137	165	163	65	190	86	219	130	88	228	209	111	107	116	256	166	74	148	89	194	2941	1.82	4	
2nd tier FG inventory level (I)		137	165	163	65	190	86	219	130	88	228	209	111	107	116	256	166	74	148	89	194	2941	1.50	5	
2nd tier RM inventory level (I)		100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	2000	1.24	6	
3rd tier FG inventory level (I)		200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	4000	2.47	7	
																						Sum	11882.00	7.03	

**Table M.3: Table for Inventory Level**

Table M.3 is to illustrate the structure and method to calculate *Inventory Level*. The step-by-step procedure is as follow:

1. Enter the date in the header row (coloured in grey).
2. Enter the daily OEM usage quantity ( $U_i$ ) in Row No. 1 (coloured in green).
3. Enter the daily inventory level ( $I_i$ ) from Row 2 to Row 7 (coloured in blue).
4. The “ $\Sigma$ ” column sum up the quantities in each row.

5. The “*Inv Level in days*” column shows the inventory level of each SC level by dividing the sum of inventory quantities ( $\sum I_i$ ) by the sum of OEM usage volume ( $U_i$ ), i.e. Equation 3.3.
6. The sum of these individual SC level is the inventory level for the entire SC, as shown in the “*Sum*” highlighted in purple.

#### Step 4

Table M.4 is to illustrate the structure and method calculate *Dock-to-Dock Time*. The step-by-step procedure is as follow:

1. Enter the time in hour for each process from Row 1 to Row 12 in the column labelled as “*Time*” (coloured in yellow).
2. The sum of all the process time is shown in the row labelled as “*Total*”. This is also the Dock-to-dock Time for the entire SC, as shown in the “*SC D2D Time*”.
3. The “*Value Adding Time*” shows the total time of value adding processes (highlighted in blue) in the entire SC.
4. The “*Value Adding Ratio*” shows the percentage of “*Value Adding Time*” in comparison to the “*SC D2D Time*”.



Table M.5 is to illustrate the structure and method calculate *Stockout Level* and *Backorder Level*. The step-by-step procedure is as follow:

<b>SC D2D Time (in working hours) = 123.32</b>	
<b>Value Adding Time (in working hours) = 4.60</b>	
<b>Value Adding Ratio (vs SC D2D Time) = 3.73%</b>	
<b>Process</b>	<b>Time (hours)</b>
Transit from 1st Tier to OEM	0.30
1st Tier FG Buffer	0.00
1st Tier Process Time	0.60
1st Tier RM Buffer	29.08
Transit from 2nd Tier to 1st Tier	3.00
2nd Tier FG Buffer	24.00
2nd Tier Process Time	1.50
2nd Tier RM Buffer	19.78
Transit from 3rd Tier to 2nd Tier	3.00
3rd Tier FG Buffer	39.56
3rd Tier Process Time	2.50
<b>Total (in hours)</b>	<b>123.32</b>

Row No.

1

2

3

4

5

6

7

8

9

10

11

12

**Table M.4: Table for Dock-To-Dock Time**

### Step 5

Analysis Days		02-Sep	03-Sep	04-Sep	05-Sep	06-Sep	09-Sep	10-Sep	11-Sep	12-Sep	13-Sep	16-Sep	17-Sep	18-Sep	19-Sep	20-Sep	23-Sep	24-Sep	25-Sep	26-Sep	30-Sep	$\bar{X}$	SL	BL	Row No.	
OEM	$S_1$	1	0	0	2	0	0	0	3	0	0	0	0	1	0	0	0	0	0	2	0	9	0.45	-	1	
	$B_1$	4	0	0	5	0	0	0	4	0	0	0	0	3	0	0	0	0	0	5	0	21	-	2.33	2	
1st tier supplier	$S_1$	0	0	0	2	0	0	0	0	0	1	1	0	0	0	0	2	0	0	0	0	6	0.3	-	3	
	$B_1$	0	0	0	4	0	0	0	0	0	2	1	0	0	0	0	3	0	0	0	0	10	-	1.67	4	
2nd tier supplier	$S_1$	0	2	0	0	0	3	0	0	0	0	1	0	0	0	0	0	2	0	1	0	9	0.45	-	5	
	$B_1$	0	5	0	0	0	4	0	0	0	0	3	0	0	0	0	0	5	0	3	0	20	-	2.22	6	
3rd tier supplier	$S_1$	0	0	2	0	0	0	0	0	1	1	0	0	0	0	2	0	0	0	0	1	7	0.35	-	7	
	$B_1$	0	0	4	0	0	0	0	0	2	1	0	0	0	0	3	0	0	0	0	2	12	-	1.71	8	
Sample size (n) = 20																						0.39		1.98		10
																						(SC SL)		(SC BL)		

**Table M.5: Table for Stockout Level and Backorder Level**

Table M.5 is to illustrate the structure and method calculate *Stockout Level* and *Backorder Level*. The step-by-step procedure is as follow:

1. Enter the date in the header row (coloured in grey).
2. Enter the number of stockout incident for each day in Row 2, 4, 6 and 8(coloured in yellow).
3. Enter the quantities of parts that are backordered on each day in Row 3, 5, 7 and 9 (coloured in blue).
4. The “ $\Sigma$ ” column sum up the quantities in each row.
5. The “*SL*” column shows the *Stockout Level* by dividing the sum of stockout quantity ( $\Sigma S_i$ ) by the sample size ( $n$ ), i.e. Equation 3.4.
6. The “*BL*” column shows the *Backorder Level* by dividing the sum of backorder ( $\Sigma B_i$ ) parts by the sum of stockout quantity ( $\Sigma S_i$ ), i.e. Equation 3.5.
7. The *Stockout Level* for the entire SC is shown in Row 10 labelled as “*SC SL*”, by taking the average of the *Stockout Level* “*SL*” of all SC levels.
8. The *Backorder Level* for the entire SC is shown in Row 10 labelled as “*SC BL*”, by taking the average of the *Backorder Level* “*BL*” of all SC levels.



**Step 6**

Column No.	1	2	3	4	5	
SC Level	Cost Per Delivery (C)	Delivery Batch Size (U)	Cost per Unit ( $T_u$ )	Delivery Per Month (Q)	Delivery Cost Per Month ( $T_m$ )	Row No.
1st Tier - OEM	£150.00	48	£3.13	160	£24,000.00	1
2nd Tier - 1st Tier	£98.50	28	£3.52	20	£1,970.00	2
3rd Tier - 2nd Tier	£85.10	20	£4.26	20	£1,702.00	3
SC Transportation Cost			£3.63		£27,672.00	4

**Table M.6: Table for Transportation Cost**

Table M.6 is to illustrate the structure and method to calculate *Transportation Cost*. The step-by-step procedure is as follow:

1. Enter cost per delivery (C) in column 1 for each SC level (coloured in red).
2. Enter delivery batch size (U) in column 2 for each SC level (coloured in green).
3. Enter number of delivery per month (Q) in column 4 for each SC level (coloured in blue).
4. The delivery cost per unit ( $T_u$ ) is shown in column 3 by dividing the cost per delivery (C) with the delivery batch size (U), i.e. Equation 3.6.
5. The delivery cost per month ( $T_m$ ) is shown in column 5 by multiplying the cost per delivery (C) with the number of delivery per month (Q), i.e. Equation 3.7.

6. The *Transportation Cost Per Unit* for the entire SC is shown in Row 4 by taking the average of *Cost per Unit* " $T_u$ " from individual SC levels.
7. The *Transportation Cost Per Month* " $T_m$ " for the entire SC is shown in Row 4 by taking the total of *Delivery Cost per Month* " $T_m$ " from individual SC levels.

### Step 7

					Row No.
<b>Cost Centre:</b>	<b>% of Inventory Value</b>		<b>Inventory Carrying Cost</b>		<b>1</b>
Interest on capital cost ( $I$ )	7.00%	per year	£45.31	LI	<b>2</b>
Storage ( $S$ )	3.00%	per year	£19.42	SC	<b>3</b>
Obsolescence and depreciation ( $O$ )	6.00%	per year	£38.84	OC	<b>4</b>
Opportunity cost ( $P$ )	10.00%	per year	£64.73	PC	<b>5</b>
<b>SC Inventory Carrying Cost Per Month =</b>			£168.31		<b>6</b>
<b>Inventory Qty Per Month =</b>			11,882		<b>7</b>
<b>SC Inventory Carrying Cost Per Unit =</b>			£0.01		<b>8</b>
					<b>9</b>
					<b>10</b>
<b>Inventory Type</b>	<b>Inventory Level (<math>IL</math>)</b>	<b>Avrg Daily Volume (<math>DV</math>)</b>	<b>Cost Per Unit (<math>C</math>)</b>	<b>Inventory Value (<math>V</math>)</b>	<b>11</b>
OEM RM inventory level	0.00	80.90	£750.00	£0.00	<b>12</b>
1st tier FG inventory level	0.00		£750.00	£0.00	<b>13</b>
1st tier RM inventory level	1.82		£20.00	£2,941.00	<b>14</b>
2nd tier FG inventory level	1.50		£20.00	£2,427.00	<b>15</b>
2nd tier RM inventory level	1.24		£8.00	£800.00	<b>16</b>
3rd tier FG inventory level	2.47		£8.00	£1,600.00	<b>17</b>
	7.03	<b>Total Inventory Value =</b>		£7,768.00	<b>19</b>

**Table M.7: Table for Inventory Carrying Cost**



Table M.7 is to illustrate the structure and method to calculate *Inventory Carrying Cost*. The step-by-step procedure is as follow:

1. Enter annual rate for the four individual inventory cost centres (coloured in purple).
2. Enter the "*Inventory Quantity Per Month*" in Row 7 (coloured in red) with the total inventory quantity identified in Table 3.4.
3. Enter the inventory levels identified in Table 3.4 in the column labelled as "*Inventory Level*" (coloured in yellow).
4. Enter the OEM average daily usage volume in the column labelled as "*Avrg Daily Volume*" (coloured in green).
5. Enter the cost per unit in the column labelled as "*Cost Per Unit*" (coloured in blue).
6. The inventory value for each SC level is shown in the column labelled as "*Inventory Value*", by multiplying "*Inventory Level*" with "*Avrg Daily Volume*" and "*Cost Per Unit*", i.e. Equation 3.8.
7. The sum of the inventory value from each SC level gives the total inventory value of the entire SC, as shown in Row 19, labelled as "*Total Inventory Value (V)*".
8. The inventory carrying cost based on the four cost centres are shown in the column labelled as "*Inventory Carrying Cost*", by multiplying the "*Total Inventory Value*" ( $V$ ) with the "*% of Inventory Level*" and divided by 12 to give the monthly carrying cost from Row 2 to Row 5, based on Equation 3.9, 3.10, 3.11 and 3.12.
9. The "*SC Inventory Carrying Cost Per Month*" in Row 6 shows the monthly inventory carrying cost per month for the entire SC, which is the sum of the monthly inventory carrying cost from the four cost centres.

10. The “SC Inventory Carrying Cost Per Unit” in Row 8 shows the inventory carrying cost of the entire SC per unit by dividing the “Total Inventory Carrying Cost Per Month” in Row 6 by the “Inventory Quantity Per Month” in Row 7.

### Step 8

The following information are extracted from the following tables into the summary scorecard:

1. Table 3.2 for *Demand MAD* metric: “*Demand MAD*” of individual SC level from Row 3, 5 and 7; “*Avrg Demand MAD*”
2. Table 3.3 for *Bullwhip Coefficient* metric: “*B.C.*” of individual SC level from Row 2, 3 and 4; “*OEM - 3rd Tier Bullwhip Coefficient*”
3. Table 3.4 for *Inventory Level* metric: “*Inv Level in days*” from Row 2 to 7; the sum of “*Inv Level in days*”
4. Table 3.5 for *Dock-to-dock Time* metric: “*SC D2D Time*”
5. Table 3.6 for *Stockout Level* metric: “*SL*” of individual SC level from Row 2, 4, 6 and 8
6. Table 3.6 for *Backorder Level* metric: “*BL*” of individual SC level from Row 3, 5, 7 and 9
7. Table 3.7 for *Transportation Cost* metric: “*Cost Per Unit ( $T_u$ )*” of individual SC level from Row 1 to 3; the “SC Transportation Cost” of “*Cost Per Unit ( $T_u$ )*” and “*Delivery Cost Per Month ( $T_m$ )*” from Row 4
8. Table 3.8 for *Inventory Carrying Cost* metric: “*SC Inventory Carrying Cost Per Month*” and “*SC Inventory Carrying Cost Per Unit*”

Metrics	Level	SC A	SC B	SC C
Demand MAD	Supply Chain	77.56%	91.04%	20.35%
	OEM - 1st tier supplier	0.00%	0.00%	0.00%
	OEM - 2nd tier supplier	118.24%	110.59%	40.70%
	OEM - 3rd tier supplier	114.45%	162.54%	150.00%
BullWhip Coefficient	Supply Chain	3.96	4.52	N/A
	OEM - 1st tier supplier	1.00	1.00	1.00
	1st tier supplier - 2nd tier supplier	2.66	2.05	1.49
	2nd tier supplier - 3rd tier supplier	1.51	5.01	3.00
Inventory Level (days of stock)	Supply Chain	18.22	30.07	9.66
	OEM RM inv level	0.00	0.00	0.00
	1st tier FG inv level	0.00	0.00	0.00
	1st tier RM inv level	5.06	19.14	1.99
	2nd tier FG inv level	1.50	2.03	1.50
	2nd tier RM inv level	1.86	6.91	2.00
	3rd tier FG inv level	6.45	2.00	4.17
Dock-to-Dock Time (hours)	Supply Chain	123.32	661.29	234.55
Stockout Level	Supply Chain	0	0	0
Backorder Level	Supply Chain	0	0	0
Transportation Cost (cost per unit)	Supply Chain	£3.63	£1.44	£0.99
	1st Tier - OEM	£3.13	£0.66	£1.64
	2nd Tier - 1st Tier	£3.52	£3.39	£0.34
	3rd Tier - 2nd Tier	£4.26	£0.26	£1.25
Transportation Cost (cost per month)	Supply Chain	£27,672.00	£34,828.18	N/A
Inventory Carrying Cost (cost per unit)	Supply Chain	£0.01	£0.0019	£0.01
Inventory Carrying Cost (cost per month)	Supply Chain	£168.31	£49.63	£65.88

Table M.8: Summary Scorecard