Re-engineering the UK private house building supply chain

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by

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Declaration and Statements

Declaration

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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Abstract

The UK private house building industry suffers, like the rest of the construction industry, from many problems. The performance of this industry needs to be greatly improved if it is to survive increasing pressures from reduction of land availability, increased customer expectations and international competition. The house building industry is still very traditional with adversarial relationships, focus on costs (and not on value) and a functional silo approach. However, it also benefits from repeat processes and an established supply chain.

The aim of this thesis is to test if supply chain management principles can be utilised in the UK private house building industry and then to analyse the effect it has on performance. The performance measures used combine supply chain management criteria, house building specific criteria and system dynamics criteria, particularly focusing on demand amplification. The research analyses three different supply chains for the main material categories necessary for the construction of houses. These three supply chains are the house shell, the high-value fit-out and the low-value fit-out supply chains. A case study approach is used in the context of action-based research. A system dynamics model has been utilised to assess the dynamic performance of several different scenarios utilising different supply chain management principles. The impact on performance of each strategy is analysed to understand the specific implications of implementing specific supply chain management principles.

It is concluded that the reduction of the supplier base and the centralisation of supply greatly improved the performance. The reduction in manufacturing lead-times proves to be beneficial especially from a dynamic point of view. A change in technology not only has supply chain advantages (shortening it) but also has quality, speed of assembly on site, reduce demand on labour and cash flow implications. The compression of ordering cycle time and construction time reduce the total supply chain inventory costs by 20% and the amount of labour required by 49%.

Finally it is concluded that several different supply chain management principles *can* be implemented in the house building industry (i.e. time compression, partnering, information systems, customer focus, etc.) and that these principles *can* improve the overall performance of the UK private house building industry.

Dedicated to:

Jürgen

Thank you for encouraging me, being there for me and supporting me.

Without your encouragement, this thesis would not be.

Wir werden gewinnen.

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Nomenclature

APIOBPCS	Automated Pipeline feedback compensated Inventory and Order Based Production Control System
B&B	Brick and Block
BPE	Business Process Engineering
BPI	Business Process Improvement
BPR	Business Process Re-engineering
COMPOSE	“Innovation in Standardisation Component Systems in House Building” research project
ECR	Efficient Customer Response
EDI	Electronic Data Interchange
EPOS	Electronic Point Of Sale
ER	Efficient Replenishment
IAE	Integrated Absolute Error
IOBPCS	Inventory and Order Based Production Control System
IT	Information Technology
JIT	Just-In-Time
KPI	Key Performance Indicator
LSDG	Logistics Systems Dynamics Group
MAUT	Multi-Attribute Utility Theory
MCDM	Multi-Criteria Decision Making
MD	Managing Director
PIP	Product Introduction Process
PIVS	Positive Input Ventilation System
QR	Quick Response
SAP	Standard Assessment Procedure
SC	Supply Chain
SCM	Supply Chain Management

SP	Supplier Partnering
SSM	Soft Systems Methodology
SWOT	Strengths Weaknesses Opportunities and Threats
T_a	Time to average demand
T_i	Time to adjust inventory
T_p	Actual production lead-time
TSM	Terrain Scanning Methodology
UDSO	Understand Document Simplify and Optimise
UK	United Kingdom
WIP	Work In Progress

Chapter 1 Introduction

1.1 Background to the research

Sir Michael Latham produced a report in 1994 entitled "Constructing the Team" (Latham, 1994). This report is now considered as the key driver for change in the construction industry in the UK. It revealed to the public all the problems of the construction industry and offered some guidelines to improve the performance of that industry. The report was meant to be thought provoking and its findings and recommendations are radical. For example, the report states that clients do not always get what they asked for, i.e. value for money, pleasing to look at, free from defects on completion, delivered on time, fit for purpose, supported by worthwhile guarantees, reasonable running costs, and satisfactory durability. "Traditional construction" is also defined as the most familiar route for the industry but it has also been identified as the route where many of the problems emerge through lack of coordination between design and construction. A recommendation to solve that problem is to effectively pre-plan the design process and to efficiently administer the project for the client. Recommendations on contract types and content, on tendering procedures, and on selection of subcontractors have also been made. The use of partnering agreements are recommended especially for large programmes *"where it is desirable to build up expert teams and keep them together"* (Latham, 1994, p. 62).

A second report, known as the Egan report, followed in 1998 studying the construction industry with a specific focus on the house building industry (Egan, 1998). This report acknowledges the good results of some parts of the industry, for some specific construction projects, but reiterated the need for overall performance improvements. It identified five key drivers of change: committed leadership, a focus on the customer, integrated processes and teams, a quality driven agenda and commitment to people. The report also sets some challenging but achievable targets such as an annual reduction of 10% in construction costs and construction times and a 20% reduction in defects. The changes should focus on processes and they should consider four key elements: product development, project implementation, partnering the supply chain and production of components. Finally it encourages the construction industry to learn from other industries to improve performance.

The COMPOSE research project, of which the author is a member, is one of the projects which were set up in response to both Latham and Egan reports to specifically explore the possible applications and benefits of off-site manufacturing and supply chain management principles in the context of the house building industry. This UK government sponsored project through the auspices of the Department of Environment, Transport and Regions, Innovative Manufacturing Initiative and Engineering and Physical Sciences Research Council entitled "Innovation in Standardised Component Systems in House Building" (COMPOSE) in collaboration with nine industrial partners encompasses theoretical and action-based research. The nine companies each represent an element of the housing industry supply chain as indicated in Table 1.1, which gives the companies' profiles.

Company	Role	Approx. number of employees	Turnover £M	Construction sector	Customer type
A	Manufacturer	700	80	Social / Private	Contractors
B	Manufacturer	340	30	Social / Private	Contractors / Housing Association
C	Main Contractor	300	90	Social	Housing Association
D	Developer	1,000	312	Private	Individual Customers
E	Architects	130	5	Social	Housing Association / Contractor
F	Housing Association	370	45 (only for rental)	Social	Social Tenants
G	System Integrator	20	1.4	Social / Private	Individual Customers / Developers
H	Manufacturer	1,000	171	Social / Private	Merchant
I	Consultant	1	0.05	Social / Private	Developer / Contractor

Table 1.1 Summary of company profiles involved in the COMPOSE research project (Source: Hong-Minh et al., 2001)

The project is researching a component-based approach to the UK house building industry, investigating ways to improve customer choice and optimising the supply chain processes.

The research undertaken by the author is specifically aimed at determining the appropriate supply chain processes that will support a component-based approach.

During the research, the author developed a strong interest in supply chain management (SCM) and its potential for improvement in different industries such as the automotive and retailing industries. An obvious lack of published work on the implementation of SCM principles in the house building industry was also realised. Therefore this work, born from a need to improve the construction industry in the UK and from a personal interest in the applicability and impact of SCM, investigates ways in which SCM principles can be implemented in the UK house building industry.

1.2 Research questions

The general aim of the research is to investigate if supply chain management principles can improve the UK private house building performance. This is realised by studying the impact of SCM principles on house building performance and the way in which it is influencing it.

As will be seen in Chapter 3, three different supply chains have been identified. The research questions are therefore:

- Which SCM principles can be applied to the:
    - House shell's supply chain?
    - High-value fit-out's supply chain?
    - Low-value fit-out's supply chain?
- How do these principles impact on the performance of the:
    - House shell's supply chain?
    - High-value fit-out's supply chain?
    - Low-value fit-out's supply chain?

1.3 Delimitation of scope and key definitions

As will be shown in Chapter 4, the house building industry is very different from the construction industry. Furthermore, the private or speculative house building industry also needs to be distinguished from social housing. Therefore, this work is limited to the speculative house building industry in the UK, which does not include the general construction industry, social housing and repair and maintenance work. In addition, 75% of the UK house builders build a minimum of 500 units a year utilising a portfolio composed of 20 or more standard house type designs. Hence, as it is the repeatability aspect, which is being studied in this work, the results will be especially applicable to such house developers building 500 units per year or more.

For clarity and ease of understanding, key definitions of words used throughout this thesis are given below:

- Developer: The word developer in this work means the company/organisation developing the land privately (in contrast with social). Speculative house builder may be used as a synonym. Speculative house builders can be defined as organisations building houses to then sell them to customers and therefore face the risk of not selling them (Ball, 1996). When the word "developer" is used it represents the whole organisation including the headquarters, regional offices, and sites.

- Customer is used in this work in a broad sense. Every company has a customer to whom it will deliver some products or services. Therefore, a developer can be the customer of a distributor, which is in turn the customer of a manufacturer.

- End-user or buyer: in this case, the end-user or buyer represents the house buyer or in other words the final customer, the person who buys the finished product, i.e. a house.

- Sub-contractors are the people carrying out the work on site. Although in a strict sense they are not working for a main contractor but for a developer, it is common to refer to them as sub-contractors (Ball, 1996). Sub-contractors represent the labour needed to build houses.

- Manufacturers are defined in this thesis as companies producing a finished product, which will be used on site. Therefore in this sense brick manufacturer produces finished bricks, and ventilation manufacturers produce finished ventilation systems.

1.4 Structure of the thesis

Chapter 2 presents an overview of the literature used in the research for this thesis. The concepts of supply chain management, business process re-engineering, systems thinking and supply chain dynamics are presented as well as performance indicators related to supply chain management and supply chain dynamics. Chapter 3 presents the methodology followed during this research work taking a Soft System Methodology approach. The epistemological positioning of the author is described and the methods and tools used are presented.

An overview of the house building industry in the UK is given in Chapter 4. A description of a speculative house builder business processes is presented and the major problems faced by the private house building industry are reviewed. House building performance indicators are also presented. Chapter 5 describes the simulation model used in Chapters 6, 7, and 8. The model structure and main equations are given and the validation and verification of the model is presented.

The next three chapters, 6, 7, and 8, presents the research findings. Each chapter assesses the current situation's performance and analyses the impact of SCM principles on performance. Chapter 6 considers the house shell supply chain, chapter 7 the high-value fit-out supply chain, and chapter 8 the low-value fit-out supply chain.

Chapter 9 summarises the findings and discusses them in a wider context. Chapter 10 presents the conclusions, lessons to be learnt and recommendations for further work. The conclusions refer explicitly to the general aim and research questions presented in Section 1.2.

1.5 References

Ball, M. (1996). <u>Housing and Construction. A troubled relationship?</u>

Egan, J. S. (1998). Rethinking construction: the report of the Construction Task Force, Department of the Environment, Transport and the Regions, London.

Hong-Minh, S., R. Barker and M. Naim (2001). "Identifying Supply Chain Solutions: those suitable for the UK house building sector." <u>European Journal of Purchasing and Supply Management</u> **7**(1): 49-59.

Latham, M. (1994). <u>Constructing the Team</u>. London, HMSO.

Chapter 2 Literature Review

2.1 Introduction

The purpose of this chapter is to present the key publications that influenced the research in this thesis. The literature is not always presented in a strict chronological order but grouped by main subject area for ease of presentation and understanding. There is a near endless number of publications available for the research area concerned in this thesis, however this chapter only attempts to present the main guiding references, which were used for the foundation of this thesis. Other references for more specific issues are presented in each chapter when and where required.

This chapter first presents the research area specific to this thesis, supply chain management. The research covered encompasses a number of different bodies of knowledge, which overlap each other. Each specific area is then presented by giving an overview of the main contributing authors' work.

2.2 Research area

The area of research studied in this thesis was elaborated through a mental flow (see Figure 2.1), where one area was first considered which then led to the study of another area. Supply chain management (SCM) was the starting point for this research. SCM led to the concept of lean, business process re-engineering (BPR) for its similarities with SCM and to system dynamics for its study of supply chain dynamics. The concept of lean led to agile and leagility, this then led to the tools necessary to implement lean and agile concepts. The author also took interest most particularly in the simulations side of system dynamics, especially with regards to supply chain simulations. Figure 2.1 also represents the overlap of these research areas and the main authors who influenced this thesis.

As will be seen in this chapter, the author takes a holistic SCM point of view in this thesis. The concepts of BPR, lean and agile are considered as tools to successful SCM and applied in a system dynamics context.

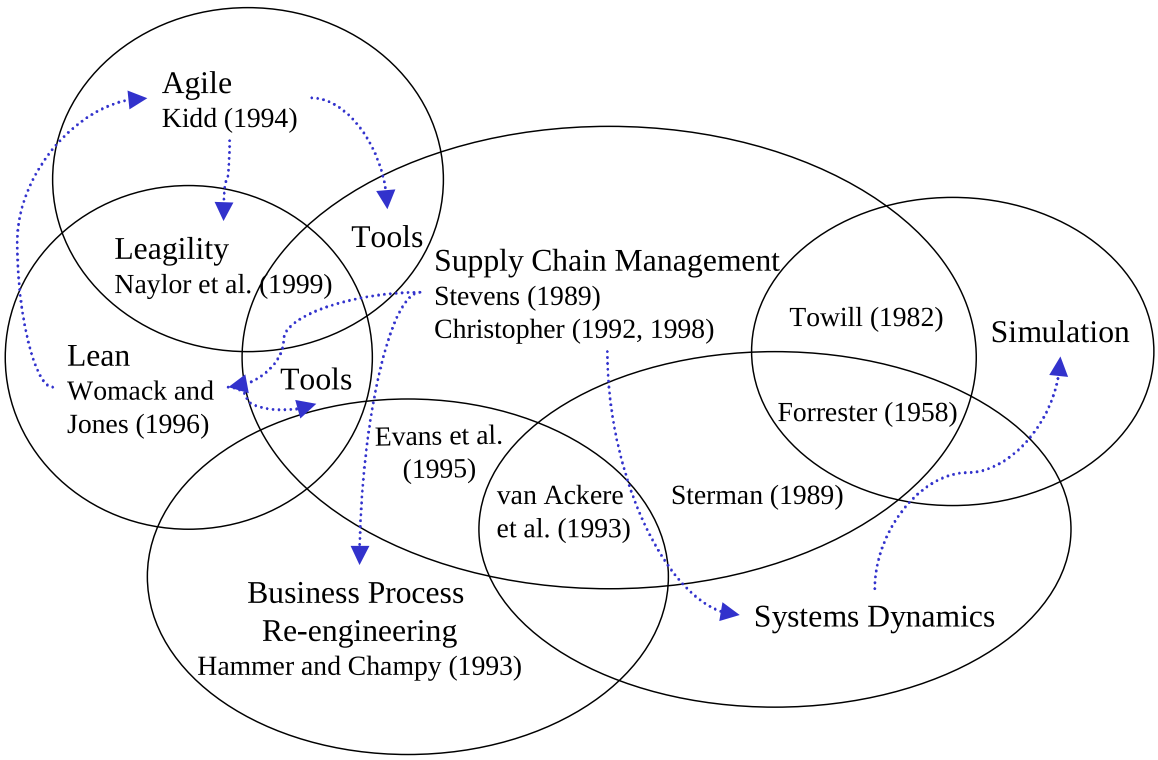

Figure 2.1 Research area

This chapter will review the main contributing authors for the research areas presented in Figure 2.1. SCM definition, principles and applications are presented. The literature on SCM is presented in three categories: supply chain structure, relationships in supply chains and operational strategies for SCM. Supply chain dynamics will then be introduced, including the main references in terms of supply chain simulations using a system dynamics approach. Finally, a summary will be drawn where the gap in the literature will be highlighted.

2.3 Supply Chain Management

Historically, companies have focused on their own organisation with the aim to increase their profits. They saw themselves as one single company "fighting" against other companies to increase their market shares and profitability. In order to survive, companies had to compete against each other; however, this focus is now changing and it is common to hear about supply chains competing with each other (Christopher, 1998).

2.3.1 Definitions

2.3.1.1 Definition of a supply chain

There are several different supply chain definitions available. Harland (1996) distinguishes four categories of use for the term supply chain:

1. Internal supply chain: focuses on the internal flow of materials and information within one specific company.
2. Dyadic or two party relationships, which looks at the relationship between a company and its immediate supplier or customer.
3. Entire supply chain including the supplier's supplier and the customer's customer.
4. Network of organisations involved in the provision of a product or service required by the end-customer.

These distinct points of view are represented in the literature by different authors referring to the different definitions. For example, the first and second categories of supply chain are described by Oliver and Webber (1982), Houlihan (1984), Stevens (1989) and Davis (1993). References to entire supply chains can be found for example in Forrester (1961) and Burbidge (1961) although not explicitly using the term supply chain, and Jones and Riley (1985) and Towill (1991); while Ellram (1991), Lee and Billington (1992) and Christopher (1992) refer to supply chains as a network.

In this thesis the term supply chain refers to the third and fourth definitions, where an entire supply chain involving the supplier's supplier and the customer's customer is studied but also multiple distributors and manufacturers are also taken into consideration.

Some possible definitions for a supply chain are summarised in Table 2.1.

Author(s)	*Definition of Supply Chain*
Jones and Riley, 1985	The planning and control of total material flow from suppliers through manufacturing and distribution chain to the end-users.
Stevens, 1989	A system whose constituent parts include suppliers of materials, production facilities, distribution services and customers, all linked together via the feed forward flow of materials and the feedback flow of information.
Ellram, 1991	A network of firms interacting to deliver a product or service to the end customer, linking flows from material supply to final delivery.
Christopher, 1992	The network of organisations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer.
Davis, 1993	A network of processing cells with the following characteristics: supply, transformation and demand.
Cooper et al., 1997	The integration of business processes from end-user through original suppliers that provides products, services and information that add value to customers.
Christopher, 1998	The network of connected and interdependent organisations mutually and co-operatively working together to control, manage and improve the flow of materials and information from suppliers to end users.
Handfield and Nichols, 1999	It encompasses all activities associated with the flow and transformation of goods from raw materials stage, through to the end user, as well as the associated information flow. Materials and information flow up and down the supply chain.
van der Vorst, 2000	A network of (physical and decision making) activities connected by material and information flows that cross organisational boundaries.

Table 2.1 Definitions of Supply Chain

Close to the concept of the supply chain is the value chain concept proposed by Porter (1985). The value chain provides a systematic way of examining the activities of not only one individual company, but also the activities of component companies within a supply chain. As can be seen from Figure 2.2, the value chain consists of nine generic value activities and the margin. Theses activities are divided into primary and support activities, and all are linked together in characteristic ways.

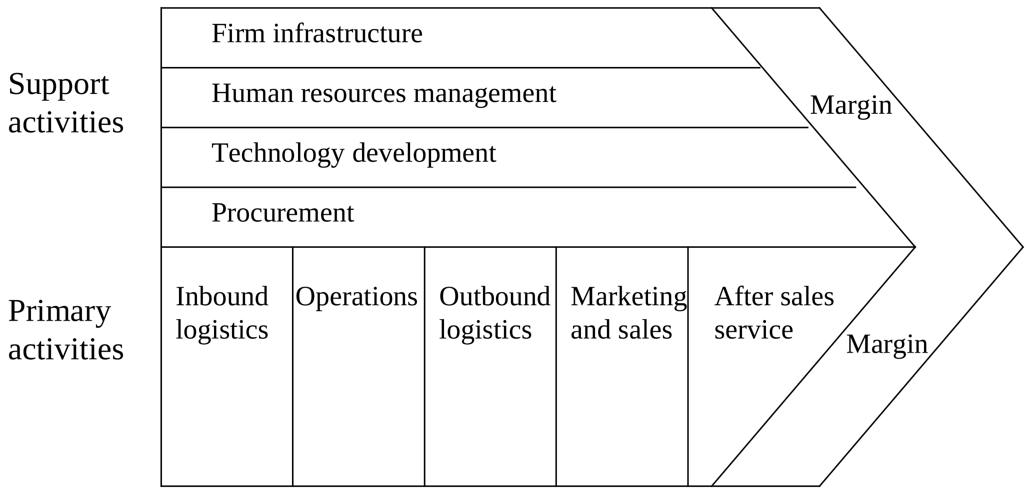

Figure 2.2 The value chain (Porter, 1985)

For the purpose of this thesis, a supply chain will be defined as *a chain of organisations linked to each other through flows of material, labour and information from the end-customer to the raw material supplier.* Labour is included in this definition as in the case of the construction industry; labour is required to carry out a specific task, such as electrical sub-contractors who are specially hired to carry out electrical work on site. The "delivery" of labour on site needs, in the same way as material, to be on time, at the right place, the right quantity, the right quality and at the right price. A representation of a typical house building supply chain can be seen from Figure 2.3.

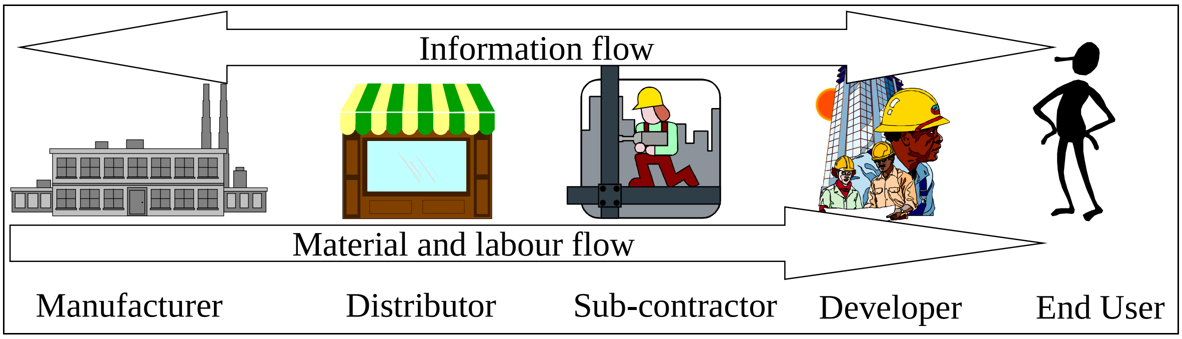

Figure 2.3 Representation of a house building supply chain

2.3.1.2 Definition of Supply Chain Management

Handfield and Nichols (1999) define supply chain management (SCM) as *"the integration of these activities [activities associated with the flow and transformation of goods from the raw materials stage through to the end user] through improved supply chain relationships, to achieve a sustainable competitive advantage"*. Christopher (1992) defines SCM as the extension of the logic of logistics, as *"logistics management is primarily concerned with optimizing flows within the organization whilst supply chain management recognizes that internal integration by itself is not sufficient."* In other words, logistics management would consider a supply chain as being an internal supply chain (within one organisation) while SCM focuses on more than one organisation. This reflects the modified definition of logistics management by the Council of Logistics Management in 1998 where *"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 customer requirements"* (Lambert et al., 1998).

Jones and Riley (1985) define SCM as *"an integrated approach to dealing with the planning and control of the material flow from suppliers to end users"*. This leads on to supply chain integration, which is defined by Boorsma and van Noord (1992) as the *"co-ordination of logistical activities between separate links in the chain in order to plan, control and execute the logistics processes as one integrated system supported by an integrated information system, and the aim of improving the logistics performance of the complete system."* Sabath (1995) defines integrated supply chain as *"linked organizationally and co-ordinated with information flows, from raw material to on-time delivery of finished products to customers."* Stevens' (1989) four stages to achieve supply chain integration as shown in Figure 2.4 indicates that the integration needs to be extended outside the company to include suppliers and customers. Furthermore, an integrated supply chain links the strategic, tactical and operational perspectives (Stevens, 1990). The first stage to supply chain integration is the Functional Integration where the focus is placed on the inward flow of material. The second stage, Internal Integration, achieves the synchronisation of customer demand with the manufacturing plan and the flow of material from suppliers. External Integration, the third stage to supply chain integration, consists of integrating suppliers and customers. This stage includes a change of focus, moving from being product-orientated to customer-orientated.

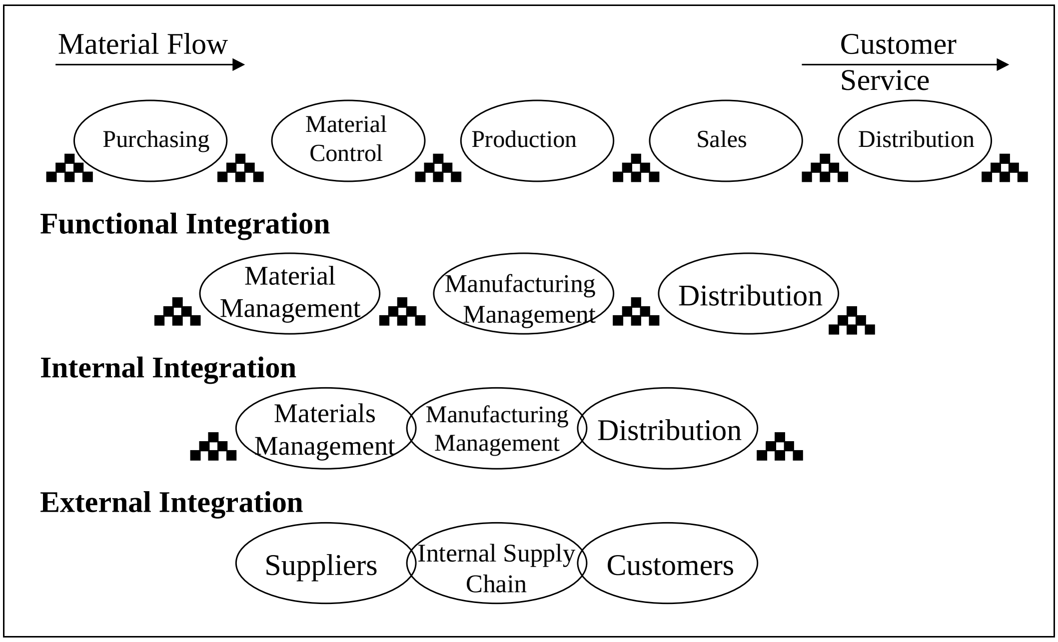

Figure 2.4 Achieving an integrated supply chain (Stevens, 1989)

In the context of this thesis, house building SCM will be defined as *"the management, control and co-ordination of material, cash, resource and information flows in order to construct habitable dwellings based on specific design requirements, including the appraisal and selection of skilled labour and material suppliers"* (Childerhouse et al., 2000).

2.3.2 Supply Chain Management enablers and opportunities

An extensive literature review on SCM revealed that publications on SCM can be categorised into three areas: literature related to supply chain structures, literature related to the type of relationships between supply chain organisations, and literature related to the operational strategies that can be used.

A wide range of SCM enablers cited by key authors have been classed under these three categories and is shown in Table 2.2. The structure category refers to SCM principles dealing with the "hard" supply chain structure, i.e. the number of echelons involved. It also takes into account the structure of the information flow.

The relationships category deals with the range of relationships that can be developed between organisations (partnering, vertical integration, co-operation). The third category, operational strategies, deals with strategic issues, such as Lean and Agile paradigms.

	Houlihan (1985)	Stevens (1989)	Jones (1990)	Lee and Billington (1992)	Cooper and Ellram (1993)	Davis (1993)	Sabath (1995)	Davies (1995)	Bowersox and Closs (1996)	Lamming (1996)	Tan et al. (1998).	Handfield and Nichols (1999)
Structure												
Reduction of supplier base			✓					✓			✓	
Reduce SC uncertainties				✓		✓	✓		✓		✓	
EPOS							✓				✓	
Demand Forecast				✓			✓		✓			✓
IT, information system	✓		✓	✓			✓	✓	✓	✓	✓	✓
Communication information sharing	✓	✓		✓	✓		✓	✓	✓		✓	✓
Globalisation			✓		✓				✓			
One point of control										✓		✓
One entity, holistic view	✓				✓			✓		✓		
Relationships												
Partnership							✓	✓	✓			✓
Culture, trust, confidence					✓			✓				✓
Operation strategies												
Reduced delays	✓								✓			✓
Reduce cycle time							✓		✓		✓	✓
JIT					✓	✓				✓		
ECR/Rapid response					✓				✓	✓		✓
Focus on customers	✓					✓		✓	✓	✓	✓	✓
Information on inventory							✓	✓	✓		✓	✓
Cost transparency					✓			✓		✓		
Process orientation	✓	✓					✓		✓			✓
Synchronisation		✓					✓					
Co-ordination				✓					✓			✓

Table 2.2 SCM enablers in the literature

2.3.2.1 Structures of supply chains

An important rule for effective SCM structure is to reduce the supplier base by reducing the number of suppliers (Jones, 1990;Davies, 1995; Tan et al., 1998). This can also be complemented by eliminating unwanted echelons (Towill, 1991; Wikner et al., 1991). Furthermore, as Lamming (1996) argues, another fundamental to SCM is the notion of one point of control in the supply chain, *"usually occupied by the firm or organization conducting the last significant transformation of the product before it reaches the consumer"* p. 186. This is combined with a strategic vision of the supply chain, by taking a holistic point of view (Lamming, 1996). Many authors agree with this point of view (e.g. Houlihan, 1985; Cooper and Ellram, 1993; Davies, 1995; Dornier et al., 1998; Handfield and Nichols, 1999).

Another important feature in supply chain structures is the information flow structure, where IT systems are advocated to transfer information in a more efficient manner (Stevens, 1989; Lee and Billington, 1992; Sabath, 1995). The information also needs to be shared through the supply chain (Cooper and Ellram, 1993; Bowersox and Closs, 1996; Handfield and Nichols, 1999).

Stevens (1990), for example, shows that in very simple terms, when a supply chain is properly designed and managed it should improve customer service, achieve the necessary balance between costs and service and give companies a competitive advantage. In addition, Davis (1993) promotes SCM as a means to reduce uncertainties. He identifies three sources of uncertainties: suppliers, manufacturing and customers. The supplier uncertainty is related to supplier performance, the second source of uncertainty comes from the manufacturing process itself and irregular customer orders form the third source of uncertainty.

Some quantified benefits can be found in the literature on the impact of supply chain structures on performance. For example, a case study from the retail sector shows the benefits from the use of IT. *"Empire Stores Group, in the home shopping sector, has developed Editrack to track the progress of orders – Empire Stores and its suppliers both have access to the information. The system has allowed Empire to monitor and control suppliers more effectively, and has increased the productivity of staff managing suppliers by over 40%"* (Charatan, 1999, p. 165).

Furthermore, the centralisation of supply on a national and regional level in the retail sector has almost always proved beneficial (Charatan, 1999). This holds in all cases except for a particular need to distribute customised products to local markets requirements within short lead-times. Centralisation allows savings to be made as the capital tied up in warehouses is reduced and efficiency is increased due to larger distribution centres. In addition, it increases customer service level and reduces inventory levels (Charatan, 1999).

The centralisation of supply also proved itself very beneficial in the electronic industry. *"In two years National Semiconductor reduced distribution costs by 2.5 %, decreased delivery time by 47%, and increased sales by 34% by closing six warehouses around the globe and air-freighting microchips to customers from a new centralised distribution centre in Singapore."* (Henkoff, 1994).

2.3.2.2 Relationships in supply chains

Supply chain relationships are the focus of numerous publications. Especially in the construction sector, whenever the term SCM is used, the focus is mainly placed on the improvement of relationships (e.g. Lorraine, 1994; Barlow, 1996; Larson, 1997; Construction Productivity Network, 1999; Construction Productivity Network, 2000c). Often quoted cases of SCM in the construction industry, are in fact only addressing the issue of relationship via partnering.

Ellram (1991) proposes a spectrum of relationships as shown in Figure 2.5. Supply chain relationships may take on various legal forms including market transaction, long-term contract, joint venture and acquisition (or vertical integration). Ellram (1991) views SCM as lying between fully vertically integrated systems (acquisition) and short-term contract where each channel member operates independently.

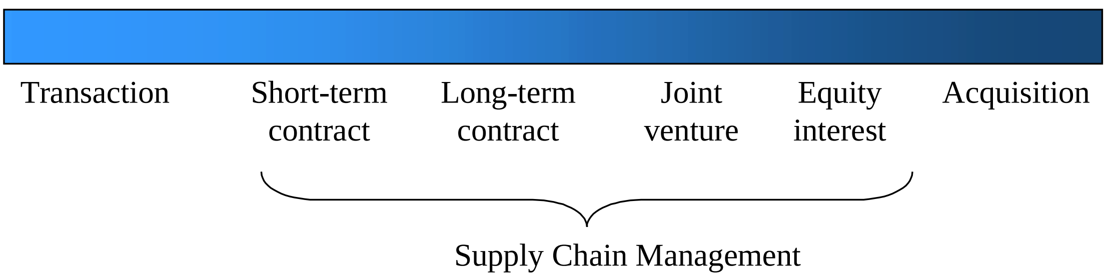

Figure 2.5 Types of competitive relationships (Ellram, 1991)

The relationships studied in the SCM literature can be placed in the spectrum between strategic partnership and vertical integration (acquisition).

Strategic Partnering

LaLonde and Cooper (1989) define partnering as *"a relationship between two entities in the logistics channel that entails a sharing of benefits and burden over some agreed time horizon"*. Ellram (1991) utilises a similar definition: *"an ongoing relationship between two organisations which involves a commitment over an extended time period, and a mutual sharing of the risks and rewards of the relationships"*. Partnering is a tailored business relationship featuring mutual trust, openness, and shared risk and reward that yields strategic competitive advantage (Handfield and Nichols, 1999).

More particularly in the construction industry, many definitions of partnering can be found (Lamming, 1993; Lorraine, 1994; Cooper et al., 1996; Lemmink and Wetzels, 1996; Loraine, 1996; Brooke and Litwin, 1997; Crane et al., 1997; Barlow, 1998). The most frequently exercised definition proposed by the Construction Industry Institute's Partnering Task Force (1991, p. 2) and the National Economic Development Council (1991, p. 5) is as follows:

"A long term commitment between two or more organisations for the purpose of achieving specific business objectives by maximising the effectiveness of each participants' resources. This requires changing the traditional relationships to a shared culture without regard to organisational boundaries. The relationship is based upon trust, dedication to common goals, and an understanding of each other's individual expectations and values. Expected benefits include improved efficiency and cost effectiveness, increased opportunity for innovation, and continuous improvement of quality products and services."

Dornier et al. (1998) summarises the main differences between a traditional approach and a supplier partnerships approach as presented in Table 2.3. While van der Vorst (2000) summarises the critical success factors for partnerships as shown in Table 2.4.

Traditional Approach	Supplier Partnerships
Primary emphasis on price Short term contracts Evaluation by bids Many suppliers Improvement benefits shared based on relative power Improvement at discrete time intervals Problems are suppliers' responsibility to correct Clear delineation of business responsibility Information is proprietary	Multi criteria Longer term contracts Intensive and extensive evaluation Fewer selected suppliers Improvement benefits are shared more equitably Continuous improvement is sought Problems are jointly solved Quasi-vertical integration Information is shared

Table 2.3 Traditional versus supplier partnerships (Dornier et al., 1998)

Drivers for partnerships	**Main partnership facilitators**	**Successful partnership characteristics**
Asset-cost efficiencies (cost reduction) Customer service (e.g. shorter cycle times) Marketing advantage (e.g. entrance into new markets) Profit stability/growth	Strategic complementarity Corporate compatibility (culture and business goals) Compatibility of managerial philosophy and techniques Mutuality (joint objectives, share sensitive information) Symmetry in power	Joint planning Global SC operating controls Systematic operational information exchange (rapid and accurate transfer) Sharing of benefits / burdens Trust and commitment Extendedness (the relationship will continue in the future) Corporate culture bridge-building

Table 2.4 Critical success factors for partnerships (van der Vorst, 2000)

Ellram and Krause (1994) have carried out an interesting and important study, where they compared manufacturing and non-manufacturing companies. This study refers to "supplier partnering" (SP) being defined as *"an ongoing relationship between firms which involves a commitment over an extended time period, and a mutual sharing of information and the risks and rewards of the relationship"* (Ellram and Krause 1994, p. 43). The study was undertaken using an in-depth survey sent to a variety of companies including chemical and related products, electronics and electronic equipment, industrial equipment and machinery, banks and banking services, air transportation, trucking and warehousing.

Ellram and Krause (1994) indicated the estimated improvement resulting from supplier partnership. Both manufacturing and non-manufacturing companies showed considerable reduction of incoming defects (21.2 and 6.4% respectively), percentage on time delivery (25.6 and 22.9% improvement respectively), cycle time reduction (24.7 and 7 days respectively) and percentage of orders received complete (16.8 and 15.6% improvement respectively).

Akintoye et al. (2000) also presented a good survey on supply chain collaboration in the UK construction industry. This survey showed that the principal objectives for developing construction supply chain collaboration are to achieve benefits to the client, improve customer service, reduced bureaucracy and paperwork, increased profitability, reduced costs within the organisations, and increased market competitiveness. In the same manner, Proverbs and Holt (2000) argue that the best way to reduce costs in the construction industry is to develop downstream strategic alliances (for a specific project) between the main contractor and material suppliers, sub-contractors, plant and equipment providers, etc.

Vertical integration

Vertical integration can be viewed as the ultimate partnerships between companies. Ellram (1991) views vertical integration as an alternative to SCM "*in that it attempts to manage and control efficiency through ownership*". Williamson (1985) argues that vertical integration is most likely to take place when, as assets become more specific to a single user, there is no advantage to purchasing outside; or in other words, in the case of recurrent transactions, which require very specialised assets. While Houlihan (1985) promotes vertical integration for effective international supply.

Ellram (1991) summarises the advantages and disadvantages of vertical integration in three broad categories (Table 2.5).

Advantages of vertical integration	Disadvantages of vertical integration
Improves control: • Reduction of uncertainty • Convergent expectations • Reduced probability of opportunism and externalities (e.g. dependency on monopoly suppliers) • Ease of conflict resolution	*Limits competition:* • More difficult for non-integrated firms to enter business • Weakens non-integrated competitors • Inability to replicate market incentives • Internal information distortion
Improves communication: • Improved co-ordination of processes • Greater goal congruence	*Increases risk:* • Asset concentration • Perpetuates obsolete processes • Exaggerates synergies
Improves cost structure: • Economies of scale through avoidance of intermediaries • Process integration (improved asset utilisation) • Avoids switching/transaction costs	*Diseconomies of scale:* • Balancing scale economies • Inability of management to control large organisation efficiently • Limits on span of control • Increased difficulty in communication

Table 2.5 Advantages and disadvantages of vertical integration (Ellram, 1991)

Examples of partnering successful implementation

Many examples can be found in the literature on the advantages and benefits of partnerships in all types of industries.

For example, in the retail industry, close relationships between manufacturers and suppliers have proved to be beneficial. *"Procter & Gamble estimates that it saved retail customers $65 million over the past 18 months. According to Procter & Gamble, the essence of its approach lies in the manufacturers and suppliers working closely together … jointly creating business plans to eliminate the source of wasteful practices across the entire supply chain"* (Journal of Business Strategy, 1997).

Another example, taken from the construction industry, comes from Denmark, where focus was placed upon the logistic planning of material flow. The logistics model used was composed of different features. First of all, all parties were involved at an early stage. *"The material and construction method were chosen/designed to minimize production, transport and wastage on site"* (Agapiou et al., 1998, p. 133). Partnering arrangements between the project participants were also made. The suppliers were responsible for arranging transportation and managing inventory. Agapiou et al. (1998) report that their logistic model achieved a total savings of 5% of the construction costs. These savings were achieved through *"a reduction in materials wastage and breakage and early completion of the project"* (Agapiou et al., 1998, p 135).

Another example is of the relationship between Newydd Housing Association (client) and E. Turner & Sons (main contractor)(Construction Productivity Network, 1998). This represents an example of a social housing industry supply chain. The 8-phase project utilised E. Turner & Sons, the contractor, who won the tender on price alone. The results were clearly not satisfactory as indicated in Table 2.6. The first two phases (Phases 1 and 3) under-performed and the programme over-ran, resulting in increased costs. In addition there were many major complaints from the tenants.

	Phase 1	Phase 3	Phase 5	Phase 4
Cost	+18%	+15%	-5%	-10%
Construction Programme Adherence	+28% (due to relationships problems)	+25% (due to relationships problems)	+11% (handover problems)	+8% (due to additional work and not due to relationship problems)
Major complaints	13	18	nil	nil

Table 2.6 Newydd Housing Association and E. Turner & Sons results (Sources: Construction Productivity Network, 1998 updated by author following discussion with the Property Services Manager of Cadarn Housing Group February-November 1999)

A need for change was clear. The client and the main contractor, with the aim of improving the quality of work and reducing costs, decided to adopt partnering. Hence they created a team comprising the client, the design team, the project manager, tenant associations and the main contractor.

The next two phases (Phases 5 and 4) in Table 2.6 show a considerable improvement in performance. The six-week delay in completion of Phase 5 was due to delays during transition from traditional to partnership working; quality and cost were not a problem. The budget and programme were constantly monitored, the design was developed against the budget and a problem resolution procedure was agreed (Construction Productivity Network, 1998).

Finally Crutcher et al. (2001) give a successful example of partnering implementation where a contractor relies solely on a distributor to procure all electrical material. This partnership agreement reduced non-value adding activities, assured the customer that only approved materials were supplied, reduced overheads costs and reduced total costs for the customer.

It is however also very important to note that the major barriers in implementing SCM are people-based. As Andraski (1994) claims, in real world supply chains *"80 per cent of problems that arise are due to people, not technology"*. One of the main barriers to supply chain integration is the non-integrated structures of supply chains where co-ordination and governance problems arise (Mason-Jones et al., 2001). In fact, supply chains are often represented as linear with clearly defined boundaries. However in reality, each company supplies to a large number of customers where some of them might be direct competitors (Mason-Jones et al., 2001).

Other major barriers to SCM, especially with regards to partnering or closer relationships, are the cultural differences, lack of trust and unwillingness of senior management to provide necessary support (P-E International, 1994). Handfield and Nichols (1999) confirm this by adding that one major barrier is the companies' fear to change. Akintoye et al. (2000) highlight the same barriers in implementing supply chain relationships: a lack of management commitment, the poor understanding of the concept, an inappropriate organisation structure, low commitment from the partners, lack of appropriate technology and unclear strategic benefits.

2.3.2.3 Operational strategies for Supply Chain Management

Operational strategies for SCM cover a wide range of issues such as reduction of cycle times, JIT techniques, quick response, process orientation, synchronisation, etc. One objective of SCM is the synchronisation of customer requirements with the flow of material (from suppliers) in order to balance high customer service, low inventory investment and low unit cost (Stevens, 1989), these objectives being very often conflicting (Stevens, 1989; Davis, 1993).

Towill (1999) proposes twelve rules to simplify material flow across supply chains and they are presented in Table 2.7. These rules are the starting point for smoother material flow throughout the supply chain. These rules combine the five Burbidge (1989) "rules to avoid bankruptcy", simplified manufacturing control rules (Schonberger, 1982), and system dynamics rules (Wikner et al., 1991). The aim of these rules is to build simple material flow within supply chains instead of building in complexity.

Rule 1	Only make products which you can quickly despatch and invoice to customers.
Rule 2	Only make in one period those components you need for assembly in the next period.
Rule 3	Minimise the material throughput time, i.e. compress all lead times.
Rule 4	Use the shortest planning period, i.e. the smallest run quantity which can be managed efficiently.
Rule 5	Only take deliveries from suppliers in small batches as and when needed for processing or assembly.
Rule 6	Synchronise "Time Buckets" throughout the chain.
Rule 7	Form natural clusters of products and design processes appropriate to each value stream.
Rule 8	Eliminate all process uncertainties
Rule 9	Understand, document, simplify and only then optimise (UDSO) the supply chain
Rule 10	Streamline and make highly visible all information flows.
Rule 11	Use only proven simple but robust Decision Support Systems.
Rule 12	The business process target is the seamless supply chain, i.e. all players "think and act as one".

Table 2.7 Twelve rules for simplifying material flow (Towill, 1999)

Operational strategies for effective SCM can be split into three broad overlapping categories: business process re-engineering, lean, and agile. Business process re-engineering is a complementary concept to SCM and some of the tools used during business process re-engineering are common to SCM techniques (Evans et al., 1995). As lean and agile can be interpreted as concepts to achieve effective SCM, the review will be focused on the tools they use more than on the philosophies.

Business Process Re-engineering

Business Process Re-engineering (BPR) emerged in the 90's with Hammer (Hammer, 1990) and Davenport and Short (1990, p.11) where BPR is defined as *"the analysis and design of workflows and processes within and between organisations"*.

However Hammer and Champy's (1993) definition of BPR: *"Re-engineering is the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures in performance, such as cost, quality,* *service and speed."* has strong synergies with Jenkin's (1971) definition of systems engineering: *"The science of designing complex systems in their totality to ensure that the component sub-systems making up the system are designed, fitted together, checked and operated in the most efficient way"*.

Now that definitions of business processes have been reviewed, definition of BPR can be presented. According to Spencer (1992, p. 2), BPR is *"a potent, customer based approach to improving productivity and quality through processes."* Love and Gunasekaran (1997) based their definition on Hammer and Champy (1993) and highlighted the importance of IT *"process reengineering can be considered to be a combination of industrial engineering techniques, operations research methods, management theory, and information systems analysis that utilise the power of information technology (IT) to radically change an organization processes to achieve dramatic performance improvements so that they can effectively compete in their markets within which they operate"* (Love and Gunasekaran, 1997, p.184-185). More than one author refers to IT in their definition of BPR, e.g. Hammer (1990, p.104) already states that re-engineering is carried out using *"the power of modern information technology to radically redesign our business processes in order to achieve dramatic improvements in their performance"*, King (1991, p. 55) also states that *"re-engineering aims to use the power of information technology to radically redesign business processes to improve speed, service and quality"*.

However, BPR can be seen as being one element of a larger concept, Business Systems Engineering (BSE). BSE refers to a methodology to improve a company by analysing its sub-systems and their interactions. Early adopters of BSE include Watson (1994) in the USA and Parnaby (1994) in the UK. Evans at al. (1999) recognise BPR as one of the three *modi operanti* of BSE as shown in Table 2.8. Business Process Engineering (BPE) is concerned with new processes, Business Process Improvement (BPI) is concerned with continuous enhancement of existing processes while BPR is defined as a step change in operations.

Defining Characteristic	Strand of Business Systems Engineering (BSE)		
	BPE	**BPR**	**BPI**
Area of application	New business process	Existing business processes	Existing business processes
Timing	Prior to implementing new business processes	Periodic step changes during the life of the business process	Continuous during the life of the business process
Engineers responsible	Multi-discipline task force with finite life	Multi-discipline task force with finite life	Part of normal duties of the process competition
Purpose	To seize a new market opportunity	To make a breakthrough to overtake the competition	To keep ahead of the competition

Table 2.8 The three separate strands of business systems engineering (Source: Evans et al. (1999) based on Towill (1997c))

Very importantly, BPR has also been compared with SCM. Evans et al. (1995) have studied the main differences and overlap between BPR and SCM. According to their study, BPR and SCM are two complementary philosophies, and BPR cannot be considered as a completely new concept. SCM already takes the point of view that companies need to move away from functional silo by integrating their internal processes (Stevens, 1989). Table 2.9 shows the overlap and differences between the two philosophies.

Area for change	BPR terminology	SCM terminology
Process	**- Elimination of waste around the core processes - Speed up core processes - Concentration on core processes**	**- Reduce non value add activities - Lead time reduction - "SCM positions each firm to do what it does best"**
People	**- Board level commitment - A management that questions - A work force that questions - Multi-skilled work force - Attitudinal changes**	**- Board level commitment with a SCM or logistics champion at board level - A management that questions - A work force that questions - Multi-skilled work force - Attitudinal changes**
Technology	**- Technological change - IT – a key to BPR**	**- Technological change - IT – a key to SCM**
Innovation	**- "Break the rules…(that states)" treat vendors as adversaries" - Customer focus - Constant innovation at the interfaces of the company - Constant product / process innovation**	**- "Partnership sourcing" - Deep penetration into customer base - Constant innovation at the interfaces of the company - Streamline processes**
Analysis	**- Analysis by paralysis is not beneficial - Take an holistic view**	**- Aggregate modelling can aid the redesign strategy - Take a systems view**

Table 2.9 Parallels between business re-engineering and supply chain management (Evans et al., 1995)

Fried (1991, p. 91) stated the aim of the BPR when defining it as *"a methodology for transforming the business processes of an enterprise to achieve breakthroughs in the quality, responsiveness, flexibility and costs to compete more effectively and efficiently in a chosen market"*. Furthermore, BPR makes *"a company more customer-focused and process-based, instead of the traditional procedure-focused and function based"* (Gunasekaran et al., 2000, p. 271).

According to Chan and Peel (1998), benefits resulting from BPR can be achieved in terms of improved customer service, improved technology, increased efficiency, reduced costs and defined strategic focus. Love and Gunasekaran (1997, p. 196) state that *"process reengineering can potentially improve the competitiveness and performance of organisations by radically changing their existing processes and replacing them with new ones"*. Gunasekaran et al. (2000) also mention speed up processes, reduced costs and overheads and increased efficiency as potential benefits from BPR.

BPR often advocates a radical approach to change. Essentially, when re-engineering, companies are re-inventing the ways to conduct their business (Love et al., 1998). BPR looks at the real value-adding activities that can be offered to the customer within the core process activities (Evans et al. 1995). Van Ackere et al. (1993) insist on the fact that if BPR is to be successful, all parties who are affected by the process redesign, have to be involved.

Furthermore, Love and Gunasekaran (1997) recognise four enablers to BPR: information technology, organisational, human resources and total quality management. These enablers are interdependent and changes in one will affect the other three. IT is a potentially powerful tool for BPR and can transform traditional functional processes. The organisational enabler considers the social system formed by a company and its interdependent elements (people, organisation, technology and structure) (Leavitt, 1964). Human resources consider the need for appropriate people to enable the change to take place.

Examples of successful BPR programmes

Many examples of successful BPR programmes can be found in the literature. For example, Berry and Naim (1996) studied the redesign of a PC supply chain. At each stage, improvements have been recorded. The first phase considered the implementation of Just-In-Time (JIT) technique across the whole company. *"The application of JIT techniques have achieved very significant reductions in lead-times and inventory. In European plants, the average manufacturing cycle time from component start to finished good shipment has been reduced by around 50% with an accompanying drop in inventory."* (Berry and Naim, 1996, p. 187). The second phase looked at interplant planning and logistics integration. In this case, the focus was placed upon the information flow associated with materials planning between the company's manufacturing locations. *"A global material planning system, where all the company's manufacturing plants are considered as production lines in a global manufacturing entity"* (Berry and Naim, 1996, p. 187) was developed. *"Altering the flow of demand from serial to parallel mode has brought about a reduction in information flow delays through the chain of more than 75%."* (Berry and Naim, 1996, p. 188). The supplier base was also reduced to include only the best source of supply. Finally, the customer ordering processes and the product distribution channels have been redesigned. This resulted in the removal of an echelon in the supply chain.

Examples of improvements for project based industries (such as Aerospace actuation systems) were presented by Parnaby (1994), with the results being adapted for construction by Evans et al. (1997). This case study looked at several business processes including Product Introduction Process (PIP). The PIP is comparable with the construction process, as it has different phases such as conceptual design, detail design, choice of suppliers, production process and hand-over. The results are significant: 43% reduction in PIP costs, 95% reduction in changes per drawing, 15-20% reduction in product costs and 30% reduction in PIP lead time.

One example in the construction industry is that of Skanska AB, a major Swedish contractor and developer, who adopted a business process approach with the purpose of improving and reducing total cycle times (Hewitt, 1982). Skanska implemented a new management tool titled Think Total Time, or 3T. 3T is a process that forces Skanska to delegate responsibility and authority. The main drivers are client focus, dedication and willingness to change (Skanska, undated). 3T ensures satisfied customers, the right quality and lower costs and greater job satisfaction for everyone. Quantitative improvements are significant. During a design-construct joint venture for a hydro-electric plant, Skanska completed the work 2 years ahead of schedule and the electricity generated during that time was worth 30% of the construction costs. A road structure replacement has been finished within 9 weeks instead of 13 weeks; i.e. 31% faster.

Another well known example can be taken from Doyle Wilson, a US house builder, who, by re-engineering their business processes, improved dramatically their performance in house construction, including a lead time reduction from 21 to 4 weeks (Towill, 1997a). Finally, Ibbs (1994) analyses the case of the US Navy Public Works Centre that had to respond more quickly to customer needs. They changed their way of working by moving from a functional approach towards a business process approach. As indicated in Figure 2.6 they reduced their completion time of construction work from 364 days to 127 days; in other words they reduced their lead-time by 65%.

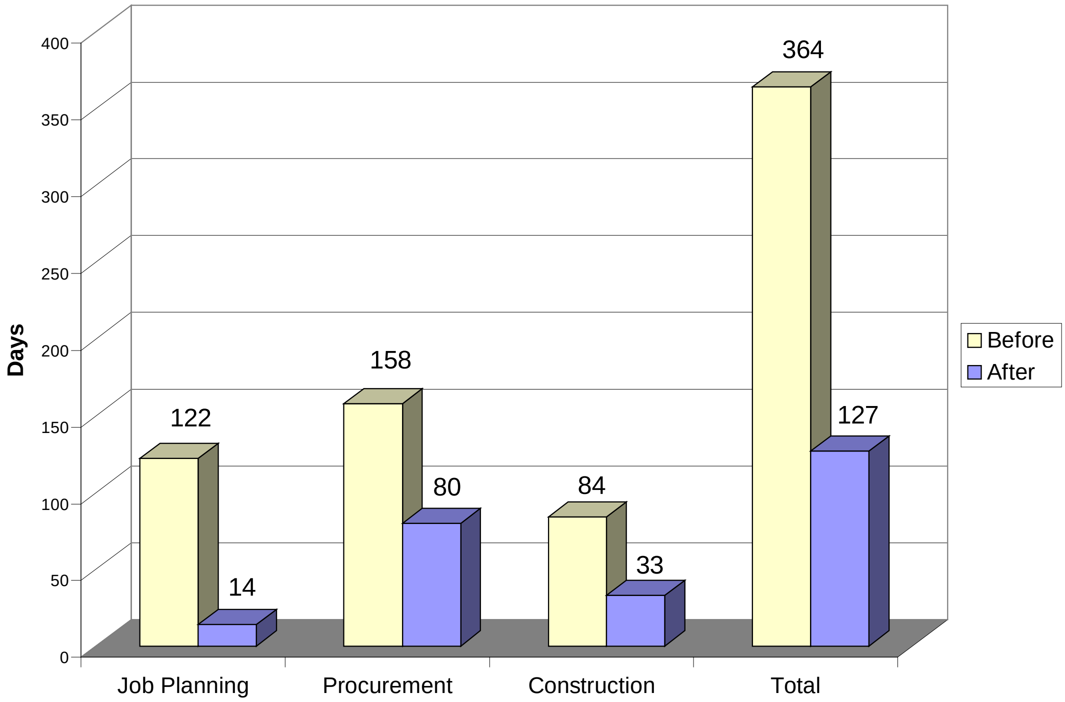

Figure 2.6 Time savings attributable to re-engineering the US Navy public works centre (Ibbs, 1994)

However, Hammer and Champy (1993) claim that 70% of the organisations fail to achieve any benefits from their own reengineering efforts. This goes along with Deakins and Makgill (1997) who claim that a majority of BPR initiatives fail due to the lack of attention paid to change and people issues. As Ibbs (1994, p. 44) states *"It has been said that 10% of any innovation is the research and development, and 90% is the implementation. Analogously, it could be said that 10% of any reengineering effort is the work process study and redesign, and 90% is soothing the affected people"*.

Chan and Choi (1997) studied the reasons for failures and split them into two categories: the lack of understanding of BPR and the inability to perform BPR. The lack of understanding of BPR is concerned with the misunderstanding of BPR and the unrealistic expectations placed upon BPR projects. The inability to perform BPR comes from a lack of effective methodology, the inability to re-conceptualise processes, wrong objectives, a lack of recognition of benefits, over-reliance on IT, and a lack of top management commitment.

Lean

Lean production, linked with Just-In-Time (JIT) has been articulated and implemented by Taiichi Ohno in Toyota's production system and has been publicised through Womack and Jones book "Lean Thinking" (1996). The Toyota Production System is characterised by a JIT production, a production smoothing or level scheduling, a mixed model scheduling, a set-up time reduction to allow for small-lot and single piece flow production, standard operations, autonomous machinery and continuous improvement (Monden, 1983). This concurs with the SCM objective of reducing order-fulfilment cycle times across the supply chain so that costs are reduced and customer satisfaction increased (Handfield and Nichols, 1999). The reduction of cycle-time across the supply chain focuses on materials planning and scheduling, purchase order cycle, manufacturing processes and customer order processes (Handfield and Nichols, 1999).

The objective of lean production is to achieve "zero waste" by not only removing waste but also initiating strategic co-operation between companies (Womack and Jones, 1994). Seven sources of wastes can be identified: (1) overproduction, (2) waiting, (3) transportation, (4) inappropriate Processing, (5) unnecessary inventory, (6) unnecessary motion, (7) defects (Hines and Taylor, 2000).

Since its emergence in the 1950s, lean production has provided a major competitive advantage to Japanese manufacturing companies. However, it is only recently that the construction industry became interested in its principles. Koskela's (1992) seminal report marks the beginning of the construction industry's interest in lean production. Some lean concepts have already been translated to the construction industry. Howell et al. (1993) discuss how buffers of materials can alleviate the dependencies and worker idle time. Tommelein (1998) describes how pull techniques with feedback regarding progress on site to fabricators off site can improve construction process performance.

The construction industry has however traditionally focused on production management (scheduling of discrete activities in the building process) rather than taking a manufacturing process point of view involving the management of resources across a network of companies (Barlow, 1996). After such criticisms, the construction industry has started work on SCM, design for buildability, JIT and other "lean construction" techniques

(Koskela, 1992; Akintoye, 1995; O'Brien, 1995). However such work has only been published for the construction industry and not for the house building industry.

Lean construction reported the use of multiple tools to apply lean production: vision and values, policy deployment, value stream management, continuous improvement, supply development, integration, synchronisation, knowledge management (Construction Productivity Network, 2000b). Successful implementation of lean principles in the construction industry are also reported with 20% reduction in project duration, 50% fewer faults with cost implications and 7.5 % reduction in costs (Construction Productivity Network, 2000a).

In the computer industry, the synchronisation of production through a make-to-order decision rule improved the performance. *"Dell switched from make-to-stock to make-to-order. Personal computers are manufactured to individual customer orders within one to two days, with order-to-delivery times to customer addresses in Europe of two to five days. The benefits include: a consumer proposition better than the competition; stock across Europe reduced by 97%, releasing almost $200 million of capital; and warehouses closed across Europe."* (Charatan, 1999).

Charatan (1999) also studied the benefits of utilising continuous replenishment in the retail industry. In this case, the supplier delivers replenishment shipments triggered by the demand communicated by the retailer. Ideally, the data is exchanged via EDI links automatically to the supplier. The supplier benefits from market data and regular demand, while the retailer benefits in reduced stock (as the replenishments are carried out on a regular basis, the safety stock can be lowered). Furthermore, the supplier reliability increases as the data available to him is the real customer demand and reduces the need for guesswork. Charatan's (1999) study in Europe shows that the service levels between distribution centres and stores increased from 97.5% to 99.7%, category profits rose by 30%, inventory levels decreased by 65% and warehouse space costs fell by 45%.

Agile

From the criticisms of Lean for its rigidity, especially in terms of level schedule, agile manufacturing has emerged. Agility can be defined as "*using market knowledge and a virtual corporation to exploit profitable opportunities in a **volatile** marke*t" (Naylor et al., 1999). The key feature of agile manufacturing is its responsiveness to volatile market requirements.

Goldman et al. (1995) p. 358 define the four basic dimensions of agility:

1. Enriching the customer
2. Cooperating to enhance competitiveness
3. Organizing to master change and uncertainty
4. Leveraging the impact of people and information

Kidd (1994) promotes three major concepts to achieve flexibility in an agile manufacturing environment: (1) introducing "response" buffers, (2) postponing decisions in manufacturing, and (3) late-configuration of products. The use of decoupling points for late customisation is extensively presented by Naylor (2000).

Responsiveness to customer requirements is addressed with the concepts of QR (Quick Response), ECR (Efficient Consumer Response) and ER (Efficient Replenishment). QR emerged in the 1980's for general merchandise retailers and their suppliers (Kurt Salmon Associates, 1993). QR is concerned with sharing market information (Point-of-Sale) in order to jointly forecast future demand (Fisher, 1997). These principles have then been transferred to the retailing sector as ECR strategy (Lamming, 1996). In accordance with SCM, the goal of ECR is to achieve a responsive, consumer-driven system in which suppliers work together to maximise consumer satisfaction and minimise system costs (Kurt Salmon Associates, 1993). ER is concerned with the optimisation of product flow through the supply chain (van der Vorst, 2000).

Van der Vorst (2000) argues that ECR includes ER concepts and that ECR is a sub-concept of SCM (Figure 2.7) as SCM is a much broader concept including political, governmental and environmental issues.

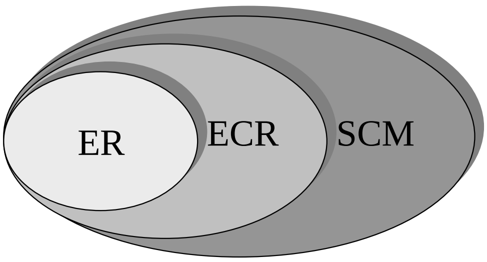

Figure 2.7 View on the relationship between ER, ECR and SCM (van der Vorst, 2000)

Lean vs. agile and leagility

Fisher's (1997) supply chain matrix shows in simple terms where lean and agile techniques are the most appropriate as can be seen from Figure 2.8.

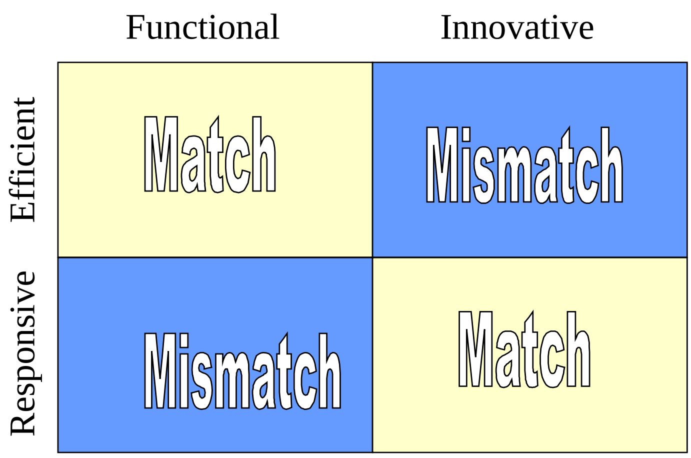

Figure 2.8 Fisher's Supply Chain Matrix (Fisher, 1997)

However, Naylor et al. (1999) proposes a new concept named Leagility combining both the lean and the agile paradigms. The definition of leagility is given as:

"Leagility is the combination of the lean and agile paradigm within a total supply chain strategy by positioning the decoupling point so as to best suit the need for responding to a volatile demand downstream yet providing level scheduling from the decoupling point." (Naylor et al., 1999)

Leagility can therefore be seen as a halfway house where both lean and agile concepts are used within one supply chain. Christopher and Towill (2000) suggest three ways in marrying lean and agile:

- To use a Pareto analysis and apply lean techniques to make the high-volume parts to forecast at 80%, and make the low volume parts to order.
- To use a de-coupling point in the supply chain that enables the creation of stable schedules upstream of the de-coupling point and to use agile to enable customisation of end-customer products.
- To separate demand into base and surge demand and apply lean and agile respectively.

2.3.2.4 Supply Chain Management enablers and opportunities summary

A wide range of SCM enablers have been reviewed in this section. The key enablers to successful SCM that will be studied in this thesis can be summarised as:

- Reducing total cycle time across the supply chain
- Reducing the supplier base
- Improving supplier relationships by developing partnering
- Focus on customers and use end-customer information (via EPOS) enabled through an integrated information system transferring useful and up-to-date information across the supply chain
- Synchronisation of the supply chain

Furthermore, it has been seen that the application of effective SCM can achieve a wide range of benefits and these are summarised below:

- Improved customer service,
- Customer satisfaction,
- Clearer customer demand visibility,
- Competitive advantage,
- Reduced demand amplification,
- Reduced uncertainties,
- Reduced inventory investment,
- Reduce stock levels,
- Compressed order-fulfilment cycle times.

2.3.3 Supply Chain Management performance measures

According to Bowersox and Closs (1996) the objectives of performance measurement and controlling activities in logistics are to track performance against operating plans and to identify opportunities for enhanced efficiency and effectiveness. In other words, if one does not measure, one cannot improve. Clearly defined performance indicators need to be related to the system objectives. A useful way to distinguish the critical performance indicators from the "secondary" ones is offered by Hill (1993) with the "order-winning" and market "qualifying" factors. An order-winner factor represents the reason why customers buy that specific item. It is considered by customers as the key reason for purchasing the product or service. Market qualifier factors on the other hand are the aspects driven by competitiveness, these are minimum attributes that a product or service needs to possess to enter the market. Without these attributes, customers would not even consider the products or services.

Possible performance criteria studied by different authors are summarised in Table 2.10 under four categories: customer satisfaction/quality, inventory, time and costs/assets.

Authors	Customer satisfaction/ Quality	Inventory	Time	Costs / Assets
Jones, 1989	- Quality - Service - Innovation - Product range		- Delivery	- Price
Lee and Billington, 1992	- Service, fill rate - Order lateness	- Inventory measures across the SC - Average backlog levels	- Total response time - Total order cycle time	
Christopher, 1992	- Customer satisfaction - Delivery reliability - Claim procedure	- Stock level	- Order cycle time	- Inventory costs
Bowersox and Closs, 1996	- Delivery to committed date - Warranty costs - Customer inquiry response and resolution time	- Inventory obsolescence	- Source/Make cycle time - SC response time - Production plan achievement	- Order fulfilment costs - Material acquisition costs - Total inventory carrying costs - Logistics-related finance and management information systems costs - Manufacturing labour and inventory overhead costs - Forecast accuracy - Capacity utilisation
Hughes et al., 1998	- Quality defects	- Inventory levels	- Order cycle time - New product development cycle	- Raw material purchase costs - Cost of distribution - Total resource deployed
Handfield and Nichols, 1999	- Perfect order fulfilment - Customer satisfaction - Product quality	- Inventory days of supply	- Order fulfilment lead time	- Total SC costs - Cash-to-cash cycle time - Asset performance

Table 2.10 SCM performance measures in the literature

From Table 2.10 it can be seen that for the customer satisfaction / quality category there are four main measures of performance: service level, product quality, customer satisfaction and reliability of delivery. Customer satisfaction is usually measured comparing perceived performance by customers and expected performance. Inventory measures of performance are mainly stock levels carried by the SC. Performance measures related to time can be summarised by total response time and total order cycle time. Finally costs/assets performance indicators are inventory costs and forecast accuracy.

For this thesis, the performance criteria will be defined as:

- **Stock levels / safety stock**: The level of stock carried by the manufacturer will be measured. This stock level will be calculated for a 100% customer service level, i.e. there is always enough stock available to meet customer demand.
- **Total response time** is defined as the lead-time from order of the product to the time the product is assembled or installed on site.
- **Order cycle time** is defined as the lead-time from order to delivery of the product.
- **Inventory costs:** The costs of holding inventory across the entire supply chain will be calculated. This will include the cost of holding inventory and the cost of being out of stock.
- **Customer satisfaction** will be measured considering the developer as the customer of the supply chain.

These performance criteria have been selected as they cover the most frequently cited measures of performance and due to data availability constraints.

2.4 Systems thinking and system dynamics

2.4.1 Systems thinking

Systems thinking appeared in the 20’s when most academic disciplines were faced with increasingly complex problems to solve (von Bertalanffy, 1968). In all fields, the traditional method of research was becoming less and less adequate to deal with complex problems (Kramer and de Smit, 1977). For example, in the engineering field, control theory emerged as a result of complex systems composed of interdependent elements. In the field of biology, von Bertalanffy (1928), one of the founders of general systems theory, realised that some phenomena could not be explained through the molecular biology and required a different approach.

The basis of systems thinking is that a *"holistic approach, in which emphasis is put mainly on the interrelationship of individual parts"* improves the results (Kramer and de Smit, 1977, p. 2). This is based on the premise that *"the whole is more important than the sum of its parts"*, also known as "Gestalt" (Wertheimer, 1923; Koehler, 1924). Systems thinking is a methodology to approach and solve problems. Kramer and de Smit (1977, p. 14) give a definition of a system as *being "a set of interrelated entities, of which no subset is unrelated to any other subset"* and is represented in Figure 2.9. The elements or constituents of the system are interdependent.

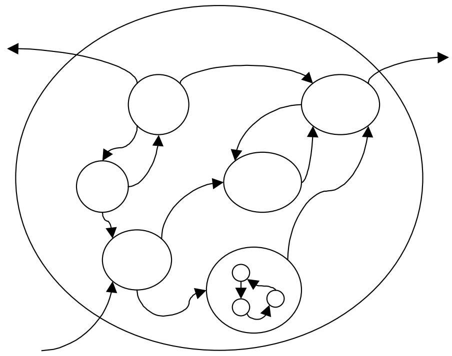

Figure 2.9 A system

Another important concept in system thinking is the concept of environment and system boundary. The boundary is *"determined by a number of criteria which entities (elements) have to fulfil to be considered part of the system"* (Kramer and de Smit, 1977, p. 31), while the environment can be defined as the *"set of entities (elements) outside the system, the state of which set is affected by the system or which affect the state of the system itself"* (Kramer and de Smit, 1977, p. 34).

2.4.2 System dynamics

Where does System dynamics fit into systems thinking? Coyle (1977, p.2) gives an answer by defining System dynamics as *"that branch of control theory which deals with socio-economic systems, and that branch of Management Science which deals with problems of controllability"*. In more specific terms System dynamics can be defined as *"a method of analysing problems in which time is an important factor, and which involves the study of how a system can be defended against, or made to benefit from, the shocks which fall upon it from the outside world"* (Coyle, 1977, p. 2).

System dynamics emerged from Jay Forrester's key work Industrial Dynamics (Forrester, 1961). Nowadays, System dynamics is utilised to many fields to solve any problem as long as it can be thought of in terms of systems. However a predominant part of System dynamics deals with supply chains or what is known as supply chain dynamics.

Supply chain dynamics is concerned with the study of dynamic behaviour in a supply chain. Forrester (1958) studied a production and distribution supply chain using a computer model. In his model, he considered four echelons: a retailer, a distributor, a factory warehouse and a factory. He showed that by introducing a small step increase in the end customer demand, the demand was amplified as it was transmitted upstream in the supply chain. Not only did the demand increase, but the inventory level also decreased with stronger amplitude further down the supply chain. The inventory also took longer to settle back to a steady state.

He explained that this effect, now known as the "Forrester effect" (also called demand amplification and bullwhip effect (Lee et al., 1997)), was due to the delays in the system and the poor decision making concerning information and material flows. He further concluded that the effect was induced by the system structure itself. Forrester offered some solutions to reduce this amplification effect through a reduction of lead times, the use of retail sales information at the factory level, and changing the time to adjust inventory.

Sterman (1989) extensively studied Forrester's work and used a role-playing simulation game representing a production and distribution system for beer, known as the MIT Beer Game, to study in more detail the human decision-making policies as described by Senge (1990). The game represents a four-echelon supply chain including a retailer, a wholesaler, a distributor and a factory. A flow of information (orders) goes from the retailer to the factory and a flow of products return. The game involves different delays: two weeks delay for the order to reach the next echelon and two weeks transport delay from the inventory of an echelon to the next. The aim of the game is to minimise cumulative costs over the length of the game due to excess inventory and stock outs. The purpose of the game is to demonstrate to the players the existence of the demand amplification phenomenon which is not caused by any external disturbances but is due to the lead-times in the supply chain, coupled with the players' feedback based decision making. Typical results from the Beer Game are presented in Figure 2.10.

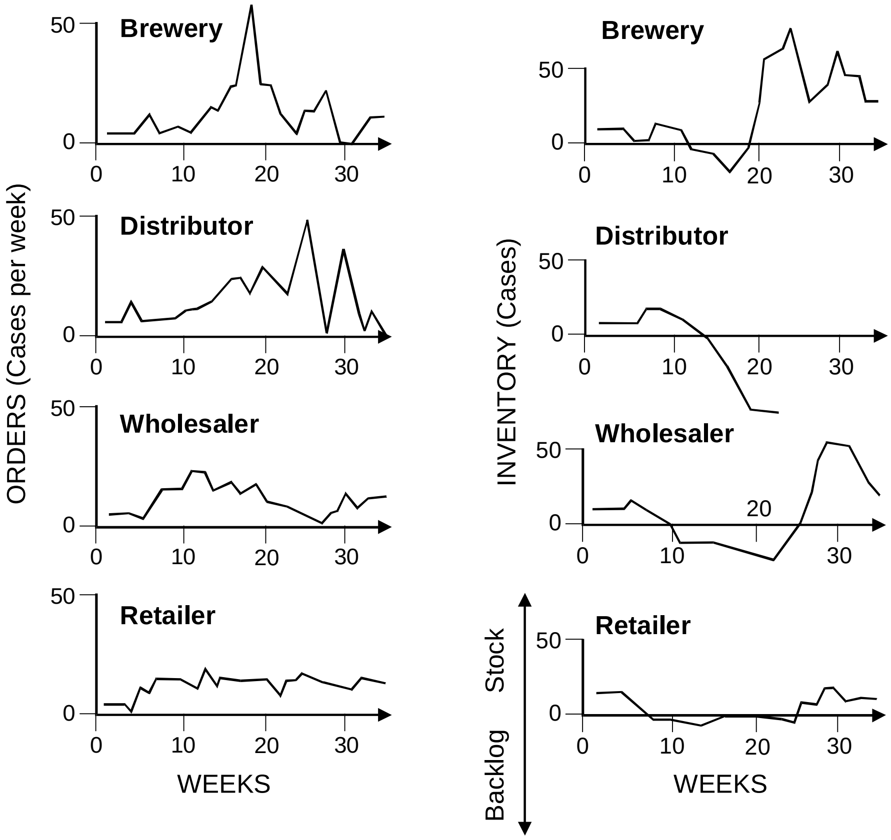

Figure 2.10 Sample simulation results from the Beer Game (Sterman, 1989)

Sterman (1989) explains the amplification effect by a misperception of time lags *"between placing and receiving orders – the order line. The results show that most subjects failed to account adequately for the supply line"* p.334. Sterman (1989) further identified a "No strategy policy" where the players simply pass on the order they receive without taking into account any inventory level or what is in the pipeline. The results showed that an astonishing 75% of cases played performed worse than a "no strategy" policy, 25% performed better, of which only 10% performed very much better. Sterman (1989) concluded that the top 10% that performed very much better based their decisions on present usage, the free stock and the amount of material in the pipeline.

Burbidge (1961; 1984) identifies a further supply chain dynamics behaviour and expresses it as the Law of Industrial Dynamics: *"if demand is transmitted along a series of inventories using Stock Control ordering, then the amplitude of the demand variation will increase with each transfer"* (Burbidge, 1984). Burbidge considers the fact that typically, orders will be fulfilled by sending large batches of products at a low frequency. This will have a "batch and queue" dynamic effect (Towill, 1997b).

Towill (1992; 1997b) studied both demand amplification phenomenon exposed by Forrester and Burbidge as illustrated in Figure 2.11. Figure 2.11(c) shows the effect of poor information flow plus multi-phase ordering, as caused by the Burbidge effect, while Figure 2.11(b) shows the effect of poor information flow and decision making as identified by Forrester. Figure 2.11(a) shows that demand amplification can be further reduced via good information flow.

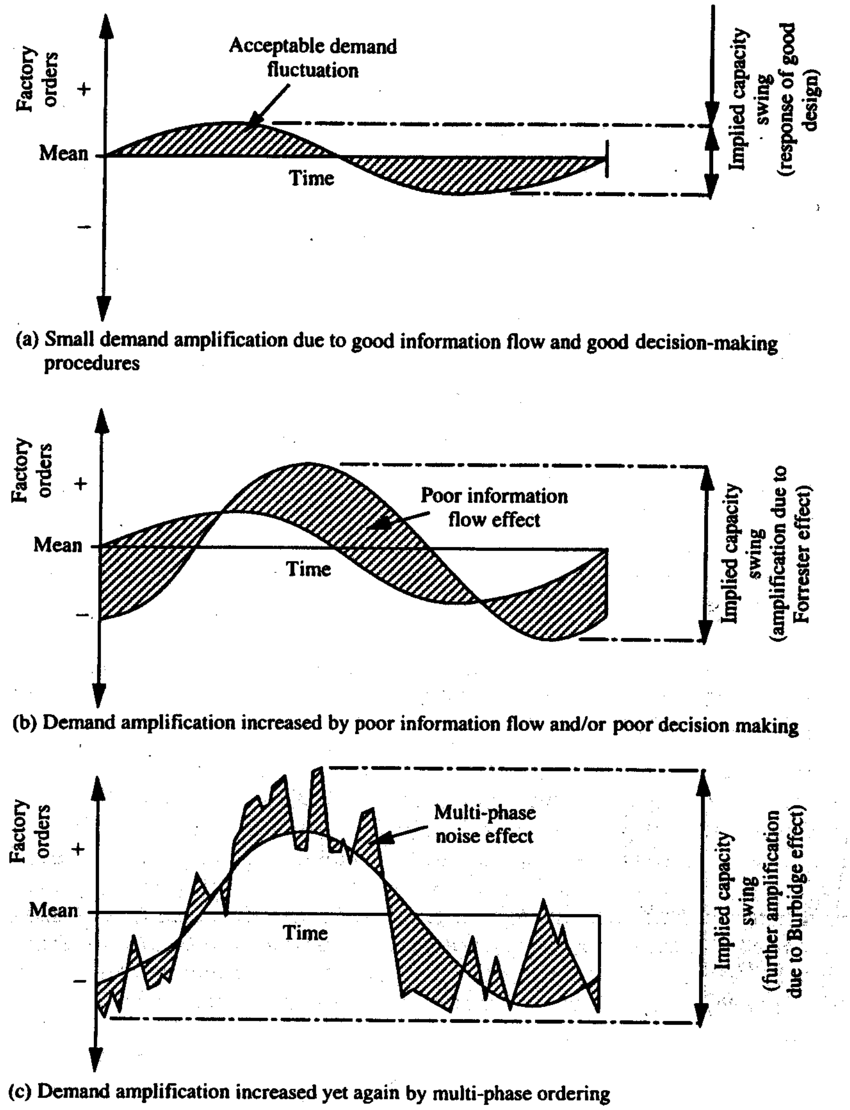

Figure 2.11 Typical supply chain dynamic behaviour illustrating presence of both "Forrester" and "Burbidge" effects (Towill, 1992)

2.4.3 Strategies to reduce the "Forrester" effect

The focus in terms of supply chain will be placed upon the Forrester effect. Many strategies have been advocated over the last few decades to reduce demand amplification in supply chains. This section will review key papers on strategies to reduce bullwhip and therefore to improve supply chain performance. As it will be seen many strategies advocated to reduce demand amplification have already been reviewed in the SCM section in terms of enablers for effective SCM.

Wikner et al. (1991) suggest five strategies to improve supply chain dynamics:

1. "Fine tuning" the existing ordering policy parameters
2. Reducing system delays
3. Removal of the distributor echelon
4. Changing the individual echelon decision rules
5. Better use of information flow throughout the supply chain.

These five strategies have been simulated and show a major reduction in factory production "on-costs" (as explained in Section 2.4.4) as can be seen from Figure 2.12. The chart is plotted to show the cumulative effects of the different improvement strategies.

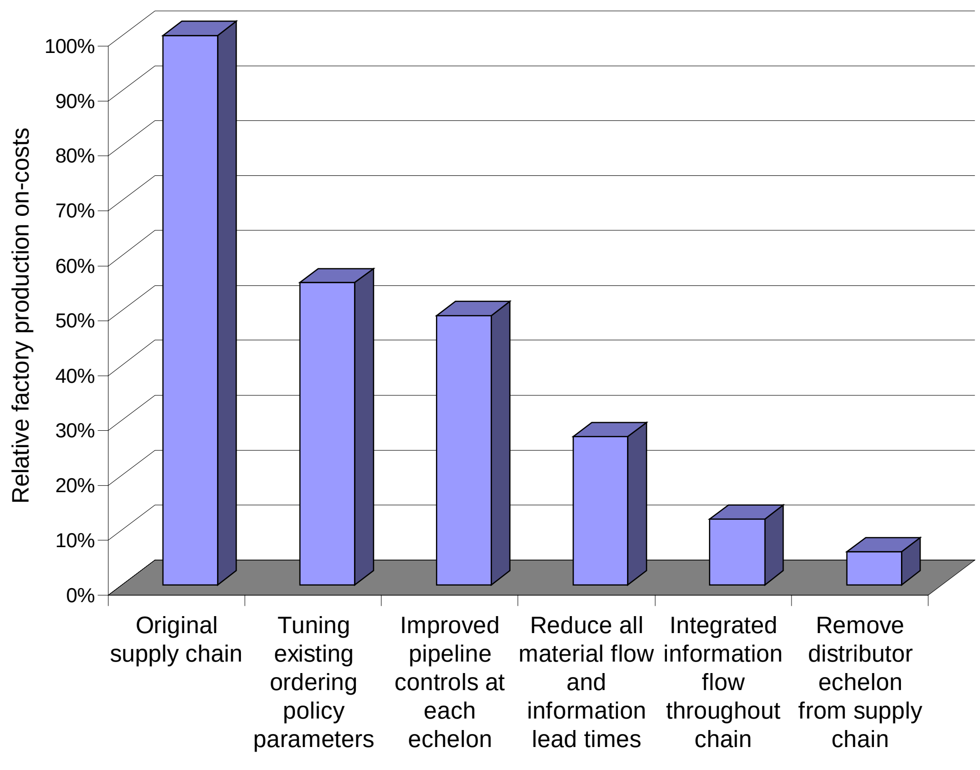

Figure 2.12 Bar chart comparison of the on-costs reduction resulting from simulation of various supply chain re-engineering strategies (Towill, 1997d)

Towill and Del Vecchio (1994) studied the impact of filter theory on supply chain dynamics. They showed that by filtering the noise from the input signal, great reduction of demand amplification could be achieved. Further Berry et al. (1994) simulated four re-engineering phases: (1) JIT techniques, (2) interplant planning and logistics integration, (3) vendor integration, and (4) time based management. The results showed that *"demand amplification has been greatly reduced at each phase of supply chain re-engineering"* p. 31. The demand amplification peak at the factory level was estimated to be only 1.35:1.

Larsen et al. (1999) simulated a model based on the MIT Beer game and showed a wide range of non-linear dynamic phenomena. They also report on the usefulness of a sophisticated management information system, whereby all sectors can be aware of the end-customer demand. This reduced order amplification from 900% to 200% and the cost of operation by a factor 3 (van Ackere et al., 1993). Van Ackere et al. (1993) also report a reduction of demand amplification by 50% and a reduction of costs by 30% for a reduction in information delay.

Mason-Jones et al. (1997) studied the impact of a pipeline feedback system as a means to reducing demand amplification. The model structure termed an Automatic Pipeline Inventory and Order Based Production Control System (APIOBPCS) demonstrated great benefits at each echelon. The demand amplification at the factory level was halved.

Mason-Jones and Towill (1998) also studied the effect of total cycle time compression (information pipeline and material flow pipeline time compression). They concluded that the compression of material flow lead-time allow the supply chain to react faster to customer changes, while the compression of information flow leads to greater control of the supply chain response, especially by providing a greater visibility of the consumer behaviour. Finally, they concluded that total cycle time compression further improved the reaction to customer demand.

Mason-Jones (1998) also proved the positive impact of information enrichment on supply chain dynamics. She demonstrated that an information enrichment of 50 to 75% achieved the best dynamic behaviour, leading to a reduction in demand amplification.

Simulations have also been carried out to assess the impact of Vendor Management Inventory on supply chain dynamics (Holmström, 1998; Disney, 2001; Disney et al., 2001). Holmström (1998) reports great improvements through the implementation of a

VMI system (reduction of vendor variability from 75% to 26% and a reduction of stock of 30%). Disney (2001) modelled and simulated extensively the effect of VMI on supply chain dynamics, and although few VMI supply chain designs perform worse than some "traditional" supply chains, in most cases VMI supply chains performed better in terms of demand amplification.

Hong-Minh et al. (2000) studied the basic MIT beer game supply chain utilising different strategies to reduce the bullwhip effect. The utilisation of end-customer demand by all echelons (through EPOS information), the elimination of the distributor, and the utilisation of an emergency supply system (between the retailer and the distributor) all proved to reduce demand amplification.

Strohhecker (2000) also simulated different strategies to improve supply chain dynamics. The strategies considered were the reduction of information delays, the use of a demand forecasting function, the synchronisation and optimisation of demand forecast and the optimisation of the decision rule to determine the level of desired inventory. Each strategy is reported to improve greatly the inventory levels across the supply chain.

Finally, the work of McCullen and Towill (2001) can be reported where four material flow principles are tested within a company strategy: (1) control systems principle (selection of the decision support system), (2) cycle time compression principle (information and material flow lead-times), (3) information transparency principle (information sharing), and (4) echelon elimination principle. The implementation of these four principles resulted in an average bullwhip reduction of 36%.

2.4.4 System dynamics performance measures

The dynamic behaviour of a supply chain, as seen above, is very important and therefore dynamic performance also needs to be looked at to complement the static performance (see section 2.3.3) of the different re-engineering strategies studied. Dynamic performance takes a particular look at the demand amplification phenomenon in the supply chain.

Therefore, the dynamics measures of performance utilised in this thesis need to be selected. The System dynamics performance criteria are used to assess the dynamic behaviour of different models presented in Chapter 5 and utilised in Chapter 6, 7 and 8. The dynamic behaviour needs to be assessed for a step change in the demand.

A review of key authors on supply chain dynamics simulation showed that the main performance criteria studied are the level of inventory (Hong-Minh et al., 2000; Strohhecker, 2000), the level of bullwhip (Chen et al., 2000; Fransoo and Wouters, 2000; Disney, 2001), the peak value, peak time and order recovery for the order rate (Towill, 1969; Mason-Jones, 1998), production on-costs (Wikner et al., 1991; Berry, 1994; Berry and Naim, 1996; Towill and McCullen, 1999), and the integral absolute error for the inventory level (Hong-Minh, 1998).

Therefore, a starting point is to consider the criteria originating from control theory, these being especially applicable to a step change in the demand (Towill, 1969; Nise, 1995). The performance is measured using six criteria: peak value, peak time, order recovery, stock depletion, trough time and stock recovery (Mason-Jones, 1998). The first three criteria are calculated for the "order rate" while the last three are based on the actual inventory level.

- **Peak value** assesses the overshoot value of the order rate.
- **Peak time** is the time at which the peak occurs.
- **Order recovery** or settling time is the time needed for the system to reach a stable state.
- **Stock depletion** is the trough value for the actual inventory level.
- **Trough time** is the time at which the stock depletion occurs.
- **Stock recovery** or settling time is the time needed for the system to reach a stable state.

However, these six criteria can be summarised using only two criteria: production on-costs and Integrated Absolute Error (IAE). The production on-costs originates from the Boston Consultancy Group where, based on Forrester work, it was estimated that the increase in business overheads due to demand amplification is *"… the cubic function of the area between the oscillating (amplified) output curve for the factory and the neutral axis"* (Stalk and Hout, 1990, p.65) as illustrated in Figure 2.13.

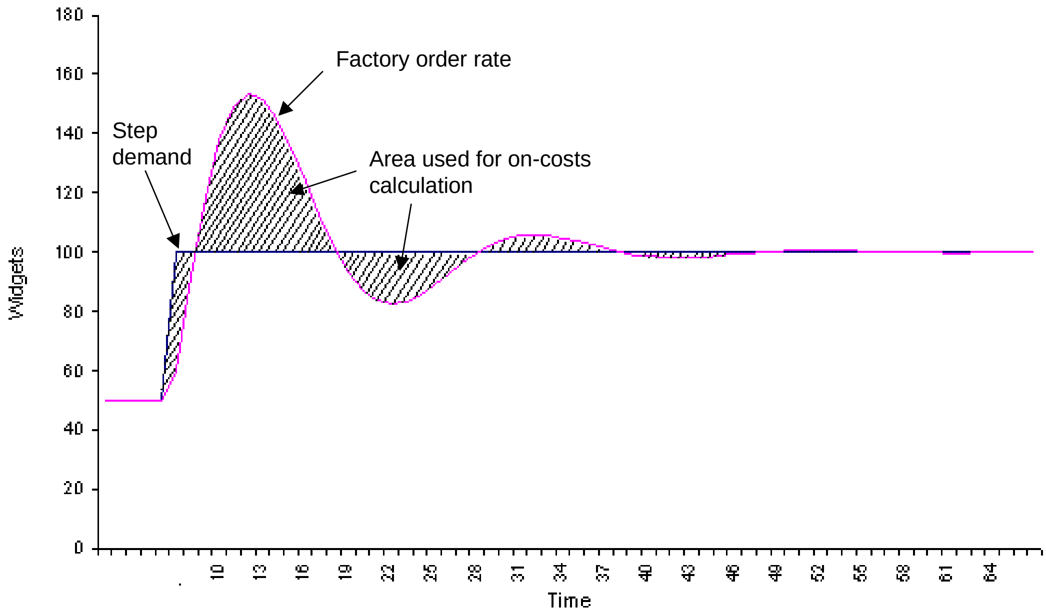

Figure 2.13 The Boston Consultancy Group metric for estimation of on-costs associated with demand amplification (Wikner et al., 1991 based on Stalk and Hout, 1990)

The IAE is calculated for the actual inventory level and is based on the same principle as for the production on-costs. The area considered is the difference between the actual inventory level and the target inventory.

2.5 Conclusion

A review of key concepts for this thesis has been presented. Supply chain management was the focus of this review, however other concepts such as BPR, lean, agile and supply chain dynamics are directly related to SCM. It has been seen that BPR had strong similarities with SCM and that the tools used were common to SCM tools. Lean and agile paradigms have been briefly reviewed and the tools they offer have been presented in relation with SCM. Finally, supply chain dynamics has been presented showing that a wide range of authors have simulated many SCM principles in order to study their impact on demand amplification.

It was seen in this chapter that the SCM enablers that will be studied in this thesis are as follows:

- Reducing total cycle time across the supply chain
- Reducing the supplier base
- Improving supplier relationships by developing partnering

- Focus on customers and use end-customer information (via EPOS) enabled through an integrated information system transferring useful and up-to-date information across the supply chain
- Synchronisation of the supply chain

Although SCM is not a new concept, studies on SCM application in the house building industry in the UK have not yet been reported. The literature review revealed a lack of publication on SCM in the house building industry. Although the awareness of this philosophy is growing in the construction industry (Akintoye et al., 2000) and many authors have reported examples of its implementation, the house building industry seems unaffected. This does not mean that SCM is not utilised in the house building industry, but that the work has not been reported. This thesis aims at bridging this gap by presenting some results on the impact of SCM principles on the house building performance.

Further, this thesis will combine both the "static" and "dynamic" assessment of performance to take into account as many performance criteria as possible. Finally, some of the SCM principles that will be simulated have not yet been studied by other authors. First of all, the reduction of lead-times in the supply chain will be simulated. Although part of this work has already been carried out in a different context (e.g. Towill, 1991; Mason-Jones, 1998; Mason-Jones and Towill, 1998), the emphasis here will be placed on the reduction of cycle time utilising an ordering and call-off mechanism, which has not yet been studied.

The reduction of supplier base, moving from multiple suppliers to central supplier, will also be simulated. The literature review did not reveal any previous work studying the impact of centralised supply onto supply chain dynamics. Finally, the development of trust between trading partners will be simulated. Once again, no previous work has been found on the simulation of trust within a supply chain and its effect on demand amplification.

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Chapter 3 Research Methodology

3.1 Introduction

The purpose of this chapter is to present the research framework and the research methods utilised by the author during the research. The first part of this chapter presents the research framework based on the Soft Systems Methodology. The second section considers the epistemological position of the author. The next section presents the research methods utilised. The focus is placed on the strengths and weaknesses of the methods used. First of all, two methods for the background research have been utilised: the Terrain Scanning Methodology and a Quasi-Delphi study. Then the case study method is presented and the choice of cases is argued. Modelling and simulation have also been utilised and are presented. Finally the analysis tools are looked at; the Strengths, Weaknesses, Opportunities and Threats analysis and the Multi-Attribute Utility Theory.

3.2 Soft Systems Methodology and research framework

Soft Systems Methodology (SSM) is a strand of systems thinking developed by Peter Checkland in the 1970's from an action research programme at Lancaster University. SSM emerged from the recognition of the lack of methodology to tackle unstructured problems, *"which are manifest in a feeling of unease but which cannot be explicitly stated without this appearing to oversimplify the situation"* (Checkland, 1981, p. 154).

Checkland defined SSM as a clear process through which accommodation of conflicting viewpoints can be sought. SSM is defined as a process to tackle real-world problems in all their richness (Checkland and Scholes, 1990), and it allows formal expression of the problem, which enables lessons to be learned. SSM is *based "on an organized set of principles (methodology) which guide action in trying to manage (in the broad sense) real-world problem situations"* (Checkland and Scholes, 1990, p. 5). SSM is a methodology examining problem situations to lead to decisions on action at the level of both "what" and "how".

The updated version of the SSM model from Checkland (1988) was used here as presented in Figure 3.1 rather than the earlier traditional seven-stage model which was presented as a sequential process. SSM was used during the research process to define the "what" and "how" of this thesis. The "how" question is understood here in a broad sense and not in a "method" sense, such as which research tools should be utilised.

The SSM method starts with the fact that at least one person regards a situation as problematic. *"There is a feeling that this situation should be managed in order to bring about improvement. The whats and hows of the improvement will all need attention, as will consideration of through whose eyes improvement is to be judged"* (Checkland, 1988, p. 28).

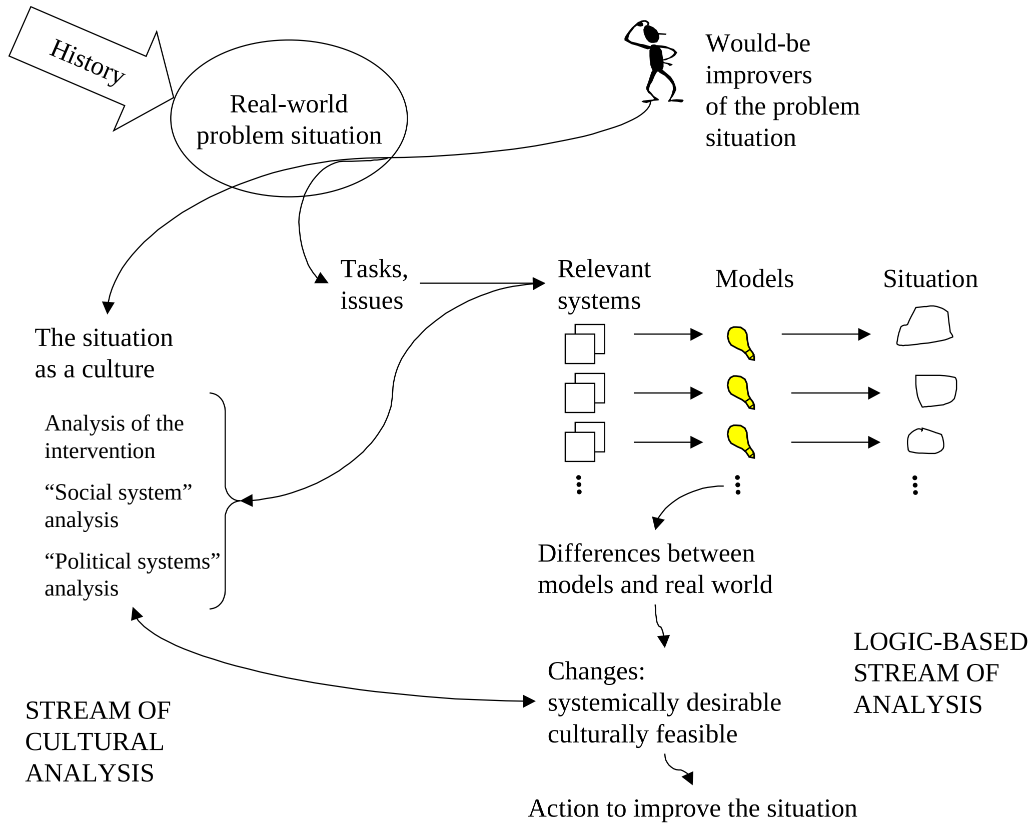

Figure 3.1 The process of SSM (Checkland, 1988)

For this thesis, the real-world problem situation considered was the poor performance of the UK private house building industry (as described in Chapter 4). This leads to the questions of *what are the problems of the house building industry?* and *how are they related to SCM issues?* The next question was then *what is SCM?* and *what benefits can be expected?* The next logical question is *how can the performance be measured*. The relevant sub-systems were then chosen (see section 3.4.2.2) to analyse *what benefits SCM could bring to private house building performance?* Finally, the action to improve the situation can then be summarised.

Following this logic, a research framework was developed and is presented in Figure 3.2. The framework shows the flow of ideas followed for this thesis and the circled number indicates the chapter number in which it is discussed. It can be seen that the theoretical foundations have been developed through a literature review of the relevant theories and concepts. The measure of performance criteria were then selected and defined. The methodology to carry out the work was then developed. Background studies gave an insight into the characteristics of the UK private house building industry and its problems related to supply chain issues. Simulation models were developed and case studies for the relevant systems were carried out and analysed to assess the impact of SCM on performance. Finally recommendations are given on actions to improve the UK private house building industry performance.

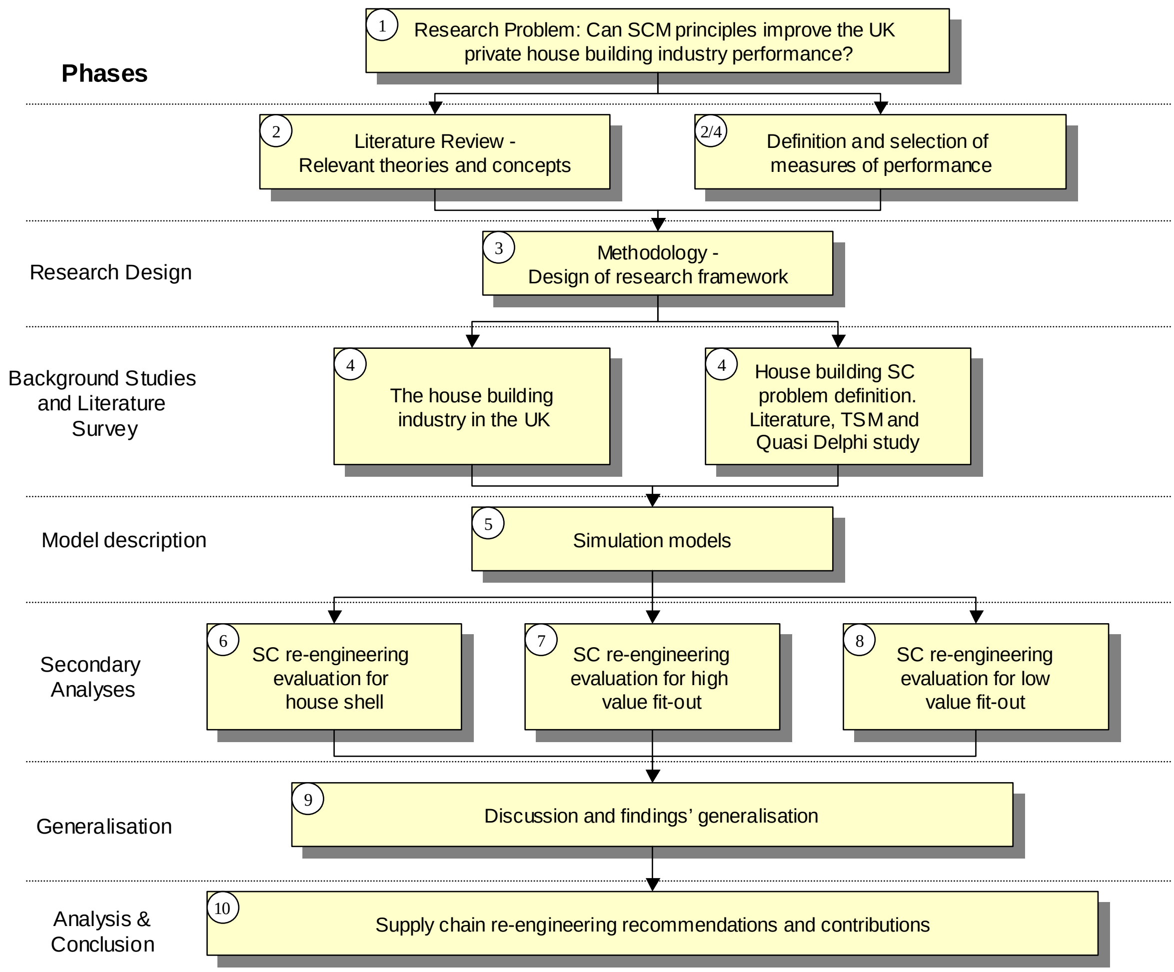

Figure 3.2 Research framework

3.3 Epistemological positioning

When carrying out research, it is important to understand the epistemological positioning of the methodology applied to understand its applicability. Epistemology is the branch of philosophy concerned with the study of the criteria by which what does and does not constitute warranted or valid knowledge is determined. Therefore the different philosophical approaches to science need to be understood. The epistemological positioning of the researcher can have implications on the interpretation of the findings and the evaluation of their scientific validity.

Wass and Wells (1994) refer to three epistemological perspectives relevant to management research: positivism, realism and naturalism. Positivism is defined as *"a philosophical position in relation to the pursuit of knowledge which draws from the role model of knowledge creation developed in the natural sciences. […] The logic of the scientific experiment forms the blueprint for positivist social science research."* (Wass and Wells, 1994, p. 8). The positivist approach utilises quantitative, systematic and precise type of data, which are directly observable and measurable. Naturalism is defined as *"an anti-positivist position predicated on a set of alternative 'idealist' prior assumptions about the study of social reality, in particular the denial of the independence of the social world from subjective interpretation."* (Wass and Wells, 1994, p. 13). The naturalist approach utilises qualitative, intangible, subjective conceptions and interpretations of actors types of data. It is also usually intensive and contextual, and very detailed. Finally realism *"seeks to reconcile the realist (etic) and idealist (emic) understanding of human action: recognizing the existence of an external reality, its subjective interpretation and the role of human agency in affecting the external social world."* (Wass and Wells, 1994, p. 16). In this case, all data relevant to the subject can be utilised, including quantitative and qualitative, and observable and interpretative data.

Based on Wass and Wells' (1994) descriptions of the three epistemological perspectives, the author positions her research as being positivistic realist. On the positivism side, quantitative data has been utilised as much as possible and modelling and simulation was used to collect data. On the realism side, the research carried out can be qualified as action research. Qualitative data was also collected and observations were made during the study. Finally a case study approach was utilised to gather the data. Therefore in order to compensate the bias emerging from a positivist approach, methods were combined so as to triangulate the data.

3.4 Research method

It is important to clearly understand which research method has been used, for what reason, and what the strengths and weaknesses of these methods are to fully understand the results of the research. This section will review the different research methods utilised for this thesis. First of all the research methods used for the background research will be reviewed with a focus on their strengths and weaknesses. Then the main research method will be presented, i.e. case studies. The specific research tools will be reviewed as well as the reasoning behind the choice of these specific case studies. Then a review of simulation and modelling methods will be carried out and finally the analysis tools utilised will be presented.

3.4.1 Background research method

The background research was carried out using first of all a Terrain Scanning Methodology to understand the current state of the industrial partner's supply chain and find area of improvements. Then a Quasi-Delphi study was used to achieve a consensus from the industrial partners on what needs to be done to improve the private house building supply chain. The results of the TSM and of the Quasi-Delphi results are presented in Chapter 4.

3.4.1.1 Terrain Scanning Methodology

As part of the research project COMPOSE, the Terrain Scanning Methodology (TSM) was developed (Barker et al., 2000). TSM is firmly based on Watson's (1994) adage of Understand, Document, Simplify and Optimise (UDSO) and is an adaptation of a "Quick Scan" methodology developed by the author's research team in the automotive sector (Lewis et al., 1998; Childerhouse et al., 1999). The TSM also builds on the systems engineering expertise from analysis, re-design, re-engineering and implementation of new processes in a variety of market sectors including construction, steel, electronics, automotive, fast moving consumer goods and aerospace. The methods, tools and techniques have most recently been documented in Berry et al (1998a; 1998b).

The TSM has been developed to:

- Understand and document the industrial partners' current practices in relation to their supply chain (how they interface with others).
- Find areas of improvement at
  - individual work and business process levels (processes within the organisation).
  - supply chain and interface levels (reaching outside, including overall Project Management).
  - a house building industry level via generalisation of the TSM application outputs.
- Find opportunities to support and promote the use of standardised components via standardised supply chain processes.
- Provide radical and innovative "quick hits" (not "quick fixes") and recommendations for long term change programmes.

An overview of the TSM process is shown in Figure 3.3. The initial visit to the industrial partners in the Project aimed first of all to introduce the TSM philosophy, establish the key contacts for questionnaires and interviews, identify two representative products/services and for both of these a representative supplier and customer. These two products/services are used as a means of guiding the interviewees through the questionnaire, process mapping and general information gathering stages, as they can more easily relate to specifics. Top level awareness of business process and supply chain information is also sought in the form of methodologies or flow charts, often these being drawn jointly by the researchers and the industrialists. The location and timing of the site visit for the main data collection are also ascertained. This is especially useful for building site visits where several other contacts will be involved. Assurances of confidentiality and anonymity are discussed and given as necessary.

As agreed previously with the industrialists, a week prior to the main visit, three different questionnaires are sent to appropriate personnel. One questionnaire is aimed at internal operational information while the other two are aimed at the supplier and customer interfaces data acquisition; Appendix 1 gives an example of the "customer interface" questionnaire. Confirmation via telephone of receipt prior to the main visit is made which is also utilised to answer any queries about the questionnaires. Despite the lack of heterogeneity amongst supply chain members a consistent approach to questionnaire and interview format was adopted to allow a valid comparative study to be undertaken wherever possible in order to determine relevant supply chain practices.

The main visit consists of:

a) Checking through questionnaires and where necessary clarifying information.
b) Walking and mapping the business and supply chain processes, obtaining material flow and information flow data, usually initially hand drawn for expediency on-site.
c) Carrying out semi-structured interviews, where a pre-scripted data collection sheet is used to prompt the most useful data required.
d) Obtaining relevant archival and analytical information, which is often uncovered in the questionnaires or the semi-structured interview.

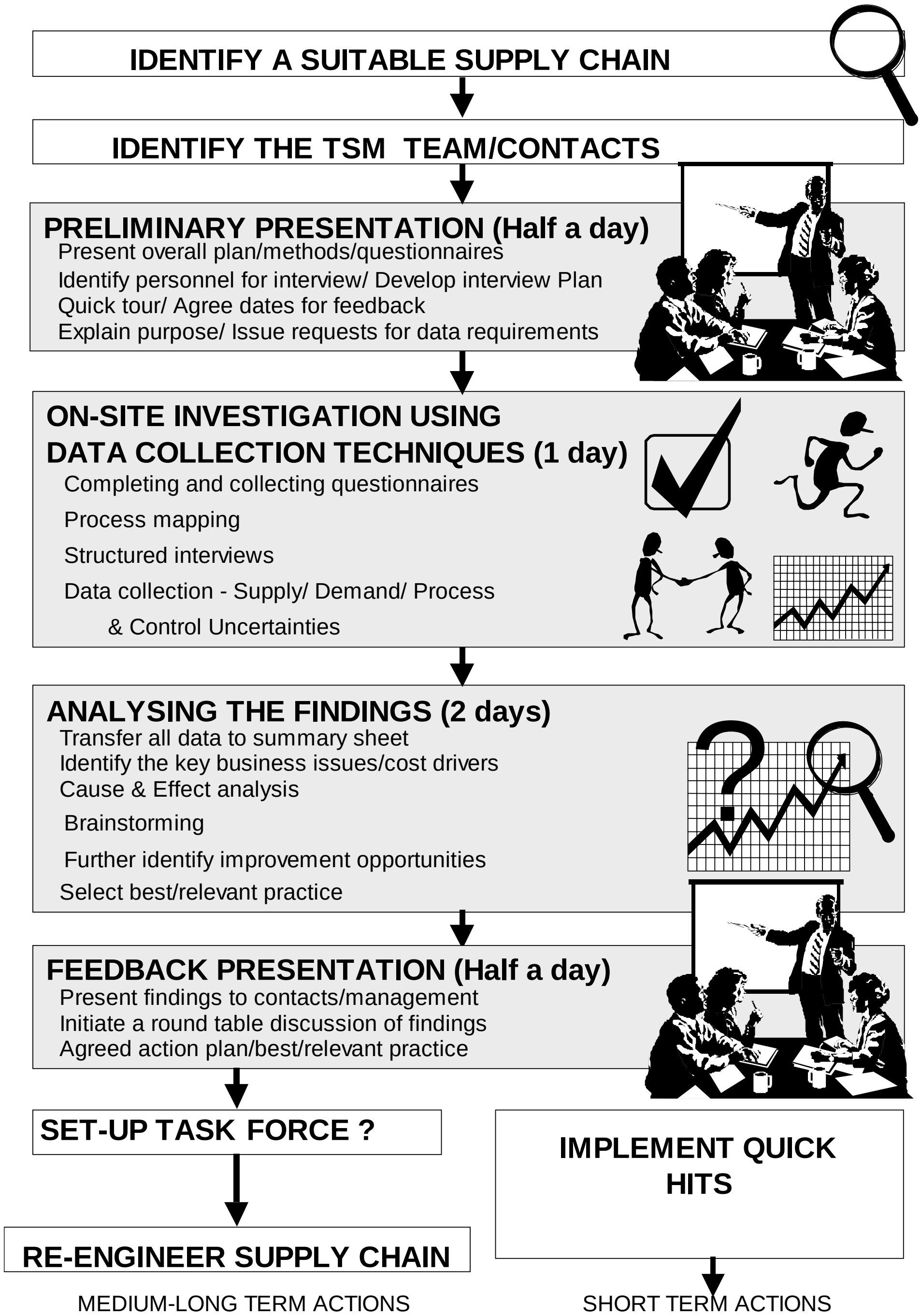

Figure 3.3 Process outline of the Terrain Scanning Methodology (Barker et al. (2000) adapted from the Quick Scan Methodology, (Childerhouse et al., 1999))

The TSM attempts to triangulate data as much as possible. Thus data sources utilised encapsulate the four main areas, namely:

- Opinion: personal thought and ideas obtained via interviews and brainstorming sessions.

- Archival: obtaining previous analysis undertaken by the companies, company literature and documentation.
- Analytical: analysis of readily available data such as stock or inventory profiles, resource utilisation, time series of company measures of performance.
- Empirical: process mapping and flow-charting, recursive input-output analysis, issuing questionnaires.

Triangulation, including repeat and reverse questioning, aimed to verify the “as is” rather than the “as stated” or the “as believed” situation regarding business and supply chain processes. The main areas targeted were material flows, information flows, measures of performance, customer interfaces, and supplier interfaces.

The TSM was undertaken in as short a time as possible so as to minimise disruption. A typical TSM is approximately four days in length for each company, with less than two days of direct interaction with personnel. During the study the TSM team consisted of two full-time researchers, the aid of off-line support from the rest of the academic team when required plus part-time involvement of company personnel.

The limitations of the TSM were discussed with the industrial partners and are presented in Table 3.1. Although not an in-depth study, TSM can identify key problems by giving the researchers a good holistic overview of the company and its supply chain operations.

Strengths	Weaknesses
Quick, saves on time & resources	Low level of detail – not to activity level
Identifies key problems, focuses on specific and critical issues	Limited opportunities for information validation / triangulation
Quick learning curve for process analysis	Mainly focused on short / medium term opportunities
Low “total cost” of undertaking diagnostic	Limited understanding of all the problems in the supply chain
Good holistic overview of current supply chain state	Although based on empirical and opinion sources limited archival information obtained
Not paralysed by excessive analysis	

Table 3.1 A strengths and weaknesses analysis of the TSM (Hong-Minh et al., 2001)

The weaknesses of the TSM were recognised, as there has been a feeling by some of the industrialists that the TSM is only “skin deep”. Others felt that the TSM is an important pre-requisite to change. It should be realised that the TSM is, as the name implies, a “terrain scan” and therefore only a relatively shallow analysis tool. It can though be invaluable as a means of efficient identification of areas of potential improvement, understanding of the current situation, and a prerequisite to a deeper study using for example a Quick Scan or study that can lead to a full change programme.

3.4.1.2 Quasi-Delphi Study

The Delphi technique dates back to the post-war years and was first developed by a team led by Olaf Helmer and Norman Dalkey at the RAND Corporation. The Delphi method is a qualitative environmental forecasting method incorporating the subjective judgements of individuals or groups, where experts are questioned repeatedly about their views of the future. The Delphi technique can be defined as a *“method for the systematic solicitation and collation of expert opinions”* (Helmer, 1996, p. 1). A Delphi study is undertaken for several rounds where, between sessions, experts review the answers of the other experts’ panel (CSC et al., 1997).

The aim of the technique is to predict future situations in complex subjects. However, it can be used for different purposes as argued by Delbecq et al. (1975, p. 10-11):

1. To determine or develop a range of possible program alternatives
2. To explore or expose underlying assumptions or information leading to different judgements
3. To seek out information which may generate a consensus on the part of the respondent group
4. To correlate informed judgements on a topic spanning a wide range of disciplines
5. To educate the respondent group as to the diverse and interrelated aspects of the topic.

Ziglio (1996, p. 75) argues that the Delphi technique can be used as a starting point for further studies:

“A Delphi exercise could be commissioned with the intention of using the information generated as an input to a committee activity. Once a Delphi exercise has been accomplished the committee may utilise the results to establish all the differing positions advocated on a given issue and the principal pros and cons of each of those positions.”

In a same manner, the Delphi study was used in this thesis to obtain a consensus from the companies questioned (the industrial partners) on what needs to be done and to determine further research in SCM in the house building industry.

In the case of this thesis, the Quasi Delphi study was based on a research tool used by Nissan and their suppliers (Evans and Foxley, 1999) which means that it was only carried out once. The Quasi Delphi study was carried out with twelve executives and managers, from each of the research project industry partners, being asked to answer different questions about their views of the future. The Quasi Delphi study focuses on the perception of the problems, causes and remedies for the housing industry.

There is debate on the optimum group size, below five is considered to be to low, while 30 is usually considered as the upper limit as too large group can generate too many conflicting ideas (Gould, 2000). The optimum size is often thought to be between 15 and 20 people (Delbecq et al., 1975; Gould, 2000).

The companies who participated in the Quasi Delphi study were the same ones involved in the TSM diagnostics. And the methodology used was as follows:

1. The twelve participants were put into a future situation, i.e.: “You are in 2004 and your house building industry is now working as a fully integrated supply chain meeting customer needs; high quality, low cost, short lead-times, excellent service.”
2. The participants were asked to answer the following question: “What did you and your company do to achieve that result?” The answers were written on stickers and then displayed on a wall chart.
3. Next, the answers were classified by mutual consent between the participants. This suppressed the possible misunderstanding of some answers and increased the communication and understanding between the participants.
4. The whole process was then repeated asking a second question: “What obstacles did you have to overcome?”
5. The results were analysed by the researchers.
6. The results were fed back to the industry participants and actions for supply chain programmes agreed.

The aim of the study was to achieve a shared vision and understanding of how the housing industry supply chains need to be re-engineered. The Quasi Delphi study uses little time and few resources, it optimises the participants' knowledge through "brainstorming" and finally it achieves a general consensus by everyone on the important issues that need to be tackled.

A strengths and weaknesses analysis has also been carried out for the Quasi Delphi study and is presented in Table 3.2. Although based on the participants' opinion, the Quasi Delphi study is an excellent mechanism to achieve consensus by everybody (across the housing industry) to target specific change programmes.

Strengths	**Weaknesses**
Quick, saves on time & resources	Perception based
Based on participants' expertise	Danger that participants may be myopic
Get consensus by all participants	May be seen as simply "common sense"
Large amount of answers ("brainstorming")	Needs a strong facilitation
Consensual categorisation of answers (no misunderstanding)	Needs multiple sessions to capture a wide range of opinions

Table 3.2 A strengths and weaknesses analysis of the Quasi Delphi study

Furthermore, even though the problems and causes identified were based on the participants' perception, they directly relate to the same ideas emerging from the literature review section.

3.4.2 Case study

Case studies have been used for this thesis and have been defined by Yin (1994, p. 13) as *"an empirical enquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between the phenomenon and context are not clearly evident; and in which multiple sources of evidence are used"*. Harley (1994, p. 209) argues that case studies are less a method of research than "a strategy of research", which implies that case studies usually involve several different data collection methods to deal with the complexity of data and aid to triangulation.

Kitay and Callus (1998, p. 103) define case study as *"a research strategy that is used to understand or explain the phenomena by placing them in their wider context"*. The case study is a research strategy, which focuses on understanding the dynamics present within single settings (Eisenhart, 1989). The case study typically uses a combination of specific methods: interview, observation, questionnaires, and documentary sources.

Yin (1981a; 1981b) argues that case studies can be of three types: exploratory, descriptive or explanatory. The objective of explanatory case studies is to pose competing explanations for the same set of events and to indicate how such explanations may apply to other situations (Yin, 1994). Descriptive case studies aim to describe a certain phenomenon. The exploratory case studies set out to explore a certain phenomenon. What is important is the type of research question it answers, i.e. "what", "who", "where", "how", and "why". The case studies utilised in this work can be defined as exploratory as they aim at answering the question *"Can SCM improve the house building industry performance?"*. They also help to answer the sub-question *"What is the impact of implementing SCM principles on performance?"* and *"How do SCM principles impact on performance?"*.

Stake (1998) distinguishes different foci of case studies. He identifies three foci or purposes for which the researchers conduct case studies:

- Intrinsic cases are carried out to gain a better understanding of a case. Here the purpose is not to theorise but to gain a greater insight into a particular phenomenon. These cases are therefore of intrinsic interest rather than being able to be generalised.
- Instrumental cases aim at providing an insight into a particular issue or refinement of a theory. Here the case itself is of secondary importance, the choice of case study is based on the expectation that it will advance the understanding of that other interest.
- Collective cases: In this case, several case studies can be carried out to inquire into the phenomenon, population or general condition. A collective case can be an instrumental study extended to several cases. The understanding of these cases should lead to better theorising.

This leads to a fundamental issue in case study analysis; the decision whether a single case study or multiple case studies should be used (Yin, 1981b). Ellram (1996) continues the argument as when a multiple case study is chosen, then the main "question becomes how many cases are necessary to achieve the desired generalizability of results?". To answer this question, one important fact needs to be kept in mind, each case study is an *experiment* in itself which should not be confused with one *observation* during an experiment (Yin, 1994). Therefore one single case study is utilised to test a well-formulated theory. In this case, background research needs to be carried out to select the case and minimise misrepresentation. Multiple cases are usually the replication of one experiment to allow the development of a theoretical framework. Therefore, cases must be chosen to either replicate the results or to show contrasting results, but for predictable and explainable reasons (Ellram, 1996).

For this work, a multiple case has been chosen and its justification will be presented later in this section.

There are many criticisms and misconceptions related to case study research. Ellram (1996) identifies seven common misconceptions presented in Table 3.3. The first misconception comes from the confusion between case studies utilised as teaching material to give student the opportunity to make decisions and solve problems in a real-world environment and the case study as a research methodology to explain, explore or describe a phenomenon of interest.

1. Case study research and teaching are closely related.
2. The case study method is only a qualitative research tool.
3. The case study method is an exploratory tool that is appropriate only for the exploratory phase of investigation
4. Each case represents the equivalent of one research observation. Thus, extremely large numbers of case studies are required to produce any meaningful results.
5. Case studies do not use a rigorous design methodology.
6. Anyone can do a case study; it's just an ad-hoc method.
7. Results based on the case study methodology are not generalisable.

Table 3.3 Misconceptions related to the use of the case study method (Ellram, 1996)

Misconceptions two and three have already been discussed above where it was seen that case studies can be exploratory, explanatory, or descriptive. Furthermore, case studies can also be used to gather quantitative data, however it usually only concerns a small number of cases due to the depth of research required. Simulation and modelling can also be used in the case study to give quantitative data.

Misconception four has been explained above, as each case is the equivalent to one experiment and not to one observation. Misconception five and six are overcome by developing a research framework (as presented in Figure 3.2).

Finally misconception seven is concerned with the impossibility of generalising the results. It must be kept in mind that, as for experiments, case study results are generalisable to theoretical propositions and not to populations or universes (Yin, 1994). Furthermore, the more sound the research methodology appears, the greater the validity and generalisability of results (Yin, 1994). Silverman (2000) suggests three approaches to overcome the problems of generalization:

- Combining quantitative and qualitative research methods: The idea behind this approach is to collect data through different ways so as to validate the findings. Comparison can also be made with similar case studies results in the literature.
- Purposive sampling deals with the choice of the case to be studied. This choice is based on the fact that the case illustrates some feature or processes that the researcher is interested in. The cases are chosen for the research aim.
- Theoretical sampling means selecting groups or categories to study based on their relevance to the research question. Theoretical sampling is concerned with "constructing sample … which is meaningful theoretically because it builds in certain characteristics or criteria which help to develop and test you theory and explanation" (Silverman, 2000, p. 93-94).

3.4.2.1 Methods

The case studies have been carried out in the context of an action-based research. This type of research is undertaken for and with companies, which expect applicable outcomes. The research takes place in a "real" organisation situation and the outcomes need not only to be applied and validated by the organisation but also contribute to knowledge (Gummesson, 1991). Therefore, an action-based researcher has to combine the skills of almost a consultant and of an academic researcher (Gummesson, 1991). Gummesson (1991) describes action-based research as the most demanding and far-reaching way of conducting case study research.

In the Logistics Systems Dynamics Groups (LSDG) at Cardiff University, action-based research often takes the form of task forces. The task force methodology presented in Figure 3.4 starts with the company business strategy as the task force needs to fit with the company strategy. Then a specific business process can be selected for in-depth study. A task force is therefore set up by combining the academic input and the industrial input. An important point to highlight is that the research team does not carry out the task force *for* the company but *with* the company. Then the UDSO (Understand, Document, Simplify and then Optimise) (Watson, 1994) methodology is applied and the company can then implement the recommendations. The findings can then be generalised to be fed into the generic research knowledge.

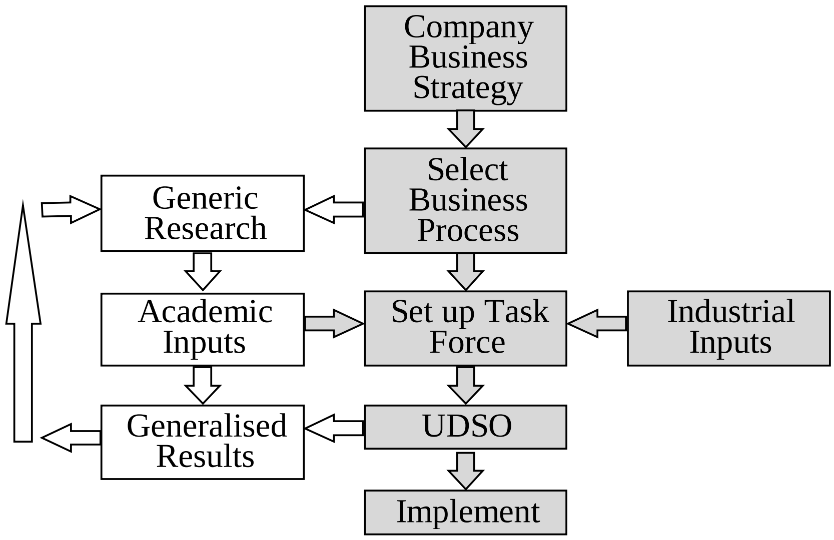

Figure 3.4 Cardiff methodology for task force with the industry

The tools used for a task force or a traditional case study are the same: interviews, collection of documentation and archival records and direct observations. Furthermore, the case studies were also based on the data already collected during the TSM, such as the process maps and questionnaire answers.

Yin (1994) gives a good summary of the strengths and weaknesses of these sources of evidence and are presented in Table 3.4.

Source of evidence	**Strengths**	**Weaknesses**
Documentation	• Stable – can be reviewed repeatedly • Unobtrusive – not created as a result of the case study • Exact – contains exact names, references, and details of an event • Broad coverage – long span of time, many events, and many settings	• Retrievability – can be low • Biased selectivity, if collection is incomplete • Reporting bias – reflects (unknown) bias of author • Access – may be deliberately blocked
Archival records	• [Same as above for documentation] • precise and quantitative	• [Same as above for documentation] • accessibility due to privacy reasons
Direct observations	• Reality – covers events in real time • Contextual – covers context of event	• Time-consuming • Selectivity – unless broad coverage • Reflexivity – event may proceed differently because it is being observed • Cost – hours needed by human observers
Interviews	• Targeted – focuses directly on case study topic • Insightful – provides perceived causal inferences	• Bias due to poorly constructed questions • Response bias • Inaccuracies due to poor recall • Reflexivity – interviewer wants to hear

Table 3.4 Sources of evidence: Strengths and weaknesses (adapted from Yin, 1994)

Documentation can take the form of letters, memoranda, agenda, minutes of meetings, other written reports, administrative documents (progress reports, proposals), formal studies or evaluation of the same "site" under study and newspaper clippings (Yin, 1994). These documents need to be carefully used and should not be accepted literally. Documentation used in case study is mainly for corroboration of other evidence sources.

Archival records are often in computerised form and can include service records, organisational records (organisational charts and budgets), maps and charts of the geographic characteristics of a place, lists of names, survey data, and personal records (diaries, calendars, and telephone listings)(Yin, 1994). The importance and use of archival data varies from one case study to another and its use needs to be carefully considered.

Direct observations happen during "site" visits and can be collected through formal or casual activities (Yin, 1994). Observation can be made during specific "site" visits or during other activities, such as interviews. Usually observation data is used as additional information.

The interview is the primary means of accessing data for case study research. Interviews can vary from unstructured to fully structured interviews. The author used semi-structured interviews for this work. The characteristic of semi-structured interviews is that it generally mixes open and closed questions in the form of an interview guide (Flick, 1998). It combines the flexibility of unstructured interviews, leaving flexibility to the researcher to ask more questions, and the logic of structured interviews following a guide to cover all the areas concerned (May, 1997). All the interviews conducted for this research were face to face and in most cases on a one-to-one basis. However, telephone interviews were also utilised to complement the data collected during the face-to-face interviews or when new issues needed to be discussed.

The list of people interviewed and organisation/site visited is presented in Appendix 2.

3.4.2.2 Choice of case studies

Taking an open building approach, a house can be decomposed into core elements: the foundations, the shell and roof, and the fit-out and services (Gann et al., 1999; Naim and Barlow, 2000). The COMPOSE research project only focuses on the construction of houses once the foundations have been laid. Therefore, the main remaining components to build a house are the shell and the roof, and the fit-out and services. The shell represents the structure of the house, including the roof. The high-value fit-out includes kitchen units, bathroom fit-out and electrical systems such as heating and ventilation systems. The low-value fit-out encompasses all the material needed for house fit-out such as doors, skirting boards, wardrobes, lintels, doorframes, and nuts and bolts. As shown in Figure 3.5, the supply network for the house building industry is very complicated. Only two supply chains are structurally identifiable, the multiple merchants-multiple manufacturer and labour only supply network (for both shell and low-value fit-out) and the specialised supply chain (for high-value fit-out). However, the different requirements on products availability and the specific problems related to shell and low-value fit-out promote the need to distinguish the shell supply chain from the low-value fit-out supply chain. The need to identify three categories of products utilising three types of supply chain was recognise by the house developer involved in the research.

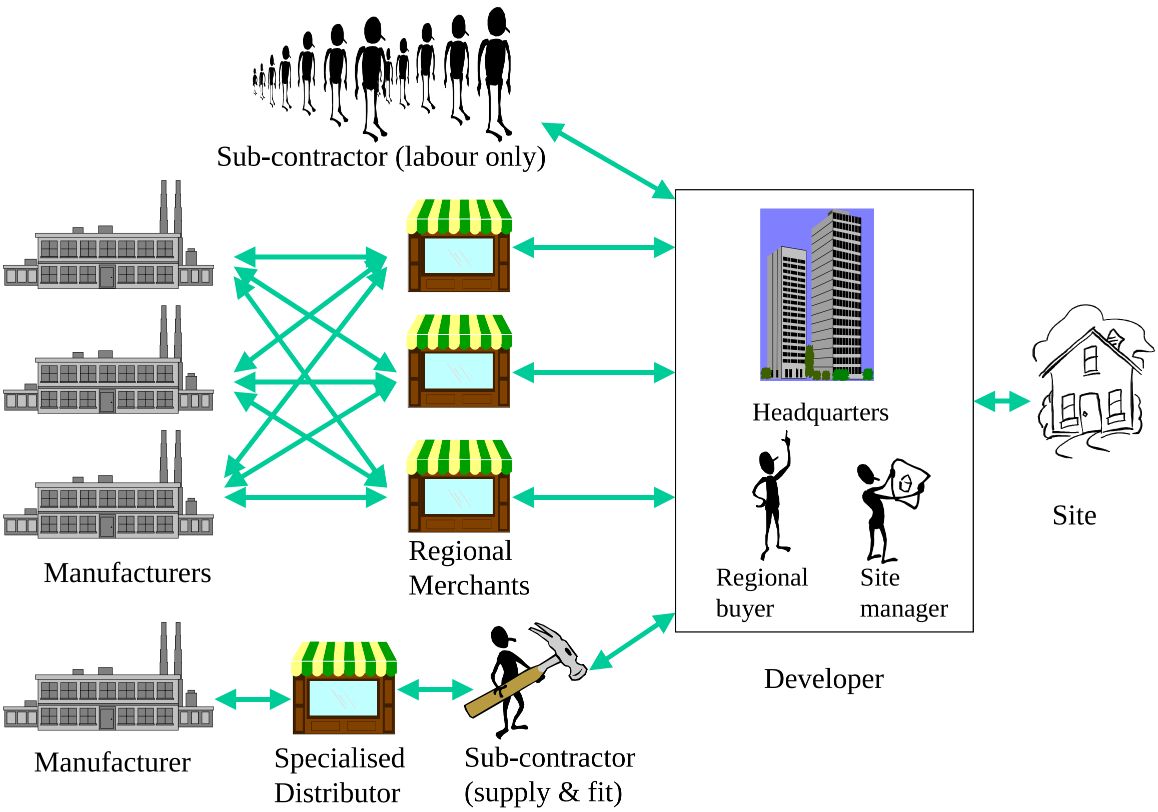

Figure 3.5 Traditional supply network for the private house building industry

More specifically, the shell supply chain can be viewed as shown in Figure 3.6. Two supply chains have been identified, a traditional supply chain utilising a merchant and an alternative supply chain utilising a framing system. The shaded area represents the organisations/sites visited for the research. The developer that will be named Home Builder includes the head quarters, a regional office and a number of sites. The timber frame manufacturer studied shall be called Timshell and this was also included in the action-based research activity.

Two task forces were set up with Home Builder. The first one aimed at evaluating timber frame construction in comparison with conventional construction using brick and block and involved evaluation and assessment at all three organisational levels, strategic, tactical and operational. The objective of the second task force was then to understand and document the information flows across the interfaces of the supply chain, specifically between Home Builder and Timshell, with an aim to identify opportunities to improve the integration of the supply chain.

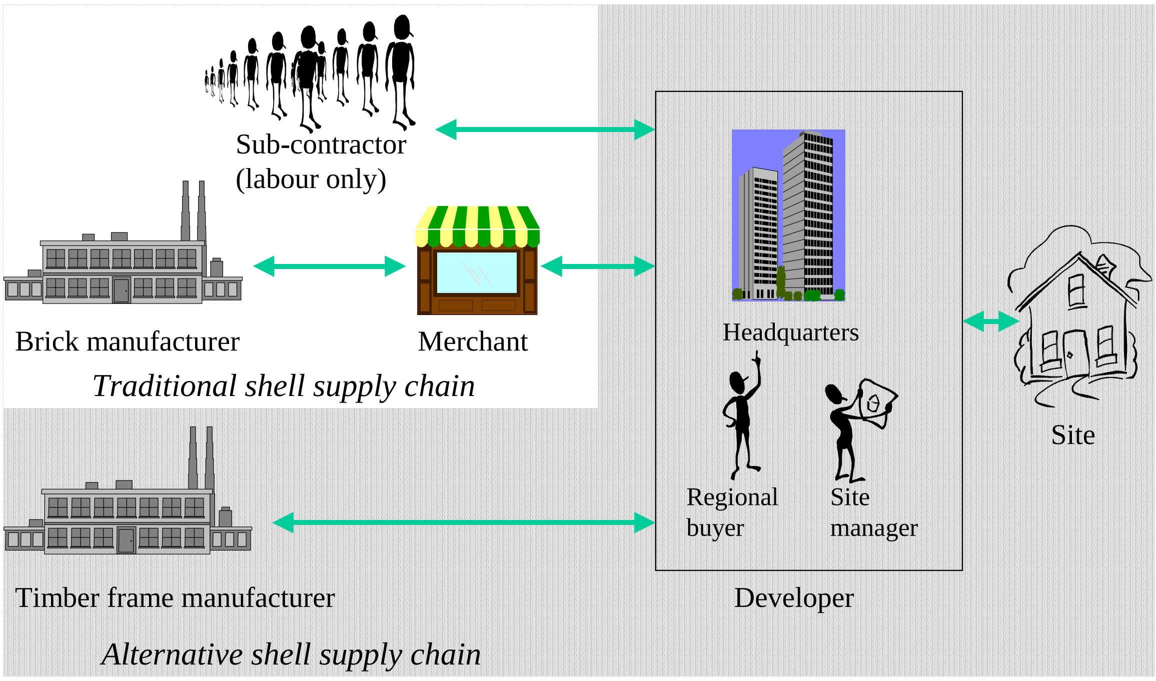

Figure 3.6 The house shell supply chains

The high-value fit-out supply chain, presented in Figure 3.7, was studied via information collected at Home Builder and at Ventair (the ventilation system manufacturer).

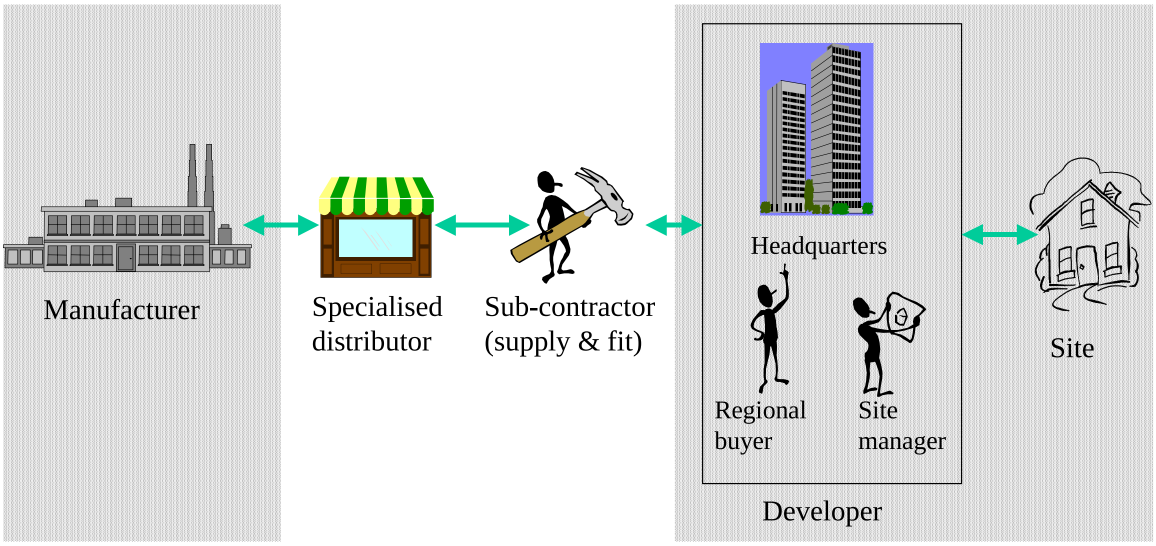

Figure 3.7 The high-value fit-out supply chain

The low-value fit-out supply chains, as shown in Figure 3.8, includes the analysis of two supply chains. A traditional supply chain via a merchant and an alternative supply chain utilising Kitter, a merchant pre-packing the material for different build stages (see Chapter 8).

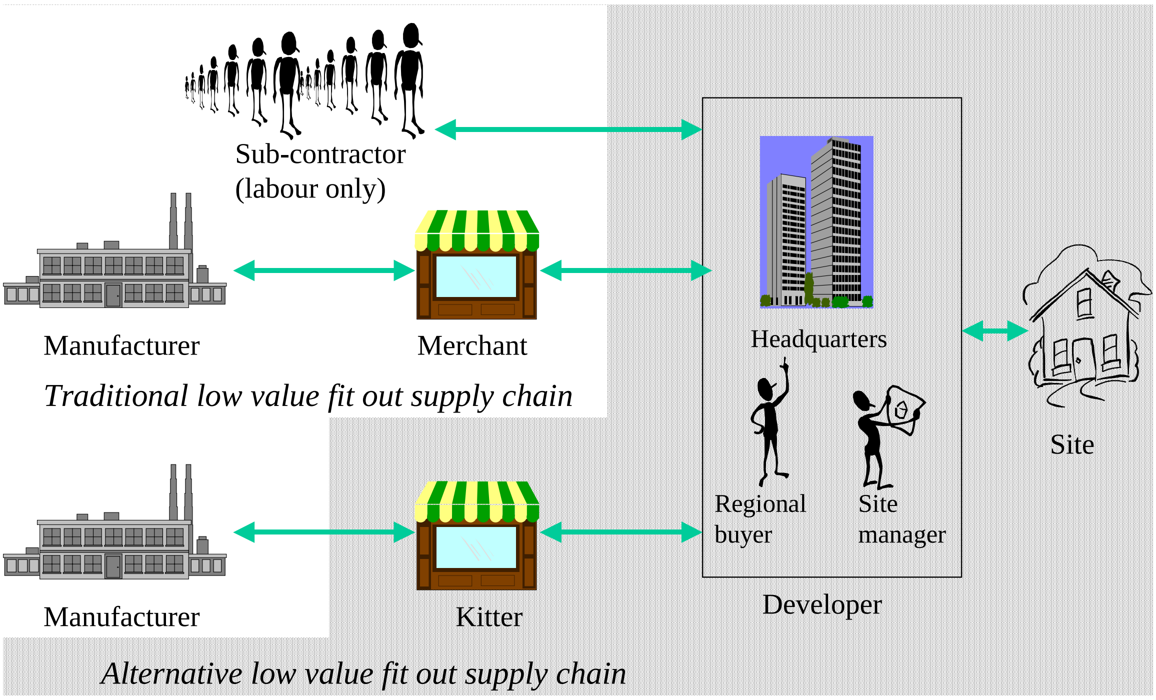

Figure 3.8 The low-value fit-out supply chain

Therefore, it can be seen that four main companies have been studied: Home Builder, Timshell, Ventair, and Kitter. The choice of these companies was partly due to the circumstances as some of these companies are industrial partners in the COMPOSE project and partly for their representation of the industry. Home Builder is the fifth largest house builder (as of 2000) in the UK with a 3% market share and 150 sites all over the UK. It builds around 4700 units a year and is regionally organised and controlled by a headquarter. This is representative of the house building industry in the UK (see Chapter 4). Furthermore, as Home Builder is very progressive, innovative and forward thinking, it was an ideal company to study for possible re-engineering strategies of its supply chains.

Timshell is one of the 56 timber frame manufacturers in the UK. Framing systems are the most popular alternative to brick and block house shell construction and timber frame is representative of a framing system supply chain (see Chapter 6). Timshell is a medium-size manufacturer and is also representative of much of the UK timber frame manufacturers. Their manufacturing techniques are identical to other timber frame manufacturers.

Ventair is an industrial partner taking part in the COMPOSE project. This £50 million turnover manufacturer has been supplying to the construction market for the last fifty-five years. Their forward looking attitude to business and innovative approaches to manufacturing using a postponement technique (Prickett, 1994) made them an ideal candidate to study future supply chain re-engineering strategies for the high-value fit-out supply chain.

Finally, Kitter is a new type of merchant, which packages the products for different build stages. Kitter is solely supplying Home Builder and was set up by the developer as traditional merchants could not offer the service level required. This new approach to merchant made it a very interesting case to study.

3.4.3 Modelling and simulation

Models and simulations have also been used in this thesis. But what is meant by model? A model is a representation of the reality and the study of which is easier than the real system. Apostel (1960) identified nine different purpose for constructing models:

1. Models can be used in fields where no theory exists yet, but has resemblance with another field. Models can then help to develop knowledge.
2. When there is a completely valid theory but which cannot be solved mathematically, models can solve the problem by interpreting the fundamental concepts.
3. Models can be used to relate two unrelated theories, by using one as a model of the other, or by introducing a common model relating them together.
4. Models can be set up for confirmed theories but which are incomplete.
5. A more generic model can be constructed which would embrace the old model and show that the old theory was a particular case of the new one.
6. Models can provide an explanation for some facts within a theory.
7. Models are used in the case of too far away, too small, too large, or too dangerous experiments.
8. Models, that visualise or realise a theory, can formalise a theory.
9. Models can be introduced to bridge the gap between theory and observations.

In all cases, models are used to produce new results, or to verify results, or to demonstrate relationships (Kramer and de Smit, 1977).

Naylor et al. (1966) define simulation as *"a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models that describe the behavior of a system over extended periods of real time."*

Hoover and Perry (1989) and Law and Kelton (1991) identify three dimensions of simulation:

- **Static vs. dynamic:** Static simulation is a representation of simulation at a particular time such as the Monte-Carlo simulation, whereas dynamic simulation represents the system as it evolves over time.
- **Deterministic vs. stochastic:** The lack of any random components makes a simulation model deterministic, i.e. the outcome is determined once the model relationships and initial stages have been defined, whereas the outcome of stochastic models are random variables.
- **Continuous vs. discrete:** In discrete simulation, the state variables change instantaneously at separate points in time. These points in time are called events. This means that the system states can change only in a countable number of points in time. In the continuous simulation the system state can change continuously.

In this work, the simulations used are dynamic, deterministic, and continuous. It is very important to not only study the static performance of the different cases studied but also the dynamic performance.

Van Ackere et al. (1993) demonstrated that continuous simulation using system thinking is appropriate for studying the impact of BPR programmes as BPR has its origins in system engineering (Jenkins, 1971). Furthermore, Sterman (2000) states that models provide high quality outcome feedback. Modelling offers *"the learner greater control over strategy, lead to more consistent decision making, and deter implementation failure and game playing"* (Sterman, 2000, p. 35). The role of simulation is to test the models (mental models) as without simulation, *"even the best conceptual models can only be tested and improved by relying on the learning feedback through the real world*" (Sterman, 2000, p. 37). However this real world feedback is often very long, costly, and the feedback can be inadequate and ambiguous. Therefore, simulation *"becomes the only reliable way to test hypotheses and evaluate the likely effects of policies"* (Sterman, 2000, p. 37). Hoover and Perry (Hoover and Perry, 1989) view simulation as a powerful problem solving method.

Some authors argue however, that at best models can provide quantitative precision for an already known problem but cannot lead to new fundamental conceptions (Dreyfus and Dreyfus, 1986; Lane, 1994). Sterman (2000, p. 37) argues this point of view that on the contrary, models (formalised and tested via simulation) often lead "to radical changes in the way we understand reality".

The main advantages of dynamic simulation can be summarised as:

- It incorporates the impact of time into performance evaluation (Bowersox et al., 1986).
- It is flexible, especially in comparison with analytical tools, details can be included which could not be possible with analytical models (Hoover and Perry, 1989).
- The researcher has control over the other variables in comparison with the real system (Johnsson, 1992).

3.4.4 Analysis tools

Two specific analysis tools have been used to analyse the data collected: a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis and the Multi-Attribute Utility Theory (MAUT).

SWOT analysis is the most commonly used analytical tool for strategic planning used by executives and consultants (Piercy and Giles, 1989). The original source of this technique is unknown, however, Abell and Hammond (1979) give a very good early technical description.

The advantages of the SWOT analysis are (Piercy and Giles, 1989):

- The technique is simple and readily accessible.
- The analysis can be carried out without the need of extensive corporate or market information, but is flexible enough to incorporate it if necessary.
- The SWOT analysis gives a structure to analyse a mixture of quantitative and qualitative data, familiar and unfamiliar facts, known and half-known understandings.

The shortcoming of the SWOT techniques can be summarised as (Piercy and Giles, 1990):

- One danger is that the technique may produce only introspection and unwarranted optimism and not a realistic appraisal of the situation.
- The technique is highly susceptible to subjectivity and bias.
- Without a specific market-place focus, it is impossible to validly identify and evaluate the SWOT attributes.
- For more sophisticated formulation, corporate characteristics may become separated from environmental characteristics.

- Finally as the formulation becomes more sophisticated, accessibility and user-friendliness may be lost.

The MAUT can often be found under the Multi-Criteria Decision Making (MCDM) theory. MAUT is a standard tool in decision making. Its principle is very simple, in a multi-attribute environment, alternative A is preferred to alternative B when the utility of A is larger/smaller than the utility of B (Keeney and Raiffa, 1976; von Winterfeldt and Edwards, 1986). The MAUT principle is based on the fact that *"the utility of an alternative is the weighted sum of conditional utilities of an alternative's attributes"* (von Nitzsch and Weber, 1993, p. 937).

MAUT deals effectively with both qualitative and quantitative factors in multiple criteria and uncertain decision environment (Min, 1994). MAUT embraces both *"a large body of mathematical theory for utility models and a wide range of practical assessment techniques that pay attention to limited abilities of assessors"* (Dyer et al., 1992, p. 647). The strengths of MAUT are that it (Zionts, 1992; Min, 1994):

- Can deal with both deterministic and stochastic decision environments.
- Has no constraints to consider explicitly.
- Enables the decision-maker to structure a complex problem in the form of a simple hierarchy.
- Deals with both qualitative and quantitative factors.
- Can handle multiple conflicting attributes.
- Enables the evaluation of "what if?" scenarios for company policy changes.

3.5 Conclusion

This chapter has described in detail the research strategy, techniques and methodologies proposed for this work and the reasoning behind them. The research framework has been presented, which is based on a SSM approach. The epistemological positioning of the author, positivistic realist, has been argued and the research methods have been presented with their strengths and weaknesses. As a summary, a TSM, Quasi-Delphi study, multiple case study and system dynamics modelling and simulation have been used to collect data. The main analysis tools used are the SWOT analysis and the MAUT.

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Chapter 4 The private house building industry in the UK

4.1 Introduction

This chapter aims at introducing the private house building industry in the UK to show its characteristics and common features with other industries. First of all a general overview of the private house building industry is given, positioning it in the more generic construction framework and differentiating it from the social house building industry. The house building industry is then compared to manufacturing, focusing on the characteristics of its product and the similarities in its processes.

An overview of speculative house builder processes is then given by following a generic value stream. Each step of the process is explained. Next, problems specific to the house building industry are introduced. These problems have not only been highlighted in the literature but have also been identified during the TSM exercises carried out in "the real world" and further approved during a Quasi Delphi study. Then house building performance criteria used in this thesis are selected and presented. To summarise, conclusions are drawn on the characteristics of the house building industry and its problems.

4.2 Overview of the private house building industry

Before presenting in detail the house building industry in the UK, it is first important to put it in the context of the construction industry. The house building industry is part of the construction industry, which plays an important role in the UK economy, as in most developed countries, by representing between 5.5 to 7.5% of the GDP over the past 20 years (Knutt, 1998). However, house building alone is only a small proportion of total construction work value with an average of 38% for 1997 (Ball, 1996; Department of the Environment, 1998), where housing includes new work and repair and maintenance.

In 1988, house building accounted for 31.2% of the overall construction industry turnover and 60.4% of its profits. However, by 1990 it fell to only 19.7% of the turnover and 22.5% of profits (Hewes, 1991). This highlights the problem encountered by most firms in the early 1990's, which was to maintain their financial viability.

Compared with other developed countries, the UK builds relatively few new housing as shown in Table 4.1. As Meikle (1999) demonstrates, to replace a unit of existing stock, the UK would need 5 times longer than Japan, 30% longer than France and twice as long as the Netherlands or Germany.

Country	**1990**	**1992**	**1994**	**1996**
France	5.4	4.7	5.1	4.7
Germany	4.1	4.8	7.0	7.2
Italy	4.5	4.9	4.9	4.6
Netherlands	6.5	5.7	5.7	5.7
Spain	7.2	5.3	5.6	6.5
UK	3.4	3.0	3.2	3.0
All EU15	4.9	4.8	5.3	5.2
Japan	13.5	11.4	12.5	13.0
USA	5.2	4.5	5.2	5.3

Table 4.1 Numbers of Dwellings built per 1,000 persons from Meikle (1999)

New housing only represented 10 to 12% of the total annual housing market transactions in England and Wales in the 1990's (Department of the Environment, 2000). The new homes market is also dominated by owner-occupiers rather than first-time buyers (Barlow, 2000).

As for the future of new housing, the UK Government has recently projected that the number of households will increased by 3.8m between 1996 and 2021 in England and Wales which implies an increasing demand in dwellings to house these new households.

House builders in the UK have built over 7.5 million new dwellings over the past three decades (Barlow and Ball, 1999). However a distinction between private and social housing needs to be made. In 1999, approximately 180,000 dwellings were completed in the UK, housing associations were responsible for 20,000 while private house builders built 160,000. The private house building sector was responsible for 80% of new production in the 1990's (Hooper and Nicol, 2000). Social housing refers to dwellings provided and managed by local authorities. The essential characteristic of social housing is that it is provided by non-profit making companies. Contrary to social house providers, speculative house building is centred on making profit. For this thesis, only the private house building industry will be considered and more specifically the speculative house building, where house builders build houses to then sell them and therefore facing the risk of not selling them (Ball, 1996).

The current structure of the speculative house building industry in the UK emerged after the 1973 crisis when housing starts fell to only half of the previous year (Ball, 1983). Consequently, many companies collapsed. Following this crisis the industry became more concentrated and centralised. For example, between 1981 and 1994, house builders building 500 units a year or more have increased their market share from 39 to 51% (Ball, 1996; Nicol and Hooper, 1999). The top 25 firms are now responsible for almost 60% of the UK annual completion (Barlow, 2000) (see Table 4.2). However, although the industry has become increasingly concentrated, it is still less in comparison with other manufacturing and service sector industries.

Speculative house building distinguishes itself from the rest of the construction industry in many ways. First of all, the work is repetitive, fairly simple and often carried out on greenfield sites, although more and more developments are carried out on brownfield sites. Furthermore, most speculative house builders, with few exceptions, are independent entities or parts of larger firms where the only link with the parent firm lies in the financial control and overall corporate strategies (Ball, 1983). Another specificity of private house building lies in the investment. Most construction works are generally financed by the client on a monthly basis depending on the work progress. Speculative house building has on the contrary to invest a large amount of money in the land and its development (groundwork and infrastructure) and will only receive revenue when the house is sold. Competition between speculative house building firms also differs from the rest of the industry. Competition takes place at the time of land purchase and house sale, rather than just prior to the start of work on site (during the tendering process) (Ball, 1983).

Rank	Company name	Units	Turnover £m	House average price	Year ending
1	Barratt Developments Plc	10,636	£1,259	£112,600	30/06/00
2	Beazer Group Plc	8,233	£841	£102,100	30/06/00
3	Persimmon Plc	7,101	£695.9	£96,055	31/12/99
4	Wimpey Homes Holdings Ltd	6,760	£553	£85,000	31/12/99
5	Bellway Plc	5,714	£634	£106,400	31/07/00
6	McLean Homes Holdings Ltd	5,605	£607.5	£108,000	31/12/99
7	Wilson Connolly Plc	4,700	£469.1	£94,000	31/12/99
8	Westbury Homes Ltd	4,355	£475.9	£104,700	29/02/00
9	Alfred McAlpine Plc	4,013	£412.6	£113,500	31/12/99
10	Bryan Group Plc	3,961	£593.9	£147,500	31/05/00
11	Wilson Bowden Plc	3,623	£506.4		31/12/99
12	Redrow Group Plc	3,338	£405	£118,800	30/06/00
13	Berkeley Group Plc	2,915	£799	£251,000	30/04/00
14	Bovis Homes Group Plc	2,429	£277.8	£114,100	31/12/99
15	Crest Nicholson Plc	2,422	£309.5	£124,500	31/10/99
16	Fairclough Homes Ltd	1,717		£100,000	31/12/98
17	Taywood Homes Ltd	1,658	£251		31/12/99
18	Fairview New Homes Plc	1,640	£192.7		31/12/99
19	Prowting Plc	1,579	£218.5	£124,000	29/02/00
20	McCarthy & Stone Developments Ltd	1,470	£123	£80,200	31/08/99
21	Miller Homes Ltd	1,415		£74,000	31/12/99
22	Laing Homes Ltd	1,281	£319.7	£207,000	31/12/99
23	Tay Homes Plc	931	£87.5	£97,000	30/06/00
24	Countryside Properties Plc	924	£244.2	£165,000	30/09/99
25	Gleeson Homes Plc	720	£170	£124,600	30/06/00

Table 4.2 Leading UK house builders by Units of completion (based on Property Data Ltd, 2001)

4.3 House building and manufacturing

A number of authors (e.g. Latham, 1994; Gann, 1996; Egan, 1998) argue that the house building industry could learn lessons from manufacturing industry such as the implementation of SCM principles. It is therefore important here to understand the specificity of the house building industry and its common features with the manufacturing industry. The first thing the author was told when interviewing people from the construction industry is that it is different from other industries as each product is unique and therefore everything carried out is also unique. This argument is often used to argue that the house building industry cannot learn lessons from the manufacturing sector. Although it is true that the product has its uniqueness, this section will argue that house building is similar to manufacturing in terms of processes.

The first specificity of the house building industry lies in the product itself (a house) as it is very large and immobile. The number of components needed to construct a house is four times greater than for assembling a car, depending on how the parts are counted, i.e. a house needs around 40,000 components, while a car only requires 10,000 components (Gann, 2000). The houses are built on a specific site with a mobile workforce which implies that the construction of houses can be highly influenced by weather conditions. Furthermore, in the UK, houses are expected to last long and are more likely to be regarded as an investment; people buy and sell houses relatively frequently (Gann, 1996; Ball, 1999; Ozaki, 1999). Contrary to manufactured products, which are transported to the market as finished goods, houses are assembled at the point of consumption.

In addition, there are also differences in the business strategies between the two industries. Traditionally house builders have focused more on the profits they can make out of the land rather than on the product itself (Ball, 1983; Bramley et al., 1995). Land acquisition is critical to house builders as it represents a third of the costs. The competitive advantage of UK house builders has been historically through land holdings and house price inflation (Ball, 1983; Bramley et al., 1995).

The next point is to study the differences between house building and manufacturing in terms of processes. The Cassell Concise English Dictionary (1994) gives the following definitions:

To manufacture: the making of articles by means of labour and machinery especially on a large scale.

To build: to make by putting together parts and materials.

Therefore the question under study is: “does house building uses industrial processes?”, which would suggest that the house building industry is equivalent to manufacturing.

Looking back in the history of construction, it can be seen that the construction industry went through different stages: craft, machine age and digital age. In the 1850’s, the traditional construction techniques developed into industrialised construction techniques

(Gann, 2000). This phase of industrialisation affected components and materials used on site, instead of being created on site, they were manufactured off-site and then assembled on site. With this came the idea of using standardised components and mass production. Le Corbusier already argued in the first half on the 20^{th} century that *“houses must go up all of a piece, made by machine tools in a factory, assembled as Ford assembles cars, on moving conveyor belts”* (Russell, 1981). According to Gann (1996) manufacturing offers three main advantages over craft:

- Economies of scale, when the cost per unit drops more quickly than production, costs decrease as the volume of materials being processed increases,
- Technical possibilities to develop and deploy capital equipment, and
- The opportunity for tighter managerial control.

Then in the mid 1990’s, construction moved into the digital age, where information and communication technologies brought some opportunities for the design and construction processes (see Gann (2000) for an in-depth study).

The move from craft to the machine age shows that the construction industry became industrialised. In other words it already started using some manufacturing principles with the aim to raise the *“efficiency by rationalizing the process through the application of scientific method”* (Gann, 2000). However construction continued to suffer from high production costs (Gann, 2000).

Focusing on the processes for the construction of houses, Egan (1998) argues that the processes are repetitive. Repeat processes are comparable with the designing and planning of the production of a new car model, even more so for private house building as a specific house design will be built more than once.

In order to place the house building industry in a manufacturing matrix, it is important to first understand the possible manufacturing classifications. Manufacturing uses different processes depending on the product structure, these are: project, jobbing, batch, line or continuous processing (Hill, 2000). Project process is applicable for low volume order quantities, it is usually adopted to meet the specific requirements of a customer. Jobbing is also concerned with low volume products and low standardisation. Batch process is required for low to medium volume orders for multiple products. High to medium volume orders for few major products are appropriate for line processes and finally continuous processing is used for high volume and highly standardised commodity products (Hayes and Wheelwright, 1984).

In the same manner, Woodward (1980) classifies production systems according to the manufacturing cycle and defines them as:

- unit and small batch,
- large batch and mass production and
- process.

The unit and small batch production system encompasses project, jobbing and batch manufacturing processes and are defined through the manufacturing cycle as “marketing-development-production”. In this case, the production does not start before there is a firm order and specific products can be developed for that order. The large batch and mass production system cover batch, line and continuous processing and is defined as “development-production-marketing”. In this case, the production schedules are not directly dependent on firm orders, but plans are made based on sales forecast. The production can be a mixture of make-to-stock and make-to-order. Finally, the process production system includes the same production processes as previously, but the manufacturing cycle is defined as “development-marketing-production”. In this case the development stage is critical as it is developing new products, then it is important that these new products are secured on the market before sending them for production (Woodward, 1980).

Figure 4.1 illustrates where speculative house building can be placed using both Woodward’s and Hill’s classifications. Considering Woodward’s (1980) classification, house building lies in the second category namely the large batch and mass production as most of the main house builders in the UK start by developing a house type, then build it and then try to sell it to customers. From Hill’s (2000) classification in process manufacturing, the construction of houses by major house builders in the UK would fit his definition of batch production as the volume of production is medium and there are several different products, when considering a different house type as a different product.

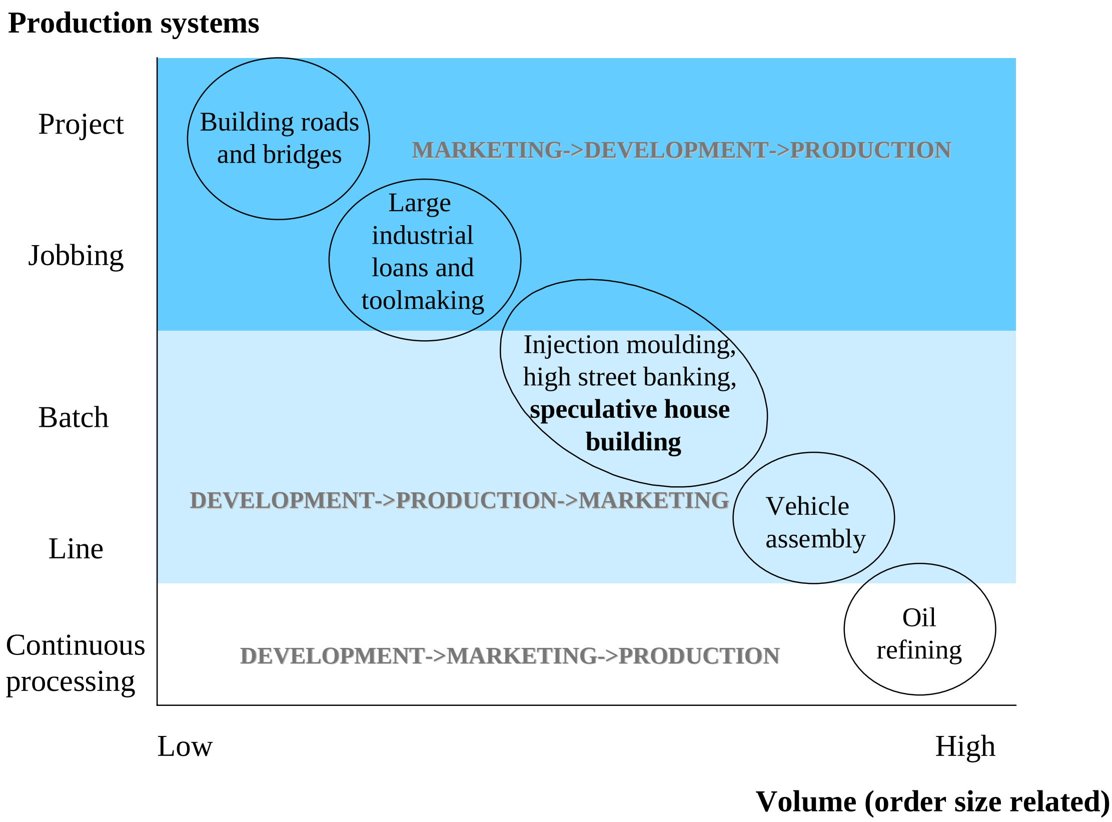

Figure 4.1 Process positioning of the house building industry and characteristics of the production systems (adapted from Hill (2000) and Woodward (1980))

The house building industry may therefore be classified as a batching process with medium volumes. This implies that the house building is similar to the manufacturing industry in terms of processes with its specificity in terms of product.

4.4 A speculative house builder

It is now important to understand the internal processes of a speculative house builder in the UK. Many of the speculative house builders in the UK, i.e. Barratt, Beazer, Westbury, Wimpey, Wilcon, etc., have a national presence. However they operate on a regional basis. This means that a head office provides the strategic information, orientation and the corporate identity while the regional offices are responsible for operational issues such as local advertisement, land appraisal, site layout and site construction. This holds true for Home Builder who operates strategically from a head office based in England and runs nine regions in the UK. These regions cover the whole of the UK except for Northern Ireland. Each region has an office from which the 120 sites (over the UK) are managed.

A generic value stream representing the current UK house building sector activities is illustrated in Figure 4.2. Seven major stages are represented with the private developer involvement. The generic value stream presented has a great deal of variants in practice, however the major stages hold for all house building projects. For example, in some instances private developers are able to by-pass the first three stages because local authorities have already defined the private housing requirements and acquired planning permission. Furthermore, although the value stream is shown as being a sequential process, in reality it is a concurrent process. For example, a developer already possesses a house design portfolio and does not have to develop new construction design for every new site.

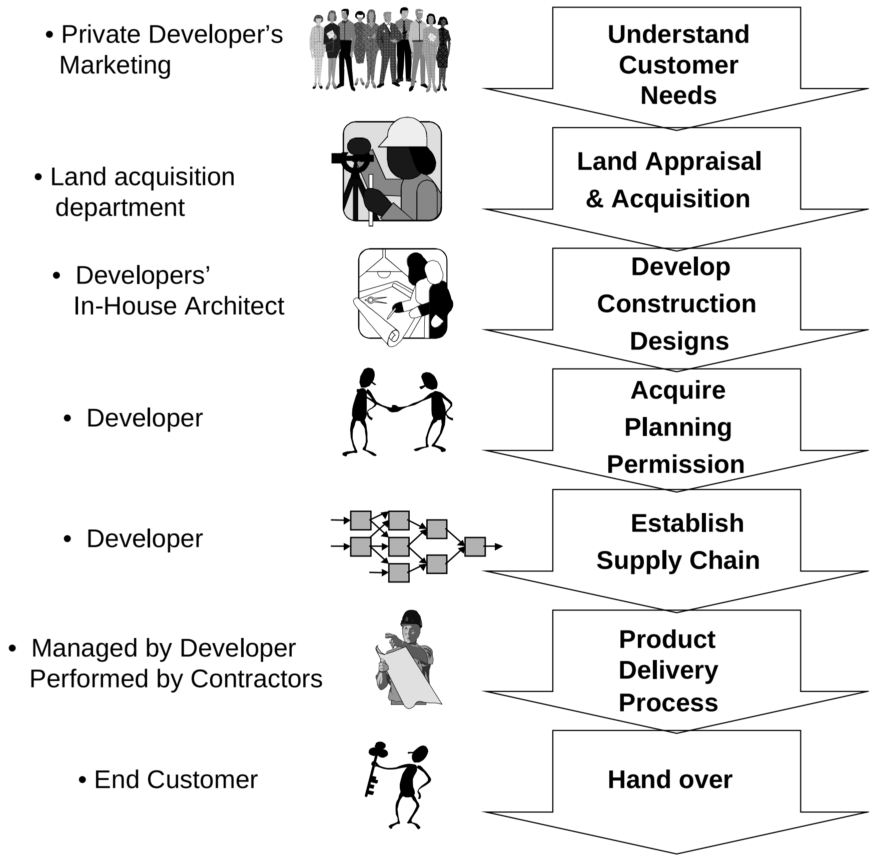

Figure 4.2 Generic UK house building value stream for private housing (based on Childerhouse et al. (2000))

4.4.1 Understand customer needs

Initially the demands of the marketplace must be understood by the marketing department of the private developers. It is critical for house developers, as with any industry, to fully understand their customer requirements to be able to offer the appropriate product.

In 1998, "2000 Homes" (now the Housing Forum[1]) carried out a survey of 1,000 people. This opinion survey revealed that more than 83% of the participants would like increased flexibility, offering greater choice over the initial design of their homes. Furthermore, a survey of 271 purchasers of new houses showed that 80% of the respondents wanted more choices for their house interior, such as floor finishes, storage space and additional energy saving devices (Barlow and Ozaki, 2000).

However, in practice, the main house builders in the UK are focused on production and sales targets and not on their customers' requirements (Roy and Gaze, 1999). This is not too dissimilar to the situation in the Western manufacturing sector in the 1960's and 1970's (from Merli, in Johansson et al. (1993)). Traditionally, a speculative house builder will offer a standard range of products with variation in the number of rooms and their layout (see Section 4.4.3). As for finished choices, customers have a very limited range such as the choice of the colour of the kitchen and bathroom tiles, the colour of the kitchen units and the colour of the carpets (Hong-Minh and Naim, 2001).

Ball (1996) also criticises the industry for the excessive standardisation in end products and the relatively poor quality of houses. In other words, private house builders are not customer focused which, in the case of the house building industry, usually refers to the need to react more responsively and to improve market understanding (Barlow and Ozaki, 2000). One way to offer more choice to customers is via mass customisation as it allows economies of scope through mass production of standard parts and customisation through late configuration (Pine II, 1993; Lampel and Mintzberg, 1996). Mass customisation promotes choice in an efficient manner while still keeping a small basic product range. Customer focused volume manufacturers have already started to develop flexible business and production processes so as to respond rapidly to customer requirements and profiting from economies of scales (Roy and Cochrane, 1999).

4.4.2 Land appraisal and acquisition

The next stage is land appraisal and acquisition. Private housing developers traditionally appraise and acquire land themselves. Appraisal and acquisition is carried out on the basis of speculative regional market demands. The detailed process of land appraisal and acquisition by Home Builder is represented in Figure 4.3 where the shaded area represents

[1]www.thehousingforum.org.uk

the people involved in the management team. This rich picture was developed during the case study and gives an understanding of the processes involved in land acquisition and appraisal.

The land appraisal is mainly regionally based. The headquarter usually gives a growth target that the regions have to meet. The regional MD then prepares a 3-5 year plan. Once the management team has decided what the company wants to build, i.e. high profile sites, first buyers homes; the Land Manager is tasked to find a suitable site. Potential sites are then assessed and an initial market research is carried out. The information is then passed on to the whole management team composed of the Sales Director, the Regional MD, the Commercial and Technical Director and the Land Director.

Some detail work on the site can then be carried out such as the road access, services and the planning status for the site. The Land Team can then brief the Technical Director on what needs to be done (e.g. roads, special sewers). The number and type of houses to be built is then decided. The planning application can already dictate the number of units required.

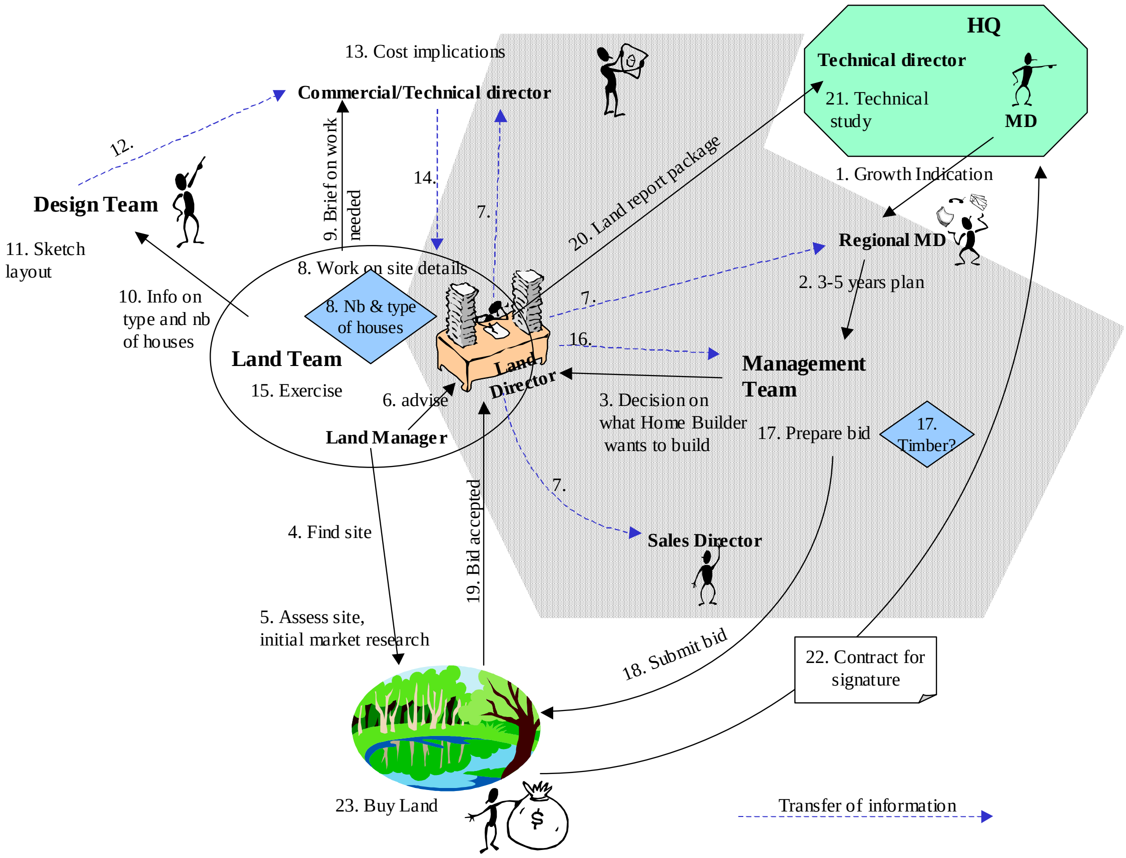

Figure 4.3 Rich picture for land appraisal process

The site design stage can then begin, the design team prepare a sketch layout from the standard houses design available. The technical team considers the costs implications (e.g. retaining wall, soil condition). Once this information is fed to the land team, the land appraisal exercise may then start. This exercise allows the house builder to estimate the profits or losses that can be made on the land. If it is viable, the Management Team then prepares a bid for the land. It is during this preparation that the choice of construction method can be made (i.e. timber frame versus brick and block) as it influences the cash flow (see Chapter 6). If the bid is then accepted, a land report package is sent to the Technical Director who will study the file from a technical point of view. If it gets the "go ahead" the contracts are then sent to the MD for signature to buy the land.

4.4.3 Develop construction designs

Designs of house types need to be developed so that they can be used on specific sites. Generally, private developers utilise in-house architects to perform this operation. House developers often use a house portfolio. 75% of the house developers building more than 500 units a year utilise a portfolio composed of 20 or more standard house types to cover the market (Nicol and Hooper, 1999).

Utilising a portfolio of houses allow the private house developers to build repetitively "standard" houses all over the country. Therefore, developers move away from one-off construction to repeat production. The "standard" designs try to cover the customer choices and there has been an increase in the number of house types utilised since 1990 (an average of 73% increase for all house building firms) (Hooper and Nicol, 2000).

For example, Home Builder offers a range from a one bedroom flat to a six bedroom luxurious home from £40,000 to £1,500,000. Each house type tries to meet a specific customer segment, for example in the three bedroom house types, several different designs can be offered where the layout has changed. A breakfast bar might be an option or an open plan kitchen and diner. Customers can therefore make their choices depending on the generic house designs. However if customers require alterations in terms of layouts, 63% of house builder building between 501 and 2000 units per year would not allow such change (Nicol and Hooper, 1999). In terms of finishes, 56% of these house builders would allow changes (Nicol and Hooper, 1999).

4.4.4 Planning permission

Once a site has been identified and purchased, the site layout prepared, house builders need to apply for planning. This can very often be a very lengthy procedure where much time is lost. However a large amount of sites already have a planning permission "attached" to them with specific requirements such as the number and type of units that will have to be built and the nature of the development (i.e. mixed site with social and private houses, industrial and habitation site). In these cases, planning application can become a swifter process.

4.4.5 Establish supply chain

Private house builders usually have their supply chain already set up and, as seen in Chapter 2, the house building supply chain is defined as *a chain of organisations linked to each other through flows of material, labour and information from the end-customer to the raw material supplier.*

The house building supply chain has however its specificity. First of all, as shown previously, most house builders are organised regionally and the purchase of material is often carried out from the regional offices. Due to local taste and local authorities, the appearance of the dwellings is strictly regulated and cladding material (mainly bricks) have to be procured locally. Most materials are procured from local merchants. Therefore the number of suppliers for one specific developer is very high. Secondly, house building supply chains are characterised by the extensive use of merchants and other specialist distributors (such as electrical merchants) (Agapiou et al., 1998).

Thirdly, as seen in the definition of house building supply chain, labour also needs to be procured. Labour is usually sub-contracted (the term sub-contracted is commonly used, although the private developer is not a main contractor in the strict terms) (Ball, 1996) on either a "supply-and-fit" or a "labour only" basis. "Supply-and-fit" sub-contractors usually procure the material needed for the construction themselves and then fit/build them. This is often the case of electrical sub-contractors. "Labour only" sub-contractors are hired to perform a specific task and the material is procured by the developer itself. Typically, bricklayers are hired on a labour only basis.

The last important characteristic of the house building supply chain lies in the fact that there is more than one delivery location. For example in the case of Home Builder there are around 120 sites all over the country at any point of time where materials are required.

4.4.6 Product delivery process

The penultimate stage of the UK house building value stream is the product delivery process, during which developers manage the material, cash, resources and information flows in conjunction with on-site construction processes.

The construction process starts with the groundwork where the services such as water and gas are laid. The main roads to and out of the site are also often prepared. Work can then start on the houses with the foundations. The ground floor work follows with the insulation and traditionally cavity walls. Traditional brick cladding is also built together with internal load bearing walls. Windows and doors frames are also installed. The first floor can then be constructed followed by the roof, which is traditionally assembled using trusses. The roof is then battened and tiled.

The internal work then starts, as the houses are waterproof. Internal work includes glazing, plumbing, insulation, sanitary fittings, non load-bearing walls, staircase, heating installation, floor boarding, electrical installation, gas installation, plasterboards and plastering, and architrave and skirting. Finally the finishes can be made such as painting and decoration and floor finishes.

4.4.7 Hand over

The final stage is hand over, during which the end consumer, the buyer, acquires the new dwelling. Traditionally, a hand-over date is given to the buyers, however, this date is typically a one-month window and not a specific date. A common problem lies in the interpretation of this date. Often a site manager will announce the completion date to be for example March, meaning end of March. However for the customer will often understand that date as meaning the beginning of March.

At the hand-over stage, the customer will then be able to list all the faults they have discovered in their houses, this list is commonly called the “snag list”. The developer will usually strive to complete the “snag work” within a set period of time (i.e. 3 months after the moving-in date).

4.5 Private house building problem definition

After having seen the typical processes of a speculative house builder in the UK, it is now important to highlight the problem of the house building industry. The private house building industry suffers from many problems, some inherited from the construction industry in general such as cultural problems, others inherent to the speculative house building industry. This section does not intend to undertake an in depth study of all these problems, nevertheless a brief summary of some of the principal issues may provide a clearer picture of the current state of the house building industry within the UK.

4.5.1 Customer needs

From a customer point of view, private house building may be perceived as not delivering the right product or the right quality or in the right location. Indeed, at present, new housing can be accused of being excessively standardised offering relatively low quality for expensive costs (Ball, 1996). This can be explained as house builders in the UK are focused on production and sales targets and not on their customers' requirements (Roy and Gaze, 1999). A general lack of customisation of the products offered by house developers has been acknowledge (Barlow, 2000). Customers expect more specifications for their dwelling and to be offered more choices (Home Builder, 2000). Furthermore, regulations fail to stimulate the construction process and lengthen the lead-times (especially for planning application), although they do not hamper innovation as they are flexible enough to allow changes (Gann et al., 1998).

Another problem lies in the construction rate. At present new house building completions are insufficient to replace the oldest or poorest quality stock (Meikle and Connaughton, 1994). At the current construction rate, some housing would have to last up to 1,000 years (Meikle and Connaughton, 1994).

4.5.2 Land banks and land acquisition

Another important problem for private house developers is the reduction of land available for development. Developers' land banks have reduced in size during the last decades and finding suitable land for housing development is becoming an increasingly difficult task (Ball, 1996; Barlow, 2000). One major reason why house developers have not focused on customers and on the products (houses) is that developers reach higher profits through land acquisition and speculation than through the construction of the houses themselves. House builders are fully focused on land, however more and more brownfield sites are becoming available for construction, which require additional costs and activities such as land decontamination and stronger foundations issues (Home Builder, 2000). Thus the building activity may receive more focus in the future.

4.5.3 Planning application

The acquisition of the planning permission is also problematic as very often assembling all the information required can become a very lengthy and time-consuming task (Home Builder, 2000). Furthermore, regulations are restricting and do not promote change and innovation (Gann et al., 1998).

4.5.4 Construction stage

During the construction stage, supplier performance reveals itself as being a problem. Getting the right material to site at the right time for the right cost is not an easy task (Home Builder, 2000). Furthermore, the construction process is weather dependent, which can cause long delays. The private house building industry is also plagued like the rest of the construction industry by a skilled labour shortage (Latham, 1994; Ball, 1996). This shortage in skilled labour is directly linked to the lack of appropriate training (Gann and Senker, 1998).

4.5.5 Demand amplification

As for all industries, the house building industry suffers from demand amplification along its supply chain. Evidence of this phenomenon in the housing industry was reported by Lewis (1997) and is presented in Table 4.3. Lewis' (1997) example of demand amplification comes from the study of Ventair. Table 4.3 reveals that as demand is passed along the supply chain from customers to suppliers, it is distorted and amplified.

Average weekly demand from customers	Variability in weekly demand from customers	Average demand placed on suppliers and frequency	Variability in demands placed upon suppliers
48 per week	Up to 150%	400 every 6 weeks or 200 every 3 weeks	From 100% up to 300% depending upon frequency

Table 4.3 Amplification and variability in demand as it is passed along Ventair supply chain (Lewis, 1997)

4.5.6 The "mind-set"

There are other critiques to be made to house builders, those related to the house building culture and the way the companies involved in a housing project work with each other. Typically the relationships between the different disciplines involved in a construction project tend to be adversarial, as there is a lack of trust and commitment between parties (Bresnen, 1996; Holti, 1996; Larson, 1997; Barlow, 1998; Construction Productivity Network, 1998). The current "mind-set" may be defined as (Hong-Minh et al., 2001):

- Poor communication: as the different trading partners cannot completely trust each other, they try to limit the exchange of information as much as possible. Consequently, due to a lack of co-ordination they often have insufficient or incorrect information to complete their work, which leads to a run over deadlines (Latham, 1994; Egan, 1998).

- Win-lose relationships: companies try to procure benefits out of their relationships and often finish with a lose-lose relationship. Contracts are often the fallback used to gain recompense when problems arise (Holti, 1996; Gann, 1998).

- Lack of commitment: as a result of a lack of commitment between trading partners, the work is often of a poor quality requiring a time consuming checking process (Burnes and Coram, 1999). In the same way, the companies are not committed to completing their work on time and consequently will not fulfil their professional obligations and meet the agreed deadlines (Ballard and Howell, 1994).

This problem of "mind set" has not only been identified in the literature but also during the TSM exercises. The relationships between organisations are generally contractually based and so indicate little trust. Reference to, or legal use of, contracts with penalty clauses is common (Barker et al., 2000). Such an adversarial state of affairs, although obviously based on previous bad experience is a potential area for uncompetitiveness.

4.5.7 Functional silo approach

Another generic problem to the house building industry lies in its functional silo approach to their work, which means that barriers can emerge between each discipline of their business. As a result such firms cannot establish a business process view of their work, neither can they fully focus on their customers' needs and requirements (Christopher, 1992). This problem is present not only at a company level but also at a project level involving several companies.

Better integration between all those involved in a construction project, such as customers, contractors and suppliers has been emphasised in the UK by Latham (Latham, 1994). The need for integration of processes within the UK construction industry supply chain process is also given prominence by the Office of Science and Technology (OST) (Office of Science and Technology, 1995).

Even in the USA, the need for process-based research in construction so as to maintain a strong competitive position and a need for a greater visibility of clients' needs is emphasised (Halpin, 1993).

Here again the TSM revealed that several companies visited appeared to be working in a functional silo approach. That is, areas of activities are compartmentalised and work on a flow principle of passing on the work from one area to the next without understanding the whole process.

4.5.8 Communication and learning

Due to the problem of adversarial relationships, communication between companies is very often not effective. In many cases, information is not always readily available (Latham, 1994) and is often incomplete or inconsistent (Construction Productivity Network, 1997). As stated by Latham (1994), there are serious deficiencies in information needed by builders. At the start of a project, requirements are often not fully defined, which impacts upon construction performance (Howell and Ballard, 1994; Bresnen, 1996).

The success or failure of a construction project's execution depends on the understanding of the information needs and requirements of the different parties (Love et al., 1999). Inadequate, incomplete and outdated information can lead to delays and extra costs during the design stage but also during the execution of a construction project.

This lack of communication and willingness to learn was also highlighted during the TSM exercises. Some of the companies studied proved to be reluctant to communicate with trading partners and even more reluctant to learn from other organisations or industries.

4.5.9 The need for change

Until now, the private house building industry had very little incentive to change partly due to the fact that they make more profits on the land resale price, more than on the product (houses) they sell. Furthermore, entry to market by more innovative foreign companies, i.e. Japanese, Dutch or Swedish, is made difficult by the lack of appropriate suppliers and labour (Barlow, 1999). They would therefore require to import innovative materials and trained labour which would considerably increase their costs. Thirdly, demand is higher than supply for new houses in the UK (Meikle, 1999).

This comfortable situation is however starting to change and the private house building industry will need to react. First of all, the environmental legislation will continue to require better performance from the dwellings. Currently these regulations are easily met or exceeded by the developers using traditional construction techniques. However as the regulations and standards will become tighter, developers will undoubtedly need to seek new ways of construction (Barlow, 1999). Secondly, the government's pressure to build on brownfield sites is increasing. A percentage as high as 45-50% of new housebuilding will have to be developed on brownfield sites has been quoted by the government (Barlow, 1999). This has severe consequences on construction costs. Thirdly, the shortage of skilled labour is continuously increasing the construction costs (Barlow, 1999).

Therefore, ideas for improvement and change are required. As Gann (1998, p. 157) states, *"current levels of inefficiency and wasted materials, labour and time, as well as pollution, could be substantially lowered by streamlining supply chains and by introducing better management practices"*.

4.5.10 Quasi Delphi study results

The results of the Quasi Delphi study, carried out with the industrial companies involved in the COMPOSE project, concurred with the above listed problems identified in the literature and during the TSM exercises. The Quasi Delphi study gives an insight into what is believed to be needed and what are the likely barriers to be encountered by the house building industry to work as a fully integrated supply chain meeting customer needs; high quality, low cost, short lead-times, excellent service.

The answers given by the participants during the Quasi Delphi study were first categorised with the participant consensus and finely tuned by the author using the Business System

Engineering Scope Model (Evans et al., 1999) as a basis. The summaries of the results are illustrated in Figures 4.4 and 4.5.

Figure 4.4 shows that changing attitudes represent 30% of the 114 answers for actions that need to be taken to improve the housing supply chains. At the same time, it can be highlighted that 52% of the obstacles (75 answers) are expected to arise from attitudinal problems.

Changing and improving work/construction processes scores 21% of the answers against 14% for improving the product itself. This agrees with Thurow's (1993, p. 45) statement that *"in the twenty-first century sustainable competitive advantage will come much more out of new process technologies and much less out of new product technologies."* Improving information focus (type, amount and frequency of information exchanged) is another important area of action accounting for 17% of the answers.

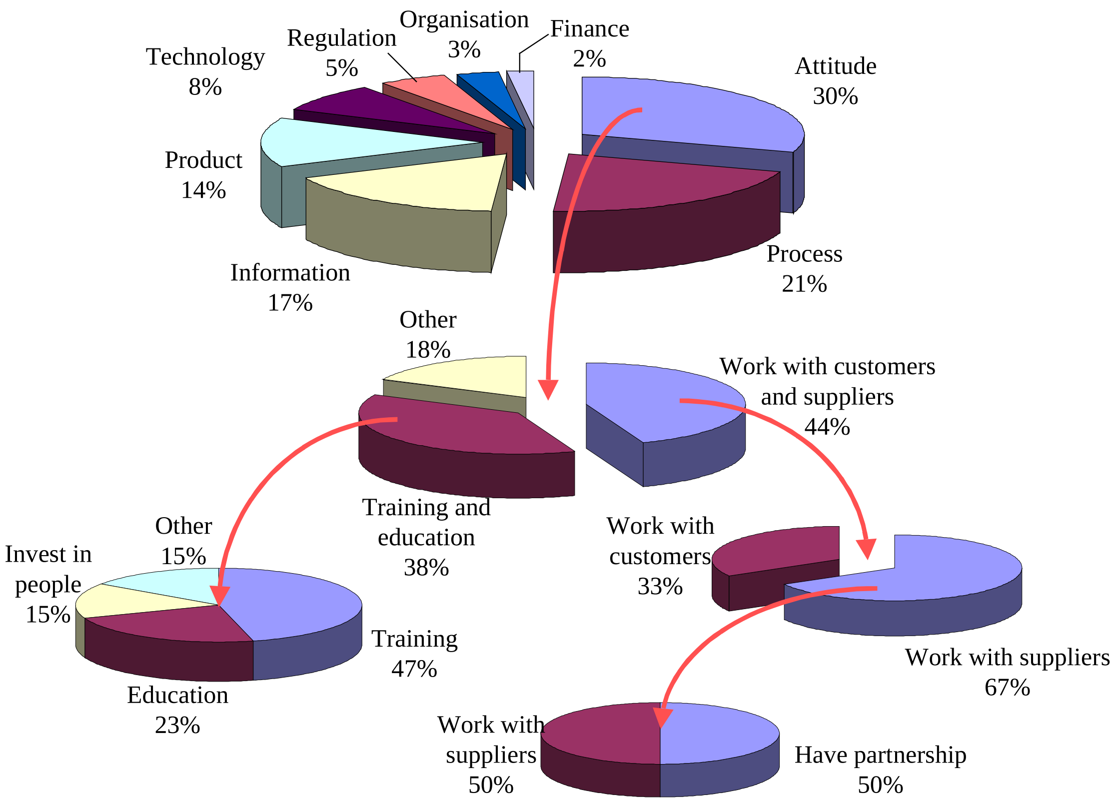

Figure 4.4 Quasi Delphi study results: Actions' results and attitudinal actions breakdown (Hong-Minh et al., 2001)

The type of attitudinal actions needed to be taken is further broken down into issues related to working with customers and suppliers and training and education. This shows that housing supply chain companies are becoming aware of their supply chain. It is, however, not surprising that the split between "working with customers" and "working with suppliers" is one third, two thirds respectively, as it is easier to initiate change with suppliers than it is with customers (Mason-Jones and Towill, 1998).

The participants were divided on the supplier issues. Half of the answers were for the development and implementation of partnering while the other half were for working closer with suppliers without involving partnering. This may be explained by the different companies' level of supply chain maturity. Some of the industrial partners have already started working with their suppliers and felt that they should start moving towards partnering. Other companies are not yet working closely with their suppliers and thus need to start developing trust.

Another action to change attitudes is training and education. Through better training and further education, the participants felt that the current attitude/behaviour of employees could be improved.

Figure 4.5 shows that the main concern with obstacles lies in attitudes. However, it is interesting to note that the second main obstacle is seen as coming from regulations (12% of the answers) which are seen as too rigid to promote innovation and improvements. Attitude includes here mentality and culture and the right skills. 80% of the attitude problems are due to mentality and culture which includes resistance to change as identified by Akintoye et al. (2000). This is not surprising as resistance to change is a universal phenomenon (Child, 1984). Here, culture means the current attitudes and behaviour of the housing industry, i.e. adversarial relationships, lack of trust and commitment, win-lose relationships. Finally, the Quasi Delphi study demonstrates that the participants are also concerned with finding employees with the right skills which they believe could be due to a lack of effective training availability.

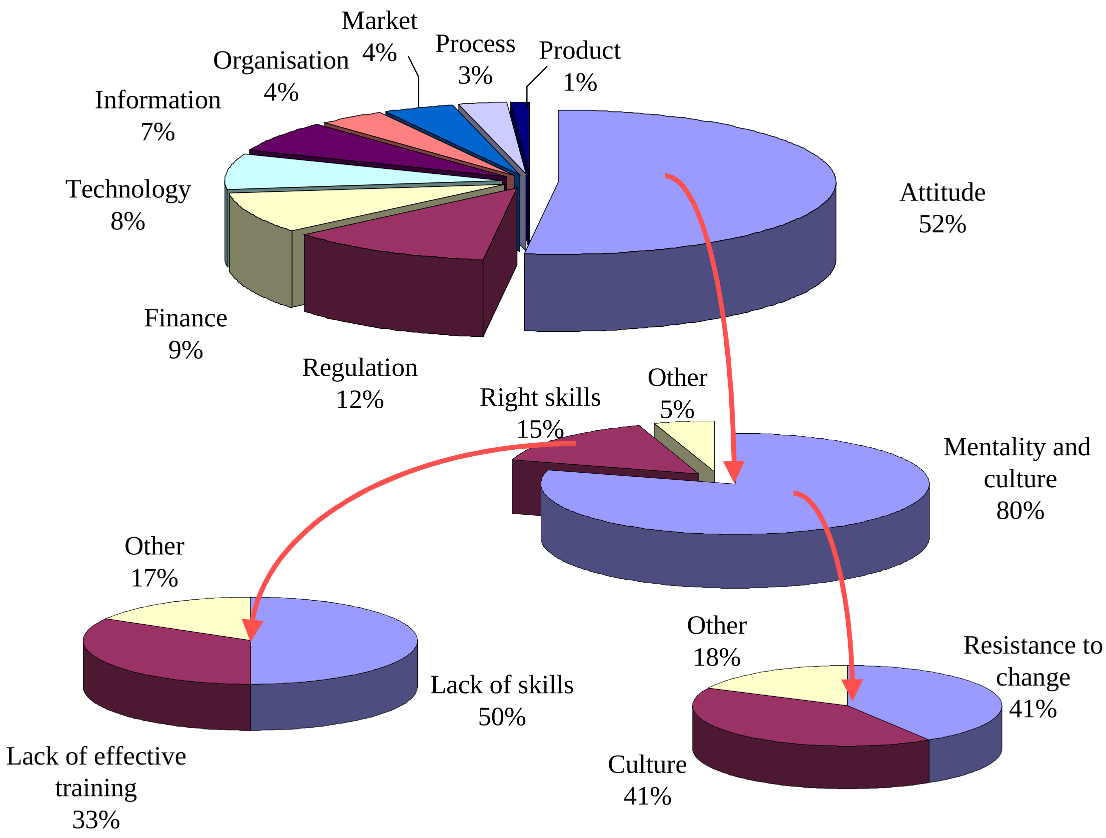

Figure 4.5 Quasi Delphi study results: Obstacles' results and attitudinal obstacles breakdown (Hong-Minh et al., 2001)

Consequently, the main action areas that need to be considered are Attitude, Process, Information, Product and Technology, while mentalities, resistance to change and lack of skills need to be looked at if change is to be successfully implemented.

The problems that will be tackled in this thesis are the ones directly related to SCM issues. Therefore the low level of supplier performance will be considered as well as the problems related to the house building "mind-set". The functional silo approach to business will also be under scrutiny and the communication and learning related problems. Finally a customer focus approach through SCM will try to find some answers to unmet customer requirements.

4.6 House building industry performance measures

The construction industry in general is striving to measure performance in a uniform manner across the UK. For that purpose, the Department of the Environment, Transport and the Regions, the Construction Industry Board and the Movement for Innovation have through the Construction Best Practice Programme published some handbooks and wall charts on Key Performance Indicators (KPIs) for the construction industry. In order to adhere to the uniformity of KPIs in the construction industry, these KPIs have been chosen for this thesis. The need for KPIs was identified as clients in the construction industry want their project delivered on time, on budget, free from defects, efficiently, right first time, safely and by profitable companies (The KPI Working Group, 2000).

The KPIs have been developed to serve different purposes (Construction Best Practice Programme, 1999):

1. To set performance targets at the start of a project
2. To monitor progress during a project
3. To assess a completed project to measure the team's performance and learn from feedback
4. To set targets for improvement
5. To form part of the selection/award process on "best value" rather than lowest price

For this thesis, the KPIs are utilised to meet the third purpose; assess a completed project. The Construction Best Practice Programme has set up 10 different KPIs for the new private house building, these are:

- **Client satisfaction (product)** objective is to determine the overall level of client satisfaction with the completed facility.
- **Client satisfaction (service)** objective is to determine the overall level of client satisfaction with the service of the consultants and main contractor during the project.
  For this thesis, client satisfaction is measured for both product and service, the client is the end-user/customer, i.e. the home buyer. The objective is to determine the overall level of customer satisfaction with the service and the product received.
- **Defects** assess the impact on the client of any defects at the point of handover. For this thesis defects is understood as the product quality.
- **Predictability (cost)** measures the reliability of cost estimated for both design and construction.
- **Predictability (time)** measures the reliability of time estimated for both design and construction.
- **Construction time** measures the change in construction time from one year to the next. In this thesis, construction time measures the construction or installation time for the product considered.

- **Construction cost** measures the change in real cost of construction from one year to the next. In this thesis the construction cost is measured for the specific product looked at. Construction costs considers the installation costs for specific products.
- **Profitability** measures the profitability of a construction company before tax interest. Here profitability is used as a comparative measure of profitability from one project to another.
- **Productivity** determines the Value-Added per employee of a construction company. This measure is not applicable for this thesis for lack of data availability.
- **Safety** measures the number of reportable accidents per 100,000 employed – the accident incidence rate (AIR). This measure is not applicable for this thesis as only part of the construction process is studied and data unavailability.

4.7 Conclusion

It has been shown that the house building industry is only a small proportion of the construction industry in the UK. The private house building industry is however responsible for 80% of the construction of new dwellings. This industry is increasingly important as the forecast in number of household required, and therefore houses demand, is of a 3.8m increase between 1996 and 2021. The concentration of the industry makes it easier to study as the top 25 companies are responsible for almost 60% of the UK annual completion. These top 25 companies have some common features such as a large amount of units built per year, a regional organisation and a portfolio of standard designs.

It was also shown that the private house building industry utilised processes similar to manufacturing and can be considered as a batching production system. This would suggest that lessons can be learnt from the manufacturing industry such as the implementation of SCM principles. The house building value stream explained the speculative house builder processes and an overview of the house building industry problems was given. Numerous problems were highlighted however only a few will be further studied in this work. The problems under scrutiny are namely the low level of performance by suppliers, the “mind-set” or adversarial relationships, the functional silo approach to business, the lack of communication and learning, and the unmet customer requirements. Finally, the house building measures of performance have been identified for this thesis as: customer satisfaction, product quality, predictability (cost and time), construction cost and time, and profitability.

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Chapter 5 Model Description

5.1 Introduction

This chapter describes the model used to assess the performance of three different supply chains - house shell, low-value fit-out, and high-value fit-out – for the private house building industry in the UK. The necessity of using models was reviewed in Chapter 3 and will therefore not be repeated in this chapter.

The development process for a simulation model starts from simple to more complex systems as Richardson (1996) states *"connections between model structure and behaviour come from a sequential modelling process that moves from simpler formulation to more complex structure"*. Therefore the methodology followed to develop the model under study in this thesis started from a simple well-known model, an Inventory and Order Based Production Control System (IOBPCS) described later in this chapter, which was then further developed to incorporate characteristics of the real system.

The development of any simulation model is not a linear process as can be seen from Figure 5.1. The model development process is iterative, starting from the problem description of the situation and the description of the aim of the model. The system development deals with the development of the model itself by identifying the structure and main components of the real system and translating them in terms of relationships. Finally the model is constantly validated during the development process.

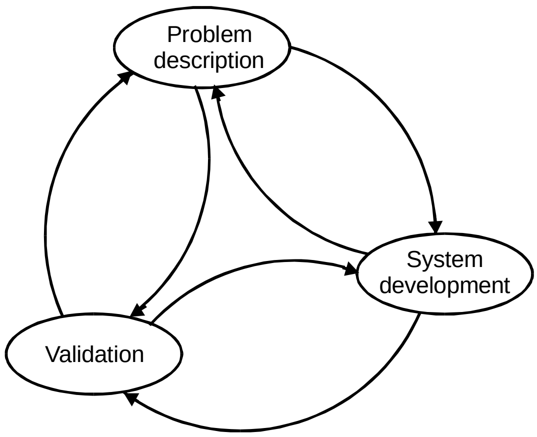

Figure 5.1 Model development process (Strohhecker, 1998)

Therefore a key step in model development is the problem description with the clear statement of the model's aim (Forrester, 1961). Modelling and simulation are used in this thesis in order to assess the potential impact of different supply chain management principles on house building supply chains in terms of dynamic behaviour. Hence the aim of the model is to compare different scenarios derived from a main model and study in particular the effects these scenarios have on demand amplification.

This chapter will first present the structure of the model utilised in this thesis by describing several sub-systems. Then the initial settings for the parameters used in the model will be reviewed. This process is carried out for the three different types of supply chain studied. The validation and verification process of the model will also be presented.

5.2 Model structure

Several different models are used in this thesis, all of which are based on common features and on the same basic model. The structure overview of this basic model is presented in Figure 5.2 and is composed of six sub-systems. The demand represented by the construction plan is exogenous. This demand is inputted into the Home Builder sub-system, the developer. Home Builder generates orders and call offs which are transmitted to the merchants. The merchants utilise this information to generate their own orders, which are sent to the manufacturer. The manufacturer then decides on the appropriate production level to fulfil these orders. A production allocation system has been implemented so as to decide which merchant should receive which quantities of material in the case of shortages. Then construction on site can take place using the material delivered by the merchants. Finally some performance indicators are calculated to assess the model.

The full documentation for the equations utilised in the model can be found in Appendix 3.

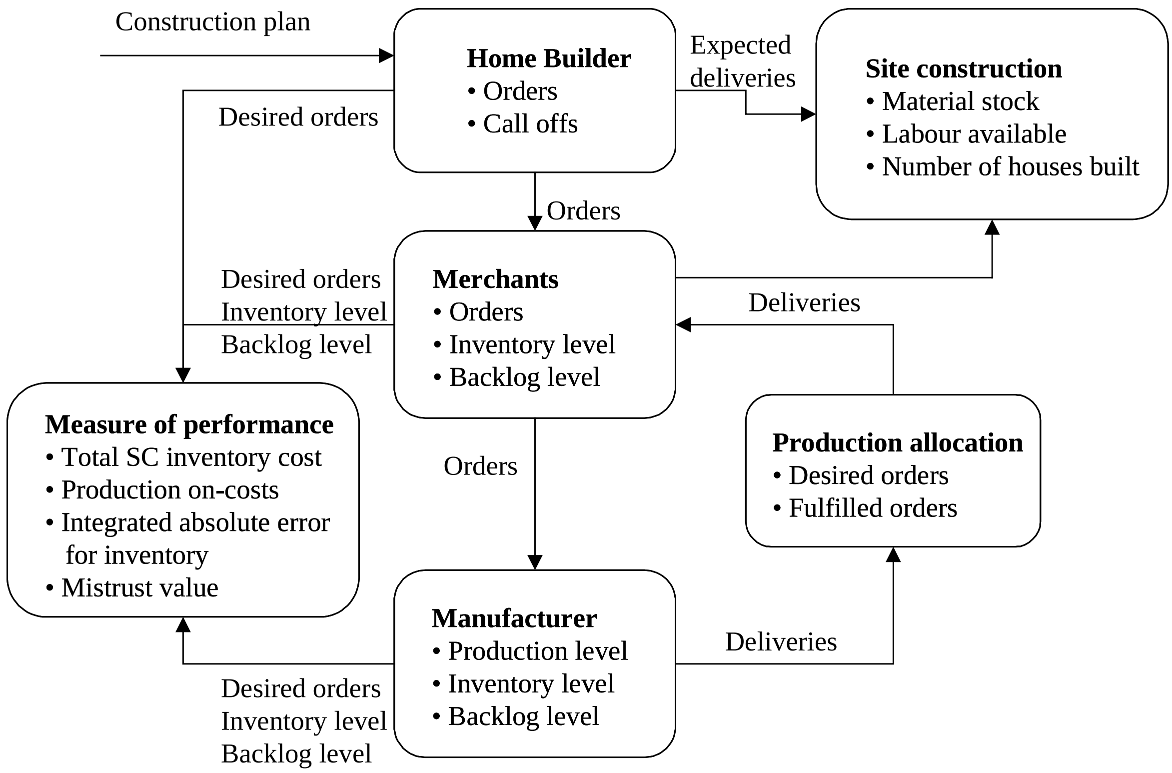

Figure 5.2 Model structure overview

Home Builder

Figure 5.3 represents the causal structure of the variables. This shows which variable influences what and how (negative or positive influence). Home Builder sub-system utilises the construction plan to generate the orders as shown in Figure 5.3. These orders after a pure time delay (which is represented by a crossed-line) become call offs. "Call off for the products" (C_p) is therefore equal to the orders (O) for houses delayed by λ_o multiplied by the product coefficient (p) (number of products needed to build one house).

$$C_{p(t)} = O_{(t-\lambda_o)} * p \quad (1)$$

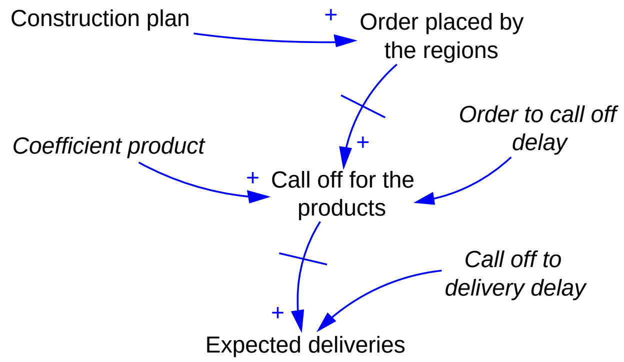

Figure 5.3 Causal structure for Home Builder

Finally expected deliveries is equal to "Call off for the products" delayed by a pure time delay of "Call off to delivery delay".

Merchants and Manufacturer

Several merchants have been modelled, however all merchants follow the same structure and are exact duplicates. Just the quantities they order are different and based on "Coefficient merchant n". Merchants and manufacturer sub-systems are similar and both based on Forrester's production and distribution system (Forrester, 1958) and an Inventory and Order Based Production Control System (IOBPCS) model (Towill, 1982). The IOBPCS model, first analysed by Coyle (1977), has been extensively studied by the Logistics Systems Dynamics Group at Cardiff University since 1982 following a framework outlined by Naim and Towill (1993) (see Ferris and Towill, 1993; John et al., 1994; Cheema, 1994; Towill et al., 1997; Lewis, 1997; Disney et al., 2000).

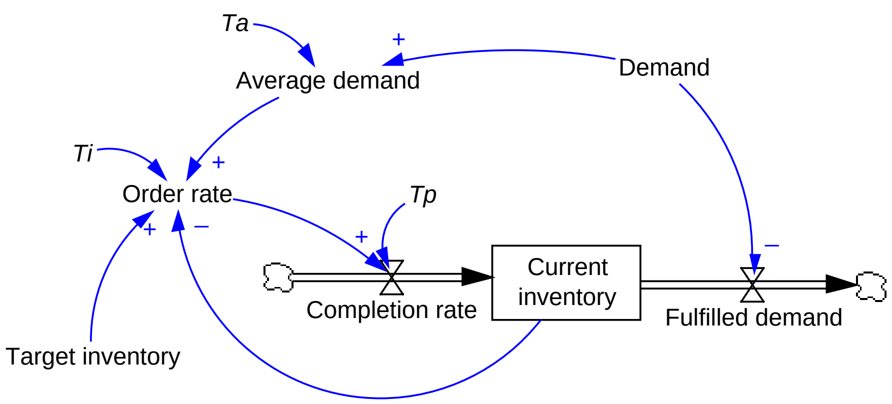

Figure 5.4 Stock and flow diagram for an IOBPCS model

Although the model is a simplified representation of the real world situation, it is held to be representative of much UK industrial practice associated with manual production control system (Coyle, 1977). Furthermore, the model includes variables that are common to a range of companies, such as production completion rate, stock levels and lead times (Berry, 1994) and it is able to replicate the dynamic behaviour of real world systems to a reasonable degree of accuracy (Edghill, 1990).

Figure 5.4 illustrates an IOBPCS model using a stock and flow representation. The IOBPCS model represents an inventory and order based production system. This means that the level of production required (order rate) is based upon the level of demand which has been averaged over a period of time T_a and the level of current inventory in comparison with a target inventory. T_i represents the time to adjust the inventory and T_p the production delay.

The order rate is a function of the stock error and the average demand. Therefore, in terms of practical implementation issues, the assumption that current finished stock levels are accurately known has to be made (Edghill, 1990). The IOBPCS model is particularly suited to demands which are fairly constant (Lewis, 1997), however to cope with higher variable demands, the target inventory level can be updated continually by making it a function of the average demand, which is the case in this work.

The IOBPCS model was used as a basis to represent merchants and manufacturer after discussions with several different managers from the companies modelled. They all declared that their ordering rule was solely based on the level of current demand and the level of stock in comparison with a target stock expressed as a function of the demand level. Only the distributor in the high-value fit-out supply chain model also declared to take into account the level of products in the pipeline. This will be discussed later in the chapter.

However a feature present in Forrester's (1958) original model and not represented in the IOBPCS was added to the IOBPCS model. Usually an IOBPCS model is linear and it is assumed that whatever is asked for will come out of the pipeline after a delay. Forrester incorporated a backlog function utilising a non-linear representation. In this case if there are no products available in stock, then the products cannot be delivered. This feature takes into account the unfilled orders or order backlog (B_t), which are equal to the previous backlog (B_{t-1}) plus new orders (incoming call off) (C_I) minus shipment (processed call off) (P_B) as can be seen from Figures 5.5 and 5.6.

$$B_t = B_{t-1} + C_I - P_B \tag{2}$$

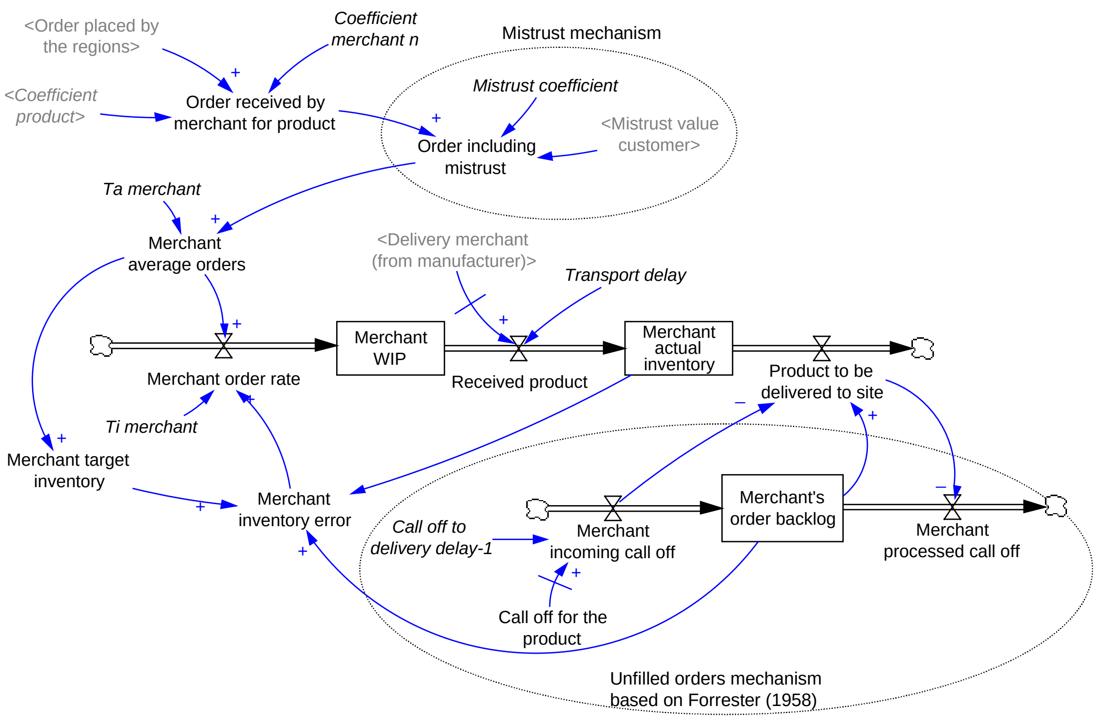

Figure 5.5 Simplified stock and flow diagram for Merchants

The equations for the ordering system are based on the IOBPCS and are as follows:

1. Average orders (A_O) equal the order including mistrust (O_m) smoothed over a period of time T_a:

$$A_{O(t)} = A_{O(t-1)} + \alpha A\left(O_{m(t)} - A_{O(t-1)}\right) \tag{3}$$

where $\alpha A = \dfrac{1}{1 + \dfrac{T_a}{\Delta t}}$

2. Order rate (R_O) is equal to the average orders (A_O) plus a fraction of any inventory errors (I_e):

$$R_{O(t)} = A_{O(t)} + \frac{I_{e(t-1)}}{T_i} \tag{4}$$

3. Completion rate (R_C) is equal to the order rate (R_O) divided by the production delay (T_p):

$$R_{C(t)} = \frac{R_O}{T_p} \tag{5}$$

4. Actual inventory (I_A) equals previous actual inventory plus the products produced (completion rate R_C) minus shipment (product to be delivered P_D):

$$I_{A(t)} = I_{A(t-1)} + R_{C(t)} - P_{D(t)} \tag{6}$$

Assuming $\Delta t = 1$

5. Inventory error (I_e) equals the target inventory (I_T) minus the actual inventory (I_A) plus the order backlog (B):

$$I_{e(t)} = I_T - I_{A(t)} + B_t \tag{7}$$

6. Target inventory (I_T) is a multiple of the average orders (A_O):

$$I_T = \beta A_O \tag{8}$$

The settings of T_a (time to average consumption), T_i (time to adjust inventory) and T_p (production delay) are based on John et al. (1994), Towill and Del Vecchio (1994), Mason-Jones et al. (1997) and Mason-Jones (1998). Several studies showed that in order to reduce demand amplification in IOBPCS models, a good setting would be $T_a = 2T_p$ and $T_i = T_p$ (John et al., 1994; Mason-Jones, 1998). However in Towill and Del Vecchio's (1994) work, it was seen that different settings could be used depending on the purpose of the model and where the company is positioned in the supply chain. Therefore the settings proposed by John et al. were used for the manufacturer and those of Towill and Del Vecchio for the merchants, i.e. $T_a = T_i = 2T_p$.

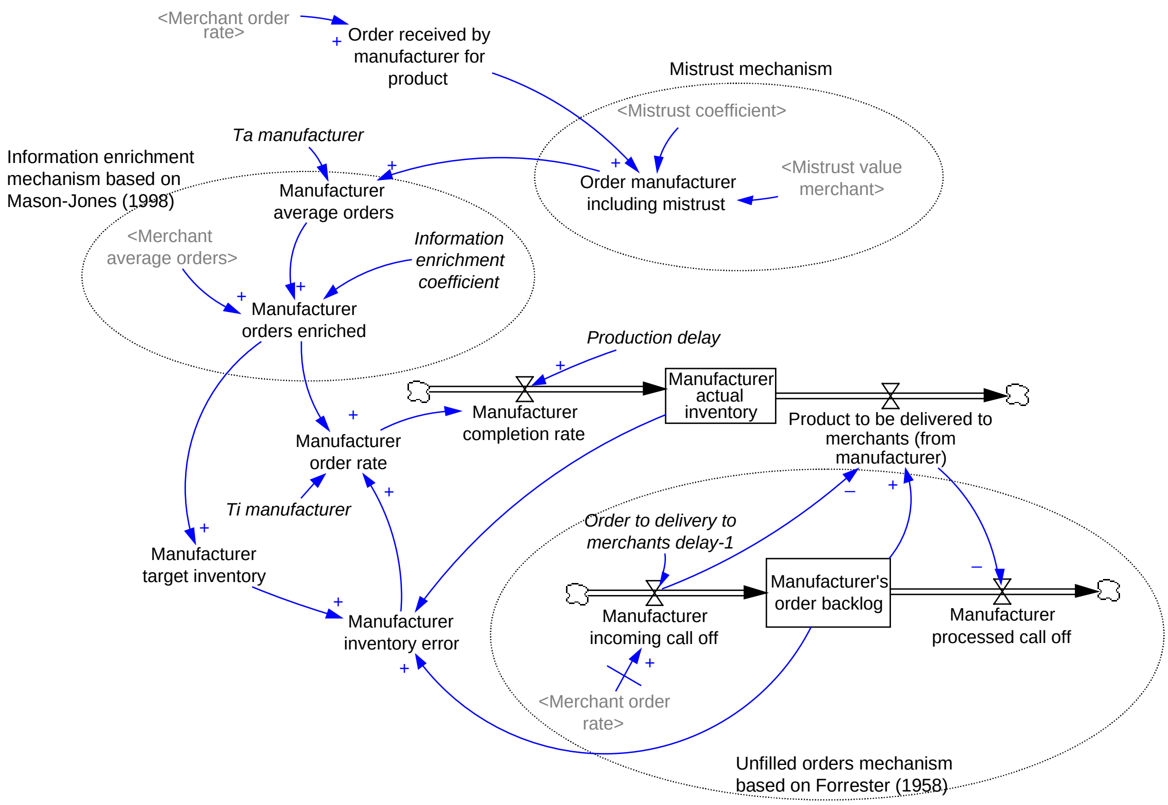

Figure 5.6 Simplified stock and flow diagram for Manufacturers

A mistrust mechanism has been included in the model as can be seen from Figures 5.5 and 5.6. The modelling of mistrust is based on real life observations during the case studies and on Sterman (2000). Mistrust is understood as being the lack of trust between trading partners. Very often this lack of trust is especially tangible when customers do not receive the full quantity of what they have ordered. Instead of trusting the supplier that he will deliver the missing products as soon as they become available, customers over-order to make sure that they will receive the real quantities they need. This principle has therefore been reflected in the model as follows: whenever the customers do not receive the full delivery of what they have ordered (O), the next order (O_m) they will place will be increased by a percentage (mistrust coefficient κ_m) of the quantity of product undelivered (mistrust value M). κ_m equals 1 when mistrust is set at 100% and 0 in the case of no mistrust. The calculation of the “mistrust value” is explained later in this chapter.

$$O_m = O * (1 + (\kappa_m M)) \tag{9}$$

An information enrichment mechanism has also been incorporated into the model and can, as easily as in the case of mistrust, be switched off. This mechanism, based on Mason-Jones’s (1998) work, has been placed at the manufacturer level and allows it to utilise the smoothed market demand (merchant average orders A_{Od}) and the smoothed customer orders (manufacturer average orders A_{Om}) to decide on a desired level of demand (manufacturer orders enriched O_E). The information enrichment coefficient (δ) in Figure 5.6 determines how much of the market demand needs to be used.

$$O_E = \delta A_{Od} + \left((1-\delta) * A_{Om}\right) \qquad (10)$$

Therefore when $\delta = 1$ (i.e. 100% information enrichment), the manufacturer is relying only on the market sales data from Home Builder to decide how many products to produce and could thus easily respond incorrectly to customer demand (merchants). If $\delta = 0.5$ (i.e. 50% information enrichment) then the manufacturer will base his decision on 50% of the market demand and 50% of its customer demand. Finally setting $\delta = 0$ switches off the information enrichment mechanism and the manufacturer relies solely on its customer demand (merchants).

Production allocation

The production allocation sub-system takes into account the overall demand (total merchant order rate) from the different merchants simulated. The rule followed for the production allocation is based on real life observations made during the case studies, where, whenever there is insufficient product available to satisfy the demands of all the merchants, the distribution of the available product will be carried out based on a priority system. Here, the priority system has been set up so as to serve the largest customers first, then the second largest and so on until there is no more product available. The customer ordering the greatest quantities is defined as the largest customer.

The priority is modelled using the “coefficient merchant” which is used to distribute Home Builder overall demand among the different merchants. Therefore if “coefficient merchant 3” is equal to 0.6, it means that Merchant 3 will receive 60% of Home Builder orders and therefore represent 60% of the orders passed on to the manufacturer.

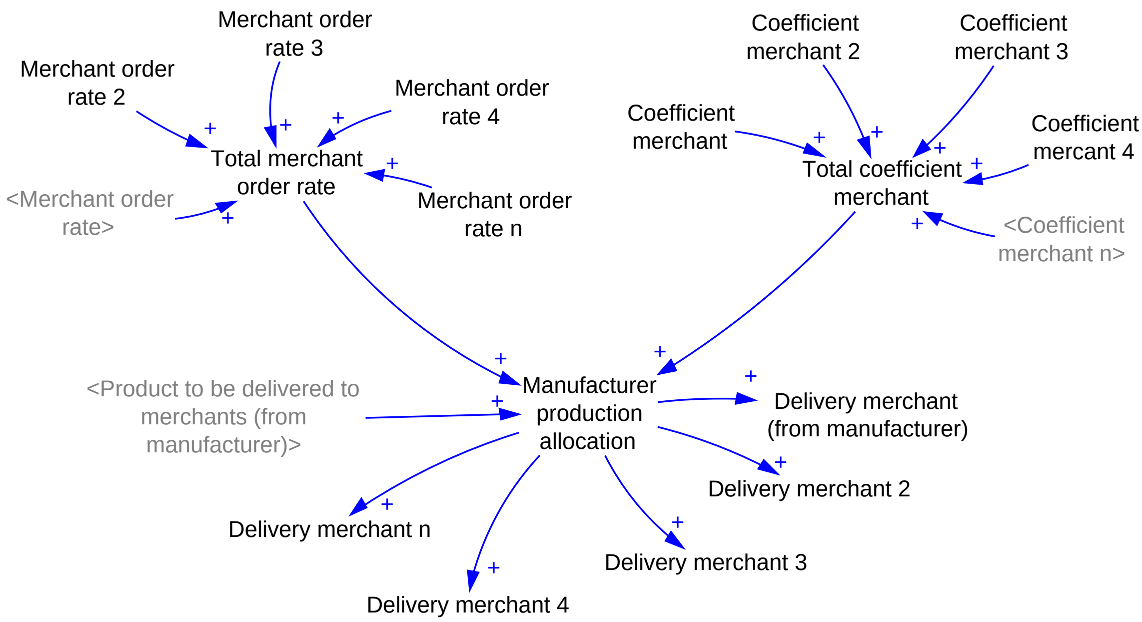

Figure 5.7 Simplified causal loop for production allocation

As can be seen from Figure 5.7, production allocation utilises the “total merchant order rate” as the overall demand, the “total coefficient merchant” to prioritise the allocation and finally “product to be delivered to merchants” as the quantity of products available for allocation. The results of the production allocation are then given in “delivery to merchant n” variables. Production allocation was calculated using ALLOCATE BY PRIORITY function available in Vensim® (see Appendix 3).

Site construction

The site construction sub-system is principally made of two components; labour and material. The demand for *labour* (L_D) is derived from the call off for the *products* (demand) (C_P). C_p is transformed into a demand for labour using both product (p) and labour coefficients (l) as can be seen from Figure 5.8 and Equation (11). For example, if the call for *products* equals 200 with a product coefficient of 2, it means that there is a demand for *house* equal to 100. Now if 3 labours are needed to build one house, then the demand for labour will be equal to 300.

$$L_D = \left(\frac{C_P}{p}\right) * l \qquad (11)$$

A backlog system similar to the unfilled orders mechanism is used to register unfulfilled demand in labour. The houses can only be constructed if there are enough labour and enough products available; in case of discrepancies, the lowest of the two variables (labour and product) dictates how many houses can be built. The remaining labour or products will then stay idle on site until more products or labour become available to finish the work. After a "construction time delay" (represented by a pure time delay) the houses become weatherproofed houses and the labour is then freed and re-injected as free labour. Therefore, it is assumed that once the labour starts working on site, it will remain on site until the houses are built, only then will it be become labour available for use.

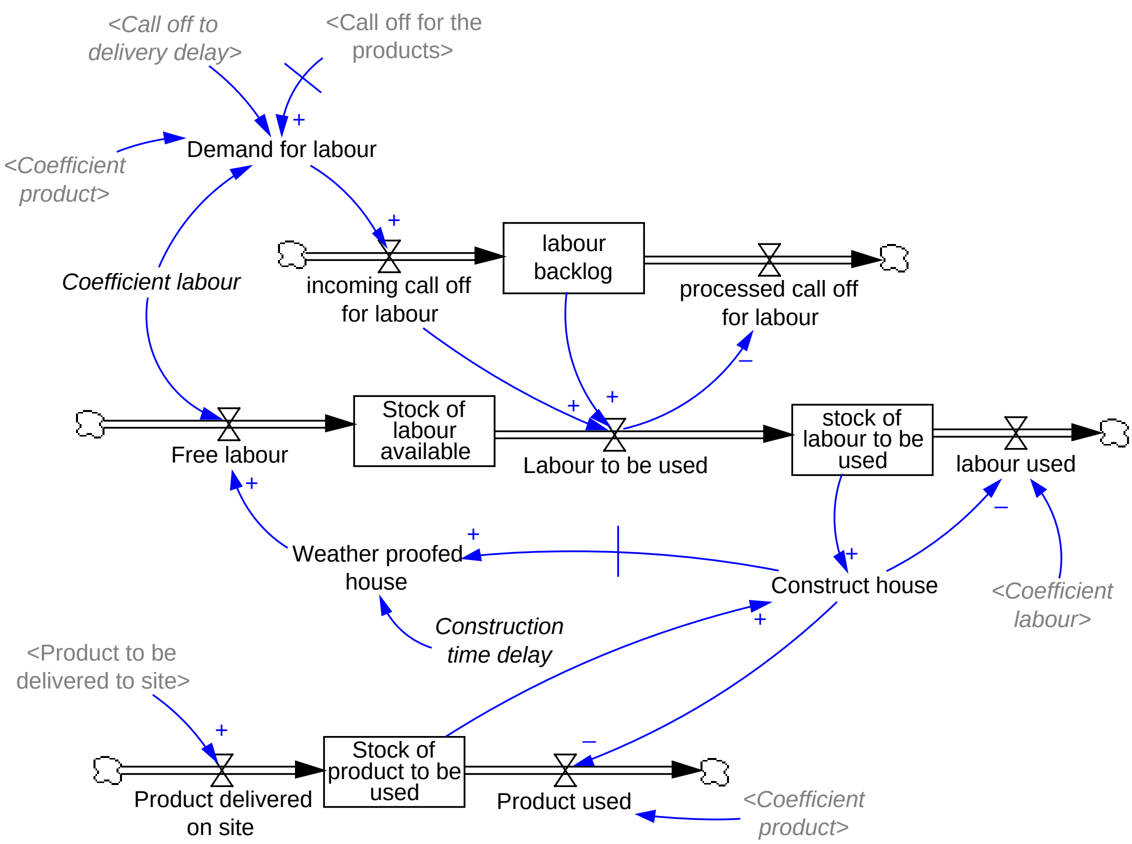

Figure 5.8 Simplified stock and flow diagram for site construction

In the case of a supply-and-fit system, the stock of product to be used on site will first be checked before calling off any labour. Therefore if there are fewer products available than the actual call off for labour, only the labour necessary for the assembly of the available products will be called off. In this case labour is only called off when there is really work to be done whereas in the previous case (labour only), labour could be called off and stay idle on site until products to be assembled became available.

Measure of performance

Several measures of performance are calculated in the model so as to assess each scenario. The performance criteria calculated directly in the model are the total inventory cost, the production on-costs, the integrated absolute error for inventory and the mistrust value.

The total supply chain inventory cost, presented in Figure 5.9, encompasses the inventory costs for the merchants and for the manufacturer. Therefore, the sub-system utilised for the merchant is used for each merchant modelled. The calculation of the inventory costs is based on the assumption that the cost for holding stock is different from the cost of being out of stock. The inventory costs (I_C) is therefore a function of the cost in stock (a), the level of stock (actual inventory I_A), the cost of stock out (b) and the level of backlog (B):

$$I_C = aI_A + bB \tag{12}$$

The inventory cost for each organisation is integrated and then summed to calculate the total supply chain inventory cost.

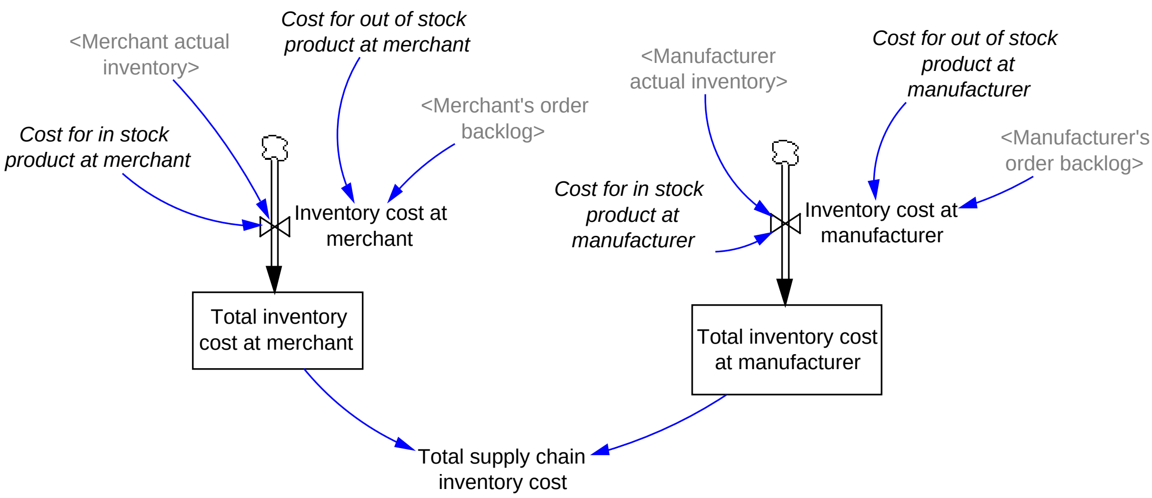

Figure 5.9 Simplified stock and flow diagram for total supply chain inventory cost

The next performance criteria are the production on-costs and the integrated absolute error (IAE) for inventory, which are calculated in a similar fashion. Both criteria accumulate the absolute error between a given behaviour and the actual behaviour. Production on-costs is concerned with the order rate at the manufacturer level. The manufacturer order rate is compared with the actual end-customer orders (the regions) and after having integrated the absolute error, the result is cubed so as to give the production on-costs (Berry, 1994). It can be seen from Figure 5.10 that the manufacturer order rate (for products) needs first to be converted into order rate for *houses* using the product coefficient.

The IAE for inventory simply uses the inventory error calculated using Equation (7) and cumulates the absolute error.

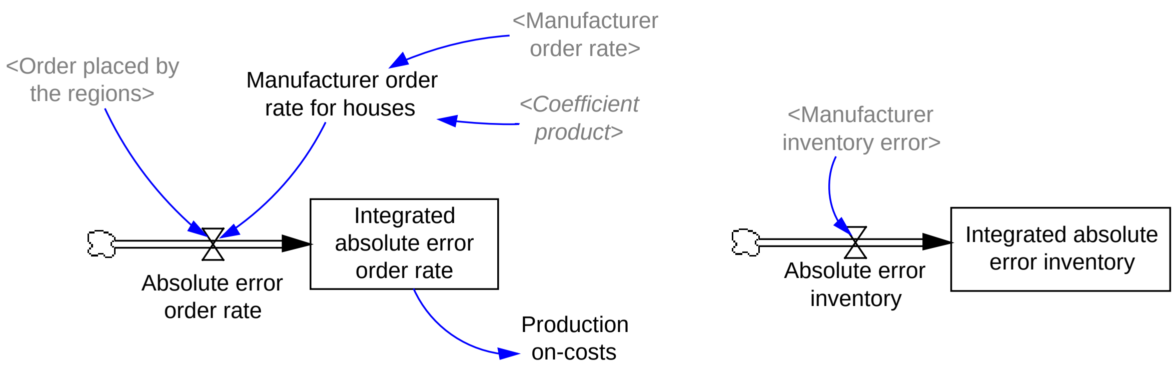

Figure 5.10 Simplified stock and flow diagram for production on-costs and integrated absolute error for inventory

Finally, the mistrust values are also calculated. There are two mistrust values, one for Home Builder at the site (customer) and one for the merchants as seen from Figure 5.11. The first one represents the percentage of products that Home Builder did not receive from the merchants while the second one considers the percentage of missing products that the merchants should have received from the manufacturer.

The expected deliveries to site are calculated from the order received by the merchant and delayed by a pure time delay (call off to delivery delay). The quantity of missing product can then be calculated by comparing the quantity of products actually delivered on site to what was expected. The percentage of the product missing can then be calculated.

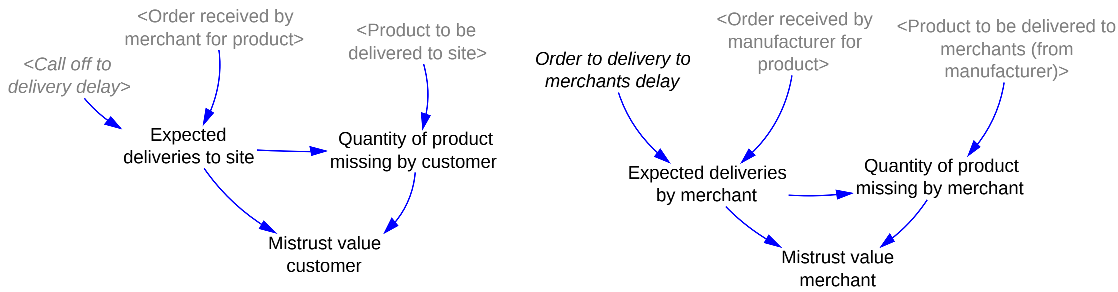

Figure 5.11 Simplified causal structure for mistrust value

5.3 Initial settings

From the generic model presented above, several scenarios have been simulated by adapting the generic model to suit the exact situation under consideration. Therefore some sub-systems have been switched off when necessary and parameters changed to suit the requirements.

However in all cases the demand pattern was kept identical. Real demand pattern for houses was unfortunately not available, however the aim of this model is to assess which scenario performs best in terms of dynamic behaviour, therefore, it was decided that a step change in demand was the most appropriate demand pattern to achieve this aim. The demand was therefore set at 100 houses with a step increase to 120 houses at time 20.

The characteristics of the different scenarios utilised in the rest of this thesis are presented below. Models have been used to simulate three different material types' supply chains: the house shell, the high-value fit-out and the low-value fit-out.

5.3.1 House shell supply chain

The house shell supply chain model utilises all the sub-systems presented above. The baseline model, named Brick and Block Baseline scenario, models Home Builder, 8 merchants, one manufacturer and the site construction. Three other scenarios are utilised: Brick and Block Improved, Timber Frame Baseline and Timber Frame Improved. Brick and Block Improved also utilises all the sub-systems, however both Timber Frame scenarios have eliminated the merchants sub-system.

Mistrust is utilised in both Brick and Block scenarios and set at 100%, while Timber Frame scenarios have switched off the mistrust sub-system. The information enrichment mechanism has been switched off for all the scenarios and finally Timber Frame Improved utilises the supply-and-fit mechanism for construction on site.

The parameters, initial values and sources for the four scenarios are listed in Table 5.1 as well as the source.

Parameters	Value for Brick and Block Baseline	Value for Brick and Block Improved	Value for Timber Frame Baseline	Value for Timber Frame Improved	Source
Home Builder					
Coefficient product	100000	100000	5	5	Judgementally set based on interviews
Order to call off delay	14 days	1 day	14 days	1 day	Set based on interviews
Call off to delivery delay	7 days	7 days	14 days	14 days	Set based on interviews
Merchants					
Coefficient Merchants	0.3; 0.05; 0.1; 0.1; 0.03; 0.2; 0.12; 0.1	0.3; 0.05; 0.1; 0.1; 0.03; 0.2; 0.12; 0.1	-	-	Judgementally set based on interviews
Mistrust coefficient	1	1	0	0	Judgementally set based on interviews
T_a merchants	14	14	-	-	Based on Towill and Del Vecchio (1994)
T_i merchants	14	14	-	-	Based on Towill and Del Vecchio (1994)
Transport delay	7	7	-	-	Set based on interviews
Merchant actual inventory	4*average orders	4*average orders	-	-	Set based on interviews
Merchant target inventory	4*average orders	4*average orders	-	-	Set based on interviews
Manufacturer					
T_a manufacturer	14	14	56	30	Based on John et al. (1994)
T_i manufacturer	7	7	28	15	Based on John et al. (1994)
Production delay	7	7	28	15	Set based on interviews
Manufacturer actual inventory	4*average orders	4*average orders	4*average orders	4*average orders	Set based on interviews
Manufacturer target inventory	4*average orders	4*average orders	4*average orders	4*average orders	Set based on interviews
Site construction					
Coefficient labour	3	3	3	3	Judgementally set based on observations
Stock of labour available	5000	5000	5000	5000	Estimated to fit
Construction time delay	63 days	35 days	7 days	7 days	Set based on interviews
Measure of performance					
Cost in stock	0.000005	0.000005	0.11	0.11	Arbitrary set
Cost stock out	0.00001	0.00001	0.22	0.22	Arbitrary set

Table 5.1 Parameters, initial values and sources for house shell scenarios

The cost for stock-out has been arbitrarily set as being twice as expensive as cost in stock. However the cost for 5 timber frames has been set at 10% more than for 100,000 bricks, this premium being based on real data collected during the case study (see Chapter 6).

5.3.2 High-value fit-out supply chain

The high-value fit-out supply chain model only utilises one merchant (here the distributor) and therefore the production allocation sub-system is unnecessary. Six scenarios have been modelled; Baseline, Phase One, Phase Two, Phase Three, Phase Four and Phase Five (see Chapter 7). Only the Baseline scenario simulates a distributor, however during discussions with managers of the manufacturer, it was declared that the distributor would not only base its production system on demand and inventory level, but also on the level of products in the pipeline. Therefore, an Automatic Pipeline feedback compensated Inventory and Order Based Production Control System (APIOBPCS) was chosen to represent the distributor.

The APIOBPCS is an improved model of IOBPCS as it adds stability to the system (John et al., 1994). The APIOBPCS has also been widely studied by LSDG at Cardiff (John et al., 1994; Lewis, 1997; Hong-Minh, 1998; Mason-Jones, 1998).

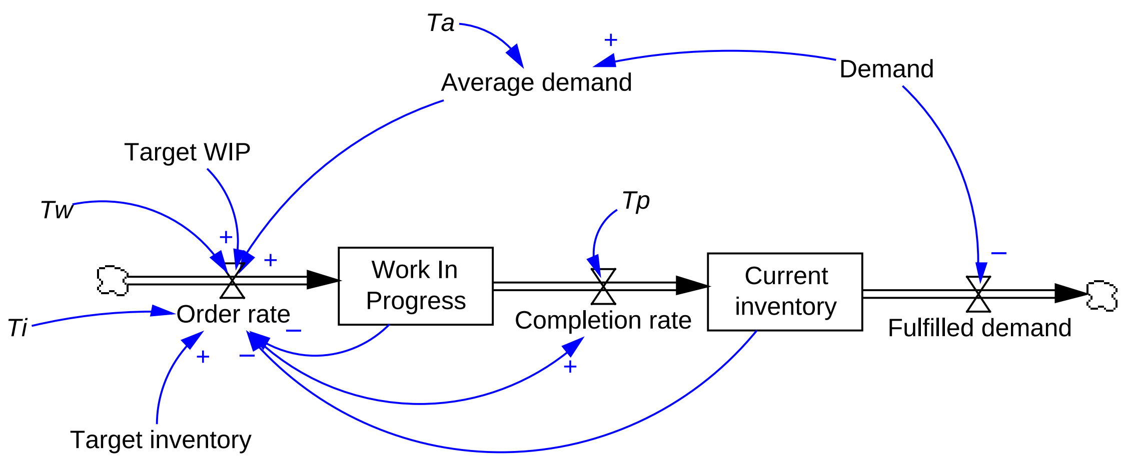

Figure 5.12 Stock and flow diagram for an APIOBPCS model

As can be seen from Figure 5.12, the APIOBPCS takes into account the WIP level to calculate the order rate. In this case order rate (R_O) is equal to the average orders (A_O) plus a fraction of any inventory errors (I_e) plus a fraction of any WIP error (W_e):

$$R_{O(t)} = A_{O(t)} + \frac{I_{e(t-1)}}{T_i} + \frac{W_{e(t-1)}}{T_w} \tag{13}$$

Both mistrust and information enrichment mechanisms have been switched off for all the scenarios. The parameter, initial value and sources are presented in Tables 5.2 and 5.3 for the high-value fit-out scenarios.

Parameters	Value for Baseline	Value for Phase one	Value for Phase two	Source
Home Builder				
Coefficient product	4	4	4	Set based on interviews
Order to call off delay	-	-	6 days	Set based on interviews
Call off to delivery delay	7 days	7 days	1 days	Set based on interviews
Merchants				
T_a merchant	4	-	-	Based on Towill and Del Vecchio (1994)
T_i merchant	2	-	-	Based on Towill and Del Vecchio (1994)
T_w merchant	2	-		Based on Towill and Del Vecchio (1994)
Transport delay	1	-	-	Set based on interviews
Merchant actual inventory	4* average orders	-	-	Set based on interviews
Merchant target inventory	4*average orders	-	-	Set based on interviews
WIP	Transport delay*average orders	-	-	Set to fit
Manufacturer				
T_a manufacturer	4	4	4	Based on John et al. (1994)
T_i manufacturer	2	2	2	Based on John et al. (1994)
Production delay	1	1	1	Set based on interviews
Manufacturer actual inventory	4*average orders	4*average orders	4*average orders	Set based on interviews
Manufacturer target inventory	4*average orders	4*average orders	4*average orders	Set based on interviews
Site construction				
Coefficient labour	1	1	1	Judgementally set based on observations
Stock of labour available	1000	1000	1000	Estimated to fit
Construction time delay	1 day	1 day	1 day	Set based on interviews
Measure of performance				
Cost in stock	0.125	0.125	0.125	Arbitrary set
Cost stock out	0.25	0.25	0.25	Arbitrary set

Table 5.2 Parameters, initial values and sources high-value fit-out Baseline, Phase One and Phase Two scenarios

Here again, the cost for stock out has been arbitrarily set as being twice as expensive as cost in stock as in the beer game (Sterman, 1989). However the cost for one ventilation system (Phase three to five) has been set at 50% more expensive than for 4 fans, this premium being based on real data collected during the case study (see Chapter 7).

Parameters	Value for Phase three	Value for Phase four	Value for Phase five	Source
Home Builder				
Coefficient product	1	1	1	Set based on interviews
Order to call off delay	1 day	5 days	1 day	Set based on interviews
Call off to delivery delay	1 day	1 day	1 days	Set based on interviews
Manufacturer				
T_a manufacturer	4	4	4	Based on John et al. (1994)
T_i manufacturer	2	2	2	Based on John et al. (1994)
Production delay	1	1	1	Set based on interviews
Manufacturer actual inventory	4*average orders	4*average orders	4*average orders	Set based on interviews
Manufacturer target inventory	4*average orders	4*average orders	4*average orders	Set based on interviews
Site construction				
Coefficient labour	1	1	1	Judgementally set based on observations
Stock of labour available	1000	1000	1000	Estimated to fit
Construction time delay	1 day	1 day	1 day	Set based on interviews
Measure of performance				
Cost in stock	0.75	0.75	0.75	Arbitrary set
Cost stock out	1.5	1.5	1.5	Arbitrary set

Table 5.3 Parameters, initial values and sources high-value fit-out Phase Three, Phase Four and Phase Five scenarios

5.3.3 Low-value fit-out supply chain

The low-value fit-out supply chain models simulate two products. The model includes eight merchants; however, as each merchant deals with both products, 16 merchants sub-systems have been utilised. In the same manner, two manufacturers have been modelled. The site sub-system is not used for the low-value fit-out supply chain models, however the mistrust and information mechanisms are.

Four scenarios are utilised for the low-value fit-out supply chain simulations and are named Baseline, Kitter, Integrated Information and Synchronised. Only Baseline utilises the 16 merchants; the other scenarios utilise only one merchant called Kitter who deals with both products. Kitter assembles packs containing the two products. The causal loop for making these packs is presented in Figure 5.13. “Making packs” variable takes into account the product coefficients for products A and B so as to ensure that the right quantities of each product are present in each pack.

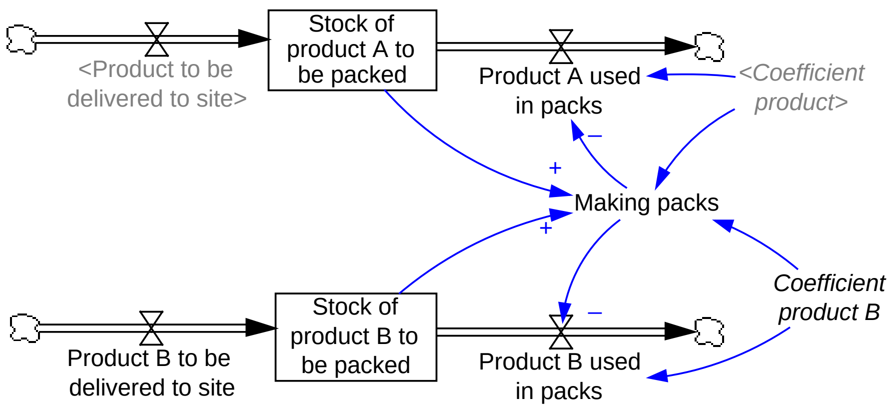

Figure 5.13 Stock and flow diagram for making packs by Kitter

The initial values, parameters and sources for the low-value fit-out scenarios are presented in Table 5.4. Cost in stock equals 0.5 and costs stock out equals 1 for two units of product A or 140 units of product B.

Parameters	Value for Baseline	Value for Kitter	Value for Integrated Information	Value for Synchronised	Source
Home Builder					
Coefficient product A/B	2/140	2/140	2/140	2/140	Judgementally set based on interviews
Order to call off delay	7 days	7 days	1 day	1 day	Set based on interviews
Call off to delivery delay	14 days	7 days	4 days	2 days	Set based on interviews
Merchants					
Coefficient Merchants A	0.3; 0.05; 0.1; 0.1; 0.03; 0.2; 0.12; 0.1	0.3; 0.05; 0.1; 0.1; 0.03; 0.2; 0.12; 0.1	-	-	Judgementally set based on interviews
Coefficient Merchants B	0.2; 0.1; 0.1; 0.12; 0.05; 0.3; 0.1; 0.03	0.2; 0.1; 0.1; 0.12; 0.05; 0.3; 0.1; 0.03	-	-	Judgementally set based on interviews
Mistrust coefficient	1	0.75	0.5	0	Judgementally set based on interviews
T_a merchants A/B	20/14	20/14	20/14	6/6	Based on Towill and Del Vecchio (1994)
T_i merchants A/B	20/14	20/14	20/14	6/6	Based on Towill and Del Vecchio (1994)
Transport delay A/B	10/7	10/7	10/7	3/3	Set based on interviews
Merchant actual inventory	4* average orders	4* average orders	4* average orders	4* average orders	Set based on interviews
Merchant target inventory	4*average orders	4*average orders	4*average orders	4*average orders	Set based on interviews
Manufacturer					
T_a manufacturer A/B	20/14	20/14	20/14	6/6	Based on John et al. (1994)
T_i manufacturer A/B	10/7	10/7	10/7	3/3	Based on John et al. (1994)
Production delay A/B	10/7	10/7	10/7	3/3	Set based on interviews
Manufacturer actual inventory	4*average orders	4*average orders	4*average orders	4*average orders	Set based on interviews
Manufacturer target inventory	4*average orders	4*average orders	4*average orders	4*average orders	Set based on interviews
Information enrichment coefficient	0	0	0.5	0.75	Judgementally set based on interviews and Mason-Jones (1998)
Measure of performance					
Cost in stock A/B	0.25/(0.5/140)	0.25/(0.5/140)	0.25/(0.5/140)	0.25/(0.5/140)	Arbitrary set
Cost stock out A/B	0.5/(1/140)	0.5/(1/140)	0.5/(1/140)	0.5/(1/140)	Arbitrary set

Table 5.4 Parameters, initial values and sources for low-value fit-out scenarios

5.4 Validation and verification

Model validation and verification are very important issues for all modellers. However, Sterman (2000) clearly states that, *"no model can ever be verified or validated"*, as by definition they are a simplified representation of the reality and therefore vary from the real world in many different ways. Forrester and Senge (1980) adds that, *"validation is the process of establishing confidence in the soundness and usefulness of a model. Validation begins as the model builder accumulates confidence that a model behaves plausibly and generates problem symptoms or modes of behavior seen in the system."* Furthermore a model can be considered as realistic *"to the extent that it can be adequately interpreted, understood, and accepted by other points of view"* (Churchman, 1973).

Solberg (1992), who promotes simple models, declares that, *"the power of a model or modelling technique is a function of validity, credibility, and generality. Usually the simplest model which expresses a valid relation will be the most powerful"*. Hence, models need, one way or another, to be validated, however there is no single test which would allow the modellers to assert that their models have been validated. Rather, the level of confidence in the model can increase gradually as the model passes more tests (Forrester and Senge, 1980).

A wide range of tests to build confidence in the model have been developed (e.g. Forrester and Senge, 1980; Barlas, 1989; Barlas, 1990; Barlas, 1996), of which Sterman (2000) presents a summary. These twelve tests are as follows:

The boundary adequacy test is concerned with the appropriateness of the model's boundary. For this test the main question to answer is if the appropriate concepts have been included in the model to address the problem. As stated previously, the aim of the model for this thesis is to compare different supply chain scenarios where a few parameters change, and assess the impact of these changes on the dynamic behaviour. The area concerned is the house building supply chain. The main players in the supply chain have been represented (i.e. Home Builder, merchants and distributor). The focus of the model is placed upon the material and information flow. Both flows have been repeatedly and successfully studied previously using a member of the IOBPCS model, also used here. Furthermore, although simplified, the model was considered as representative of the real situation by managers from the companies modelled.

The structure assessment test, as its name indicates, is concerned with the consistency of the structure of the model by verifying if the structure of the model represents the real system. As previously presented, the basis of the model uses two IOBPCS models to represent merchants and manufacturer. In addition, Coyle (1977) and Edghill (1990) asserted that the IOBPCS model was representative of the UK manufacturing practice and replicate the dynamic behaviour of real world systems to a reasonable degree of accuracy. Finally some changes have been made to the basic IOBPCS model to take into account some real life issues such as unfulfilled orders and the distinction between orders and call offs.

The dimensional consistency test examines if the units of measures used in the model are consistent. This was carried out using the dimensional consistency function available in Vensim®.

The parameter assessment test compares the model parameters to knowledge of the real system to determine if the parameters correspond conceptually and numerically to real life. The parameter values have been presented in Tables 5.1 to 5.4 and have been based, as can be seen from the Tables, principally on real data collected during interviews.

The extreme condition test analyses the behaviour of the model under extreme conditions to verify that the model behaves in a realistic fashion. In the model studied in this thesis, the extreme condition test was carried out for an extremely high demand, the stock level and the amount of labour available then dropped to zero. The number of houses completed reflected the labour capacity. However, as no manufacturing capacity restriction has been made in the model, the stock level still recovered using an extremely high production level. Manufacturing capacity restriction was not introduced into the model so as to keep it as simple as possible, and also because the purpose of the model is not to study capacity issues but broader issues of dynamic behaviour.

The integration error test verifies if the time step utilised for the simulation and the integration method are appropriate for the purpose of the model. In the present case the time step was set at one day, however in order to test the model, the time step has been cut in half, in quarter and in eights and the results compared. For the purpose of this model, the differences were marginal. The test was also carried out using a different integration method.

The behaviour reproduction test assesses the model's ability to reproduce the behaviour of the real system. This test is generally used for a model whose purpose is to reproduce very accurately the real world system by comparing simulation results and real historical data. Although this test does not apply here and the model has already been proven to be representative of a production control system (as stated in the structure assessment test), the model was presented to the companies. They all agreed that it represented their supply chain.

The behaviour anomaly test, which examines the importance of specific relationships by deleting or modifying them, was utilised during the model development process. This test helped in analysing the influence of specific variables.

The family-member test asks whether a model could be used to represent other more particular models. As stated previously, the IOBPCS used in the model is already part of a model family. Furthermore, the model was used to simulate different scenarios by "switching on or off" the relevant sub-systems and therefore the model proves to be a general one, that can be adapted to represent specific members.

The surprise behaviour test is concerned with unexpected behaviour displayed by the model. The test is passed when the behaviour does indeed occur in the real world. This was the case for the build up of stock observed at the merchants and manufacturer level. When using a normal IOBPCS model, the stock first diminishes before regaining a stable state. However in the model studied here, the stock first increases and then diminishes. This is, however, happening in the real world where companies stock up in advance of a large order.

The sensitivity analysis tests the robustness of the model. As the model is based on an IOBPCS model, sensitivity analysis have already been carried out and showed the robustness of the IOBPCS model (e.g. Edghill, 1990; Disney et al., 2000). However, a new sensitivity analysis has also been carried out for the overall model. The analysis took into consideration the three parameters influencing the ordering policy, i.e. T_a (time to average consumption), T_i (time to adjust inventory) and production delay. The analysis was carried out to study the impact of these parameters on the manufacturer order rate and the stock of products at the manufacturer level. T_a was tested for a range from 1 to 60, T_i

from 2 to 30 and production delay from 1 to 30, which is the maximum range utilised during the simulations.

Figures 5.14 and 5.15 present the results of the sensitivity analysis for the production delay. The other sensitivity analysis graphs for T_i and T_a can be found in Appendix 4. The sensitivity analysis showed that in all cases, a stable state is reached and that it is not sensitive to changes in parameters values. Therefore the model can be considered as being robust.

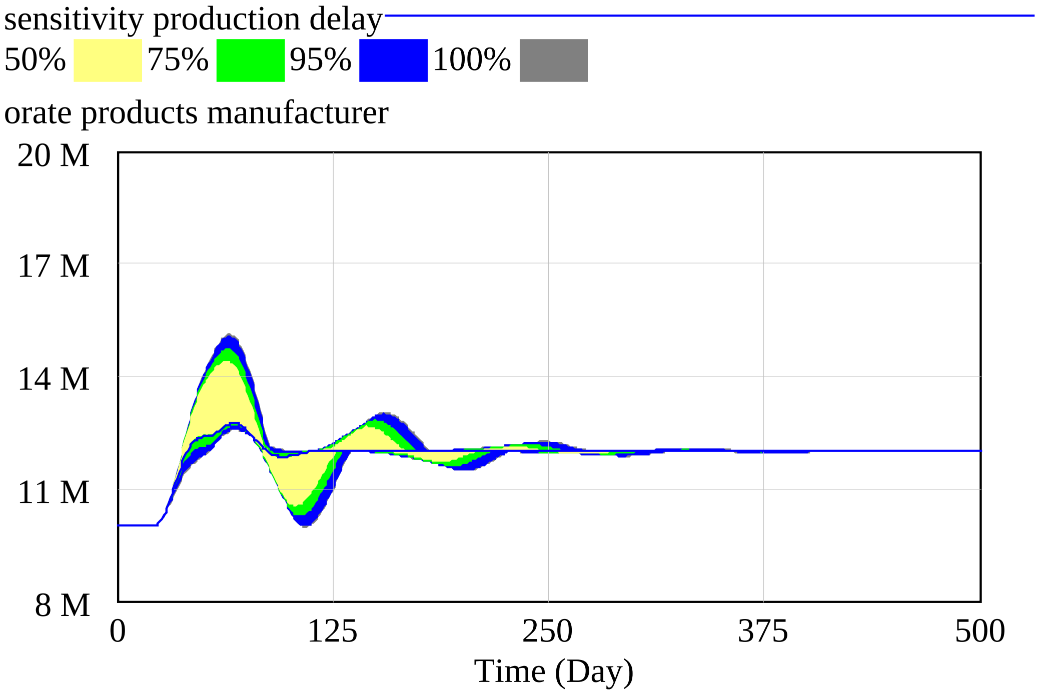

Figure 5.14 Sensitivity analysis for production delay (1 to 30) on the manufacturer's inventory level

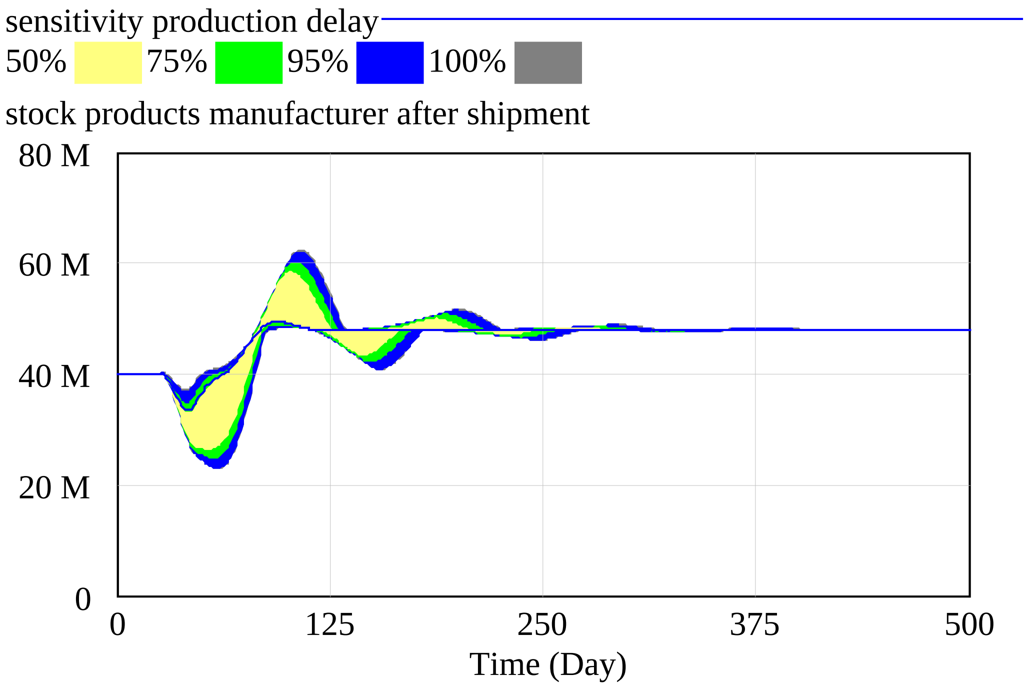

Figure 5.15 Sensitivity analysis for production delay (1 to 30) on the manufacturer's order rate

The system improvement test is concerned with the implementation of policies that improved the model. The real test lies in the successful implementation of these policies and the resulting real improvements in the real world. Unfortunately, the use of models in this thesis has been dictated by the impracticability of implementing the policies studied in the time frame available, so the system improvement test could not be carried out.

Therefore, after having undergone the twelve tests for model validation, the model studied in this thesis can be used with confidence in terms of its validity, credibility and generality.

5.5 Conclusion

It has been seen that the development of a dynamic model is not a linear process and needs to start from simple to incorporate more complexity step by step. The model used in this thesis is based on two IOBPCS models to represent Home Builder and merchants. Other features such as unfulfilled orders, information enrichment, and mistrust were then developed and implemented. The description of the different sub-systems defined the relationships of the different variables used in the model and the initial values for parameters were given together with their sources. Finally, several tests to build confidence in the model were reviewed and showed that the model can be used with confidence as it represents the main characteristics of the real system and is appropriate for the purpose of the model. This model will be presented in more detail in Chapters 6, 7 and 8 relating it to the real situation at hand, and the results of the simulations will also be presented and analysed.

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Chapter 6 The house shell supply chain

Research questions

- Which SCM principles can be applied to the house shell's supply chain?
- How do these principles impact on the performance of the house shell's supply chain?

6.1 Introduction

The current situation of the private house building industry in the UK has been reviewed by highlighting the problems related to SCM issues in Chapter 4. The literature review on SCM clearly defined what were the basic SCM principles and the benefits that could be expected from them. However the main question of this thesis remains: "Can SCM principles improve the UK private house building industry performance?". To answer this research question, it is necessary to answer a sub-set of questions. The first research question is concerned in identifying which supply chain principles can be implemented. The second research question asks how these principles impact on the performance. As seen in Chapter 3, the main components to the construction of houses can be categorised under the house shell, the high-value fit-out and the low-value fit-out. This chapter is concerned with the first category, i.e. the house shell.

All the data presented in this chapter, if not referenced otherwise, is issued from the task forces and case studies carried out as introduced in Chapter 3. The performance is assessed using the SCM, private house building industry and system dynamics KPIs as proposed in Chapters 2 and 4. Finally, the implementation of SCM principles, that were outlined in Chapter 2, in the house shell's supply chain is analysed.

This chapter will focus on answering the research question listed above. It will be shown that a change of technology is required to improve the performance of the shell's supply chain. Some SCM principles such as shortening the supply chain, strategic partnering or vertical integration and centralisation of supply can be promoted by a change of technology. In addition, further SCM principles (end-user focus and integrated information flow) can also be implemented in the shell's supply chain. Finally all these SCM principles can improve the performance of the shell's supply chain by shortening the total response time, reducing the direct construction costs and the supply chain inventory costs and promoting flexibility in construction.

The first section of this chapter will consider the current situation of the house shell's supply chain for brick and block. The implementation of SCM principles will then be taken into consideration and their impact on performance analysed. Alternatives to brick and block construction will then be considered to improve the performance of the shell's supply chain. After an overview of different framing systems, the impact on performance of some SCM principles necessary for framing system's supply chain will be analysed. Other SCM principles will then be considered to further improve the performance of the shell's supply chain. Finally, four scenarios (current brick and block, re-engineered brick and block, current frame and re-engineered frame supply chains) will be modelled and simulated so as to analyse the dynamic performance of each scenario.

6.1 Re-engineering the current house shell's supply chain

This section aims, firstly, to give an account of the current situation for house shell's supply chain. Then the performance of brick and block construction supply chain is summarised. This is then followed by a supply chain re-engineering of the traditional house shell's supply chain by considering, in turn, some SCM principles. Finally, the impact on performance is analysed.

6.1.1 Current situation

Traditionally in the UK, houses have been built using brick and block as shown in Figure 6.1. One of the main problems with this type of construction lies in the fact that brick work is on the critical path. This means that most of the rest of the work in dwellings cannot start before the houses are weather proof. Furthermore as this work is to be carried out on-site, it is weather dependent and therefore the construction lead-time can vary by up to 15% (Home Builder, 2000). This has repercussions on the completion date because, as it increases uncertainties, it is then difficult to determine a fixed completion date.

Figure 6.1 Example of a brick and block construction (Source: Matrix 1, 2001)

It can also be argued that traditional masonry construction does not meet customer requirements as customers aspire to a specific fixed completion date when buying a new house and not, as it is currently the case, a one-month time window (as seen in Chapter 4). Customers also want to have some choices over the layout of the rooms and other internal choices such as floor finishes and storage space (Barlow and Ozaki, 2000). Using traditional masonry construction restricts that choice, as it does not facilitate an open plan approach. This means that choice of layout needs to be taken at a very early stage in the construction, during the design process, if it is to be achievable. Therefore customer satisfaction is low (Barlow and Ozaki, 2000).

The construction costs for masonry construction is on average £37 per square feet as illustrated in Table 6.1.

	2 bed terraced	4 bed detached	5 bed detached	Average build cost per sq.ft.
Traditional masonry	£4348	£7283	£12699	£37

Table 6.1 Typical direct costs (including labour cost) for masonry construction (Source: Internal report from Home Builder)

From a supply chain point of view, when using masonry construction, bricks and blocks are procured from a local merchant. This is justified by the fact that the bricks used need to reflect regional taste and as the goods can be classified as heavy and low-value (commodity type of goods), transporting them over a long distance across the UK will probably not have any financial benefit. Usually local merchants then replenish their stock from brick manufacturers as shown in Figure 6.2.

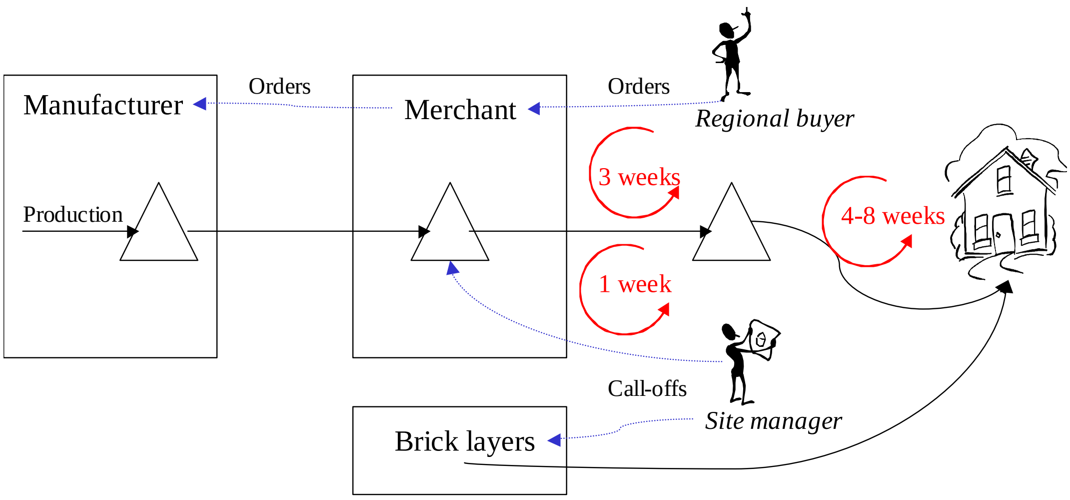


Figure 6.2 A typical brick and block supply chain

In the case of such a supply chain, the lead-times are typically as follows: the cycle time from the first order being placed by the regional buyer at the merchant to the first possible delivery on-site is on average three weeks (total order cycle time). Then the site manager will call-off the bricks as required. Here the lead-time is typically one week. This one-week lead-time can be easily achieved as merchants hold a large amount of stock which enables them to deliver from stock. Typically, bricks will remain unused for an average of a week on site. Finally, to build the superstructure of a house, the site manager will call-off brick layers who will take between 4 to 8 weeks depending upon weather conditions, the size of the house and the availability of labour. At this stage, houses are still not weather proof and another week is needed to assemble the roof trusses and tile the roof. Only then, can the internal fitting of the house start.

Table 6.2 summarises the performance appraisal for masonry construction based on the SCM and the private house building KPIs as defined in Chapters 2 and 4. The performance was assessed by Home Builder managers and documentation was utilised for lead-times appraisal. In Table 6.2 "N/A" stands for not available, however these data will be evaluated later in this chapter using simulation results.

	KPIs	Brick and Block Baseline
SCM KPIs	Stock levels/Safety stock	N/A
	Total response time	8-12 weeks
	Total order cycle time	3 weeks
	Inventory costs	N/A
House building industry KPIs	Customer satisfaction (product and service)	Medium (developer) Low (customer)
	Product quality / defects	Medium
	Predictability costs	Medium
	Predictability time	Low
	Construction time	5-9 weeks
	Construction costs	£37 per sq.ft.
	Profitability	N/A

Table 6.2 Summary of traditional masonry performance

6.1.2 Re-engineering the traditional house shell's supply chain

Taking the traditional supply chain for bricks and blocks as described above, opportunities to improve performance can now be studied. Looking at the key enablers for successful management, the potential impact on performance can be appraised.

As stated previously, brick and block are "commodity" goods, which means that they can be procured from a large number of suppliers. Therefore, suppliers of brick and block (merchants) cannot be considered as key suppliers as they can easily be replaced (Agapiou et al., 1998b; Anon, 1998). SCM promotes improved relationships through partnering and better communication using electronic links (e.g. Davies, 1995; Sabath, 1995; Bowersox and Closs, 1996), however this is only useful for key suppliers who provide expensive materials or when the number of suppliers for such products is limited. Therefore in the context of brick and block supply, these principles are of little value.

Another SCM principle considers reducing the supplier base and centralises the procurement function (e.g. Jones, 1990; Bowersox and Closs, 1996; Tan et al., 1998). As seen previously, the supply of bricks needs to be localised as bricks reflect regional taste. Blocks could be purchased from one central location but as these are low-value and heavy goods, local supply is more appropriate (Fowkes et al., 1989).

Finally, SCM promotes the reduction of total cycle time (e.g. Sabath, 1995; Tan et al., 1998; Handfield and Nichols, 1999). Total order cycle time is currently 3 weeks, however it has been seen on some sites that it can be reduced to 1 week if necessary (Home Builder, 2000). What is really critical in the case of the house building industry, is the total response time (from order to assembled product on-site) so that as soon as the house is weather proof, the rest of the work may be carried out. The total response time is, as seen previously, 8 to 12 weeks. The only time compression that can be achieved is through the ordering cycle time (see above), reducing the total response time to 6 to 10 weeks, as the construction time cannot be further compressed (Home Builder, 2000).

The performance of this improved Brick and Block supply chain is presented in Table 6.3.

	KPIs	Brick and Block Improved	% Change
SCM KPIs	Stock levels/Safety stock	N/A	-
	Total response time	6-10 weeks	-17% to -25%
	Total order cycle time	1 weeks	-67%
	Inventory costs	N/A	-
House building industry KPIs	Customer satisfaction (product and service)	Medium (developer) Low (customer)	- -
	Product quality / defects	Medium	-
	Predictability costs	Medium	-
	Predictability time	Low	-
	Construction time	5-9 weeks	0%
	Construction costs	£37 per sq.ft.	0%
	Profitability	Baseline	0%

Table 6.3 Summary of improved Brick and Block construction performance and percentage of change in comparison with Brick and Block Baseline

6.1.3 Summary

The current situation for the procurement and assembly of house shell has been studied throughout this section. Several SCM principles have been considered in turn, however due to the type of products considered, only the reduction of cycle times can be applied. Therefore, the improvements that can be made to this inherited supply chain, developed over the years, appears to be very limited.

If this part of the house building's supply chain is to be improved, a new approach needs to be considered. This approach needs to create a step change in the way the supply chain is managed. A new construction method needs to be considered to move away from on-site construction to assembly of components on-site as suggested by Ball (1996). This change of technology could then promote the need for supply chain re-engineering for house shells. This change of technology was also advocated by Barlow's (1999) study as a potential driver for change towards supply chain partnership.

6.2 Supply chain re-engineering through technological change

This section will first review the possible alternatives to masonry construction by briefly presenting some framing systems available to build house shell and then summarising the main advantages for each technique. This is followed by a review of the impact of the compulsory supply chain changes to the performance of the shell's supply chain. Finally, the implementation of further SCM principles is considered and their impact on performance is analysed.

6.2.1 Alternative to traditional masonry construction

This section will review some possible alternatives to masonry construction such as steel frame and timber fame systems, which only require on-site assembly of factory produced components.

6.2.1.1 Large panel timber frame

Timber frame has been around for many years. However, during the past few years its use has started to spread more widely across the UK. For example, Home Builder has built 40% of its houses using timber frame in 2000 and is aiming at 65% for 2001. As its name indicates, timber frame is a method of construction that uses a timber framework as its basic means of structural support. This framework (see Figure 6.3) is strengthened with plywood or other sheet material, which provides stiffness to withstand lateral loads. This structural frame is then usually covered on the inside by plasterboard and filled with non-combustible insulating material. The frame includes outer walls, partition walls, flooring and roofing structure. Typically one to two house frames can fit on one 40 foot articulated lorry.

Figure 6.3 Example of a timber frame construction (Source: Joseph Rowntree Foundation and SPRU, 2001)

Based on the task forces' results, technical brochures and Matrix 1 (2001), the main advantages of timber frame construction can be summarised as follows:

- Speed of construction, estimated 9 weeks, giving early access for trades (brickwork not on critical path)
- Less physical waste on-site
- Opportunity for pre-fitted services
- Energy efficient, the SAP ratings can be improved by up to 6 points or 7%, which represents a saving in fuel bills of up to £32 per annum for an average bill
- Reduce defects via factory quality components
- Reduced number of deliveries to site
- Reduced skilled labour
- Reduced weather dependency
- Environmentally friendly by using timber from sustainable sources
- Increase predictability of construction time and therefore of completion date
- Increases opportunities for late configuration and choice of layout as most internal partition walls are not load bearing walls and therefore give an open plan approach.

Timber frame panels are considered as small panels for lengths of up to 5 metres and large panels above 5 metres. The important difference between small and large panels lies in the fact that small timber frame panels do not require the need for a crane. Therefore, all the advantages listed above for large timber frame panels also hold for small ones.

6.2.1.2 Stick built steel frame

Stick built steel frame as opposed to panel built is made of individual members which are bolted together on-site. The frame includes external walls (structure), partition walls, floor and roof trusses (although timber trusses can be used if required) (Figure 6.4). The frame is surrounded by foil faced, phenolic insulation, which acts as a vapour barrier as well as a thermal break. The advantages of stick built steel fame can be summarised as (Joseph Rowntree Foundation and SPRU, 2001):

- Quality control, factory produced
- Superior insulation
- Less maintenance
- Increased floor spans
- Pre-punched service runs
- Enhanced thermal and acoustic performance, similar to timber frame but better than masonry
- Reduce labour size
- Recyclable
- Speed of construction
- Reduced skilled labour
- Less physical waste on-site

Figure 6.4 Example of a stick built steel construction (Source: Joseph Rowntree Foundation and SPRU, 2001)

6.2.1.3 Light steel frame

Another alternative to brick and block construction is a light steel framing system as illustrated in Figure.6.5. Such a system provides the internal framework of the building to which the plasterboard, floorboards, insulation, and external cladding are attached. The steel usually used is cold-rolled sections that are galvanised and connected together either by rivets or by crimping. The roof is usually part of the steel structure. The benefits of light steel frame can be summarised as follows (Joseph Rowntree Foundation and SPRU, 2001; Matrix 1, 2001):

- Reduced physical waste on-site
- Quicker construction times on-site, estimated 9 weeks (equivalent in speed to timber frame) giving early access for trades (brickwork not on critical path)
- Reduced defects via factory quality components
- No shrinkage
- Enhance thermal and acoustic performance, similar to timber frame but better than masonry
- Reduced number of deliveries to site
- Reduced skilled labour
- Reduced weather dependency
- Increased predictability of construction time and therefore of completion date

- Increases opportunities for late configuration and choice of layout as most internal partition walls will not be load bearing walls

Figure.6.5 Example of light steel framing system (Source: Matrix 1, 2001)

6.2.1.4 Summary

Several different framing systems can be used as alternatives to traditional brick and block construction. There are many common advantages in using framing systems and these are summarised as follows:

- Speed of construction, all the different types of framing systems studied should achieve a quicker construction time than traditional masonry. This also takes brick work off the critical path.
- Increased quality of finish, as it is factory produced
- Superior insulation
- Reduced skilled labour
- Less wastage, the generally accepted figure for waste of brick and block is 10%. Furthermore, on Pegasus Court demonstration-site, it has been identified that 37.9% of the total cost of waste during the construction phase was due to brick waste, and 22.1% due to blocks (Biffaward and Willmott Dixon, 1999).
- Increases predictability of construction time and therefore of completion date
- Increases opportunities for late configuration and choice of layout

However these potential advantages are balanced with the increase in direct costs (labour and material costs) for the supply and assembly of such framing systems. As Table 6.4 shows, light steel frames are the most expensive while small panel timber frames only cost 5% more than traditional masonry.

	2 bed terraced	4 bed detached	5 bed detached	Average build cost per sq.ft.	Extra over Trad.
Traditional	£4348	£7283	£12699	£37	0%
Large timber panel	£5085	£8518	£14852	£41	11%
Small timber panel	£4577	£7666	£13367	£39	5%
Stick built steel frame	£5080	£9125	£15024	£41	11%
Light steel frame	£5334	£9581	£15775	£43	16%

Table 6.4 Comparison of direct costs for alternatives to masonry construction (Source: Internal report from Home Builder)

A SWOT analysis was utilised during the task force to analysis the differences between brick and block and timber frame construction. The task force considered both brick and block and timber frame construction, in order to assess the potential of a framing system to overcome the problems encounters with brick and block construction (see Section 6.1.1). The results of the SWOT analysis are presented in Table 6.5. As can be seen, the main strengths that can be further studied are the shortened construction lead times, the control over the production process and the decreased reliance on skilled construction sub-contractors. However the main weaknesses that need to be born in mind lie in the increase of direct costs, the increased importance of the timber frame drawings and the decreased control due to increased sub-contracting. The opportunities that will be considered in the rest of this section are mainly the facilitation to build to order and the increase of customization. The threats that will be dealt with are the supplier capacity issues, and the reliance of Home Builder on Timshell (the timber frame manufacturer).

STRENGTHS	WEAKNESSES
Shorter construction lead time	Site managers require additional training
Early weather proofing – Can work inside and outside on parallel	In the case of a major problem, it is very expensive to put right
Greater energy efficiency for maintenance – SAP rating 7% increase	Cost 10% more than traditional building in terms of direct costs
Factory produced, thus increased quality (less cracks, dry quicker)	Need careful planning and organisation on-site to gain full benefits (i.e. crane usage)
Predictability of construction (e.g. any weather construction)	Initial drawing costs increase as they are modified into timber frame drawings
Control over production process	Decreased control due to increased sub-contracting
Improve cash flow, faster return on investment	
Reduced overhead costs	
Decreased reliance on skilled construction sub-contractors	
Decreased on-site waste	
OPPORTUNITIES	**THREATS**
Increases opportunities for late configuration even when framework complete	Perception of unsound method of construction (structural stability, fire weakness)
Warranty issues passed to timber frame manufacturer	Greater potential for injuries and harm during assembly process
Increased predictability of completion date	Supplier capacity issues due to increasing demand. Home Builder need to provide long term forecast for demand
Facilitates build to order (with shorter lead times)	Customers could perceive it as bad quality, not as good/solid as bricks and blocks
Could increase customization and give near bespoke design due to open plan	Reliant/dependant on the timber frame supplier for quality, delivery, availability, etc. Would need very good relationship with suppliers.
Longer-term manufacturing cost reductions due to economies of scale and increased process efficiencies	New framing system (even better) could emerge
	Home Builder quality reputation is reliant on timber frame manufacturer

Table 6.5 SWOT Analysis for Timber Frame Construction in Comparison with traditional construction method

As seen previously, most of the advantages for using framing systems are similar from one type of frame to another. Furthermore, large timber frame panels are already the most widely used in the UK and only incur an increase in direct costs of 11%. Finally Home Builder was interested in timber frame potential. Therefore the large timber frame construction was chosen for further study in the rest of this section which highlights the implications of using a framing system on supply chain and house building performance.

6.2.2 Essential supply chain re-engineering

When using a framing system instead of masonry construction, some principles for successful SCM are implemented. This section will look at these principles and summarise their impact on supply chain and house building performance.

6.2.2.1 Supply chain structure for timber frame construction

Using a framing system instead of masonry construction dramatically transforms the structure of the supply chain as can be seen from Figure 6.6. First of all, the developer (Home Builder), via the regional buyer and the site manager, is dealing directly with the frame manufacturer (Timshell), which removes the need for merchants. In the case of timber frame, the products delivered are not standard commodity products any more but bespoke frames manufactured to order. This means that the ordering lead-times are longer, as the manufacturers do not deliver from stock.

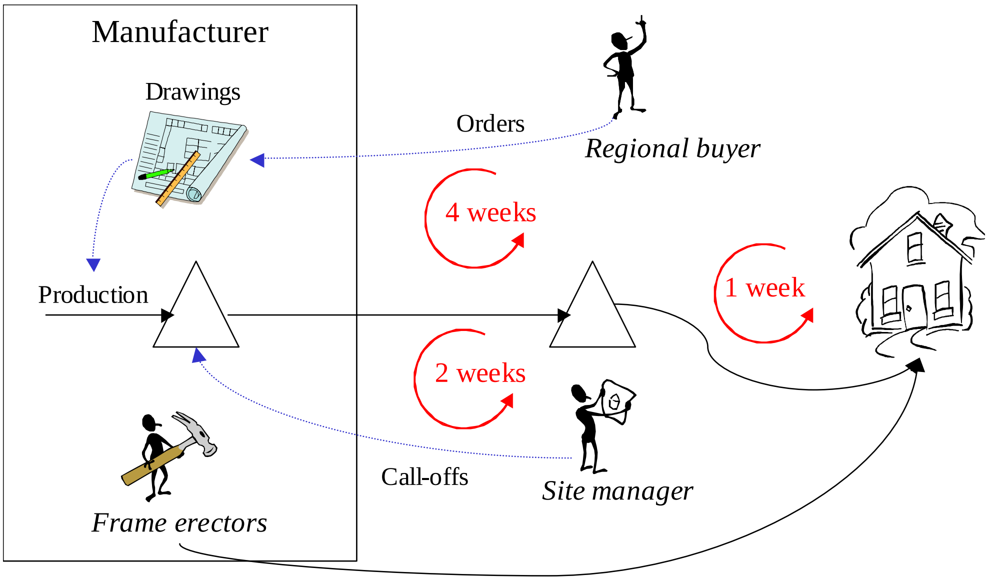


Figure 6.6 Typical timber frame supply chain

When the regional buyer places a firm order with Timshell, specific drawings have to be prepared before production can start. If the house type required has never been produced before, new drawings need to be developed. Timshell requires, on average, 2 weeks to produce the new drawings, although the real value adding time is only 5 days per house (Timshell, 2000). However as seen in Chapter 4 the private house building industry has the advantage to build repeatedly a set of house types. In this case, drawings are already available and therefore it is possible to cut out 2 weeks lead-time. However, a few minor changes in the drawings are sometimes required to suit regional taste and this would generally require 2 days to be completed (Home Builder, 2000).

Timshell will then manufacture the bespoke panels and require, on average, 2 weeks to schedule and produce them. In terms of value adding time, it usually takes only 1 day to produce all the panels for one house (Timshell, 2000).

In other words, on average, the lead-time from order to delivery (total order cycle time) will be 4 weeks, but only 6 days in terms of value adding time for a new house type.

As for all the material to be delivered on-site, first a firm order is placed with Timshell and then site managers call-off the products as and when required. In the case of timber frame, this lead-time will be 2 weeks to allow Timshell to schedule, produce and deliver the panels (Timshell, 2000).

The assembling process of the panels is, however, very rapid as it takes just over 1 week (exactly 8 days) to build a weather proofed house (data gathered during the task force). This can be broken down as follows: 2 days to erect scaffoldings, 1 day to fit wooden base surround, on which the panels will be fixed, 3 days to assemble the frame, floor, roof and partition walls and 2 days to felt, batten and tile the roof. Here again the value adding times are quite different from the number mentioned above as it only takes 1 day for scaffoldings, a few hours to fit the wooden surround, 1 day to assemble the frame, floor and roof, 2 to 3 hours for the partition walls and 1 day for the roof, which brings it to three and half days, as can been seen from Figure 6.7.

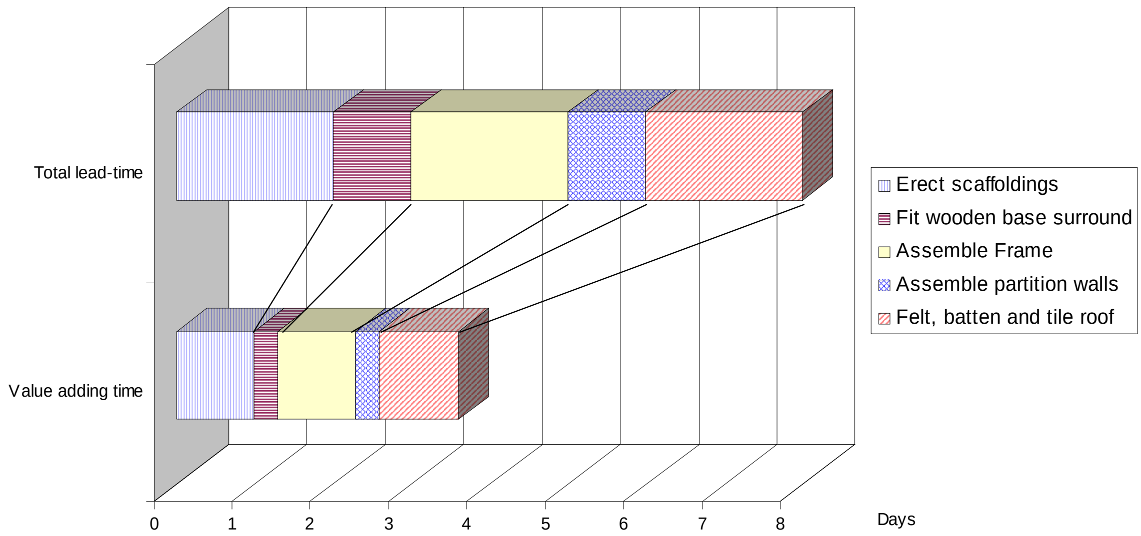


Figure 6.7 Total lead-time and value adding time comparison for the erection of a house using timber frames

In summary, the order cycle time for timber frame is 4 weeks while the total response time is 5 weeks. In other words, timber frame construction requires a long planning period up front which then allows a rapid assembly time on-site. This long lead-time up front has also been identified by Agiapiou et al. (1998a) as having a positive impact on supply chain performance.

As mentioned above, building dwellings using timber frame can reduce build-time from an average of 14 weeks to an average of 9 weeks. This can have a dramatic effect on return on investment as illustrated in Table 6.6.

Typical 30 unit site – Cash flow appraisal					
	QTR1	**QTR2**	**QTR3**	**QTR4**	**QTR5**
Traditional					
Number of houses built	-	-	13	13	4
Number of houses sold	-	-	8	13	9
Timber Frame					
Number of houses built	-	3	14	13	0
Number of houses sold	-	-	10	18	2

Key Data	**Timber Frame**	**Traditional Build**
Build cost (£/sq.ft.)	42	37
Unit size (sq.ft.)	1183	1183
Total build cost (£)	49,686	43,771
Land cost	50,000	50,000
Overhead	5%	7%
	Timber Frame	**Traditional Build**
Gross profit	+11%	Baseline
Net profit	+22%	Baseline
Return on capital	**+39%**	**Baseline**

Table 6.6 Financial appraisal – Comparison between traditional and timber frame construction (Source: Internal report from Home Builder)

Table 6.6 is a typical example for cash flow appraisal (the data being obtained during the task force), and although timber frame construction has a higher build cost than traditional built (including material and labour), the return on capital is expected to be 39% higher with an increase by 22% in net profit in comparison with traditional masonry (as 3 units can be completed in the second quarter and most dwellings will be sold during the third and fourth quarter). The difference in overhead costs, which are administrative costs, can be explained by two facts. First, these costs are partly calculated as a fixed amount for which the percentage is then derived. Therefore, the difference is not of 2 points but only one point (equivalent to £500). This difference is then explained by the fact that when timber frame construction is used, less labour is needed on site.

6.2.2.2 Strategic sourcing/partnering and vertical integration

The main threats of moving towards framing systems for the house shell construction come from the fact that the developer becomes reliant on the manufacturer in terms of quality, delivery and availability. Furthermore, timber frame represents, on average, 21% of the total build costs for a house and is therefore a crucial part of the construction process. In addition, the timber panels required to build a house are bespoke and can only be provided by a restricted number of suppliers in the UK (there are 56 manufacturers across the UK).

Therefore the frame manufacturer becomes a key supplier in contrast with merchants, which can be found anywhere in the country and are able to supply standard bricks and blocks. Strategic partnering/sourcing or vertical integration becomes then a very important concept. As Williamson (1985) explains, vertical integration is best recommended for recurrent transactions that are becoming very specialised assets. Furthermore, as seen in Chapter 2, in order for supply chain management to succeed, there is a need for timely, accurate information between the key players in the supply chain (Ellram and Cooper, 1990). This is demanding for a change in attitude and turning away from an arm's length adversarial type of relationship. This is where partnership sourcing or strategic partnering comes into play.

Therefore, when moving from brick and block construction to framing systems, developers must also consider the type of relationship they want to build with this new key supplier. As mentioned above, there are two alternatives: strategic partnering or vertical integration. The main reason to choose vertical integration lies in the fact that the developer gains some control over the operations (Ellram, 1991).

Figure 6.8 shows how the main threats faced by Home Builder led it, as a result of the task force on timber frame construction, to move towards vertical integration.

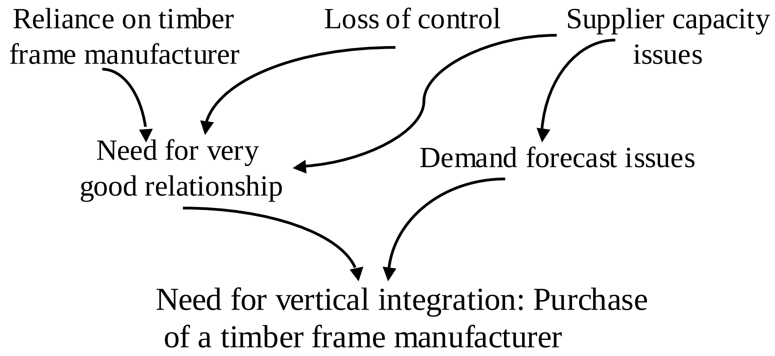


Figure 6.8 Implications of the main threats faced by the developer when using timber frame construction

Vertical integration allows Home Builder to control its supply in terms of quantity and quality. Furthermore, it allows them to work jointly on product development and to explore the ways in which they can further improve the delivery of timber frame. However the disadvantages of vertical integration must not be overlooked, such as the greater concentration of assets, the inability to replicate market incentives, the internal information distortion (Ellram, 1991).

6.2.2.3 Centralisation of supply

The last SCM principle that needs to be implemented to effectively run the shell's supply chain is the centralisation of supply. Because the products are now bespoke and highly valuable, Timshell becomes a key supplier, and only one manufacturer is needed to supply nationally. Therefore, instead of procuring from several different merchants all over the country, Home Builder procures from only Timshell. This means that the developer's supplier base is reduced and the purchase of timber frame can be centralised.

6.2.2.4 Summary

As seen in the previous sections, the SCM principles essential to the re-engineering of the shell supply chain, using a framing system, can be summarised as follows. First of all, the number of echelons has been reduced by eliminating the merchants. Secondly, the total cycle time has been compressed. Thirdly, Home Builder has vertically integrated Timshell so as to keep control and improve their relationships, as reported by Ellram and Krause (1994), Agiapiou et al. (1998a) and Proverbs and Holt (2000). Finally the supplier base has been reduced as the procurement is managed directly with Timshell on a national basis. The centralisation of supply has a positive impact on the customer service level, as identified by Charatan (1999). The impact of the implementation of all these principles is summarised in Table 6.7 and concurs with Barlow's (1999) statement that framing systems reduce overhead costs, shorten construction times and improve cash flow.

	KPIs	Timber Frame Baseline	% Change
SCM KPIs	Stock levels/Safety stock	N/A	-
	Total response time	5 weeks	-37.5% to -58%
	Total order cycle time	4 weeks	+33%
	Inventory costs	N/A	-
House building industry KPIs	Customer satisfaction (product and service)	Medium-High (developer) Medium (customer)	- -
	Product quality / defects	High	-
	Predictability costs	High	-
	Predictability time	High	-
	Construction time	1 week	-80% to -88%
	Construction costs	£41 per sq.ft.	+11%
	Profitability	Confidential	+22%

Table 6.7 Summary of Timber frame construction performance and percentage of change in comparison with Brick and Block Baseline

6.2.3 Implementation of further supply chain principles

Once the supply chain for the house shell has been re-engineered, as seen above, further SCM principles may be exploited to further improve the supply chain and house building performance. This section will look at these principles in turn and summarise their impact on performance.

6.2.3.1 End-user focus

Customers aspire to a specific completion date, some choice over the layout of the rooms and an energy efficient house. Timber frame can enable the construction of houses on an open plan basis, which means that the design of the internal layout is not constrained via load bearing walls. Furthermore as the assembly process on-site is very prompt and can be carried out under any weather conditions, dwellings become weather proof within a few days and the rest of the work can be carried out in parallel. This gives greater certainty on construction time and developers can then give a fixed completion date to their customers with minimum risk of change. Finally, timber frame is environmentally friendly and is more energy efficient than masonry construction, with an averaged 7% improvement in SAP ratings.

Therefore, if the developer desires to focus on the end-customer, framing systems can become the enabler to meet its customers' requirements. What is then required is to develop designs allowing an open plan approach and to offer some choice over the internal layout of the rooms. Focusing on the customer being a way to become a market leader as reported by Stalk and Hout (1990) about Wal-Mart and by Hewitt (1982) for the case of Skanska.

6.2.3.2 From product manufacturer to service provider

In the case of timber frame, the site manager does not need to arrange for carpenters to arrive on-site at the same time as the panels, as the manufacturer is providing a supply-and-fit service. Therefore, labour is arranged directly by the manufacturer who can synchronise it with the delivery of the panels. This means that the developer is buying a complete package, i.e. an assembled frame.

As the task force revealed, the advantages for Home Builder are as follows. It simplifies co-ordination on-site, as only the panels need to be called-off, labour does not need to be organised. In the same way, a crane does need to be organised. Finally, it minimises problems with the shortages of skilled labour. However the problem of buying a whole service instead of a product is that Home Builder loses some control over the production of dwellings. As already discussed, this problem can and has been solved by moving towards vertical integration. Home Builder moves even further into the role of integrator by buying service packages and co-ordinating them with one another. This reflects Ball's (1996) comment on the Dutch and German sites where a greater number of specialist sub-contractors are co-ordinated on-site. Furthermore, as shown by Carbone's (2000) survey in the electronic industry, 52% of the buyers purchase more value added services from their distributor than they did 2 years ago and 82% say they expect to buy more from distributor offering value adding services.

From Timshell's point of view, the main advantage is that it gains some control over its products as it provides the labour assembling the panels on-site. Therefore, it can train carpenters as required and use their feedback to improve the products. It is therefore easier for Timshell to ensure its product's quality as it has control over the assembly process. However, conversely, it means more responsibility for Timshell and increased complexity, as it has to synchronise the delivery of material with labour availability. This is however more easily achieved by Timshell than by Home Builder, as it knows exactly when the panels will be produced and are ready for delivery.

Finally, from a customer's point of view, although buying an assembled frame instead of the frame on its own does not directly affect end customers, it can be noted that the quality of the assembled frame is likely to be higher as the carpenters are familiar with the manufacturer's frames. As it is a repetitive process, carpenters will go through a learning curve and be able to achieve a high standard of quality (Ball, 1996).

6.2.3.3 Integrated information flow

A second task force, as presented in Chapter 3, was carried out with the emphasis placed upon investigating the information flow between the two companies to achieve a closer integration of the supply chain. This section presents some results from this task force.

As seen previously in this chapter, Timshell requires 4 weeks from a firm order to the first delivery. These 4 weeks can be split into two sets of 2 weeks. The first set allows Timshell to develop the drawings required for production while the other set is for production scheduling. The emphasis for improvements was placed upon the first set.

In order to speed up the first process, EDI links have been set up between the two companies. They have also agreed on common design software to facilitate the exchange of drawings. Furthermore, as Home Builder repeatedly uses a set of house designs for sites all over the UK, it was agreed that "tweaks" (changes) requested from the regions to these designs would not be allowed any longer so as to avoid unnecessary and time wasting redrawing. The resulting effects of these recommendations are to compress the two weeks drawing time down to one day (to process data and issue a cutting list). This concurs with Berry and Naim (1996) findings where a focus was placed on the information flow to reduce lead-times and Towill's (2000) 12 rules to enable the seamless supply chains.

Furthermore, it was identified that long-term demand was also critical to Timshell to allow it to smooth its production schedule and plan ahead on capacity requirements. Therefore it was agreed that Home Builder's supply chain manager would provide Timshell with long-term forecast of demand.

The forecasts and capacity orders are also very helpful for Timshell to plan its capacity requirements on a monthly basis. This also gives one single point of contact to Timshell for questions and updates. However, it was strongly recommended during the task force that an intranet be used to display updates on the site's status. This would allow all persons concerned (key suppliers, regional purchaser, supply chain manager, site managers) to obtain up-to-date information, with call-offs being triggered directly from this intranet. This has not been implemented yet, but is under consideration for implementation in the course of next year. However, a first step has already been taken using SAP/R3.

6.2.3.4 Summary

As seen in the previous section, further improvements can be made to the shell's supply chain by implementing a few more SCM principles. First of all, Home Builder is now given the opportunity to meet its customer requirements. Secondly, Timshell is no longer delivering products but becomes a service provider for a supply-and-fit framing system. Finally, emphasis can be placed upon the information flow between the two companies to reduce the drawing time, to give long term demand requirements, and to access up-to-date information. The effects of these principles upon supply chain and house building performance indicators are summarised in Table 6.8.

	KPIs	Timber Frame Baseline	Timber Frame Improved
SCM KPIs	Stock levels/Safety stock	N/A	N/A
	Total response time	5 weeks	**3 weeks and 1 day**
	Total order cycle time	4 weeks	**2 weeks and 1 day**
	Inventory costs	N/A	N/A
House building industry KPIs	Customer satisfaction (product and service)	Medium-High (developer) Medium (customer)	**High (developer)** **High (customer)**
	Product quality / defects	High	High
	Predictability costs	High	High
	Predictability time	High	High
	Construction time	1 week	1 week
	Construction costs	£41 per sq.ft.	£41 per sq.ft.
	Profitability	+22%	+22%

Table 6.8 Summary of Timber frame performance before and after further improvements

6.2.4 Summary of the re-engineering scenarios

Table 6.9 summarises the four different scenarios for the house shell supply chain in terms of supply chain structure, the involvement of each agent, the type of innovation introduced and the total response time.

Scenarios	Brick and Block Baseline	Brick and Block Improved	Timber Frame Baseline	Timber Frame Improved
Supply chain structure	Developer, multiple merchants, labour only, manufacturer		Developer, manufacturer, labour only	Developer, manufacturer
Developer	Order from merchants. Employ sub-contractors (labour only).		Order from manufacturer. Employ sub-contractor (labour only)	Order from manufacturer (supply-and-fit)
Merchants	Procure from manufacturer		-	-
Manufacturer	Supply to merchants		Supply to developer	
Innovation	-	Cycle time reduction	Alternative technology	Value added service by manufacturer
Total response time	8-12 weeks	6-10 weeks	5 weeks	3 weeks and 1 day

Table 6.9 Summary of the re-engineering scenarios

6.3 Supply chain re-engineering implications on supply chain dynamics

In sections 6.1 and 6.2, the impact on performance for traditional masonry and framing supply chains was studied. However, as argued in Chapter 3, the dynamic behaviour of these supply chains also needs to be taken into account. Therefore, models have been developed (Chapter 5) to simulate four different scenarios. This section will first describe the characteristics of each scenario, the simulation results are then presented and finally a summary of the results is presented.

6.3.1 Scenarios description

Based on the previous sections' work, four different scenarios have been identified. These are the current situation for brick and block (Brick and Block Baseline scenario), the re-engineered traditional house shell's supply chain (Brick and Block Improved scenario), the timber frame supply chain (Timber Frame Baseline scenario) and finally the re-engineered timber frame supply chain (Timber Frame Improved scenario).

Brick and Block Baseline scenario, illustrated in Figure 6.9, is based on the description of the current situation in Section 6.1.1 and is therefore composed of 8 merchants and one brick manufacturer. The regional buyer places orders, which are called off 2 weeks later by the site manager. The merchants will take 1 week (7 days) to fulfil that order. They in turn place orders to the manufacturer, who takes another 7 days to fulfil the order. Once the bricks arrive on-site, they will be kept idle for a week before being used to build houses. The site manager also calls off bricklayers and they will work on-site for 9 weeks (construction time).

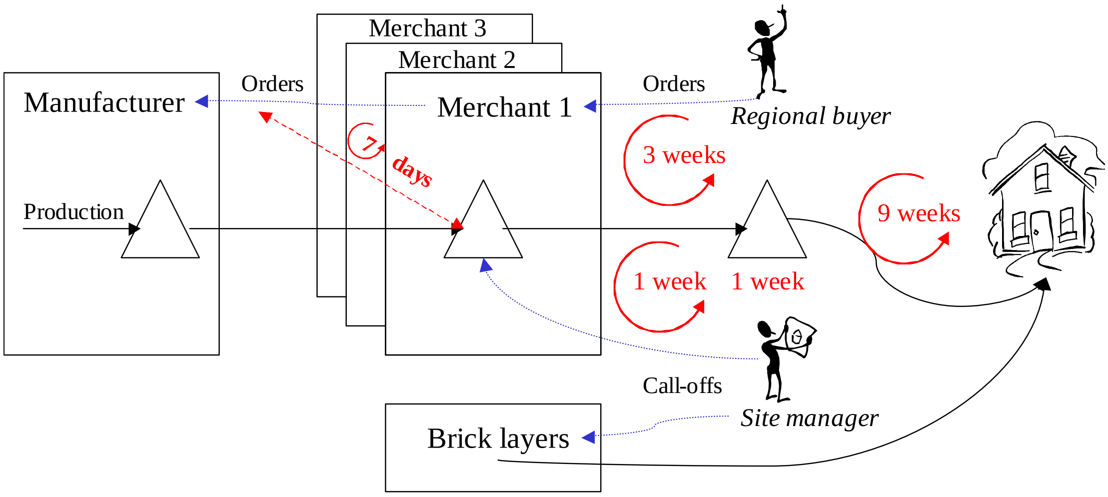


Figure 6.9 Brick and Block Baseline scenario

Brick and Block Improved scenario, illustrated in Figure 6.10, is based on the same model as the Brick and Block Baseline. The differences, as seen in Section 6.1.2 are firstly, the delay between the regional buyer placing orders and the site manager calling off bricks (1 day), secondly, the bricks on-site are immediately used and finally, the construction time is reduced to 5 weeks.

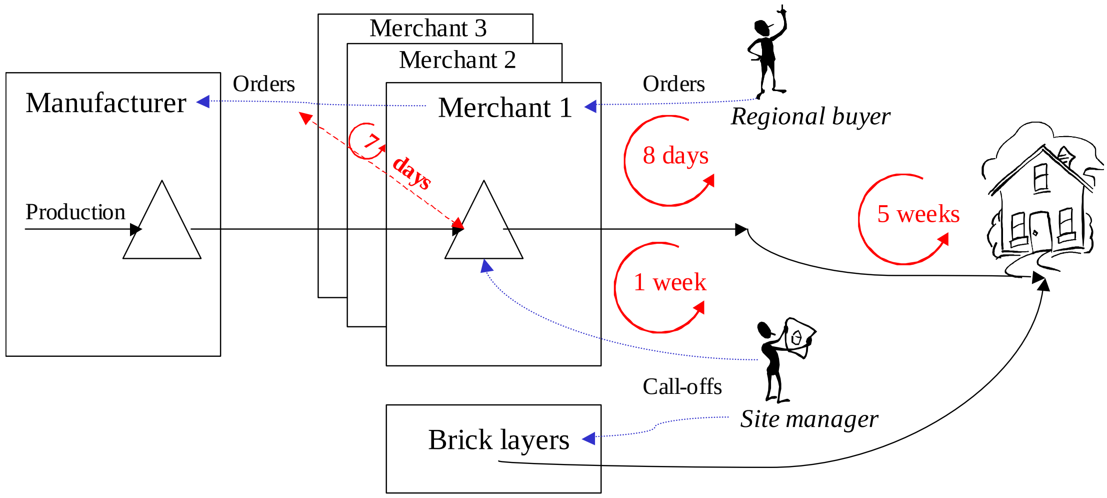


Figure 6.10 Brick and Block Improved scenario

Timber Frame Baseline scenario, illustrated in Figure 6.11, is based on the supply chain described in Section 6.2.2 and is only composed of Home Builder (through the regional buyer and the site manager) and Timshell. Here the call off for timber frame can only be done 2 weeks after the order has been placed. Timshell then takes 4 weeks to fulfil the order. The frame erectors, which are called off by the site manager, will then take a further week to build the house.

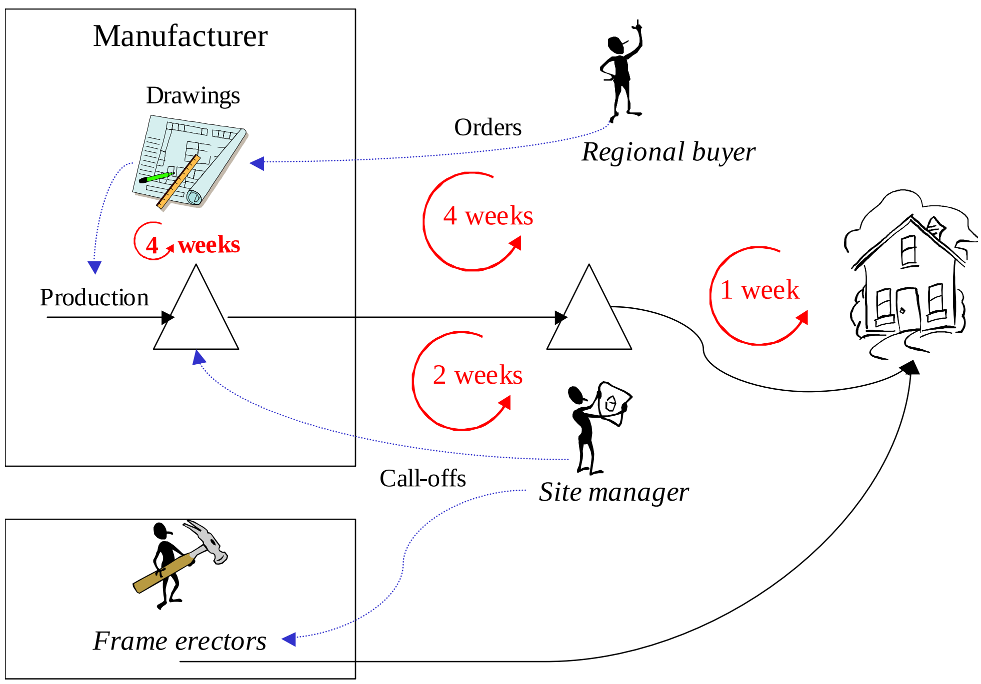


Figure 6.11 Timber Frame Baseline scenario

Timber Frame Improved scenario, illustrated in Figure 6.12, and based on the supply chain described in Section 6.2.1.1 is very similar to the Timber Frame Baseline model. The differences are as follows: the timber manufacturer production lead time is reduced to 15 days, the lead time from an order being placed to a possible call off is 1 day and, finally, labour is provided by Timshell on a supply-and-fit basis. In this case, labour is only called off if the frames required are available.

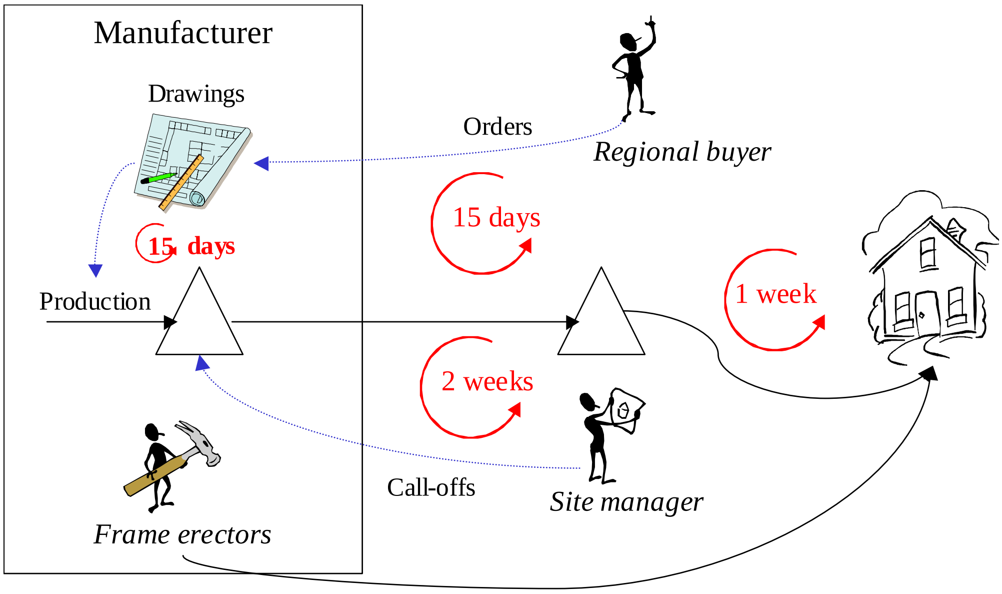


Figure 6.12 Timber Frame Improved scenario

The characteristics of each scenario can be summarised in Table 6.10. In the case of the Brick and Block scenarios, the different players' behaviour were modelled so as to include an element of mistrust, as suggested during interviews with Home Builder's personnel. Both Timber Frame scenarios do not incorporate a mistrust element based on discussion with Home Builder and Timshell's personnel. Mistrust has been modelled based on real life observations, and Sterman (2000), where whenever the customers do not receive what they have ordered, the next order they place will be increased by 100% of the quantity of product undelivered. For details on the modelling of mistrust refer to Chapter 5.

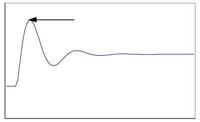
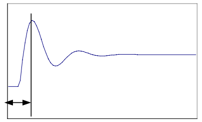
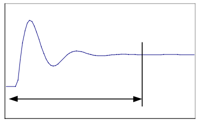
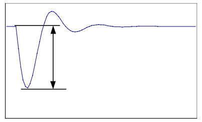
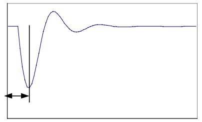
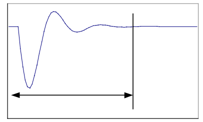
	Brick & Block Baseline	Brick & Block Improved	Timber Frame Baseline	Timber Frame Improved
Order to call off lead time	14 days	1 day	14 days	1 day
Stock on-site	7 days	-	-	-
Call off to delivery on-site	7 days	7 days	14 days	14 days
Order to delivery to merchants	7 days	7 days	-	-
Manufacturing lead time	7 days	7 days	28 days	15 days
On-site construction time	9 weeks	5 weeks	1 week	1 week
Miscellaneous	Mistrust 100%	Mistrust 100%		Supply-and-fit

Table 6.10 Summary of the parameters of the four scenarios

6.3.2 Simulation results

Each scenario has been simulated daily for a step change in demand over a period of 3 years. The step change in demand increased from 100 to 120 houses at day 20.

As indicated in Chapter 2, the dynamics of each model can be assessed using six performance criteria for a step input. These are the peak value, the peak time, the order recovery time, the stock depletion, the trough time and the stock recovery. Although the research involves analysing the whole supply chain, for ease of presentation only the manufacturers' results are illustrated. As the dynamic effects are the worst at the lowest echelon in the supply chain, it is reasonable to compare different scenarios by studying the manufacturers' performance. The performance for each scenario is presented using a linear scale using four stars for the best performance and one star for the worst. The overall scenarios' performance considers an equal weighting for each performance criteria.

Scenarios	Peak Value 	Peak Time 	Order Recovery 	Stock Depletion 	Trough Time 	Stock Recovery 	Scenarios Performance
B&B Baseline	****	**	***	****	****	****	****
B&B Improved	*	****	****	***	***	***	***
Timber Frame Baseline	***	*	*	*	*	*	*
Timber Frame Improved	**	***	**	**	**	**	**

Where **** represents the best performance and * the worst

Table 6.11 Ranking of the four different scenarios for dynamic performance criteria at the manufacturer for step change in the demand

As can be seen from Table 6.11 Brick and Block Baseline scenario achieve the best result dynamically, while the worst performance is registered for the Timber Frame Baseline scenario. This can be explained by the fact that, as displayed in Table 6.10, the manufacturing lead times are much shorter for the Brick and Block scenarios which improves the dynamic results (Towill, 2000). Furthermore, in the case of Brick and Block Baseline scenario, Timshell receives an order 21 days before the delivery is due, while it only needs 7 days to manufacture the products. Timber Frame Improved scenario performs better than Timber Frame Baseline scenario as the manufacturing lead-time is nearly halved. This means that in the case of Timber Frame Improved scenario, Timshell is able to respond in a quicker manner to the step increase in the demand and therefore recover more promptly.

For ease of understanding, the dynamic performance shown in Table 6.11 can be summarised under two performance criteria, the production on-costs and the integrated absolute error (IAE) for the inventory level for the manufacturer, as explained in Chapter 2. Furthermore, the simulations also allow the collection of other performance criteria such as the total supply chain inventory cost, the maximum amount of labour required at any point of time and the total number of houses built. As can be seen from Table 6.12, both Timber Frame scenarios achieve better performance than Brick and Block scenarios. It can be seen that for the two criteria measuring the bullwhip effect (production on-costs and IAE for inventory) both Brick and Block scenarios perform better than Timber Frame scenarios, whereas for the other three quantitative criteria, Timber Frame scenarios perform better.

Scenarios	Production on-costs	IAE inventory	Total SC inventory costs	Maximum amount of labour	Total number of houses	Scenarios performance
B&B Baseline	****	****	*	*	*	**
B&B Improved	**	***	**	**	**	**
Timber Frame Baseline	*	*	****	****	***	***
Timber Frame Improved	***	**	**	****	****	****

Where **** represents the best performance and * the worst

Table 6.12 Scenarios' ranking for a step change in demand

However, it is also very important to study the *magnitude of the impact* that each scenario has on the different criteria and not just the *ranking* of the scenarios. The results are therefore presented in graphical from as shown in Figure 6.13. The graph shows the impact of each scenario on the supply chain inventory costs using Brick and Block Baseline scenario as a starting point.

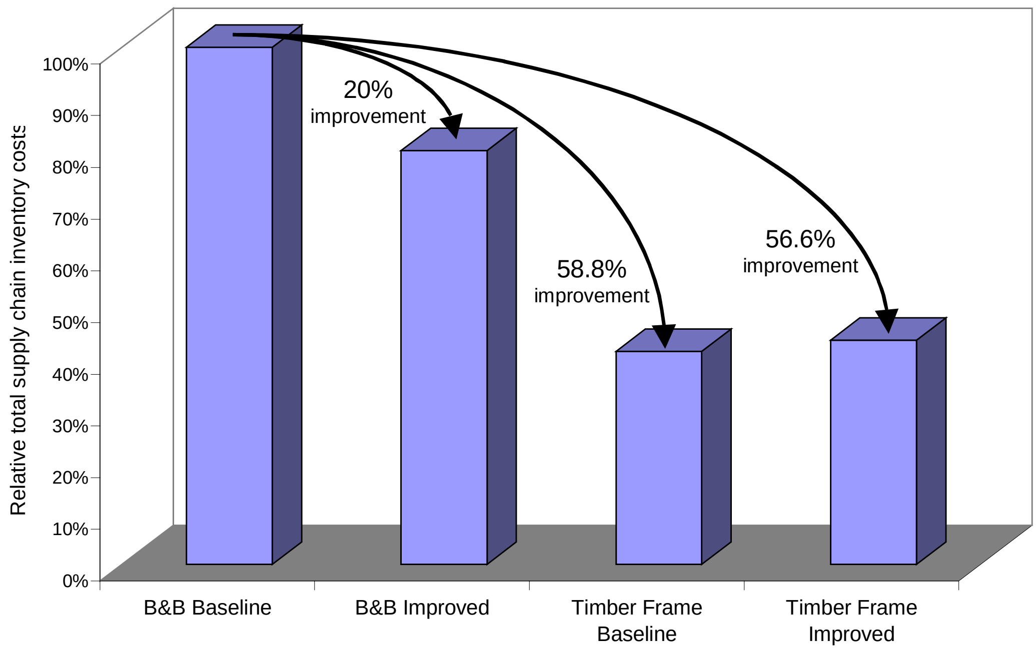


Figure 6.13 Impact of each scenario on B&B Baseline scenario for the total supply chain inventory costs

The results for all the performance criteria are summarised in Table 6.13, where, the rating has been carried out for three scenarios using Brick and Block Baseline scenario as the base scenario. It can be seen that the total supply chain inventory cost is greatly reduced for both Timber Frame scenarios (57% and 59%), as only Timshell holds stock, although the stock holding cost for timber frame has been set 10% higher than the stock holding cost for bricks (based on Table 6.4). This concurs with Charatan's (1999) and Henkoff's (1994) findings, where the centralisation of supply always proved to be beneficial. The amount of labour required and the total number of houses built are both dependent on construction time. Therefore Timber Frame models achieve a better performance by reducing the maximum amount of labour required by 89% and increase the number of houses built by 1%.

Scenarios	Production on-costs	IAE inventory	Total SC inventory costs	Maximum amount of labour	Total number of houses
B&B Improved	+394%	+45%	-20%	-49%	+0.74%
Timber Frame Baseline	+1691%	+837%	-59%	-89%	+0.86%
Timber Frame Improved	+207%	+203%	-57%	-89%	+1.05%

Table 6.13 Impact of the scenarios on performance criteria in comparison with Brick and Block Baseline scenario for a step change in demand

The results for the four different scenarios in response to a step change demand have been analysed. However the impact of each SCM principle cannot be fully understood as more than one principle is implemented from one scenario to another. Therefore, further simulations have been carried out to analyse the impact of every single change (called strategy), from one scenario to another.

Starting with the comparison between Brick and Block Baseline and Improved scenarios, the SCM principle implemented was to reduce the total cycle time across the supply chain. This has been achieved by:

- Reducing the lead-time from order to call off from 14 to 1 day: "Order to call off" strategy
- Reducing the construction time on-site from 9 to 5 weeks: "Construction time" strategy
- Eliminating the stock of bricks on-site: "Stock on-site" strategy

As can be seen from Table 6.14, only the reduction of the order to call off lead-time has an impact on the dynamics of the model, i.e. the production on-costs and the IAE for inventory. The elimination of stock of bricks on-site is responsible for the reduction in total supply chain inventory costs (by 20%), as confirmed by Stalk and Hout (1990). The reduction of construction time reduces the amount of labour required by 40% and increases the number of houses built by 0.4%. As Brick and Block Improved scenario is a combination of three strategies, their impacts on amount of labour required and number of houses built is accumulated, and therefore the best performance is registered in the case of Brick and Block Improved scenario.

Strategies	Production on-costs	IAE inventory	Total SC inventory costs	Maximum amount of labour	Total number of houses
Order to call off	+394%	+45%	-0.06%	0%	+0.2%
Construction time	0%	0%	0%	-40%	+0.4%
Stock on-site	0%	0%	-20%	-10%	+0.1%
B&B Improved	+394%	+45%	-20%	-49%	+0.7%

Table 6.14 Impact of each strategy from Brick and Block Baseline scenario to Brick and Block Improved scenario

The SCM principles implemented to move from Brick and Block Improved scenario to Timber Frame Baseline scenario consist of reducing the total cycle time across the supply chain, reducing the supplier base/centralisation of supply, and in improving company relationships (as studied in Section 6.2.2). This has been achieved by implementing 7 different strategies:

- Increase of the lead-time from order to call off from 1 to 14 days: “Order to call off” strategy
- Increase of the lead-time from call off to delivery from 7 to 14 days: “Call off to delivery” strategy
- Increase of the manufacturer production time from 7 to 28 days: “Production time” strategy
- Reduction of the construction time on-site from 5 to 1 week: “Construction time” strategy

- Elimination of merchants: “No merchant” strategy
- Increase of 10% of stock holding costs: “Stock cost” strategy
- Elimination of mistrust between the customer and the merchants: “Mistrust customer” strategy
- Elimination of mistrust between the merchants and the manufacturers: “Mistrust merchant” strategy

Table 6.15 presents the respective impact of each strategy in comparison with Brick and Block Improved scenario. It can be seen that “No merchant” strategy reduces production on-costs by 91%. This can be explained by the fact that one echelon has been eliminated and therefore the structure of the supply chain has been simplified in accordance with the results of Wikner et al. (1991). This strategy also reduced IAE for inventory 47%. However at the other extreme, “Production time” strategy increases production on-costs and IAE for inventory as was predicted by Towill (2000). The production lead-time of the manufacturer has been quadrupled and therefore it takes much longer for the manufacturer to react and adapt to the change in demand. “Orders to call off” and “Call off to delivery” strategies both reduce production on-costs by 80% and 53% respectively and IAE for inventory by 31% and 20% respectively. This was expected, as the “warning” lead-times (the manufacturer receives the order 14 days in advance of any call off and has another 14 days between the call off and the required delivery) have been increased conversely to the previous comparison between the two Brick and Block strategies.

As expected, “Stock cost” strategy increases the total supply chain inventory costs by 5%, however the impact is very minor and is totally counterbalanced by “No merchant” strategy. “Construction time” strategy reduces the amount of labour required by 78%. As construction time decreases, labour need to stay on-site for shorter periods of time and therefore they are quickly available to work on another site. Furthermore, a greater number of houses can be built when construction time is reduced.

Strategies	Production on-costs	IAE inventory	Total SC inventory costs	Maximum amount of labour	Total number of houses
Order to call off	-80%	-31%	+0.25%	0%	-0.2%
Call off to delivery	-53%	-20%	+0.14%	0%	-0.1%
Production time	+3899%	+1302%	+2%	+24%	0%
Construction time	0%	0%	0%	-78%	+0.4%
No merchant	-91%	-47%	-50%	0%	0%
Stock cost	0%	0%	+5%	0%	0%
Mistrust customer	(-7%)	(-9%)	(+0.14%)	(0%)	(0%)
Mistrust merchant	(-36%)	(-18%)	(-0.11%)	(0%)	(0%)
Timber Frame Baseline	+262%	+548%	-48%	-78%	+0.1%

Table 6.15 Impact of each strategy from Brick and Block Improved scenario to Timber Frame Baseline scenario

In order to evaluate the impact of level of mistrust on performance, target stock levels at both merchants and manufacturer levels had to be lowered so as to be in the situation of stock-out. This is necessary as customers only show their mistrust when they do not receive the quantity of products ordered. The level of mistrust was studied for two cases, mistrust between developer and merchants (Mistrust customer) and between merchants and manufacturer (Mistrust merchant). Moving from 100% mistrust to 0% mistrust, shown in brackets as the inventory level has been changed, improves in nearly all cases performance. This confirms the potential positive impact of partnering agreements as reported by Ellram and Krause (1994), Barlow (1998) and Construction Productivity Network (1998). The elimination of mistrust improves the production on-costs as well as the IAE for inventory, but has no impact on the number of houses built. As the target stock levels have been reduced to be in a backlog situation, it is important here to also take into consideration the number of days merchants and manufacturer are out of stock. Surprisingly, the results are different depending on where the mistrust is placed. When placed between merchants and manufacturer, zero mistrust performs better. However, when placed between developer and merchants, 100% mistrust performs better. Linked to this, the total supply chain inventory cost is reduced for zero mistrust between merchants and manufacturer, but not for zero mistrust between developer and merchants.

Finally we can compare Timber Frame Baseline with Improved scenarios. As seen in Section 6.2.3, the information flow can be integrated and the manufacturer can provide a supply-and-fit service. These principles have been implemented by:

- Reducing order to call off lead-time from 14 to 1 day: “Order to call off” strategy
- Reducing the manufacturer production time from 28 to 15 days: “Production time” strategy
- Offering a supply-and-fit service (in this case, the manufacturer firstly verifies that there is enough material available before calling off the labour, in other words labour is only called off when a task can be carried out): “Supply-and-fit” strategy

Table 6.16 shows that reducing production time of Timshell improves the dynamic behaviour (production on-costs and IAE for inventory criteria), as it can react more promptly to the change in demand (Towill, 2000). “Supply-and-fit” strategy was simulated in the case of a backlog in material. In this case, the strategy reduced by 55% the amount of labour needed as the labour is only called off when there is some material available on-site.

Strategies	Production on-costs	IAE inventory	Total SC inventory costs	Maximum amount of labour	Total number of houses
Order to call off	-4%	+22%	+0.4%	0%	+0.2%
Production time	-83%	-79%	+6%	0%	0%
Supply-and-fit	0%	0%	0%	-55%	0%
Timber Frame Improved	-82%	-68%	+5%	0%	+0.2%

Table 6.16 Impact of each strategy from Timber Frame Baseline scenario to Timber Frame Improved scenario

6.3.3 Dynamic results summary

The most important lessons learnt from this section are first of all, that for a step change in demand, both Brick and Block scenarios perform better than Timber Frame scenarios in terms of bullwhip effect. However in terms of quantitative criteria (total supply chain costs, maximum number of labour and total number of houses), Timber Frame scenarios perform better. Furthermore, for the overall performance, Timber Frame Improved scenario achieves the best results for a step change demand.

The most significant strategies' impact are registered for "Order to call off", "Construction time", "Production time" and "No merchant". The longer the order to call off lead-time is, the better the dynamic results for production on-costs and IAE for inventory. In other words, the longer the warning period is between an order and the actual call off, the better it is for merchants and manufacturers as they can plan ahead and build up stock if necessary. This concurs with the findings of Mason-Jones (1998) that passing long-term information to suppliers improves dynamics performance. With shorter construction time, less amount of labour is required and a larger number of houses can be built. This means that the faster houses can be built, the less labour is required. This could become a very important outcome to overcome shortages in labour. When the production lead-time of the manufacturer is reduced, the dynamic behaviour is improved, as the manufacturer can respond quicker to changes in the demand pattern (Towill, 2000). Finally, eliminating merchants reduces the total supply chain inventory costs by 50%, which concurs with Agiapiou et al.'s (1998b) findings.

6.4 House shell findings summary

In this chapter, the performance for the shell's supply chain when using masonry construction has been studied. It was established that gradual improvements to the Brick and Block Baseline supply chain had very limited effects on performance and therefore called for a more radical approach. Using a framing system to build the house shell was therefore considered. The review of different framing systems showed that most of the advantages of these systems were common, and timber frame was therefore selected for further study on the supply chain's implications.

Some principles for successful supply chain management were inevitably introduced when moving from masonry construction to framing systems. These can be summarised as the shortening of the supply chain, the need for strategic partnering or vertical integration, and the centralisation of supply. These can significantly improve the performance of the shell's supply chain, especially the centralisation of supply by removing the merchants, which had a significant impact on the total supply chain inventory costs.

However, further improvements have been identified through the implementation of additional SCM principles, such as focusing on the end-user and improving the information flow. As a result the performance has been further improved.

It was then necessary to study these four different scenarios from a dynamic point of view. It was demonstrated that on a purely dynamic point of view, Brick and Block scenarios performed better than Timber Frame scenarios. However other quantitative performance criteria achieved better results in the case of Timber Frame scenarios.

The overall results for the four scenarios are presented in Table 6.17, however as the performance criteria considered are numerous, it is difficult to conclude which scenario achieves an overall best performance. Therefore the Multi-Attribute Utility Theory (MAUT) was used (see Chapter 3). The first step was to index all the performance criteria using Brick and Block Baseline scenario as the index value of 100, and "reverse" some criteria so that in all cases the smaller the value, the better the performance. A weighting system had to be put in place. As the three KPI types (SCM, house building industry and system dynamics) are all equally important, to calculate the overall performance it was decided that they should have the same weight.

However as the safety stock criterion (SCM KPI) is directly derived from the stock depletion criterion (System Dynamics KPI), it was decided that it should only be taken into consideration once. Finally, predictability costs and predictability time criteria were considered as only one criterion. Construction costs and construction time criteria were calculated in the same manner.

The results utilising MAUT are presented in **Error! Reference source not found.** and show that the scenario achieving the best overall performance is Timber Frame Improved, followed by Brick and Block Improved. It must however be highlighted that the main reason why Timber Frame Baseline achieved the worst performance lies in the poor dynamics performance results. Therefore the importance of trade-offs must be recognised. Although the direct construction costs for Brick and Block are lower than for Timber

Frame, the amount of labour required is much higher. Furthermore, the dynamics performance for Timber Frame is poor, however at the same time, the supply chain inventory costs are much lower.

It can be concluded that a change of technology (using framing systems instead of masonry construction) is required to improve the overall performance of the shell's supply chain. Furthermore, this change of technology requires the implementation of some key SCM principles, such as strategic partnering, reduction of the supplier base and centralisation of supply. The framing system house shell's supply chain can be further improved through the implementation of other SCM principles (end-user focus and integrated information flow). Finally, the combination of all these SCM principles in Timber Frame Improved scenario achieves the best overall performance.

	KPIs	Brick and Block Baseline	Brick and Block Improved	Timber Frame Baseline	Timber Frame Improved
SCM KPIs	Stock levels/Safety stock	66*	122*	379*	195*
	Total response time	12 weeks	6 weeks	5 weeks	3 weeks and 1 day
	Total order cycle time	3 weeks	1 weeks	4 weeks	2 weeks and 1 day
	Inventory costs	£648,384*	£518,797*	£266,942*	£281,105*
House building industry KPIs	Customer satisfaction (product and service)	Medium (developer) Low (customer)	Medium (developer) Low (customer)	Medium-High (developer) Medium (customer)	High (developer) High (customer)
	Product quality / defects	Medium	Medium	High	High
	Predictability costs	Medium	Medium	High	High
	Predictability time	Low	Low	High	High
	Construction time	9 weeks	5 weeks	1 week	1 week
	Construction costs	£37 per sq.ft.	£37 per sq.ft.	£41 per sq.ft.	£41 per sq.ft.
	Profitability	baseline	baseline	+22%	+22%
	Amount of labour	4,260*	2,160*	480*	480*
	Number of houses	129,160*	130,120*	130,280*	130,520*
Dynamical KPIs	Peak value	127*	146*	130*	131*
	Peak time	67*	50*	100*	61*
	Order recovery	228*	211*	571*	310*
	Stock depletion	66*	122*	379*	195*
	Trough time	42*	46*	91*	56*
	Stock recovery	217*	242*	584*	315*

* indicates relative values from the simulations

Table 6.17 Overall performance for the four different scenarios

	KPIs	Weighting	Brick and Block Baseline		Brick and Block Improved		Timber Frame Baseline		Timber Frame Improved	
			Index	Value	Index	Value	Index	Value	Index	Value
SCM KPIs	Stock levels/Safety stock	0	100	0	184	0	574	0	295	0
	Total response time	0.0833	100	8.33	50	4.167	41.6	3.467	26	2.166
	Total order cycle time	0.0833	100	8.33	33	2.75	133	11.08	71	5.916
	Inventory costs	0.0833	100	8.33	80	6.667	41	3.417	43	3.583
	Customer satisfaction (product and service)	0.0833	100	8.33	100	8.333	87.5	7.292	75	6.25
House building industry KPIs		0.0476	100	4.76	100	4.762	75	3.571	50	2.380
	Product quality / defects	0.0476	100	4.76	100	4.762	75	3.571	75	3.571
	Predictability costs	0.0238	100	2.38	100	2.381	75	1.786	75	1.785
	Predictability time	0.0238	100	2.38	100	2.381	50	1.19	50	1.190
	Construction time	0.0238	100	2.38	55	1.31	11	0.262	11	0.261
	Construction costs	0.0238	100	2.38	100	2.381	110	2.619	110	2.619
	Profitability	0.0476	100	4.76	100	4.762	78	3.714	78	3.714
	Amount of labour	0.0476	100	4.76	50.7	2.414	11	0.524	11	0.523
	Number of houses	0.0476	100	4.76	99.3	4.729	99.2	4.724	99	4.714
Dynamical KPIs	Peak value	0.0555	100	5.55	114	6.333	102	5.667	103	5.722
	Peak time	0.0555	100	5.55	74.6	4.144	149	8.278	91	5.055
	Order recovery	0.0555	100	5.55	92	5.111	250	13.89	136	7.555
	Stock depletion	0.0555	100	5.55	184	10.22	574	31.89	295	16.388
	Trough time	0.0555	100	5.55	109	6.056	216	12	133	7.388
	Stock recovery	0.0555	100	5.55	111	6.167	269	14.94	145	8.055
		1	Total value:	**100**	Total value:	**89.83**	Total value:	**133.9**	Total value:	**88.84**

Table 6.18 Assessment of the four scenarios using MAUT technique

6.5 References

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Chapter 7 The high-value fit-out supply chain

Research questions

- Which SCM principles can be applied to the high-value fit-out's supply chain?
- How do these principles impact on the performance of high-value fit-out's supply chain?

7.2 Introduction

Following on Chapter 6, this chapter is now concerned with the high-value fit-out category for the construction of houses. All the data presented, unless stated otherwise, was collected during the in-depth case studies, as explained in Chapter 3, while performance was assessed using the SCM, private house building and system dynamics KPIs, as described in Chapters 2 and 4.

This chapter considers the high-value fit-out supply chain and analyses the impact of a five step re-engineering strategy in order to improve the overall performance and include a customer-focused strategy. First a review of the current situation is carried out followed by the analysis of the five-phase re-engineering programme. These different phases are analysed from a dynamic point of view, and the overall performance for each phase is assessed.

7.3 The high-value fit-out's supply chain current state

7.3.1 Background

As discussed in Chapter 3, the main components of a house can be divided into three categories: house shell, high-value fit-out and low-value fit-out. The high-value fit-out category encompasses kitchen units, bathroom and electrical items such as ventilation systems. Currently, customers can choose the colour and style of their kitchen units but have no choice over the type of ventilation systems. We are nowadays, spending 80% of our time indoors, therefore the quality of indoor air in homes is increasingly becoming an important issue.

Several different ventilation systems exist from the common extractor fans to more complicated heat recovery ventilation systems. The implications in direct costs (purchase cost) and running costs vary from one system to another. Unfortunately, end users or home buyers cannot choose which system they would like. As Barlow and Ozaki's (2000) survey of 271 purchasers of new houses shows, 80% of the respondents wanted additional choices for their house interior (e.g. additional energy-efficient and energy-saving devices, floor finishes, etc.). Therefore, an in-depth study for ventilation systems was chosen to investigate the possibility of giving more choice to customers by re-engineering the supply chain. The lessons learned are transferable to other high-value fit-out products as the supply chain structure, ordering and delivery processes are similar.

The results presented in this section were collected during the in-depth case study carried out in collaboration with Ventair (a ventilation system manufacturer) - one of the industrial partners taking part in the COMPOSE research project. This company, that shall be called Ventair, has very innovative ideas for manufacture, assembly and supply processes. Having been through a full manufacturing re-engineering process (Prickett, 1994; Lewis, 1997), Ventair is now in the position to integrate its supply chain. As described by Stevens (Stevens, 1989), it is only when the company has their internal processes in order that it can start integrating with its suppliers and customers. Ventair has already set up partnering agreements with its suppliers and is now in the process of getting closer to its customers; introducing change with customers being harder than with suppliers (Mason-Jones and Towill, 1998).

Ventair is able to guarantee a 24-hour delivery anywhere in the UK for all its products on the housing market. It also uses postponement for the manufacture of its products by producing standardised parts and only assembling to order, therefore customising the final product once it receives an order. This approach is similar to the production of kitchen units, where the units are standardised and only the doors change. As for the assembly of its products on-site, Ventair uses fitters who receive full training and therefore can provide a supply-and-fit service to developers.

7.3.2 Current situation's performance

In the UK, the in-house architect or technical manager of the developer usually specifies the technical requirements for the house, for example the type of heating system, doors and windows, and ventilation system. With the detailed specifications, it is then possible to calculate the SAP rating for that specific house so that it complies with the building regulations.

Once a site has been identified and a scheme approved, work can start on-site. Generally, the developer will then appoint an electrical sub-contractor who will work on a supply-and-fit basis. Thus the sub-contractor will usually purchase materials, in this case extractor fans, from an electrical distributor or stockist. The electrical distributor will then purchase the fans from a manufacturer as can be seen from Figure 7.1.

At each step of the supply process a mark-up of 7.5% to 10% of the price of the product will take place. This means that a fan bought for £5[2] from a manufacturer could be priced to the developer at £6.55; or in other words, 31% more than its initial price. Therefore, the developer will not be highly satisfied, as it pays an expensive price for medium-quality products (based on interviews with Ventair personnel). As for the end-customers, their satisfaction is compromised by the lack of choice over the ventilation system installed in their house (based on interviews with Ventair personnel).

There are implications on lead-times within this “traditional” or “baseline” supply chain. Usually the developer (i.e. Home Builder) passes on the order to the sub-contractor and expects to have the fans fitted 7 days later (total order cycle time). The sub-contractor waits for four days before passing on the order to the electrical distributor and expects a delivery 3 days later. As for the electrical distributor, he expects a next day delivery from Ventair. The sub-contractor will not place an order straight away, instead it will wait until the last minute and then the sub-contractor will expect a prompt delivery from the distributors as they keep stock. Once the sub-contractor has the fans, it will take approximately 4 hours to install them into each house.

[2] Due to confidentiality, the true costs could not be disclosed, however the proportionality has been kept.

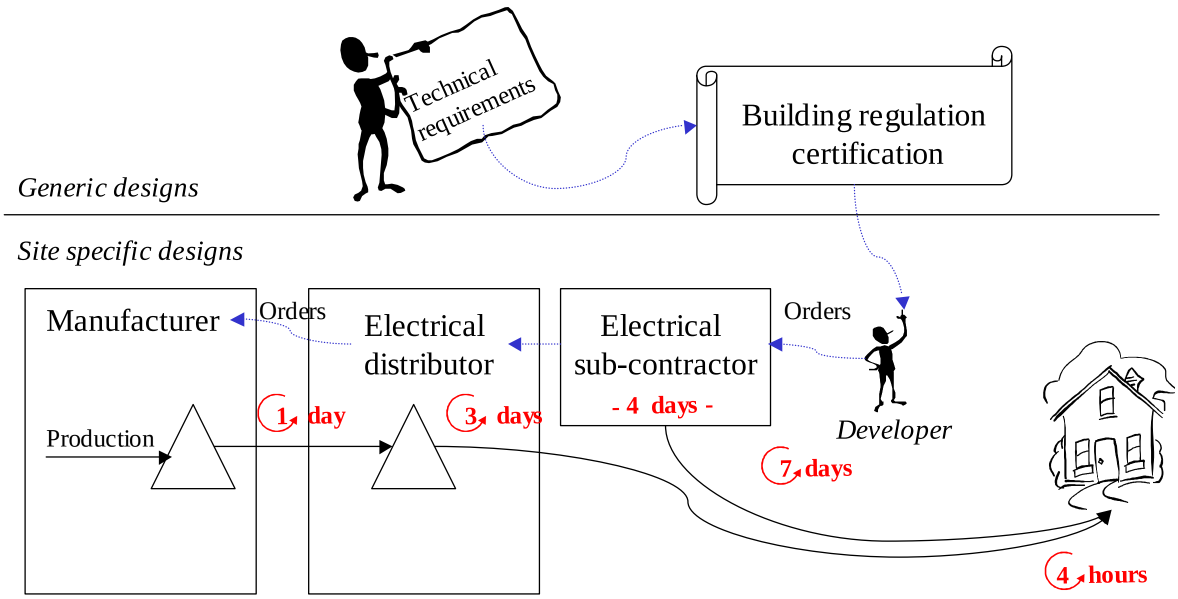


Figure 7.1 Traditional supply chain for extractor fan procurement

The direct costs for the installed ventilation system in a typical three-bedroom house is as follows. An average of four extractor fans are required (for the kitchen, bathroom, en-suite bathroom and laundry) with a total of 10 trickle vents on the windows. An extractor fan for a kitchen costs £5 while the other fans costs approximately £3 each for a total amount of £14. This price is then marked-up twice, from Ventair to the distributor and from the distributor to the sub-contractor, reaching a total amount of £17. The installation cost for each fan amounts to £4 on average, while installed trickle vents generate costs of £1 each. The total installed cost for extractor ventilation in one house amounts to £43.

Table 7.1 summarises the performance data for traditional ventilation's supply chain.

	KPIs	**Traditional extractor fans supply chain**
SCM KPIs	Stock levels/safety stock	N/A
	Total response time	8 days
	Total order cycle time	7 days
	Inventory costs	N/A
House building industry KPIs	Customer satisfaction (product and service)	Low (developer) Low (customer)
	Product quality / defects	Low
	Construction time	4 hours
	Construction costs	£43

Table 7.1 Summary of traditional extractor fans supply chain performance

7.4 Supply chain integration: five re-engineering stages

The traditional procurement method for ventilation systems in private house building, as shown previously, can be optimised so as to reduce lead-times, decrease costs and offer choice to customers. Five scenarios have been identified which improve the overall performance for the high-value fit-out. These scenarios can be taken step by step to implement an incremental change, but companies could also “jump” from the first phase to the last one to implement a step change.

7.4.1 Phase One: Shortened supply chain

The first phase is to recognise that electrical distributors could be bypassed as Ventair is highly efficient and is ready to deal with a large number of customers. This strategy is being advocated by many authors (e.g. Stevens, 1989; Wikner et al., 1991; Agapiou et al., 1998). In such a case, electrical sub-contractors procure directly from Ventair. From interviews with Ventair personnel, it was agreed that the shortening of the supply chain will have a positive effect on customer satisfaction. As there is only one mark-up taking place between the sub-contractor and the developer, it was agreed with Ventair personnel that the satisfaction of the developer is likely to increase as it gets a better product for the same price or the same product for a cheaper price.

As can be seen from Figure 7.2, Home Builder still gives the sub-contractor 7 days to procure the extractor fans, while the sub-contractor is able to receive them within 24 hours from Ventair. This time, the sub-contractor will wait 6 days before passing on its order to Ventair and expect a 24-hour delivery guaranteed by Ventair.

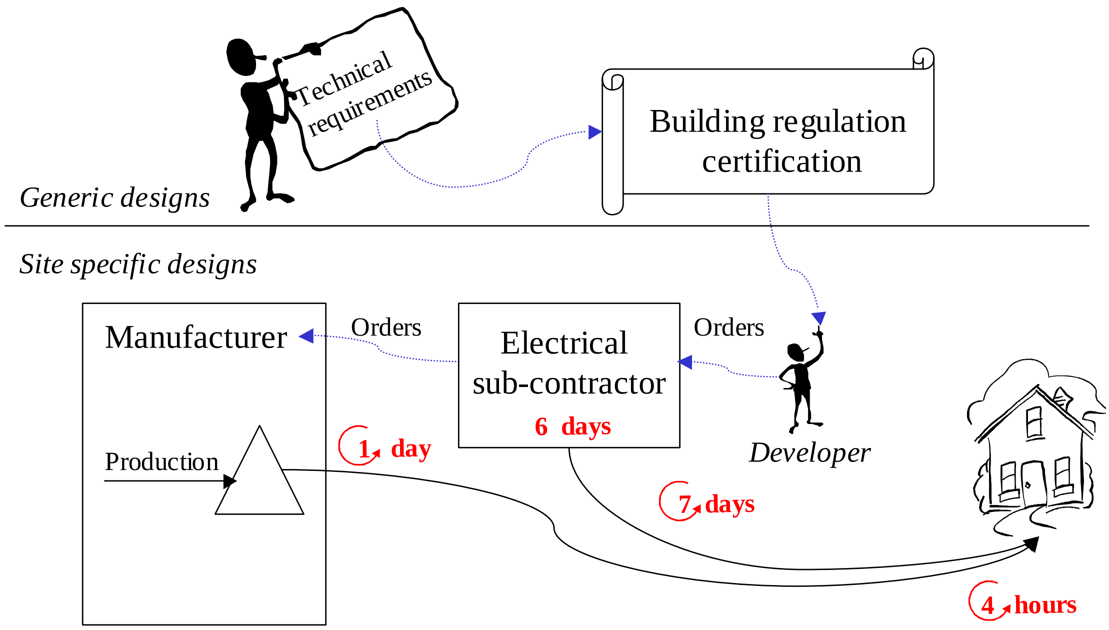


Figure 7.2 Phase one: Shortened supply chain for extractor fans procurement

Table 7.2 summarises the performance for Phase One of high-value fit-out supply chain re-engineering.

	KPIs	Phase one – Shortened supply chain
SCM KPIs	Stock levels/safety stock	N/A
	Total response time	8 days
	Total order cycle time	7 days
	Inventory costs	N/A
House building industry KPIs	Customer satisfaction (product and service)	Low-Medium (developer) Low (customer)
	Product quality / defects	Low
	Construction time	4 hours
	Construction costs	£41.5

Table 7.2 Performance summary for supply chain re-engineering phase one

7.4.2 Phase Two: Labour only

The next step is aimed at further shortening the ordering chain by having the developer ordering directly from Ventair as illustrated in Figure 7.3. For this purpose, the labour needs then to be hired on a labour only basis. Here, again, some savings are realised, as there is no opportunity for mark-up. Therefore, the developer satisfaction is improved and, as a result, customer satisfaction is also improved because the developer is more likely to spend the same amount of money for better quality fans. In this case, the developer gives notice to Ventair by first ordering and calling off the products required six days later.

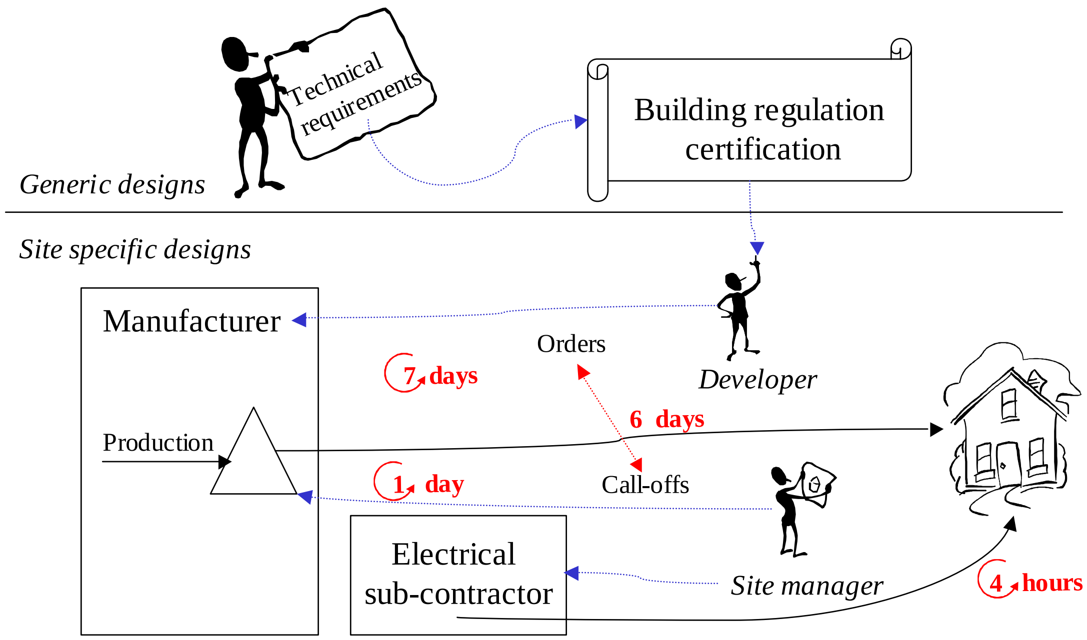


Figure 7.3 Phase Two: Shortened supply chain using labour only for extractor fans procurement

The performance summary for Phase Two of the supply chain re-engineering for high-value fit-out is presented in Table 7.3. The shortening of the supply chain, with the developer dealing directly with Ventair, has the potential to increase developer and customer satisfaction and reduce direct costs (or construction costs).

	KPIs	**Phase two – Shortened SC and labour only**
SCM KPIs	Stock levels/safety stock	N/A
	Total response time	8 days
	Total order cycle time	7 days
	Inventory costs	N/A
House building industry KPIs	Customer satisfaction (product and service)	Medium (developer) Medium (customer)
	Product quality / defects	Medium
	Construction time	4 hours
	Construction costs	£40

Table 7.3 Performance summary for supply chain re-engineering phase two

7.4.3 Phase Three: Technological change

The third phase is to consider a change of technology, which improves the high-value fit-out supply chain's performance. Instead of using extractor fans, which also require trickle vents on every window, a "Positive Input" Ventilation System (PIVS) can be utilised. PIVS inputs continuously fresher, clean and warm air into a house. It ventilates a house through air dilution, displacement and replacement. PIVS negates the use of trickle vents and any other extractor fans. The developer relies here on the 24-hour delivery promise and only gives an extra day notice to Ventair before calling off the products as seen in Figure 7.4. It is important however, to highlight that this change of technology in itself does not affect the supply chain structure. PIVS could still be procured through an electrical distributor, if required.

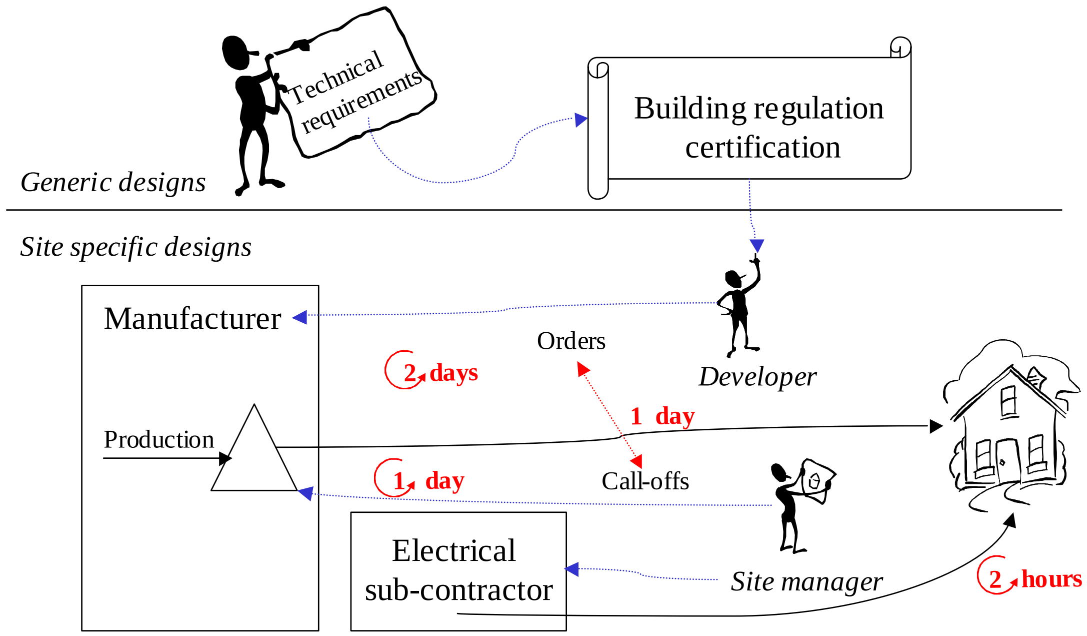


Figure 7.4 Phase Three: Shortened supply chain using labour only for PIVS procurement

Savings are made in terms of direct costs (or installed product costs) for a ventilation system in a typical three-bedroom house. In this case, the PIVS unit costs £25 and the installation £5, for a total installed cost of £30. Therefore, not only will it take less time to install a PIVS (two hours instead of four hours for extractor ventilation) but the direct costs for supply and installation are also reduced by a third. This, in turn, increases developer satisfaction; because for less money, it can procure a better ventilation system that is quicker to install.

The impact on performance of changing technology for high-value fit-out is summarised in Table 7.4.

	KPIs	Phase three – Technological change
SCM KPIs	Stock levels/safety stock	N/A
	Total response time	3 days
	Total order cycle time	2 days
	Inventory costs	N/A
House building industry KPIs	Customer satisfaction (product and service)	Medium-High (developer) Medium (customer)
	Product quality / defects	Medium-High
	Construction time	2 hours
	Construction costs	£30

Table 7.4 Performance summary for supply chain re-engineering Phase Three

7.4.4 Phase Four: Customer choice

By changing technology and shortening the supply chain, some improvements have been achieved in terms of ordering lead-times and direct costs. The customisation issue to give choice to customers has not yet been tackled and, therefore, the fourth stage is aimed at giving more choice to end-customers. For that purpose, design criteria can be developed so that a house can be fitted with four different types of ventilation systems (mechanical extract ventilation systems, positive input ventilation systems, passive stack ventilation systems and heat recovery ventilation systems). The design criteria consist of guidelines for architects, which for minimum extra costs during the construction stage allow the installation of any kind of ventilation system in a house. These guidelines can incorporate alterations ranging from a simple plug in the loft space to openable windows and “built in” ducting up to 150 mm diameter. “Build costs” (cost for the installed products) for any of these systems range from £35 to £100 depending on the quantity, the system chosen and the level of sophistication required. Even the most sophisticated system should have a delivery period, from order, of no longer than one working week.

As shown previously, it appears that customers aspire to more choice when purchasing a new house. However, the need to give the choice of ventilation *systems* to customers can be questionable. Its seems more realistic that house developers would choose one type of ventilation system (i.e. mechanical extract ventilation systems) and give choices to their customers over different *options* for that specific system. The design criteria can be reduced to that specific ventilation system and the system itself could be fitted at the last minute, once the end-user has chosen his preferred option.

As an example, if a house developer decides to utilise PIVS for all its houses, it will still be able to offer eight choices to their customers. The choices encompass the frequency for the maintenance of the unit, the option for heat recovery, options for control strategies, boost facility, and a combination of the aforementioned. The “build costs” for this, as presented above, are £30 for a three-bedroom house. In this scenario the developer advises their customer that they will have to wait 8 days from their decision for a specific unit, to the installed product, as illustrated in Figure 7.5. The developer will still be able to give 5 days notice to Ventair before calling off the products.

Customer satisfaction is improved, therefore, as choice is offered (Stalk and Hout, 1990). The performance for such a supply chain is displayed in Table 7.5.

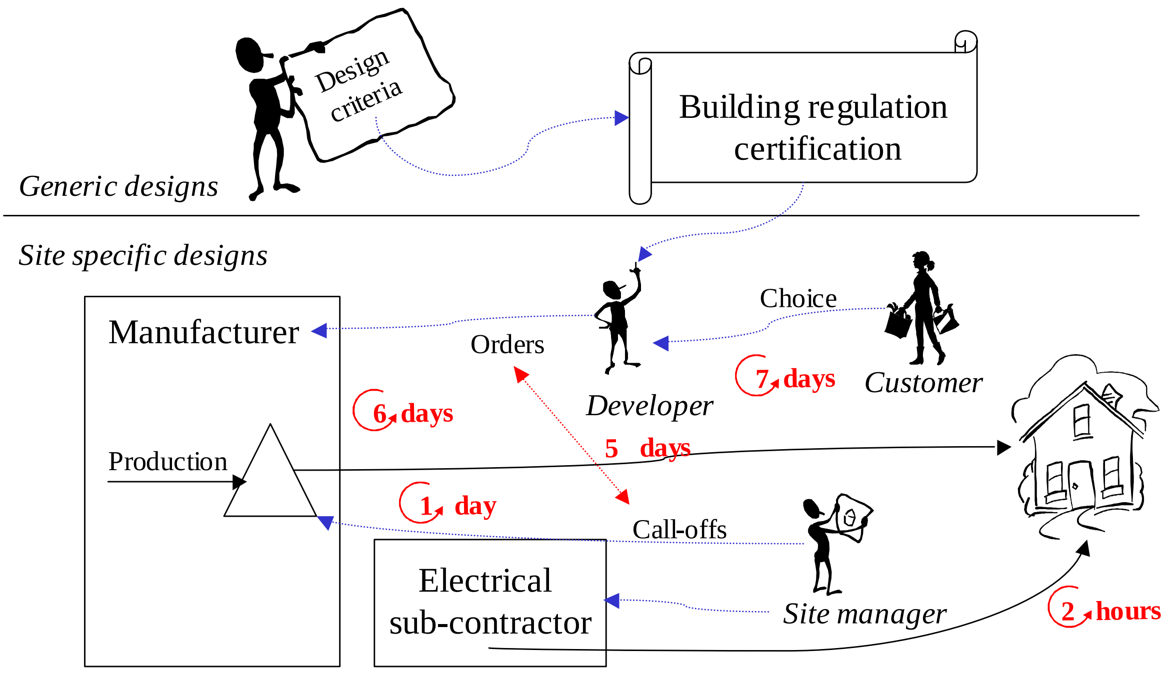


Figure 7.5 Phase Four: Customer choice for PIVS variances supply chain

	KPIs	Phase Four – Customer choice over system options
SCM KPIs	Stock levels/safety stock	N/A
	Total response time	8 days
	Total order cycle time	7 days
	Inventory costs	N/A
ouse building industry KPIs	Customer satisfaction (product and service)	High (developer) High (customer)
	Product quality / defects	Medium - High
	Construction time	2 hours
	Construction costs	£30

Table 7.5 Performance summary for supply chain re-engineering Phase Four

7.4.5 Phase Five: Supply-and-fit

Finally, in order to further improve the quality of the installed product, Ventair can offer a supply-and-fit service. In this case, the installers are fully trained by Ventair. The developer only needs to order the PIVS units and they will be delivered and fitted by Ventair as illustrated in Figure 7.6. This also has the advantage to simplify site coordination as the site manager only has to call off the products, and Ventair organises the labour.

As a further improvement, developers can also offer their customer a 3-day response time, from their choice of option to the installed product. This will still permit the developer to give an extra day's notice to Ventair.

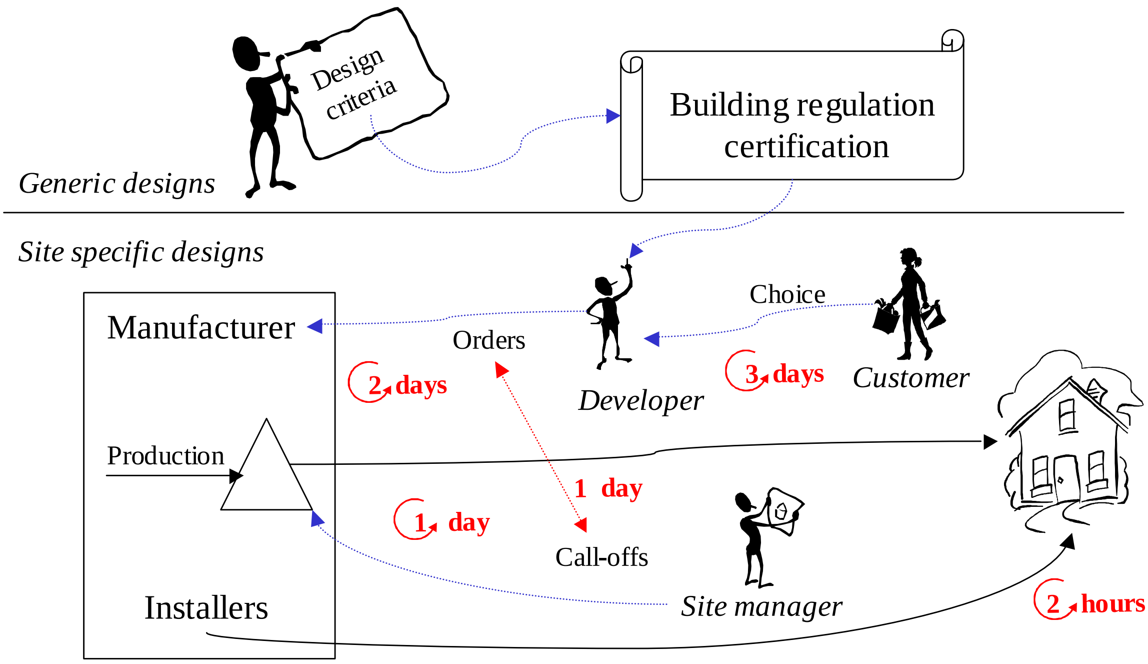


Figure 7.6 Phase Five: Supply-and-fit of PIVS variances

The performance results for a supply-and-fit service are summarised in Table 7.6.

	KPIs	Phase Five – Supply-and-fit service
SCM KPIs	Stock levels/safety stock	N/A
	Total response time	3 days
	Total order cycle time	2 days
	Inventory costs	N/A
House building industry KPIs	Customer satisfaction (product and service)	High (developer) High (customer)
	Product quality / defects	High
	Construction time	2 hours
	Construction costs	£30

Table 7.6 Performance summary for supply chain re-engineering Phase Five

7.4.6 Summary of the re-engineering scenarios

Table 7.7 summarises the baseline and the five re-engineering scenarios in terms of number of agents involved, the involvement of each agent, the level of choice, the type of innovation introduced, the customer delivery cycle time and the installation costs.

Scenario	0 (baseline)	1	2	3	4	5
No. of agents	**5**	**4**	**4**	**4**	**5**	**4**
Architect	**Makes exact ventilation system specification**				**Develop open design specifications**	**Develop bounded open design specifications**
Developer	**Employ sub-contractor. Supply & fit**		**Order direct from manufacturer Labour only**			**Order direct from manufacturer Supply & fit**
Electrical sub-contractor	**Procure from electrical distributor and install**	**Procure from manufacturer and install**	**Install only**			-
Electrical distributor	**Procure from manufacturer**	-	-	-	-	-
Manufacturer	**Supply to electrical distributor**	**Supply to electrical sub-contractor**	**Supply to developer**			**Supply to developer and install**
Customer	**No choice**				**Choice of ventilation systems**	**Choice of option in ventilation systems**
Innovation	-	**Removing one echelon from SC**	**Centralised co-ordination**	**Alternative technology**	**Modular systems**	**Modular systems and value added service by manufacturer**
Customer delivery cycle time	**8 days**	**8 days**	**8 days**	**3 days**	**8 days**	**3 days**
Installation cost (normalised)	**£43**	**£41.5**	**£40**	**£30**	**£30**	**£30**

Table 7.7 Summary of the re-engineering scenarios (Hong-Minh and Naim, 2001)

7.5 Implications on supply chain dynamics

The impact on performance for the different re-engineering stages for high-value fit-out supply chain has been analysed, however, the impact on supply chain dynamics has not yet been studied and needs to be taken into consideration if a full performance appraisal is to be carried out. This section will first briefly describe the scenarios taken into consideration, then the simulation results will be presented with a summary of those results.

7.5.1 Scenarios description

The scenarios taken into consideration are the five re-engineering phases and the Baseline scenario studied in the previous section.

The Baseline scenario models a four-echelon supply chain: developer, electrical sub-contractor, electrical distributor and Ventair. The first two echelons simply pass on the demand without distorting or amplifying it. The distributor and Ventair utilise an IOBPCS based replenishment mechanism as described in Chapter 5. The delays are as described in the previous section and summarised in Table 7.8. Phase One scenario only takes into consideration three echelons by eliminating the distributor. For both Baseline and Phase One scenarios, labour is provided on a supply-and-fit basis. Phase Two moves away from "supply-and-fit" to a "labour only" policy. In this case Home Builder supply direct from Ventair which means that the supply chain only has two echelons. The only difference with Phase Three is that instead of procuring extractor fans, PIVS units are used. This influences the stock holding cost (50% more expensive, as the one unit costs twice as much as four extractor fans) and the order cycle time is reduced from 7 to 2 days. Phase Four adds an echelon to the supply chain by incorporating the end-customer demand, which is simply passed on by Home Builder to Ventair. Here the delays are slightly different, as Home Builder gives 5 day's notice to Ventair before calling off the products, as seen in Table 7.8. Finally, Phase Five uses a supply-and-fit strategy, utilising Ventair's fitters, and shortens the ordering cycle time.

	Baseline	**Phase one** **Shortened SC**	**Phase two** **Labour only**	**Phase three** **Technology change**	**Phase four** **Customer choice**	**Phase five** **Supply & fit**
Customer order to developer	-	-	-	-	1 day	1 day
Order to call off lead time	-	-	6 days	1 day	5 days	1 day
Call off to delivery lead time	7 days	7 days	1 day	1 day	1 day	1 day
Sub-contractor retain information	4 days	6 days	-	-	-	-
Order to delivery from merchants	3 days	-	-	-	-	-
Manufacturing lead-time	1 day	1 day	1 day	1 day	1 day	1day
Miscellaneous	Supply-and-fit	Supply-and-fit	Labour only	Labour only	Labour only	Supply-and-fit

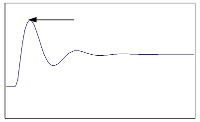
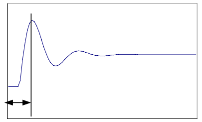
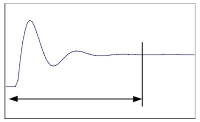
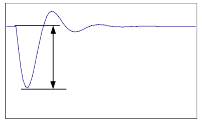
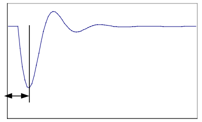
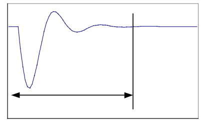
Table 7.8 Summary of the parameters for the six scenarios

7.5.2 Simulation results

Each scenario has been simulated daily for a step change in demand over a period of 3 years. The step change in demand increased from 100 to 120 houses at day 20.

Table 7.9 displays the ranking of the 6 different scenarios for the dynamic results using the system dynamics criteria presented in Chapter 2. As in the previous section, for ease of presentation, the results presented are for Ventair as the dynamic effects are the worst at the lowest echelon in the supply chain. A linear scale is used with six stars for the best and one star for the worst results.

The Baseline scenario achieves the worst performance for the order rate peak, time and recovery. This is induced by the presence of the electrical distributor, which distorts and amplifies the demand. However, the stock depletion level, time and recovery are worst for Phase One. Furthermore, it can be seen when comparing the results of Phase Two with Phase Four, and Phase Three with Phase Five, that introducing customer demand into the models deteriorates the dynamic performance.

Scenarios	Peak Value 	Peak Time 	Order Recovery 	Stock Depletion 	Trough Time 	Stock Recovery 	Scenarios Performance
Baseline	*	*	*	**	**	******	**
Phase One Shortened	**	***	**	*	*	*	*
Phase Two Labour only	******	******	***	******	******	**	******
Phase Three Technology	****	*****	******	****	*****	*****	******
Phase Four Customer choice	*****	***	*****	******	*****	****	****
Phase Five Supply-and-fit	****	****	*****	****	***	****	***

Where ****** represents the best performance and * the worst

Table 7.9 Ranking of the different scenarios for dynamic performance criteria at the manufacturers for a step change in the demand

For ease of understanding, the dynamic performance can be summarised under two performance criteria: the production on-costs and the integrated absolute error (IAE) for the inventory level for the manufacturer. In addition, the total supply chain inventory cost was also evaluated and rated from the simulations. Table 7.10 shows the ranking for these three performance criteria.

Scenarios	Production on-costs	IAE inventory	Total SC inventory costs	Scenario performance
Baseline	*	*	*	*
Phase One Shortened	**	**	******	***
Phase Two Labour only	******	******	*****	******
Phase Three Technology	****	***	***	***
Phase Four Customer choice	*****	*****	**	*****
Phase Five Supply-and-fit	***	****	****	****

Where ****** represents the best performance and * the worst

Table 7.10 Scenarios' ranking for a step change in demand

The total supply chain inventory cost achieves its best performance in Phase One scenario, this can be explained by the fact that at the same time, the stock level for Phase One is the most depleted. Therefore, the total level of stock carried by Ventair is lower (as its stock is most used to respond to the demand) and consequently the total supply chain costs are also lower. Not surprisingly, the total supply chain inventory costs is at its highest for Baseline, as it utilises an electrical distributor, which also carries stock.

The rating of each scenario is as important as the ranking, as it shows the magnitude of the impact made by each scenario in comparison with the Baseline scenario. The rating of the scenarios in comparison with the Baseline scenario is presented in Table 7.11. It can be seen that the impact on production on-costs varies between 51% and 99%. This concurs with the fact that simplifying the supply chain by removing an echelon improves the dynamic behaviour of the model (e.g. Forrester, 1961; Wikner et al., 1991). This clearly shows that having an extra echelon, the electrical distributor, amplifies greatly the demand pattern. In the same way, total supply chain inventory costs are also reduced by 25% to

50%, depending on the scenario. It should be remembered that the reason why scenarios Three, Four and Five do not impact so strongly on the inventory costs lies in the fact that the stock holding cost was set 50% more expensive for PIVS as for extractor fans.

Scenarios	Production on-costs	IAE inventory	Total SC inventory costs
Phase One Shortened	-51%	-27%	-50%
Phase Two Labour only	-99%	-73%	-50%
Phase Three Technology	-95%	-35%	-25%
Phase Four Customer choice	-98%	-70%	-25%
Phase Five Supply-and-fit	-92%	-36%	-25%

Table 7.11 Impact of the scenarios on performance criteria in comparison with the Baseline scenario for a step change in demand

It is also possible to study the impact of the re-engineering strategy from one phase to another. Table 7.12 presents the level of impact from one phase to the next for a step change in demand. When comparing Baseline with Phase One, it can be noted that by removing the electrical distributor the dynamics of the model have improved and the total supply chain inventory costs has been reduced by 50%. This concurs with Forrester (1961) and Wikner et al. (1991). When considering the differences between Phases One and Two, it can be noted that having Home Builder dealing directly with Ventair, giving it 6 day's notice, strongly improves the dynamic behaviour by improving the production on-costs and IAE for inventory, as demonstrated by Mason-Jones (1998).

To move from Phase Two to Phase Three, the order to call-off lead-time has been reduced from 6 to 1 day and the inventory costs have been increased by 50% due to the change of product. Not surprisingly, the total supply chain inventory costs increase by 50%, while the dynamic behaviour worsens as Ventair does not receive a long advance notice.

Scenarios	Production on-costs	IAE inventory	Total SC inventory costs
Phase One Shortened	-51%	-27%	-50%
Phase Two Labour only	-97%	-63%	+0.1%
Phase Three Technology	+339%	+136%	+50%
Phase Four Customer choice	-58%	-53%	+0.01%
Phase Five Supply-and-fit	+295%	+113%	-0.03%

Table 7.12 Ranking for a step by step comparison between the scenarios for a step change in demand

The differences between Phases Three and Four are that the end-customer inputs his demand and the order to call-off lead-time is increased from 1 to 5 days. This impacts on the dynamic behaviour of the model by improving production on-cost (reduced by 58%) and IAE for inventory (reduced by 53%). Finally, the only difference between Phases Four and Five is the reduction of the order to call-off lead-time from 5 to 1 day, which, once again, worsen the dynamic behaviour of the model.

In summary, it must be noted that removing an echelon in the supply chain improves the dynamic behaviour of the model and reduces overall inventory costs. Furthermore, as seen in the previous section, the more notice that is given to Ventair the better is the dynamic response.

7.6 High-value fit-out findings summary

The performance for the high-value fit-out's supply chain has been the subject of analysis in this chapter. It was seen that as the manufacturer studied here, Ventair, has its internal processes sorted out and is able to offer a 24-hour delivery service to a large a number of customers. The traditional supply chain utilising an electrical distributor can be shortened by dealing direct with Ventair. Further supply chain re-engineering can be undertaken so as to further reduce the lead times, use a different technology and offer some choices to the customers.

The supply chain principles considered in this chapter were:

1) the shortening of the supply chain,
2) the reduction of total cycle time across the supply chain and
3) focus on end-customer demand which led to offer more choices (Houlihan, 1985; Davis, 1993; Davies, 1995; Sabath, 1995; Bowersox and Closs, 1996; Lamming, 1996).

Each principle had an effect on performance. The shortening of the supply chain reduced the construction costs from £43 to £40, reduced the total supply chain inventory costs by 50% and improved the dynamic behaviour by more than 50%. The reduction of the order cycle time had a negative impact on the dynamic behaviour of the models by increasing the production on-costs and the IAE for the inventory level. Focusing on the customer by offering more choice improved customer satisfaction, but had a slightly negative impact on the dynamic behaviour of the model. Finally, the change of technology reduced direct costs and installation time.

The overall results for all the scenarios are presented in Table 7.13, while Table 7.14 presents the results utilising MAUT; allowing a comparison of the overall performance score of each strategy. An equal weighting system has been implemented for the three KPI types (SCM, house building industry and system dynamics) as they are equally important to calculate the overall performance.

Due to the fact that the safety stock level is directly derived from the stock depletion level of the simulation, it was only taken into consideration once. The overall performance results show that Phase Five achieve the best results followed by Phase three (the lower the score, the better the performance). This means that reducing the total cycle times, changing technology, being customer focused by offering choice to customers and shortening the supply chain are all impacting positively on the overall performance.

It must be highlighted, however, that if these supply chain re-engineering phases are feasible, it is thanks to Ventair, which is able to produce customised products in the extremely short lead-time of one day. Furthermore, they are willing and ready to deal with a large number of customers; they want to get as close as possible to the end-customer so as to have more control over the demand and reduce uncertainties.

The supply-and-fit service is becoming increasingly popular in the private house building industry for high-value fit-out. It allows the developer to reduce the complexity of co-ordination on-site and increases the quality of the installed product. This applies not only for ventilation systems but also for kitchens units. It also reduces the developers risk against goods being damaged during transport and installation. The strategy also gives Ventair control over the quality of the installed product, as the installer is fully trained by Ventair.

	KPIs	Traditional extractor fans supply chain	Phase one – Shortened supply chain	Phase two – Shortened SC and labour only	Phase three – Technological change	Phase Four – Customer choice over system options	Phase Five – Supply-and-Fit service
SCM KPIs	Stock levels/safety stock	17.5*	20*	0*	5*	0*	5*
	Total response time	8 days	8 days	8 days	3 days	8 days	3 days
	Total order cycle time	7 days	7 days	7 days	2 days	7 days	2 days
	Inventory costs	£523,150*	£261,440*	£261,800*	£392,550*	£392,610*	£392,490*
House building industry KPIs	Customer satisfaction (product and service)	Low (developer) Low (customer)	Low-Medium (developer) Low (customer)	Medium (developer) Medium (customer)	Medium-High (developer) Medium (customer)	High (developer) High (customer)	High (developer) High (customer)
	Product quality / defects	Low	Low	Medium	Medium-High	Medium - High	High
	Construction time	4 hours	4 hours	4 hours	2 hours	2 hours	2 hours
	Construction costs	£43	£41.5	£40	£30	£30	£30
Dynamical KPIs	Peak value	147*	135*	118*	132*	123*	132*
	Peak time	30*	29*	22*	23*	29*	24*
	Order recovery	81*	76*	70*	67*	68*	68*
	Stock depletion	17.5*	20*	0*	5*	0*	395*
	Trough time	26*	27*	21*	22*	22*	23*
	Stock recovery	60*	74*	68*	64*	65*	65*

* indicates relative values from the simulations

Table 7.13 Overall performance for the different scenarios

	KPIs	Weighting	Traditional extractor fans supply chain		Phase one – Shortened supply chain		Phase two – Shortened SC and labour only		Phase three – Technological change		Phase Four – Customer choice over sys. options		Phase Five – Supply-and-Fit service	
			Index	Value	Index	Value	Index	Value	Index	Value	Index	Value	Index	Value
SCM KPIs	Stock levels/safety stock	0	100	0	143.3	0	0	0	28.6	0	0	0	28.6	0
	Total response time	0.0833	100	8.33	100	8.33	100	8.33	37.5	3.125	100	8.33	37.5	3.12
	Total order cycle time	0.0833	100	8.33	100	8.33	100	8.33	28.6	2.38	100	8.33	28.6	2.38
	Inventory costs	0.0833	100	8.33	49.9	4.15	50	4.16	75	6.25	75	6.25	75	6.25
	Customer satisfaction (product and service)	0.0833 0.0833	100 100	8.33	87.5 100	7.29 8.33	75 75	6.25 6.25	62.5 75	5.20 6.25	50 50	4.16 4.16	50 50	4.16 4.16
House building industry KPIs	Product quality / defects	0.0833	100	8.33	100	8.33	75	6.25	62.5	5.20	62.5	5.20	50	4.16
	Construction time	0.0833	100	8.33	100	8.33	100	8.33	50	4.16	50	4.16	50	4.16
	Construction costs	0.0833	100	8.33	96.5	8.04	93	7.75	69.7	5.80	69.7	5.80	69.7	5.80
Dynamical KPIs	Peak value	0.0555	100	5.55	91.8	5.1	80.2	4.45	89.8	4.98	83.7	4.65	89.8	4.98
	Peak time	0.0555	100	5.55	96.7	5.37	73.3	4.07	76.7	4.26	96.7	5.37	80	4.44
	Order recovery	0.0555	100	5.55	93.8	5.21	86.4	4.8	82.7	4.59	83.9	4.66	83.9	4.66
	Stock depletion	0.0555	100	5.55	114.3	6.35	0	0	28.6	1.58	0	0	28.6	1.58
	Trough time	0.0555	100	5.55	103.8	5.76	80.8	4.48	84.6	4.7	84.6	4.7	88.5	4.91
	Stock recovery	0.0555	100	5.55	123.3	6.85	113.3	6.29	106.7	5.92	108.3	6.01	108.3	6.01
		1	Total value:	**100**	Total value:	**95.80**	Total value:	**79.77**	Total value:	**64.46**	Total value:	**71.83**	Total value:	**60.85**

Table 7.14 Assessment of the different scenarios using MAUT technique

7.7 References

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Chapter 8 The low-value fit-out supply chain

Research questions

- Which SCM principles can be applied to the low-value fit-out's supply chain?
- How do these principles impact on the performance of low-value fit-out's supply chain?

8.1 Introduction

Having studied the house shell and the high-value fit-out supply chains, the low-value fit-out supply chain can now be examined. The data presented in this chapter is based on an in-depth case study and data gathered during the TSM as explained in Chapter 3, while the performance is assessed using the SCM, private house building and system dynamics KPIs presented in Chapters 2 and 4.

The purpose of this chapter is to investigate which SCM principles, as defined in Chapter 2, can be implemented in the low-value fit-out supply chain. Then, the author will analyse if these principles can improve performance. To achieve this, a review of the current state of the low-value fit-out supply chain is presented where "Hot spots" have been identified. This is followed by a presentation and evaluation of possible solutions to overcome these "Hot spots". The first solution is the centralisation of supply by turning away from a regional procurement with multiple merchants. The second solution consists of sharing customer information across the supply chain and finally the third step considers the synchronisation of lead-times between trading partners.

The performance is assessed based on the data collected during the in-depth case study and simulations are used to assess the dynamic performance. Finally the results are summarised using the MAUT technique which allows taking into consideration all the performance criteria to select the "best" performing scenario.

8.2 The low-value fit-out supply chain current state

As discussed in Chapter 3, the house components can be divided into three categories, the house shell, the high-value fit-out and the low-value fit-out. This section is concerned with the latter.

Typically for bulk or low-value items such as skirting boards, steel lintels, door linings, doors, hinges, etc., the supply process is carried out via multiple merchants and manufacturers on a regional basis. Figure 8.1 illustrates as a rich picture the broad view of a house building supply chain. The focus is placed upon the major issues of planning and control for the supply chain. Seven "hot spots", summarised in Table 8.1, have been identified during the TSM by the author and have been reported in Naim and Barlow (2000).

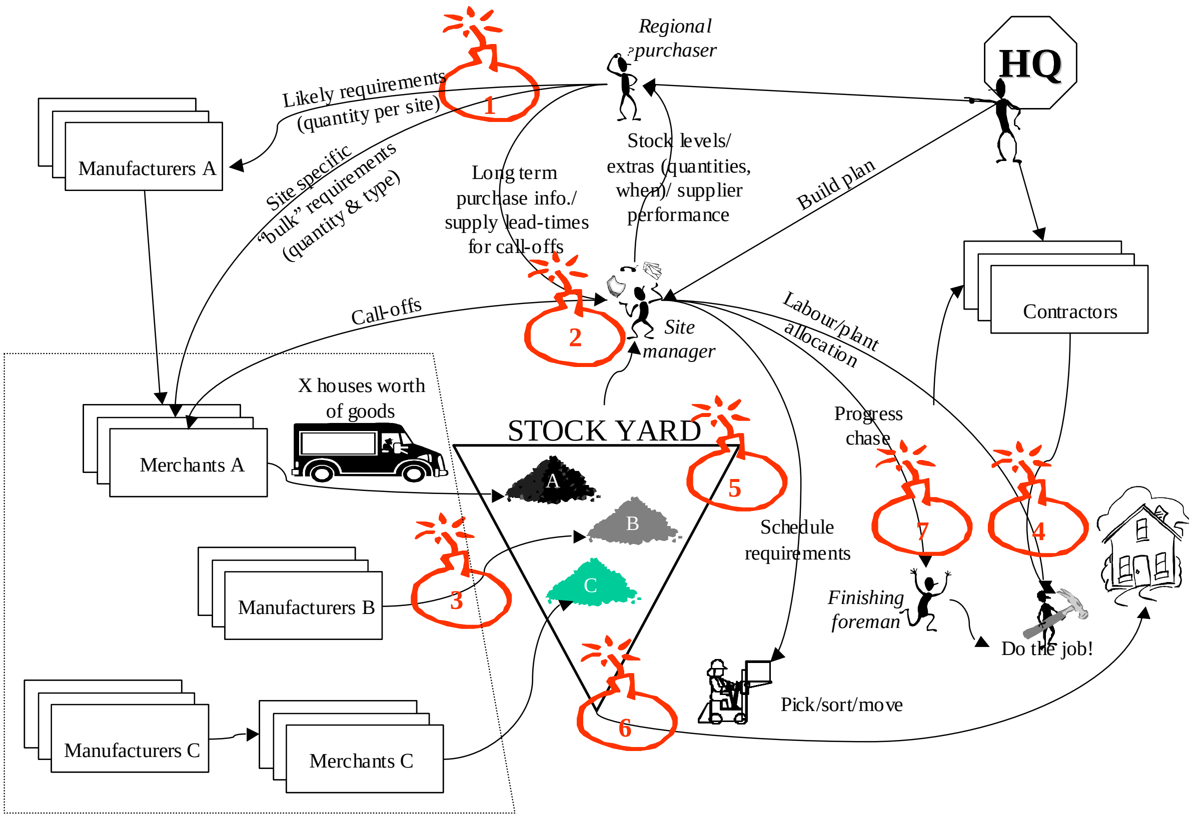


Figure 8.1 Rich picture representation of the "traditional" supply chain for low-value fit-out (Naim and Barlow, 2000)

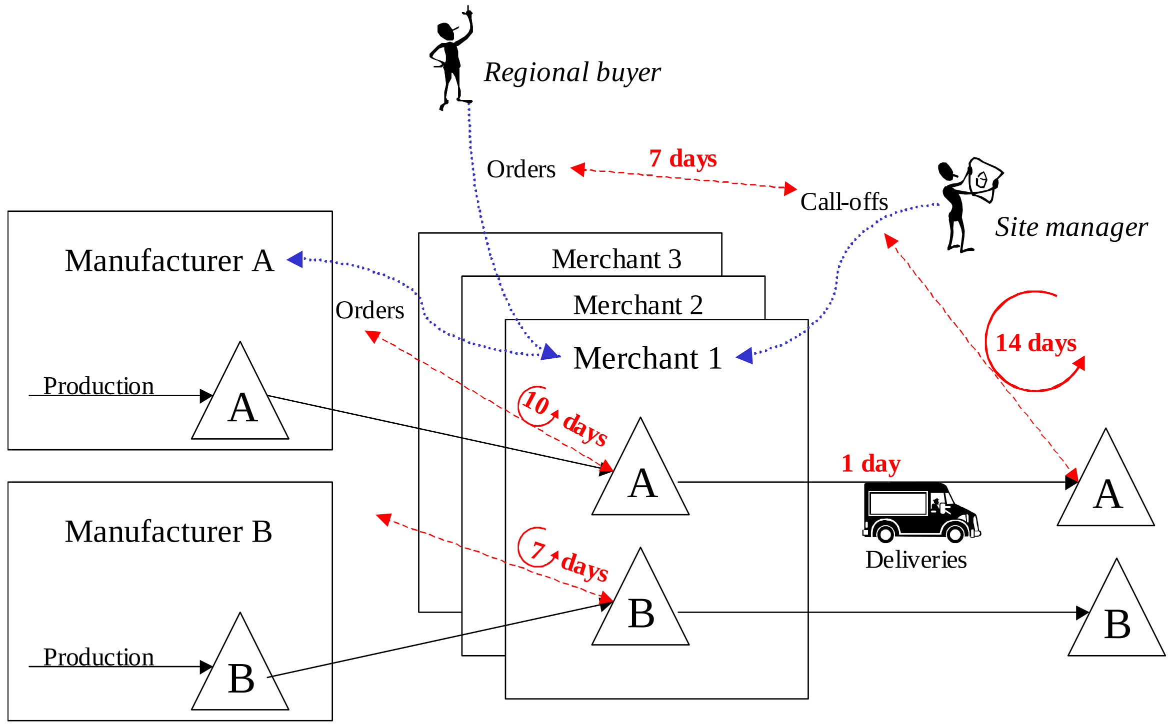
As can be seen from Figure 8.1, the products are ordered by the regional buyer and called off by the site manager when required. The products are then delivered to site in a stock yard from which the products are selected, sorted and moved to the exact construction location.

	Root Causes	Symptoms
Hot spot 1 : No use of market knowledge	• Regionally based buying agreements • Purchase based on price • No time scale guarantee for actual buying and calling off the material	Suppliers have little visibility of long-term market requirements
Hot spot 2: Lack of supply chain integration	• The site manager has co-ordinated a large amount of people and tasks • He holds a considerable amount of information • No clear strategy of how best to utilise the information	Very poor information transfer and use across the supply chain
Hot spot 3: No time compression strategy	• Lack of supplier development and adversarial relationships • Volatile short-term call off information from the site • Late changes in site requirements	Poor supplier delivery performance
Hot spot 4: Inability to rapidly re-configure	• No medium term planning horizon given to sub-contractors • High work uncertainty pushes sub-contractors to commit themselves to several tasks	Poor availability of contractors on-site
Hot spot 5 and 6: Excessive muda, or waste	• High level of stock on-site to buffer against uncertainties • No designated stocking area and proper recording mechanism lead to damage, mislaying or theft of material	Poor availability of material on-site
Hot spot 7: Muda	• Above problems lead to the need for a finishing foreman to chase material, chase labour and assign re-work and snag list	Dissatisfied customer (poor total value)

Table 8.1 Summary of Hot spots in the traditional supply chain of low-value fit-out material (Adapted from Naim and Barlow, 2000)

As can be seen from Table 8.1, the “hot spots” cover a range of issues from lack of customer information to wastage and lack of supply chain integration. These “hot spots” can be identified by their symptoms such as poor supplier delivery performance, poor availability of material on-site or unsatisfied customers. However what needs to be tackled are the root causes, for example the adversarial approach to trading, or regional buying arrangements and purchased price based on price, or even the lack of strategy for utilising the information available.

For simplicity of understanding and analysis, the traditional low-value fit-out supply chain can be simplified as shown in Figure 8.2. Only two manufacturers (A and B) have been here considered, a door manufacturer and a skirting boards manufacturer respectively. The lead times presented were collected during the in-depth case study. The site manager has to wait a minimum of 7 days after the order is being placed by the regional buyer, before he can call off the material from merchants. It usually takes 14 days for the merchant to fulfil that order, one day being taken up by the transport of material on-site. Several different merchants are used by different regional buyers, however, even within the same regions, a multiple number of merchants are used to procure different products, generally 2 to 3 per site.



Where A represents doors and B skirting boards

Figure 8.2 Traditional low-value fit-out supply chain

The replenishment of doors requires a 10-day lead-time while the replenishment of skirting board requires a 7-day lead-time. Furthermore, as identified in the hot spot, the relationships between the companies are adversarial. Home Builder's satisfaction is low with regards to the availability of material as highlighted in hot spots 5 & 6. Customer satisfaction is also low as identified in hot spot 7.

Predictability on costs and time is also low, resulting from wasted, damaged and stolen material. Some materials, believed to be in the stock yard, might have been misplaced, stolen or damage and replacement material will need to be ordered delaying the construction process. Furthermore, the unreliability of deliveries also complicates the prediction of the finishing date. Table 8.2 presents the performance appraisal for a traditional low-value fit-out supply chain based on the SCM and private house building KPIs.

	KPIs	Traditional low-value fit-out supply chain
SCM KPIs	Stock levels	N/A
	Total order cycle time	21 days
	Inventory costs	N/A
SCM KPIs / House building industry KPIs	Customer satisfaction (product and service)	Low (Home Builder) Low (customer)
House building industry KPIs	Product quality / defects	Low
	Predictability costs	Low
	Predictability time	Low

Table 8.2 Summary of traditional low-value fit-out supply chain performance

8.3 Re-engineering the low-value fit-out supply chain

The previous section highlighted seven "Hot spots" present in the traditional low-value fit-out supply chain. Three phases to improve performance have been identified and are described in this section. The first step is to move away from localised supply through multiple merchants to the use of one national distributor. The second step focuses on improving the information flow across the supply chain. Finally, the third step is concerned with the synchronisation of lead-times across the supply chain.

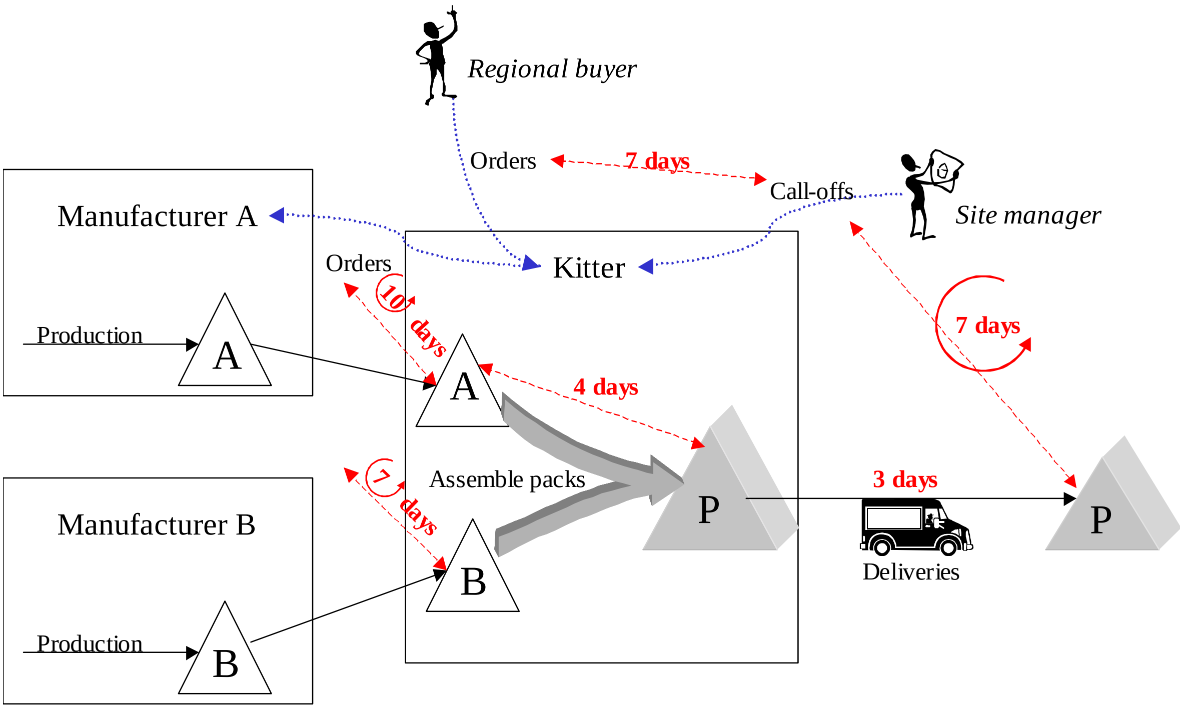
8.3.1 Merchant's integration

To address "Hot spots" 3, 5, and 6 - poor supplier delivery performance and poor availability of material on-site – one possible solution is to use only one merchant, which will be called Kitter. There are different reasons behind this strategy. First, the merchants are usually selected based on price by the regional buyers, therefore several different merchants all over the country are used for the procurement of low-value fit-out materials. Instead, one single merchant is used in this strategy. This means that regional buyers do not have to look for the cheapest merchant available but simply place their orders with that single Kitter. This is only possible as it will be seen later on, because Kitter has been vertically integrated and is therefore part of Home Builder, and the prices are guaranteed to be lower (Kitter, 2000 and documentation proof).

Second, only using Kitter to procure all material needed on a nation wide basis increases the buying power. It also allows Kitter to negotiate directly with most manufacturers, as the buying quantities are larger. The approximate turnover for a large merchant is £250 million, £40 million for Kitter and £30 million for a small to medium merchant. The builder’s merchants sector is more and more concentrated as large merchants have greater buyer power (Agapiou et al., 1998; Anon, 1998). Kitter is dealing with 26 suppliers, of which 18 are manufacturers. If one third of the materials are still purchased through third parties, it is due to the reluctance of the manufacturers to deal directly with a rather small customer (smaller than large merchants). As mentioned above, the prices are also guaranteed to be lower through Kitter. For example a specific type of skirting board would be sold at £0.45 per meter while a standard merchant would sell it for £0.53 per meter, or in other words, Kitter would be 15% cheaper. For a specific architrave, Kitter would sell at £1.13 per meter against £1.30 per meter from a merchant, which is another 13% discount.

Third, not only are all the low fit-out materials bought from Kitter, but they are also sent in packs. All materials for low-value fit-out are distributed in 7 packs for masonry construction and only 4 packs for timber frame construction. Each pack is specifically aimed at different levels of construction of a house (starter pack, roof pack, first fix pack, etc.). For example, in pack number 5, items such as external doors, skirting, architrave, doorstop, internal doors, hinges and door latches and locks are packed together for a specific house type. The idea behind the use of packs is to reduce waste on-site arising from damaged, mislaid, and stolen material in the stockyard. That way, stock on-site can be minimised. Furthermore, it also reduces deliveries on-site as one delivery of packs is the equivalent of 6 deliveries. Finally it assures a faster assembly process as the whole kit is available at once and therefore all the parts needed for one part of the construction process are readily available. This concept of packs is similar to kitting which is found mainly in the electronic industry. Bozer and McGinnis (1984) define a kit as *"a specific collection of components and/or subassemblies with other kits (if any) support one or more assembly operations for a given product"*. The use of such a system is appropriate for products with numerous parts or high-value components, of for the quality assurance of the assembly (Johansson, 1991).

Fourth, using Kitter, allows a reduction from 14 to 7 days for delivery lead-time from the call off. This 7-day lead-time is made of 4 days to prepare the packs and 3 days for the delivery of the packs, as can be seen from Figure 8.3. Furthermore, as Home Builder has vertically integrated Kitter, the control over stock is kept within Home Builder. The reason for setting up Kitter and not using traditional merchants lies in the fact that the latter's service level was too poor and they could not find sufficient resources to provide such a service to one customer when dealing with over 3000 different customers.



Where A represents doors and B skirting boards

Figure 8.3 Low-value fit-out supply chain using Kitter

Home Builder satisfaction for the new service was only rated as medium by site managers because Kitter was just starting and the service provided was not yet 100% reliable. End-customer satisfaction was rated as medium during the interviews with personnel from Home Builder and Kitter, because they received better value for money since waste on-site was minimised. Through the use of kitting, the quality of the assembled product (the house), is improved and the material is less likely to be damaged in the stockyard. Finally, as can be seen from Table 8.3, predictability of costs and time was estimated by the interviewees to be medium. As Kitter is devoted to Home Builder, the reliability of delivery is high and the costs of material is levelled as less material needs to be replaced. However, it was only rated as medium due to the fact that Kitter was just starting and therefore the service was not yet 100% reliable.

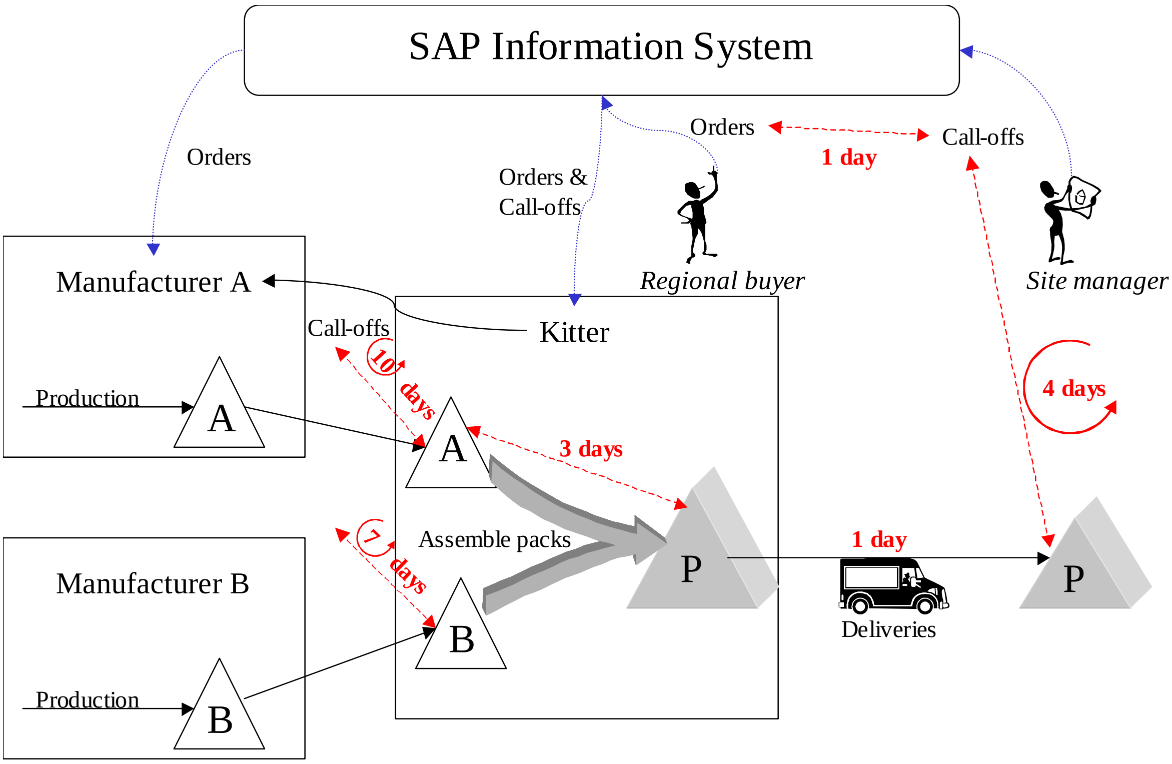
	KPIs	**Kitter's low-value fit-out supply chain**
SCM KPIs	Stock levels	N/A
	Total order cycle time	14 days
	Inventory costs	N/A
SCM KPIs / **House building industry KPIs**	Customer satisfaction (product and service)	Medium (Home Builder) Medium (customer)
House building industry KPIs	Product quality / defects	High
	Predictability costs	Medium
	Predictability time	Medium

Table 8.3 Summary of Kitter's low-value fit-out supply chain performance

8.3.2 Information flow integration

To address the "Hot spots" 1, 2 and 3 (little visibility of long term market requirements by suppliers, very poor information transfer and use across the supply chain, and poor supplier delivery performance), improvements on information flow need to be made. The root causes of the three "Hot spots" are the amount and availability of information. One way to share information with several different organisations in a timely and accurate fashion is to use IT (Jones, 1990; Lee and Billington, 1992; Handfield and Nichols, 1999). In the present case, Home Builder decided to use the SAP/R3 system. Based on the results of the task force carried out by the author, it was agreed with Home Builder that the new information system would be accessible by site managers, regional buyers, Kitter and manufacturers. The build programme will be posted on the system and up-dated as required, therefore all the organisations involved will have access to accurate information on the site progress. Furthermore, the ordering and calling off processes will also be automated and carried out via the information system.

As the system has not yet been fully implemented, the results presented here are based on the opinions of several managers working for Home Builder and Kitter. It is expected that total order cycle time will be reduced to 5 days. One day advance notice before calling off the packs will suffice for Kitter (this is based on the assumptions that the house design is standardised and that Kitter is in possession of the drawings), therefore the packs could be assembled within 3 days. Finally, as can be seen from Figure 8.4, the delivery lead-time could be cut down to 1 day. This is already happening in most cases, the three days presented in the previous section being a buffer rather than a necessity. This buffer in planned time is common in the industry (Wegelius-Lehtonen and Pahkala, 1998).



Where A represents doors and B skirting boards

Figure 8.4 Low-value fit-out supply chain with information integration

The results presented in Table 8.4 are based on interview results carried out with personnel from Home Builder and Kitter, about their views on the future plans to use the SAP information system to transfer data. The interviews suggest that Home Builder satisfaction is improved as the lead-times are reduced and the two companies, Home Builder and

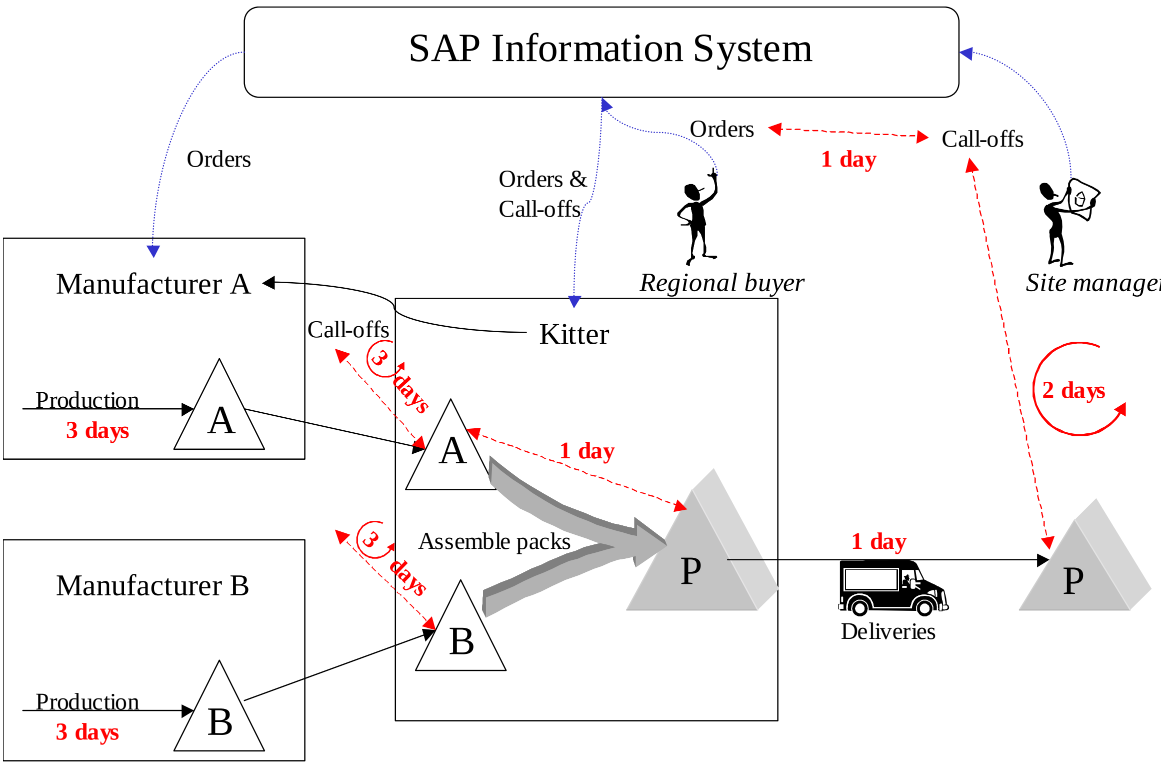
Kitter, should start to trust one another. The product quality being high, customer satisfaction is expected to be high. Finally, as Kitter will have access to accurate data, materials will be readily available and this will increase the predictability of costs and time.

	KPIs	Integrated information for low-value fit-out supply chain
SCM KPIs	Stock levels	N/A
SCM KPIs	Total order cycle time	5 days
SCM KPIs	Inventory costs	N/A
SCM KPIs / House building industry KPIs	Customer satisfaction (product and service)	Medium-High (Home Builder) High (customer)
House building industry KPIs	Product quality / defects	High
House building industry KPIs	Predictability costs	Medium-High
House building industry KPIs	Predictability time	Medium-High

Table 8.4 Summary of low-value fit-out supply chain performance for integrated information flow

8.3.3 Synchronisation

The last SCM principle that has been investigated is the synchronisation of lead-times in the supply chain (Stevens, 1989; Sabath, 1995; Towill, 2000). This scenario was developed with the collaboration of the procurement manager from Kitter. Once Kitter is working at full capacity (estimated for July 2001) and the SAP system is implemented and in use (estimated for 2002), Kitter will be able to reduce their lead-times further to achieve a total order cycle time of 3 days as shown in Figure 8.5. Pack assembly will only require 1 day, the personnel will have gone through a learning curve and as the house design will be standardised, variations from one pack to another should be limited. It will still be necessary to allow one day for the transfer of packs to site. As the relationship with the manufacturers should have shifted from being adversarial to being more collaborative and partnering, and as the manufacturers will have access to up-to-date information from the information system, the total order cycle time will be reduced to 3 days. This means that the different organisations in the supply chain will work on the same 3-day order cycle time and therefore will be synchronised.



Where A represents doors and B skirting boards

Figure 8.5 Synchronised low-value fit-out supply chain

Here again the results presented in Table 8.5 are based on the views of personnel from Home Builder and Kitter. As the relationships between the different agents in the supply chain are expected to be based more on trust and commitment, or in other words, they should be working as partners, the products and services rendered are expected to be high. Based on the four types of uncertainties from Mason–Jones and Towill (1998), the supply and demand induced uncertainties should have been reduced through the accurate and timely transfer of information and a partnering approach. The manufacturing uncertainties should have been reduced through the kitting system and the central control of stock levels by Home Builders would reduce the control uncertainties. This should lead to greater construction certainty of time and costs.

	KPIs	Synchronised low-value fit-out supply chain
SCM KPIs	Stock levels	N/A
SCM KPIs	Total order cycle time	3 days
SCM KPIs	Inventory costs	N/A
SCM KPIs / House building industry KPIs	Customer satisfaction (product and service)	High (Home Builder) High (customer)
House building industry KPIs	Product quality / defects	High
House building industry KPIs	Predictability costs	High
House building industry KPIs	Predictability time	High

Table 8.5 Summary of performance for synchronised low-value fit-out supply chain

8.3.4 Summary of the re-engineering scenarios

Table 8.6 summarises the four scenarios for the low-value fit-out supply chain in terms of supply chain structure, the involvement of each agent, the type of innovation introduced and the total order cycle time.

Scenarios	**Baseline**	**Kitter**	**Integrated information**	**Synchronised**
Supply chain structure	Developer, multiple merchants, manufacturers	Developer, single merchant, manufacturers		
Developer	Order from merchants	Order from Kitter		
Merchants / Kitter	Order from manufacturers	Order from manufacturers and prepare packs		
Manufacturers	Deliver to merchants	Deliver to Kitter		
Innovation	-	Use of Kitter	Use of an information system across the supply chain	Synchronised lead-times across the supply chain
Total order cycle time	21 days	14 days	5 days	3 days

Table 8.6 Summary of the re-engineering scenarios

8.4 Implications on supply chain dynamics

Having studied the expected impact of some SCM principles on low-value fit-out supply chain static performance, this section now aims at testing if one point of control with one stocking point, improved information flow, reduction of lead-times and synchronisation can improve dynamic performance. This section will first describe the scenarios simulated and then present the simulation results.

8.4.1 Scenarios description

The four scenarios taken into consideration are those studied in the previous sections: the Baseline scenario representing the traditional low-value fit-out supply chain, Kitter scenario where the merchants are replaced by one single organisation, Integrated Information scenario where an information system is used to transfer information across the supply chain, and finally Synchronised scenario where the lead-times across the supply chain are synchronised.

Baseline scenario is composed of the regional buyer placing the orders and the site manager calling off the material. Two types of product have been considered: doors and skirting boards. As several merchants are used across the country, eight have been modelled, for each product, therefore a total of 16 merchants has been modelled following a simple IOBPCS as described in Chapter 5. Two manufacturers have been represented, manufacturer A who produces doors and manufacturer B who produces skirting boards. Finally, mistrust has been modelled between the agents to represent the adversarial relationships. For this scenario, mistrust was set at 100%, which means that whenever the customers do not receive what they have ordered, they will increase the next order they place by 100% of the quantity of the product undelivered, as explained in Chapter 5 (Sterman, 2000).

Kitter scenario only models one distributor, Kitter, instead of 16 different merchants. Kitter assembles packs, which means that both doors and skirting boards have to be available to assemble the packs and deliver them on-site. Here again, the two manufacturers are modelled as in the previous scenario. Finally, mistrust has been lowered to 75% as it was agreed with the interviewees that the relationships in this case are not as adversarial, but a lack of trust is still present as Kitter is only starting to operate.

Integrated Information scenario is based on Kitter scenario but uses an information system to transfer information across the supply chain. An information enrichment mechanism, as utilised by Mason-Jones (1998), was implemented with an information enrichment set at 50%. This means that, as seen in Chapter 5, the manufacturer bases its requirements 50% on the original orders placed by the regional buyer and 50% on the orders received from Kitter. However, even though information is shared through the supply chain, it was agreed with the interviewees that mistrust should still be set at 50% as trust is slowly building up between companies but they are not yet ready to trust each other fully.

Synchronised scenario also uses an information system, but this time set at 75% which is, according to Mason-Jones (1998), one of the best settings. The lead-times here are synchronised across the supply chain, which means that at each level, the total order cycle time is set at 3 days (based on the interviewees' responses). Finally, mistrust has been taken out of the model by setting it at 0% which is the equivalent of total trust between the partners. Thus, even though customers may not receive what they ordered, they trust their suppliers that missing products will be delivered as soon as possible, and therefore they do not need to over-order.

The lead-times and other parameters for each scenario are summarised in Table 8.7.

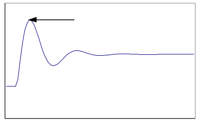
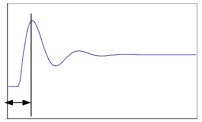
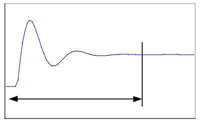
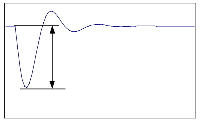
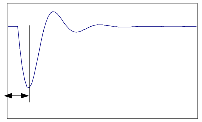
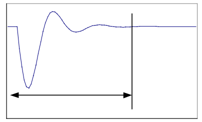
	Baseline	**Kitter**	**Integrated Information**	**Synchronised**
Order to call off lead-time	7 days	7 days	1 day	1 day
Call off to delivery lead-time	14 days	7 days	4 days	2 days
Order to delivery from Manufacturer A	10 days	10 days	10 days	3 days
Order to delivery from Manufacturer A	7 days	7 days	7 days	3 days
Mistrust	100%	75%	50%	0%
Information enrichment	0%	0%	50%	75%

Table 8.7 Summary of the parameters for the four low-value fit-out scenarios

8.4.2 Simulation results

Each scenario has been simulated daily for a a step change in demand over a period of 3 years. The step change in demand increased from 100 to 120 houses at day 20.

First of all, it is interesting to analyse the ranking of the scenarios for the step change in demand, taking into consideration the six dynamic criteria presented in Chapter 2. Using a linear scale where four stars is best and one star worst, the results presented in Table 8.8, represent the response at manufacturer level. For ease of presentation, only the door manufacturer response is presented. It can be seen that Synchronised scenario achieves the best overall performance, followed by Baseline scenario. Integrated Information scenario achieves the worst performance for Peak value, while Synchronised scenario registers the worst performance for stock depletion, which can be explained by the short lead-times. However, Synchronised scenario achieves the best performance for peak time and trough time as its lead-times are much shorter.

Scenarios	Peak Value 	Peak Time 	Order Recovery 	Stock Depletion 	Trough Time 	Stock Recovery 	Scenarios Performance
Baseline	****	*	**	****	*	****	***
Kitter	**	**	*	***	**	**	*
Integrated Information	*	***	****	**	***	*	**
Synchronised	***	****	***	*	****	***	****

*Where **** represents the best performance and * the worst*

Table 8.8 Ranking of the different scenarios for dynamical performance criteria at the manufacturers for step change in the demand

The dynamic performance assessed using the 6 criteria above, can be summarised using only two criteria, the production on-costs and integrated absolute error (IAE) for the inventory level of the manufacturers. Furthermore, the total supply chain inventory costs has been calculated using the simulations. Table 8.9 presents the ranking of the scenarios using these three performance criteria.

Scenarios	Production on-costs	IAE inventory	Total SC inventory costs	Scenario performance
Baseline	***	****	*	***
Kitter	*	**	***	*
Integrated Information	**	***	****	****
Synchronised	****	*	***	***

Where **** represents the best performance and * the worst

Table 8.9 Scenarios' ranking for a step change in demand

The production on-costs are minimised in the case of Synchronised scenario, which means that Synchronised scenario achieves the smallest demand amplification of the four scenarios. Baseline scenario registers the worst results in terms of total supply chain inventory costs. It could be suggested that this is due to the large number of merchants, however, the stock level for each merchant was set at four times the average demand, knowing that the total demand placed on the merchants is the same as for Kitter. Therefore, the high level of total supply chain inventory costs has to be explained by the structure of the scenario used. Furthermore, it must be noted that in real life, the level of safety stock for Kitter would be based on the square root law (Maister, 1976) and therefore could be reduced by a further $\frac{\sqrt{1}}{\sqrt{8}} * 100 = 35.35\%$.

In order to understand the above results better, *the magnitude of the impact* that each scenario has on performance needs to be looked at. The impact of the scenarios in comparison with Baseline scenario is presented in Table 8.10. It can be seen, that the total supply chain inventory costs is reduced for all three scenarios. Furthermore, Synchronised scenario improves the production on-costs by 30% in comparison with baseline scenario.

Finally, all three scenarios increase the IAE for inventory in comparison with Baseline scenario, especially Synchronised scenario with a 16% increase.

Scenarios	Production on-costs	IAE inventory	Total SC inventory costs
Kitter	+22%	+10%	-0.8%
Integrated Information	+21%	+6%	-1.1%
Synchronised	-30%	+16%	-0.8%

Table 8.10 Impact of the scenarios on performance criteria in comparison with Baseline scenario for a step change in demand

The results for the four strategies, for a step change in demand, have been analysed. However, the impact of each SCM principle cannot be fully understood as more than one parameter has been changed from one scenario to the next. Therefore, further simulations have been carried out to analyse the impact of every single change (called strategy) made, to move from one scenario to the next, in the case of a step change in demand.

The first comparison has been carried out between Baseline scenario and Kitter scenario. Here the SCM principles implemented were the centralisation of supply, the total cycle time reduction and improved relationships between the trading partners. This was simulated by:

- Replacing the merchants by Kitter: “No merchant” strategy
- Reducing the lead-time from order to call off from 14 to 7 days: “Delay call off” strategy
- Taking material out of stock earlier, in order to assemble packs, from 1 to 8 days: “From stock” strategy
- By reducing the mistrust level between the regional buyer and the merchants from 100% to 75%: “Mistrust customer” strategy
- By reducing the mistrust level between the merchants and the manufacturers from 100% to 75%: “Mistrust merchants” strategy

Table 8.11 presents the amplitude of impact that each strategy has in comparison with Baseline scenario. “No merchant” strategy improves both production on-costs (by 38%) and IAE inventory (by 11%), which means that it improves the dynamic behaviour. Therefore, moving away from multiple merchants on a regional basis to use one single company on a national basis, not only improves the dynamic performance but also the total supply chain inventory costs. This confirms Charatan's (Charatan, 1999) observation that centralisation on a national basis of supply has almost always been beneficial. However, reducing the lead-time between order and call off has a negative impact on the dynamic behaviour; this is understandable as "advance notice" of what is going to be called off is shorter and therefore manufacturers have less time to react to changes in demand.

In a similar manner, "From stock" strategy worsens the dynamic behaviour as materials are taken from stock earlier on and thus the manufacturers do not have as much time to build up their stock against the increase in demand. All three strategies ("No merchant", "Delay call off", and "From stock") reduce the total supply chain inventory costs, which explains the impact on that same criteria by Kitter scenario, as it is the combination of these strategies.

Finally, the impact of "Mistrust" strategies is indicated in brackets as it only has a marginal impact and does not refer to the same starting level of stock than for the other scenarios. However it gives an interesting insight into the way in which the reduction of the mistrust level, or in other words, the increase of trust between trading partners, affects performance. Interestingly, "Mistrust customer" increases the total supply chain inventory costs, while "Mistrust merchants" reduces it. Therefore, when the level of mistrust is reduced between the site and the merchants, the total supply chain inventory costs increase, while the dynamic performance at the manufacturer level improves. This can be explained by the fact that less disturbance or noise is present in the demand signal received by the manufacturers.

The reduction of mistrust between merchants and manufacturers improves production on-costs but increases IEA inventory. This can be explained by the fact that as mistrust diminishes, the demand received by the manufacturer is lower (only 75% of the product quantities that have not been received is added to the demand instead of 100%). However, it also means that the manufacturer does not overproduce and therefore its stock level diminishes more rapidly.

Scenarios	Production on-costs	IAE inventory	Total SC inventory costs
No merchants	-38%	-11%	-0.2%
Delay call off	+65%	+14%	-0.2%
From stock	+77%	+17%	-0.2%
Mistrust Customer	(-1%)	(-0.2%)	(+0.001%)
Mistrust Merchants	(-0.01%)	(+0.3%)	(-0.001%)
Kitter	+22%	+10%	-0.8%

Table 8.11 Impact of each strategy from Baseline scenario to Kitter scenario

Next, the scenarios Kitter and Integrated Information can be compared. Here the SCM principles implemented were the use of an information system to share end-customer demand, reduction of total cycle time and improved relationships between trading partners. These principles were implemented by:

- Passing on the site demand to the manufacturers. The manufacturers base their requirements 50% on the site demand and 50% on the orders received from Kitter: "Information enrichment" strategy
- Reducing the lead-time from order to call off from 7 days to 1: "Delay call off" strategy
- By reducing the mistrust level between the regional buyer and Kitter from 75% to 50%: "Mistrust customer" strategy
- By reducing the mistrust level between Kitter and the manufacturers from 75% to 50%: "Mistrust Kitter" strategy

As presented by Mason-Jones (1998), the implementation of an information enrichment mechanism improves the dynamic behaviour. It also reduces the total supply chain inventory costs. As seen previously, "Order to call off" has a negative impact on the dynamic behaviour (by increasing both production on-costs and IAE doe inventory) but improves the total supply chain inventory costs.

Here again, reducing the mistrust level from 75 to 50% increases the total supply chain inventory costs (Table 8.12). The marginal increase of IAE for inventory of "Mistrust customer" is due to a greater drop in inventory level in the case of 50% mistrust, however as there are fewer disturbances in the demand signal, the inventory level recovers more rapidly.

The increase in production on-costs for “Mistrust Kitter” is explained by the fact that the production level peaks higher than for 75% mistrust. The marginal reduction of IAE for inventory is due to a smaller trough in inventory level.

Scenarios	Production on-costs	IAE inventory	Total SC inventory costs
Information Enrichment	-21%	-13%	-0.1%
Order to call off	+13%	+8%	-0.2%
Mistrust Customer	(-4%)	(+0.1%)	(+0.1%)
Mistrust Kitter	(+0.1%)	(-2%)	(+0.01%)
Integrated Information	-1%	-3%	-0.4%

Table 8.12 Impact of each strategy from Kitter scenario to Integrated Information scenario

Finally, Integrated Information and Synchronised scenarios can be compared. The SCM principles implemented are the same as from Kitter to Integrated Information scenarios, i.e. the use of an information system to share end-customer demand, reduction of total cycle time and improved relationships between trading partners. These principles were implemented by:

- Passing on the site demand to the manufacturers. The manufacturers base their requirements 75% on the site demand and 25% on the orders received from Kitter: “Information enrichment” strategy
- Reducing the manufacturing lead-times from 10 to 3 and 7 to 3 days for Manufacturer A & B respectively: “Manufacturers lead-time” strategy
- By abolishing mistrust between the regional buyer and Kitter (from 50% to 0%): “Mistrust customer” strategy
- By abolishing the mistrust between Kitter and the manufacturers (from 50% to 0%): “Mistrust Kitter” strategy

“Information enrichment” reduces production on-costs by 9% and the total supply chain inventory costs (Table 8.13). The reduction of manufacturing lead-times reduces the production on-costs by 36%, however the IAE for inventory is increased due to a lower trough. “Mistrust customer” reduces both production on-costs and IAE inventory; this is due to the fact that in both cases, it recovers more quickly, whereas “Mistrust Kitter” increases both dynamic criteria. In this case, it peaks later and attains a lower trough in inventory level.

Scenarios	Production on-costs	IAE inventory	Total SC inventory costs
Information Enrichment	-9%	+3%	-0.1%
Manufacturers lead-time	-36%	+11%	+0.4%
Mistrust Customer	(-7%)	(-2%)	(+0.3%)
Mistrust Kitter	(+0.01%)	(+2%)	(+0.01%)
Synchronised	-42%	+9%	+0.4%

Table 8.13 Impact of each strategy from Integrated Information scenario to Synchronised scenario

8.4.3 Summary of the simulation results

The most important lessons learnt from this section are, first of all, that Integrated Information scenario achieves the best overall performance for a step change in demand. All three scenarios – Kitter, Integrated Information, and Synchronised – improve the total supply chain inventory costs in comparison with Baseline scenario.

Using one single national merchant instead of several regional merchants improves all three performance criteria (production on-costs, IAE inventory and total supply chain inventory costs). This concurs with Charatan’s (1999) and Henkoff’s (1994) observations on the positive impact of centralisation of supply. Reducing the delay between placing an order and the call off, has a negative impact on dynamic performance. This is also the case for “From stock” strategy, which takes material out of stock several days before delivery. Information enrichment improves the performance criteria studied (Mason-Jones, 1998), while reducing manufacturing lead-times has a detrimental effect on the total supply chain inventory costs and IAE for inventory. However, it has a positive effect on production on-costs.

Finally, reducing mistrust either between customer and merchants/Kitter, or between merchants/Kitter and manufacturers, has a positive effect in terms of faster recovery to a stable state. However, in all cases, reduction of the mistrust level between trading partners increases the total supply chain inventory costs.

8.5 Low-value fit-out findings summary

The low-value fit-out supply chain has been studied in this chapter. First of all, the analysis of the current state was carried out and performance assessed. Seven “Hot spots” were identified as being the major problems of the traditional low-value fit-out supply chain. In order to address these “Hot spots”, three steps were identified with the ultimate aim of improving performance. The first step is to move away from regional supply using multiple merchants to a single national supplier, who can also prepare the materials in packages to reduce the number of deliveries and wastage on-site. As seen during the simulations, this scenario (Kitter) reduces total supply chain costs but it has a negative effect on the dynamic behaviour.

The second step is to use customer information across the supply chain through an information enrichment mechanism. This not only reduced total order cycle time but also improved the dynamics of the model. Finally, the last step is to synchronise lead-times across the supply chain. Here again, total supply chain inventory costs can be minimised and total ordering cycle time reduced.

The very important lesson learnt from the simulations is that centralising the supply (No merchants strategy) has a general positive effect, by improving dynamic behaviour and reducing total supply chain inventory costs, as identified by Charatan (1999) in the retail sector. The reduction of the delay between placing the order and calling-off, or in other words, advance notice given to suppliers, has a detrimental effect on the dynamics of the models. It was confirmed that using the information enrichment strategy improves performance, while reducing the levels of mistrust between trading partners helps to return faster to a stable state.

The summary of the performance results for the four scenarios is presented in Table 8.14. In order to compare the overall results, the MAUT technique has been utilised and the results are shown in Table 8.15. All the performance results have first been indexed using Baseline scenario for the index value of 100. For all the results, the rule, “the smaller the number, the better the performance”, has been used. A weighting system has been utilised, where the three KPI types – SCM, house building industry and dynamic – are equally weighted as they are equally important to calculate the overall performance. Each performance criterion within each KPI type was also equally weighted.

However, the safety stock level was weighted as zero because it is directly derived from the stock depletion level in the dynamic KPIs. Finally, predictability costs and predictability time have been considered as a single criterion.

From Table 8.15, it is clear that Synchronised scenario achieves the best overall performance. This demonstrates that although this type of supply chain does not achieve the best results from a dynamic point of view, it is balanced by other performance criteria such as total order cycle time and customer satisfaction. Therefore, utilising a centralised supply source, sharing customer demand and synchronising lead-times across the supply chain, improve overall performance of the low-value fit-out supply chain.

	KPIs	**Traditional low value fit out supply chain**	**Kitter’s low value fit out supply chain**	**Integrated information for low value fit out supply chain**	**Synchronised low value fit out supply chain**
SCM KPIs	Stock levels	80*	126*	132*	155*
	Total order cycle time	21 days	14 days	5 days	3 days
	Inventory costs	1.037 M*	1.029 M*	1.025M*	1.029 M*
House building industry KPIs	Customer satisfaction (product and service)	Low (Home Builder) Low (customer)	Medium (Home Builder) Medium (customer)	Medium-High (Home Builder) High (customer)	High (Home Builder) High (customer)
	Product quality / defects	Low	High	High	High
	Predictability costs	Low	Medium	Medium-High	High
	Predictability time	Low	Medium	Medium-High	High
Dynamic KPIs	Peak value	132*	137*	137*	136*
	Peak time	70*	60*	58*	52*
	Order recovery	302*	313*	280*	285*
	Stock depletion	80*	126*	132*	155*
	Trough time	59*	54*	53*	46*
	Stock recovery	283*	348*	374*	342*

** indicates relative values from the simulations*

Table 8.14 Overall performance for the four different scenarios

	KPIs	**Weighting**	**Traditional low value fit out supply chain**		**Kitter's low value fit out supply chain**		**Integrated information for low value fit out supply chain**		**Synchronised low value fit out supply chain**	
			Index	Value	Index	Value	Index	Value	Index	Value
SCM KPIs	Stock levels	0	100	0	157.5	0	165	0	193.75	0
	Total order cycle time	0.1111	100	11.11	66.6	7.406	23.8	2.644	14.2	1.586
	Inventory costs	0.1111	100	11.11	99.2	11.024	98.8	10.982	99.2	11.024
	Customer satisfaction (product and service)	0.1111	100	11.11	75	8.333	62.5	6.944	50	5.555
House building industry KPIs		0.1111	100	11.11	75	8.333	50	5.555	50	5.555
	Product quality / defects	0.1111	100	11.11	50	5.555	50	5.555	50	5.555
	Predictability costs	0.0555	100	5.55	75	4.166	62.5	3.472	50	2.777
	Predictability time	0.0555	100	5.55	75	4.166	62.5	3.472	50	2.777
Dynamic KPIs	Peak value	0.0555	100	5.55	103.7	5.765	103.7	5.765	103	5.722
	Peak time	0.0555	100	5.55	85.7	4.761	82.8	4.602	74.2	4.126
	Order recovery	0.0555	100	5.55	103.6	5.757	92.7	5.150	94.3	5.242
	Stock depletion	0.0555	100	5.55	157.5	8.75	165	9.166	193.7	10.763
	Trough time	0.0555	100	5.55	91.5	5.084	89.8	4.99	77.9	4.331
	Stock recovery	0.0555	100	5.55	122.9	6.831	132.15	7.341	120.8	6.713
		1	Total value:	**100**	Total value:	**85.93**	Total value:	**75.64**	Total value:	**71.73**

Table 8.15 Assessment of the four scenarios using MAUT technique

8.6 References

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Chapter 9 Research findings and discussion

9.1 Introduction

In the previous chapters, the three different house building material supply chains have been studied, namely the shell, the high-value fit-out, and the low-value fit-out supply chains. For each supply chain, the current or traditional situation was studied and the performance assessed. Several different scenarios to improve performance were proposed. These scenarios focused on the implementation of specific supply chain management principles such as supply chain shortening, reduction of the supplier base, compression of lead-times (information and material flows), introduction of partnering, synchronisation of lead-times, and focus on the customer.

Each scenario was also assessed for its dynamic performance using system dynamics modelling and simulation. The impact of each individual change (called strategy) from one scenario to the next was studied so as to gain a greater understanding of the effect of the implementation of specific SCM principles.

The generalisation of case studies is carried out in a different manner than, for example, surveys (Yin, 1994). A very important point to keep in mind is that a case study should not be considered as one single respondent in a survey or a single subject in an experiment, but as an entire experiment (Yin, 1994). Therefore statistical generalisation is not recommended; instead, parallels can be drawn between the different case studies. One tactic is the selection of specific categories or dimensions to compare the case studies (Eisenhart, 1989; Yin, 1994). Examining literature that conflicts or affirms the results shown by the case study is another means to generalise the results and build a theory (Eisenhart, 1989; Yin, 1994).

Therefore, the aim of this chapter is to compare the findings of the three case studies with each other and with the literature in order to generalise the results. The first section of this chapter will compare the case studies utilising the Understand-Document-Simplify-Optimise framework (Watson, 1994) for a cross-case analysis. The second part of this chapter will then analyse the case studies' results with the literature for the three SCM categories; structure, relationships, and operational strategies. Finally the third section will relate the supply chain management principles to four key business drivers.

9.2 Cross-case analysis

The three case studies looked at three different supply chains for the supply of material to house building sites. The first case study considered the supply chain for the house shell procurement. This involved studying Home Builder and Timshell in detail but also gathering information on merchants. The second case study was concerned with the high-value fit-out supply chain by taking a specific example of ventilation products. The companies studied here were Home Builder and Ventair with a specific look at electrical sub-contractor and electrical distributors. The third case study considered the low-value fit-out supply chain focusing on Home Builder and Kitter but also studying merchants.

The "Understand-Document-Simplify-Optimise" (UDSO) framework outlined by Watson (1994) can be used to compare the three case studies. Furthermore, Womack and Jones (1996) described the case of a US house builder, Doyle Wilson, which carried out some work to re-engineer their business processes. This case has then been further analysed by Towill (1997a). Although the Doyle Wilson case only considers the developer and not its supply chain, it can be compared with the three supply chain case studies as shown in Tables 9.1, 9.2, 9.3 and 9.4. It can be seen that by the appropriate use of SCM principles, the performance of the house building supply chains can be significantly improved.

	Understand (Recognise the symptoms of uncompetitiveness)
House shell supply chain	▪ Long building process for the shell ▪ High levels of stocks across the supply chain ▪ Poor brick layers' performance
High-value fit-out supply chain	▪ Utilisation of cheap fans in houses ▪ No choice given to customers ▪ Decision on fans taken months before construction ▪ Poor supplier delivery performance ▪ Unsatisfied customers
Low-value fit-out supply chain	▪ Poor supplier performance ▪ Poor availability of contractor on-site ▪ Unsatisfied customers
Doyle Wilson (based on Towill, 2001)	▪ Observed large part of total cycle time was spent on non-added-value activities (NAVA) ▪ Experienced excessive and expensive warranty claims ▪ Experienced excessive hassle from customers ▪ Losing market share

Table 9.1 The Understand phase of the UDSO framework applied to the three case studies and Doyle Wilson

It can be seen from Table 9.1 that in all cases, a poor performance has been identified accompanied with unsatisfied customers. The documentation phase revealed the reasons for poor performance as can be seen from Table 9.2.

	Document (Map and measure the procurement business process)
House shell supply chain	▪ Weather dependent process ▪ Shortage of skilled labour ▪ Found brick construction on critical path
High-value fit-out supply chain	▪ Found very long supply chain ▪ Mark up of 10% at each echelon ▪ Found specification of ventilation type at design stage
Low-value fit-out supply chain	▪ Regionally based buying agreements ▪ Lack of supplier development ▪ No medium term plan horizon
Doyle Wilson (based on Towill, 2001)	▪ Established NAVA is five sixths of total cycle time ▪ Found individual sales bonuses eroded quality service ▪ Found builder bonuses achieved by cutting corners ▪ Discovered cutting corners led to extra warranty claims

Table 9.2 The Document phase of the UDSO framework applied to the three case studies and Doyle Wilson

In the simplification phase, it can be seen that all the cases studied have either reduced their supplier base or eliminated unnecessary echelons. The establishment of trust, integration of information flow, reduction of complexity and use of standardised processes has also been used.

	Simplify (Streamline the procurement business process)
House shell supply chain	▪ Use of a different technology, i.e. timber frame ▪ Reduction of supplier base ▪ Centralisation of procurement ▪ Establish trust with manufacturer
High-value fit-out supply chain	▪ Bypass electrical distributor ▪ Reduction of direct costs through use of new technology ▪ Reduction of complexity by using one product instead of multiple fans
Low-value fit-out supply chain	▪ Establish one centralised supplier (Kitter) ▪ Information integration (market information sharing) ▪ Establish trust between trading partners
Doyle Wilson based on (Towill, 2001)	▪ Standardised all work processes on a "pull" basis ▪ Established TQM programme ▪ Reduced number of suppliers by two thirds ▪ Integrated remaining suppliers into TQM programme ▪ Eliminated sales/builder bonuses

Table 9.3 The Simplify phase of the UDSO framework applied to the three case studies and Doyle Wilson

Furthermore, it was discovered through the case studies that, although not mentioned as a SCM principle, a change of technology was considered in two supply chains to improve the performance. The drivers for this change in technology were however very different from one case to the other. On the one hand, for the shell supply chain, the replacement technology (timber frames) increased direct costs and had a significant impact on the supply chain structure. It however increased the return on investment, dramatically reduced the construction lead-times and gave the potential to offer customer choice over the house internal layout. On the other hand, for the high-value fit-out, the replacement technology (PIVS) reduced direct costs and suppressed the need for multiple products. It also allowed a quicker installation time and gave the potential to offer some choices to customers (options for the PIVS).

	Optimise (Innovate to achieve an integrated supply chain)
House shell supply chain	▪ Use of a set of standard house design ▪ Integration of information flow (use of common CAD software) ▪ End-user focus by offering open building ▪ Manufacturer becomes service provider of assembled product
High-value fit-out supply chain	▪ Give customer choice over ventilation system ▪ Manufacturer becomes service provider of an installed product ▪ Compression of order and delivery cycle times
Low-value fit-out supply chain	▪ Synchronisation of lead-times across the supply chain ▪ Compression of order and delivery cycle times ▪ Further development of trust between trading partners
Doyle Wilson based on (Towill, 2001)	▪ Made mortgages available over the counter ▪ Made insurance available over the counter ▪ Exploited CAD to customize designs ▪ Added product variety (40 bricks finishes, 3000 wallpapers, 4 study styles, wide range of carpets, individual wiring schemes)

Table 9.4 The Optimise phase of the UDSO framework applied to the three case studies and Doyle Wilson

In both cases, the new technology was seen as an opportunity to offer greater choice to customers (see Table 9.4). As seen in Chapter 4, the current level of choice for house buyers in the UK is very restricted and customers aspire to have greater choice over their house layout and finishes (Barlow and Ozaki, 2000). This shows that private house developers in the UK are now focusing on their customers by developing flexible business and production processes to respond more rapidly to customer requirements, as also reported by Roy and Cochrane (1999).

Another interesting fact is that in both cases, the change of technology pushed the manufacturers to become service providers. In other words, the manufacturer not only provides the product but also installs/assembles it for the developer, Home Builder. Therefore, not only is the co-ordination complexity is reduced for the site manager (only coordinate with the manufacturer and not the labour as well) but the installers also receive appropriate training by the manufacturers. This reflects Ball's (1996) comment on the

Dutch and German sites where a greater number of specialist sub-contractors are co-ordinated on-site, demanding in total less co-ordination. Further, it also concurs with Carbone's (2000) survey in the electronic industry where 52% of the buyers purchase more value added services from their distributor than they did 2 years ago and where 82% of them say that they expect to buy more from a distributor offering value adding services.

9.3 The application of SCM principles

As seen in the literature review (Chapter 2), the supply chain management principles can be split into three categories: the structure of the supply chain (including the structure of material and information flows), the relationships between the organisations and the operational strategies such as the compression of lead-times, the use of JIT techniques and the synchronisation of lead-times across the supply chain. This section will review the case studies findings for each category.

9.3.1 Structure

As previously discussed (in Chapters 3, 4, 6, 7 and 8), the private house building supply chains are complex as they are regionally based, going through multiple echelons and include the supply of labour. A simplified representation of such a supply network is shown in Figure 9.1. The buying agreements are in this case regionally based, which means that several different merchants in the country are dealing with the same manufacturers but do not benefit from economies of scale. Further, in the case of specialised products (high-value), sub-contractors are usually hired on a supply-and-fit basis, meaning that they need to procure themselves the products they will then install. The traditional way in dealing with a supply-and-fit contract from a sub-contractor perspective is to deal with specialised distributors.

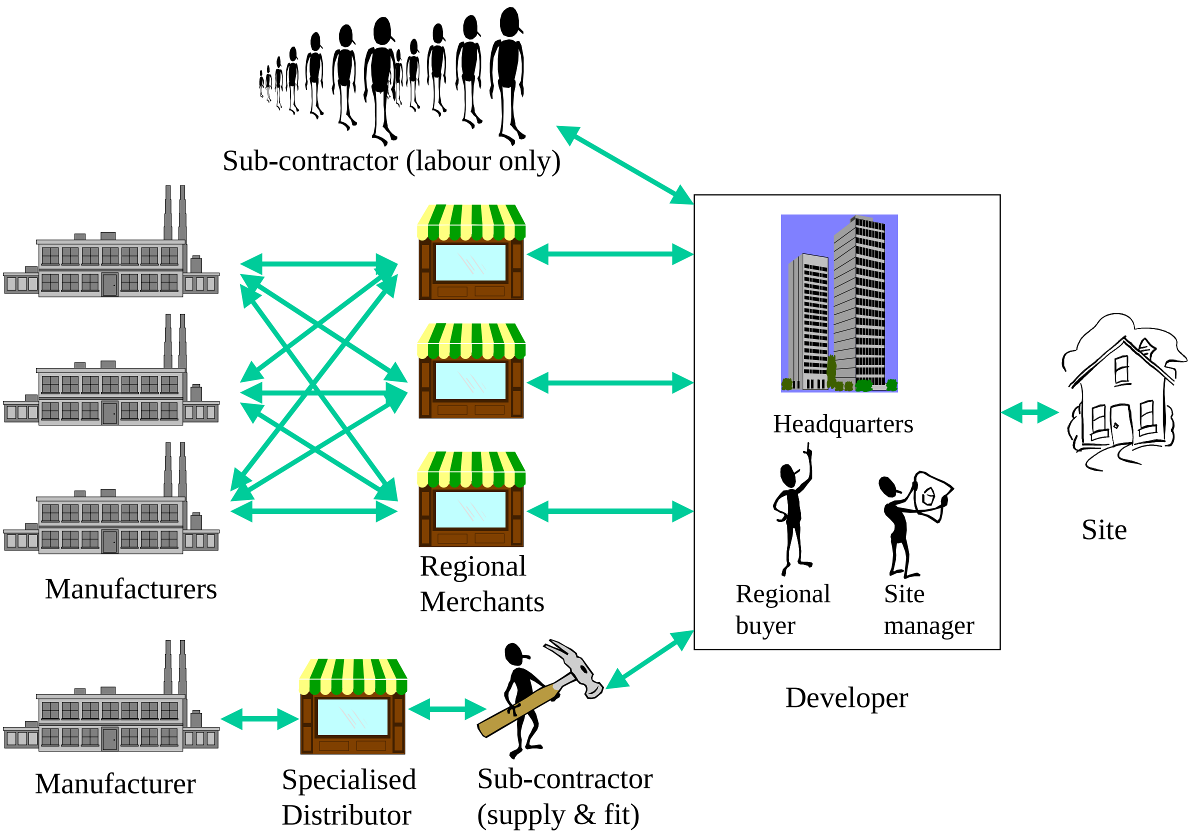

Figure 9.1 Traditional house building supply network

It was seen through this thesis that part of the changes to improve performance in the house building industry was to focus on re-engineering the structure of the supply chains. The end result is shown in Figure 9.2. In this case the three different supply chains can be easily identified. For both shell and high-value fit-out, the structure of the supply chain was dramatically changed so that the developer now deals directly with manufacturers who provide both the products and the labour to install the products on-site. The third supply chain, the low-value fit-out supply chain was only changed by dealing with a central "merchant", Kitter, which in turn deals with a small number of suppliers.

Therefore, the supply chain principles applied here are a reduction in supplier base, the centralisation of supply and the elimination of unnecessary echelons. These principles were advocated by many authors. Jones (1990), Davies (1995) and Tan et al. (1998) recommend a reduction in supplier base. Towill (1991), Wikner et al. (1991), Hong-Minh et al. (2000), and McCullen and Towill (2001) suggest the elimination of unnecessary echelons. They have all shown that the elimination of one echelon reduced the demand amplification effect. This concurs with the results of high-value fit-out simulation (Phase 2, shortened supply chain), which gave the best overall dynamic performance.

The centralisation of supply was suggested, between others, by Houlihan (1985), Lamming (1996), and Handfield and Nichols (1999). Charatan (1999) relates that the centralisation of supply, in the retail sector, was almost always beneficial. The case studies concur with these results and also showed that the centralisation of supply, from multiple regional merchants to one national merchant, not only reduced the demand amplification effect by up to 50%, but also reduced the total supply chain inventory costs (by 0.2%) (see Chapter 8, "No merchant" strategy).

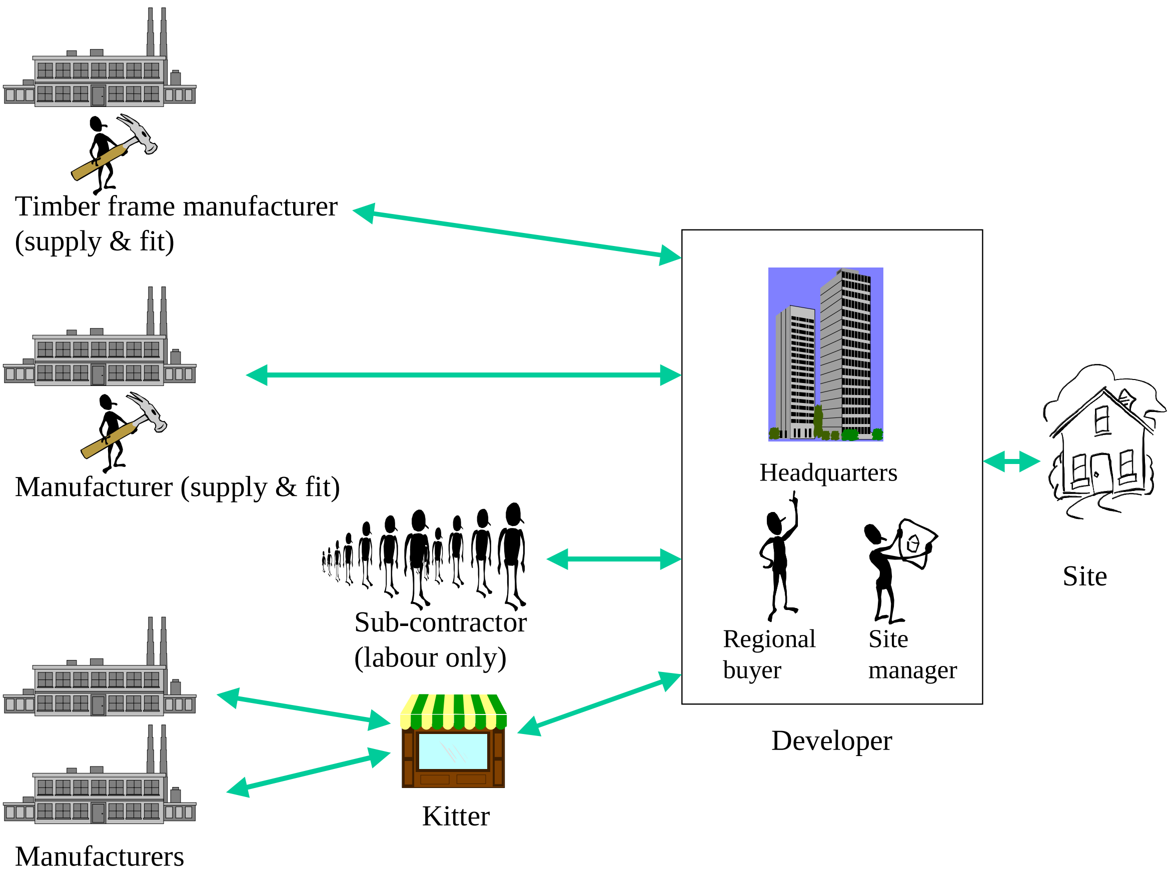

Figure 9.2 Re-engineered house building supply network

Finally, the information flow structure was also remodelled by utilising an integrated information system to link all the companies involved. The implementation of this new information system was driven by the developer. This strategy is advocated by Stevens (1989), Lee and Billington (1992), and Sabath (1995). Bowersox and Closs (1996), Handfield and Nichols (1999), and Mason-Jones (1998) all promote information sharing through the supply chain. The simulation carried out utilising this integrated information flow ("Information enrichment" strategy in Chapter 8) concurred with Mason-Jones' (1998) findings in that the demand amplification effect is reduced and the total supply chain inventory costs are minimised.

9.3.2 Relationships

The literature review (Chapter 2) revealed that often quoted cases of SCM in the construction industry are in fact only addressing the issue of relationship via partnering. Although partnering is not the only SCM principle available, it is a very important component to achieve successful SCM. Many authors recommend partnering agreements with key suppliers (Lamming, 1993; Davies, 1995; Sabath, 1995; Bowersox and Closs, 1996) or even vertical integration (Houlihan, 1985; Williamson, 1985; Ellram, 1991).

During the Quasi Delphi study, the companies involved in the COMPOSE project gained a mutual understanding of the problems each company was facing. The companies also reached a shared consensus on the actions to take, namely changing the attitudes by working more closely with customers and suppliers. The case studies proved that some of these companies wanted to take some immediate actions as all four companies, Home builder, Timshell, Kitter, and Ventair, showed a willingness to move away from the traditional adversarial relationships and took steps (through vertical integration and partnering) to change.

Further, the case studies' findings concur with the literature. In the case of the shell supply chain, Home Builder vertically integrated the timber frame manufacturer (Timshell) after having recognised the strategic importance of such a supplier. In the same manner, House Builder also vertically integrated Kitter. In this case, the choice for vertical integration was determined by the fact that no merchant already in business was able to offer the level of service they required, nor the choice of products requested. As for the high-value fit-out supply chain, vertical integration was not put in place but instead they started developing trust with the manufacturers. It can therefore be seen that for all three supply chains, the types of relationships between the companies were altered to move towards either partnering or vertical integration.

The utilisation of vertical integration allowed Home Builder to acquire the control over the product availability and quality. Furthermore, it facilitated the implementation of a common CAD software (with Timshell) and integrated information system (with Kitter). The simulation also showed that the reduction of adversarial relationships (mistrust) had a positive effect on demand amplification.

9.3.3 Operational strategies

The operational strategies utilised by the companies studied can be summarised as being the reduction of information delays, the reduction of manufacturing delays, a focus on the end customer and the synchronisation of lead-times in the supply chain. Table 9.5 shows which principle has been used in which case study. It can therefore be seen that all three case studies acted upon the information delays. This reduction in information delays was possible through the use of the information system and the use of standard designs and products. For example, in the case of the house shell supply chain, dramatic reductions from 2 weeks to one day were achieved by using standard design and forbidding regional offices to carry out localised interventions (or "tweaks"). The use of an integrated information system in the low-value fit-out supply chain not only allowed the reduction in lead-times but also the sharing of end-customer demand across the entire supply chain.

This concurs with many authors considering IT as a powerful tool to achieve dramatic performance achievements (Hammer, 1990; King, 1991; Love and Gunasekaran, 1997). Skanska, with its 3T program, also focused on the reduction of lead-times to achieve enhanced performance (Hewitt, 1982).

Case studies	Reduction of information delays	Reduction of manufacturing lead-times	Focus on the customer	Synchronisation
House shell supply chain	✓	✓	✓	
High-value fit-out supply chain	✓		✓	
Low-value fit-out supply chain	✓	✓		✓

Table 9.5 Cross-cases analysis for operational strategies

Interestingly, the simulations for the reduction in information lead-times did not achieve better results in terms of demand amplification. Therefore, at first sight, it seems not to concur with Mason-Jones and Towill (1998), Strohhecker (2000), and McCullen and

Towill (2001). However, as highlighted in Chapters 2 and 5, the ordering mechanism was based on the placement of a firm order followed by a call-off. Hence, whenever the information lead-time was reduced, it reduced the lead-time between order and call-off, and therefore, the manufacturer suffered from the reduction of “advance” warning. It could not build up stocks while waiting for the call-off as the delay between orders and call-offs was greatly reduced.

The reduction of manufacturing lead-times was not considered for the high-value fit-out supply chain as the manufacturing lead-times were already down to one day. However, Home Builder, Timshell and Kitter all recognised the possibility to compress production lead-times. This is in line with one of Towill’s (1999) twelve rules for simplified material flow. It was also seen that the reduction of manufacturing lead-times reduced the demand amplification effect as reported by Mason-Jones and Towill (1998), and Strohhecker (2000).

The synchronisation of lead-times was considered for the low-value fit-out supply chain as recommended by Stevens (1989) and Sabath (1995). As reported by Charatan (1999), the synchronisation of production through a make-to-order decision rule improves the performance. The simulation also showed a reduction in production on-costs (see “Synchronised” scenario in Chapter 8).

Table 9.5 also shows that two of the three case studies focused on the end-customer. End-customers want more choices for their house in terms of layout and finishes, however, they focus more on high-value items such as kitchen and bathroom rather than on low-value items such as skirting boards or lintels. It can be seen that Home Builder is trying to become more customer focused by being able to offer more choice (as seen through a change of technology) and especially to become responsive by compressing lead-times. Home Builder Group Design Director explicitly said that they wanted to become agile and that it was for that purpose that they had to re-engineer their supply chains (Smit, 2001).

9.4 Conclusion

As a summary, it was seen (in Chapters 6, 7, 8, and 9) that a change in technology for the construction of house shell not only had supply chain advantages (shortening of the supply chain) but also had quality, speed of assembly on-site, reduced demand for labour and positive cash flow implications. In the same manner, the change of technology for the high-value fit-out affected direct costs (material and installation costs), installation time and customer satisfaction. In all cases the reduction of the supplier base and the centralisation of supply proved to be extremely positive, affecting the total supply chain inventory cost and the dynamic performance of the supply chains. The information enrichment mechanism in the supply chain improved its performance. The introduction of trust between trading partners allowed the manufacturers to regain a stable state more rapidly. The reduction in manufacturing lead-times proved to be beneficial especially from a dynamic point of view as it allows the manufacturer to react more promptly to changes in the demand. However the reduction in information lead-times did not always improve the dynamic performance. This was the case when the warning or advance notice to manufacturer was shortened as the manufacturer had less time to respond to the new demand.

Further, the Cardiff Change Model (Towill, 1997b) may be utilised to map the actions taken in the three case studies. The supply chain improvement strategies can be drawn in a matrix as shown in Table 9.6. The SCM principles used are categorised in terms of four business drivers: technology, attitudes, finance and organisation. Although these four business drivers interact with each other, it is still possible to map the most important element(s) that drove the companies studied to change. Interestingly, both Technology and Attitudes are identified eight times as business drivers. Therefore, as the Quasi Delphi study revealed, the attitudes need to be changed to implement SCM principles.

	Technology	Attitudes	Finance	Organisation
Use of a different technology	●		●	
Reduction of supplier base				●
Centralisation of procurement				●
Establish trust with manufacturers		●		
Use of a set of standard house design	●	●		
Integration of information flow	●	●		
End-user focus by offering open building	●	●		
Manufacturer becomes service provider of assembled product		●		●
Bypass electrical distributor				●
Reduction of direct costs through use of new technology	●		●	
Reduction of complexity by using one product instead of multiple fans	●			
Give customer choice over fit-out		●		
Compression of order and delivery cycle times	●	●		
Synchronisation of lead-times across the supply chain	●	●		

Table 9.6 Supply chain improvement matrix using the Cardiff Change Model business drivers

Further, technology also plays a very important role in the successful implementation of SCM. This concurs with Towill's (2001) findings when analysing Doyle Wilson's business systems engineering routine. When mapping Doyle Wilson actions onto the Cardiff Business Change Model, the technology business driver also appeared the most frequently: "*obviously technology has a significant part to play in standardizing on-site work processes, including the widespread use of factory produced components*" (Towill, 2001, p.290).

Finally, it has been shown that SCM principles can be implemented within the three different house building supply chains and that their impacts are identical for all three supply chains. It can also be seen that these principles have a positive impact on performance, especially from a dynamic point of view. Trade offs must however not be forgotten, as some principles, such as focusing on the customer can, for example, increase the information delays. Another example could consider the will to achieve a quicker construction time, the manufacturing lead-times need then to be increased and direct costs may also increase (i.e. timber frame versus brick and block construction).

However when considering the overall performance, SCM principles improve the private house building supply chain performance. Furthermore, all four business drivers (technology, attitudes, finance, and organisation) are involved when implementing SCM principles. The technology and attitudes drivers have especially been identified as very important for the UK house building supply chain re-engineering.

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Chapter 10 Conclusions

10.1 Conclusions

The research investigated ways in which SCM principles could be implemented in three house building supply chains, namely the house shell, the high-value fit-out and the low-value fit-out supply chains. It also analysed the impact these principles have on house building performance. It concluded that not only can SCM principles be applied to the house building industry but also that, in most cases, it improves performance.

To arrive to these conclusions, a literature review has first of all highlighted the enablers for SCM as well as its key performance indicators, both static and dynamic. The methodology used to develop and carry out this research was then presented. The work has then given an overview of most of the problems which plague the UK private house building industry and has highlighted some of them to be studied in more depth -supplier performance, house building "mind-set", functional silo approach, lack of communication and lack of customer focus. The Quasi Delphi study exposed the presence of a consensus between the house building industry actors for a need to change by working more closely with customers and suppliers. House building performance indicators were then defined. After a description of the models used for this research, three case studies have been presented, where the implementation of SCM principles defined in the literature review is analysed using the previously defined performance criteria. Finally, the overall research findings have been presented as well as the generalisation of the results through cross-case analysis and reference to the literature.

Each chapter of this work covered a particular part of the research and has presented "localised" conclusions. This chapter will bring together all the conclusions in a holistic manner and will first discuss findings related to the research questions presented in Chapter 1 and will then relate these findings with the house building problems selected in Chapter 4.

Which SCM principles can be applied to the house shell's supply chain?

It was seen in this work that only the compression of ordering cycle time and construction time could be applied to the traditional brick and block construction for house shells.

However, SCM principles can be introduced via a change in technology, for example by utilising a framing system.

Some SCM principles had to be implemented with this change of technology. These principles are the shortening of the supply chain by eliminating the merchant echelon and procuring direct from the manufacturer, the use of vertical integration of the framing supplier by the house developer, the development of trust between these two organisations, and centralisation of supply on a national scale. In addition, further SCM principles can be implemented such as a focus on the end-user to offer flexibility in layout design, the procurement of a service from the frame manufacturer (assembled frame) instead of just a product and the integration of information flows resulting in total cycle time compression between the developer and the manufacturer.

How do these principles impact on the performance of the house shell's supply chain?

The compression of ordering cycle time and construction time improved performance in terms of total supply chain inventory costs (20% less for Brick and Block scenario), amount of labour required (49% less), but had a negative impact on the dynamic behaviour (due to the compression of the "warning" lead time).

The change of technology combined with the shortening of the supply chain, the implementation of strategic sourcing/partnering and centralisation of supply has an overall negative impact on performance. However it improved the total response time (58% shorter), reduced inventory costs by 59%, increased customer satisfaction, increased product quality, increased predictability in time and costs, reduced the construction lead-time by 88%, increased profitability by 22%, reduced the amount of labour required by 89%, and increased the number of houses built within the same time period.

The other SCM principles -focus on the end-user, the procurement of a service and integrated information- in addition to the previous SCM principles, achieve the best overall performance. However it has a negative effect on construction costs (11% higher) and on the dynamic behaviour.

Which SCM principles can be applied to the high-value fit-out's supply chain?

It was seen that several SCM principles could be implemented in the high-value fit-out supply chain. The principles considered were the shortening of the supply chain by eliminating the distributor and dealing directly with the manufacturer (through a labour only mechanism), a technological change, compression of ordering lead-times, focus on the end-consumer, and the procurement of a service from the manufacturer (installed product) instead of just a product.

How do these principles impact on the performance of the high-value fit-out's supply chain?

The elimination of the distributor especially improved the total supply chain inventory costs (50% reduction) and the dynamic behaviour by reducing the demand amplification effect. It also reduced the construction costs (by 3.5%).

The further shortening of the supply chain by dealing directly with the manufacturer further reduced demand amplification and construction costs. It also improved customer satisfaction and product quality. The technological change reduced the construction costs (by 30%) and construction/installation time (by 50%). The compression of ordering lead-times also improved the dynamic behaviour (in comparison with Baseline scenario).

The focus on the end-consumer increased customer satisfaction and reduced demand amplification. Finally the procurement of a service from the manufacturer by getting a supply-and-fit service and the reduction in lead-times in combination with the shortened supply chain and the change of technology achieved the overall best performance.

Which SCM principles can be applied to the low-value fit-out's supply chain?

It was seen that the number of suppliers could be reduced. Instead of using multiple merchants all over the country, one single merchant can be utilised to supply on a national scale. Ordering, delivering and manufacturing lead-times can also be compressed. Trust between partners can also be increased or, more likely, mistrust can be reduced. Furthermore, the information flow can be integrated across the supply chain by utilising a shared information system. The synchronisation of lead-times across the supply chain can also be implemented. Finally, an information enrichment mechanism can be utilised to share market information.

How do these principles impact on the performance of the low-value fit-out's supply chain?

The replacement of multiple regional merchants by one single merchant improved the dynamic behaviour of the supply chain by reducing production on-costs by 22% and reducing the IAE for inventory by 10%. It also reduced the total supply chain inventory costs by 0.8%. This combined with the reduction in ordering lead-times reduced the demand amplification and increased the reliability in costs and time.

The reduction of mistrust between trading partners mainly had a positive effect on supply chain dynamics and especially improved the recovery time to a stable state of the manufacturer. The information enrichment mechanism reduced the bullwhip effect by allowing the manufacturer to access market information. However the reduction of ordering lead-times had a negative effect on demand amplification as the "warning" lead-time has been reduced. Finally the reduction of manufacturing lead-times to achieve synchronisation across the supply chain increased IAE for inventory by 16% but reduced the total supply chain inventory costs and reduced the production on-costs by 30% in comparison with the Baseline scenario.

10.2 Lessons to be learnt

The research identified a gap in the literature for the applications and benefits of SCM in the private house building industry. No research work has been reported and published in terms of the utilisation of SCM principles in the house building industry. This work has demonstrated that such research could be carried out successfully and is intended to be the first step in bridging this gap.

It is now possible to relate the findings of this work to the house building problems highlighted in Chapter 4. The main problem areas under consideration in this work were:

- The low supplier performance towards house developers,
- The problems related to the current industry mind-set where adversarial relationships are common,
- The functional silo approach to business where departments within organisations do not communicate with one another,
- The lack of communication within and between companies and
- The lack of end user focus.

The research work showed that supplier performance could be improved by reducing the supplier base and having merchants or developers working closer with them. Furthermore, it was seen that sharing more information with them would allow them to respond more promptly to changes in demand and therefore increase their delivery reliabilities. The research showed that in order to move away from adversarial relationships, trust needed to be built upon with partnering agreements with key suppliers where benefits can be shared among the partners. This trust affects the performance and reduces distortions in the demand.

Sharing information among supply chain players about market demand reduces the demand amplification observed in the chain, which impacts on total inventory supply chain costs. Finally it was seen that greater choice could be given to customers by allowing flexibility in construction designs. This can be achieved by building-in design criteria, which will allow a late configuration of the products to be fitted and by utilising an open building approach where the final layout can be decided at a later stage.

This research has however also addressed some other problems of the house building industry, such as weather dependency and the shortage of skilled labour. The weather related problems may be tackled by utilising other construction technology such as framing systems (which only require a very short assembling time on site to build a waterproofed house). The simulation results also showed that with a faster construction process, the total amount of labour required at one time could be lessened considerably (by up to 88%).

Therefore in summary, it can be seen that:

- The structural SCM principles (e.g. reduction of supplier base, structure of the information flow, one point of control) improve the house building performance.

- The SCM principles related to relationships such as vertical integration and strategic partnering improve the house building performance.

- The operational strategy SCM principles such as reduction of lead-times, focus on the customers, synchronisation, etc. can improve the house building performance.

- Finally, this thesis has shown in a methodological manner that SCM principles *can* improve the overall performance of UK private house building.

10.3 Implications for the industry

This work has some important implications on the private house building industry. Firstly, it has some implications on developers' strategies. Private house builders in the UK now need to place an emphasis upon the product they build, as easy developments on green sites are becoming rare and developers are under pressure from the government to meet stricter standards. Furthermore, although competition from foreign house developers is still insignificant, it will increase in the near future with the development of new technologies as already seen with the increased use of timber frame. UK house builders will thus have to be prepared for foreign competition. As a result, private house developers have to focus on their customer and meet their specific requirements. Giving more choices to customers through mass customisation is the key to becoming market leader and developers will have to take action.

Second, this work also has some implications on suppliers and manufacturers for private developers. As developers are reducing their supplier base and eliminate unnecessary echelons, suppliers need to get ready to deal with a larger number of smaller customers. This also implies that they will have to carry most of the stock, especially in the case of merchants' elimination and therefore they have to change their manufacturing processes in order to minimise their stock level. Further, suppliers also have to change and be ready to offer some value-adding services such as kitting, pre-packing or supply-and-fit.

Third, this work also has some implications for the house building industry as a whole. Although the product is not moveable, the private house building industry utilised very repetitive processes and is therefore very similar to the manufacturing industry. The house building industry can be characterised by medium volume and low to medium variety. As a result, the house building industry *can* learn valuable lessons from other industries and expect similar benefits already shown by these industries.

10.4 Implications for academia

This work also has some important implications for the academic world. First of all, it was seen that both static and dynamic performance criteria can be combined to study overall performance. Studying both aspects is very important as changes might have contrary effects on static and dynamic performance and therefore the "best" solution has to take trade-offs into consideration. Further, the use of simulation and modelling has proven to be a very powerful and complementary tool to case-study analysis. It allows the case study to be taken a step further by developing and analysing "what if?" scenarios.

Another important lesson for academia is to keep a very clear distinction between the construction industry and the private house building industry. The house building industry is much more repetitive than the construction industry and the supply chain structure is also different, as private house developers have their supply chain already set up and use their suppliers repeatedly whereas the construction industry is mainly project based where a new team of suppliers is brought together for each project.

Finally, this work has contributed to the body of knowledge by showing how an "old" concept, SCM, can be successfully applied to a "new" industry, the private house building industry.

10.5 Research limitations

As in every work, this thesis has its limitations. The first one, which could be considered as an important limitation is the lack of a real demand pattern. As stated in the previous chapters, a real demand pattern for the national demand in houses for Home Builder was unfortunately not available. Therefore, this work focused on the impact of SCM principles on the dynamic behaviour using a step change in demand. Using a step change in demand allowed a clear understanding of the impact of these principles on the dynamic response. However, a real demand pattern could have given a better insight in the real impact of such actions. The seasonal variations could also have been studied. The use of a real demand pattern could have given some indications on what would happen in a more "real life" situation.

A second limitation of this work can be identified as being the lack of in-depth study of the simulation of mistrust. The dynamic impact of mistrust had not been yet studied in any previous work. The simulations showed interesting results in that depending on where the mistrust is placed in the supply chain (between the customers and the developer or between the developer and the manufacturers), mistrust could have a positive or negative impact on the dynamic behaviour of the model. Therefore, further study could have given a better insight in the reason why the model was reacting that way.

Different ways of simulating the mistrust could also have been further studied, for example, in one case the customer can increase its order but only call-off what he really needs, leaving the manufacturer with higher stock levels than necessary. The other case could be when the customer increases its orders and call-off, which then has a knock-on effect. In this case, the customer then receives more than he really needs, as the manufacturer delivers what has been ordered (the demand increased by the amount of missing products) plus what he did not deliver in the previous period. Therefore, in the next period, the customer will actually order less to compensate this extra delivery. This will then results in an even more unstable demand pattern.

Another limitation of this work can be identified as being the lack of implementation of the different strategies. For example, in the case of the high-value fit-out supply chain, Ventair was really ready to deal directly with developers and to train its own installers. It was also ready to fit-out a house with the appropriate ventilation system at the last minute. Unfortunately, Home Builder was not ready yet to include some design criteria in its house designs to allow such a late configuration of the house fit-out. Therefore, the impact of such a strategy could not be confirmed or refuted. In the same manner, the difficulties of implementing such a strategy could not be studied.

This lack of implementation is also identifiable in the case of the implementation of the SAP/R3 system. A lot of hope was put on that system, which should allow access to up-to-date data to all the concerned organisations. Therefore, the impact on, for example, information delays could not be studied in a "real life" case.

10.6 Further work

As with all research work, it is hard to know when to stop and when to pursue a new idea. However, the researcher needs to take the decision to stop at a certain point in the research to report the findings to date. This section intends to present areas where further research could be carried out.

First of all, the element of mistrust built in the model showed some interesting results, i.e. when mistrust is placed between the developer and merchants, the dynamic behaviour of the manufacturer is improved, whereas when mistrust is placed between merchants and manufacturer, the dynamic behaviour worsened. More research could be carried out in studying the effect of mistrust in a supply chain by, for example, analysing the effect it has on every single echelon of the supply chain. In addition, a memory element could be built into the model, so that the longer the supplier does not meet demand, the stronger mistrust would be and the longer the customer would take to not over-order.

The research could also be built upon by studying the effect on performance of a one-stop shop where all the orders would go through one single merchant (Kitter), these orders would encompass labour and material supply. The use of one supply channel for all labour and material could be compared with the use of three distinct supply chains as studied in this work. The advantages could be analysed from different perspectives, i.e. the developer, the merchant, the manufacturer.

On a more strategic front, transport cost implications of the different strategies studied in this work could be analysed to further enhance this work. Measures of performance such as environmental effects and transport costs could be utilised. This would enlarge this work by taking an even wider perspective. The implications on carriers could also be studied. The research could analyse the whole house building supply chain including carrier and study the type of relationships needed with carriers and more specific transport related problems, such as the size of lorries needed, the frequency of journey required and the type of transport mode used.

Finally, more research could be carried out into ways of increasing customisation in houses. The choice of a specific supply chain strategy to match the level of customisation could be analysed. Principles such as lean and agile could be utilised to design the right supply chain. Further research is also needed to identify market segments depending on the level of customisation; and strategies to meet expectations could be developed.

Appendix 1 – TSM Questionnaire

FLY-BY CUSTOMER INTERFACE QUESTIONNAIRE

This questionnaire contains product specific questions. These products have been chosen to represent your company activities in relation to housing construction. Please consider these products alone when completing this questionnaire.
Only one main customer is considered for each product (only two customers are taken into account), so please answer this questionnaire only in relation to these two customers. Thank you.

Product A: ________________________________. Customer A: ________________________

Product B: ________________________________. Customer B: ________________________

A. FINISHED GOODS DELIVERY		PRODUCT A	PRODUCT B
A.1	Customer Locations State the number of customer locations the specified products are delivered to.	1-10 O 11-20 O 21-50 O 51-100 O 101-200 O 200+ O	1 O 2-3 O 4-6 O 7-10 O 11-20 O >20 O
A.2	Handling Characteristics Please state the products handling characteristics when they are in finished goods form.	Bulk O Single Unit O Unitised (pallet, container) O Specified: ____ Other, please specified __________ O	Bulk O Single Unit O Unitised (pallet, container) O Specified: ____ Other, please specified __________ O

		CUSTOMER A	CUSTOMER B
A.3	Delivery Lead Time Please state the average time between when you receive a firm order and when the product is delivered.	________Days ________Weeks ________Months	________Days ________Weeks ________Months
A.4	Delivery Lead Time Range Please give a typical variation on this delivery time, i.e. usually late or early and by how much.	Early ________Days or Late ________Days	Early ________Days or Late ________Days

		CUSTOMER A	CUSTOMER B
A.5	Delivery Frequency How frequently do you deliver the two specified products to your customers?	________Per day ________Per week ________Per month	________Per day ________Per week ________Per month
A.6	Delivery Distance State the average delivery distance for the two specified customers.	________Miles (________km)	________Miles (________km)
A.7	Delivery Location Give the names of the nearest towns/cities for deliveries to the 2 customers give up to 5 locations – most major first.	________ ________ ________ ________ ________	________ ________ ________ ________ ________
A.8	Orders type How frequently do you receive order from your customers for the specific products?	________Per day ________Per week ________Per month	________Per day ________Per week ________Per month
A.9	Quantities Delivered State the amount of products/parts you deliver to your customer per delivery.	________Per delivery	________Per delivery
A.10	Supply Source How do your supply your customer?	O Supply to order (from production) O Supply from stock (existing stock) O Other: ________	O Supply to order (from production) O Supply from stock (existing stock) O Other: ________
A.11	Transport Organisation Who is organising the transport of the products?	O Customer O Your company O Other: ________	O Customer O Your company O Other: ________
A.12	Transport Means Provider Who is providing the transport means (e.g. trucks)?	O Customer's fleet O Own fleet O Sub-contractor/carrier's fleet O Other: ________	O Customer's fleet O Own fleet O Sub-contractor/carrier's fleet O Other: ________

		CUSTOMER A	CUSTOMER B
A.13	Special Transport Requirement Are there any specific transport requirements for the products?	O Truck size: ____ O Truck weight: ____ O Special packing: ____ O Other: ____	O Truck size: ____ O Truck weight: ____ O Special packing: ____ O Other: ____
A.14	Ordering Method How do you receive your orders from your customers?	O EDI O Paper O Fax O Telephone O E-mail O Other: ____	O EDI O Paper O Fax O Telephone O E-mail O Other: ____
A.15	Length of Customer Relationship For how long have you been their supplier?	____Years ____Months	____Years ____Months
A.16	Contract Agreement What kind of contract agreement do you have with your customers?	O Standard contract O Specific contract O Informal agreement O Other: ____	O Standard contract O Specific contract O Informal agreement O Other: ____
A.17	Customer Relationships On the whole how close a relationship do you have with these customers?	Adversarial 1 O 2 O 3 O 4 O Partnership	Adversarial 1 O 2 O 3 O 4 O Partnership
A.18	Satisfaction Level How would you rate your customer satisfaction level towards your services?	Dissatisfied 1 O 2 O 3 O 4 O Satisfied	Dissatisfied 1 O 2 O 3 O 4 O Satisfied
A.19	Problem What difficulties for you arise from working with these customers? i.e. What do you see as the biggest problem that hampers your work and why?	____ ____ ____	____ ____ ____

For the following questions, we would like you to grade your relationship with the two specific customers on particular issues.

		CUSTOMER A	CUSTOMER B
A.20	Trust	Low 1 O 2 O 3 O 4 O High	Low 1 O 2 O 3 O 4 O High
A.21	Commitment	Low 1 O 2 O 3 O 4 O High	Low 1 O 2 O 3 O 4 O High
A.22	Cost transparency	Low 1 O 2 O 3 O 4 O High	Low 1 O 2 O 3 O 4 O High
A.23	Joint R&D programmes	Low 1 O 2 O 3 O 4 O High	Low 1 O 2 O 3 O 4 O High

Perceptions of internal suppliers: In the following questions the term “internal supplier” relates to the process area that feeds (preceding) your own process area in the material flow.

Please indicate below which internal suppliers directly feed into your process and about which these questions relate concerning the two specific products studied.

____

____

____

		PRODUCT A	PRODUCT B
A.24	Your Internal Supplier Problem What do you believe is your internal supplier biggest problem with your work?	____ ____	____ ____
A.25	Problem with the Internal Supplier What difficulties arise from working with this supplier? i.e. What is your biggest dissatisfaction towards your internal supplier work?	____ ____	____ ____

Appendix 2 – Interviewees list

Home Builder

Head Office

- Group Design Director
- Group Marketing Executive
- Buyer involved in SAP implementation
- Layout Designer
- Safety Advisor
- Product Architect
- Group Marketing Manager
- Technical Manager
- Group Customer Care Manager
- Group Product Designer
- Research and Development Manager
- Commercial Manager
- Marketing Assistant
- Production Manager
- Land Appraisal Director
- Assistant Group Financial Controller
- Group Supply Chain Manager

Western Region Office

- Managing Director
- Regional Buyer
- Technical Director
- Design Manager
- Company Engineer
- Sales Director
- Land Director
- Customer Care Manager

Three sites (Rogerstone, Undy and Kingskerwell)

- 2 Construction Managers
- 3 Site Managers
- 5 Sales negotiators
- Sales Manager

Timshell

- Production Manager
- Design Office Manager
- Estimation department
- Production Scheduler-Production Planning Manager
- Finance Director
- Finance Assistant

Ventair

- Managing Director
- Southern Regional Manager
- Customer Service Director
- Material Logistics Manager
- Northern Regional Manager
- Technical Director
- Process Manager

Kitter

- Procurement Manager
- Procurement and Stock Manager
- Operation and Transport Manager
- Pickers
- Scheduler
- Customer Service Manager

Appendix 3 – Model documentation

The variables are grouped under the six sub-systems presented in Chapter 6, namely Home Builder, Manufacturer, Measure of performance, Merchants, Production allocation, Site construction plus the Control variables. For simplification of presentation, the units for each variable are not shown here.

```
********************************
   .Control
********************************

                Simulation Control Parameters

FINAL TIME  = 1095

INITIAL TIME  = 0

SAVEPER  = 1

TIME STEP  = 1

********************************
   .Home Builder
********************************

call off products by the site  =
     DELAY FIXED ( coef products
          * order placed by the regions ,order to call off delay ,
        1e+007)

call off to delivery delay  = 7

coef products  = 100000

construction plan  = 100
                        + STEP (20, 20)

expected delivery products by the site  =
      DELAY FIXED ( call off products by the site ,call off to delivery delay ,
         1e+007)

expected product merchant1  =
      DELAY FIXED ( call off for products merchant1 ,call off to delivery delay ,
         3e+006)
```

expected product merchant2 =
DELAY FIXED (call off product merchant2 ,call off to delivery delay ,
500000)

expected product merchant3 =
DELAY FIXED (call off product merchant3 ,call off to delivery delay ,
1e+006)

expected product merchant4 =
DELAY FIXED (call off product merchant4 ,call off to delivery delay ,
1e+006)

expected product merchant5 =
DELAY FIXED (call off product merchant5 ,call off to delivery delay ,
300000)

expected product merchant6 =
DELAY FIXED (call off product merchant6 ,call off to delivery delay ,
2e+006)

expected product merchant7 =
DELAY FIXED (call off product merchant7 ,call off to delivery delay ,
1.2e+006)

expected product merchant8 =
DELAY FIXED (call off product merchant8 ,call off to delivery delay ,
1e+006)

order placed by the regions =
construction plan

order to call off delay = 14

****
.Manufacturer
****

average demand products manufacturer =
SMOOTH (total demand for products manufacturer inc mistrust ,
ta products manufacturer)

completion rate products manufacturer =
DELAY1 (orate products manufacturer ,
Tp products manufacturer)

incoming backlog products manufacturer =
DELAY FIXED (total products call off manufacturer ,"order to delivery to merchants delay-1" ,
1e+007)

information enrichment coefficient = 0

inventory error manufacturer products =
target inventory products manufacturer
- stock products manufacturer after shipment
+ order backlog products manufacturer

inventory error manufacturer products delay1 =
DELAY FIXED (inventory error manufacturer products ,1,
0)

orate products manufacturer =
orders enriched manufacturer
+ inventory error manufacturer products delay1
/ Ti products manufacturer

order backlog products manufacturer =
INTEG(incoming backlog products manufacturer
- processed backlog products manufacturer ,
0)

"order to delivery to merchants delay-1" = 6

orders enriched manufacturer =
information enrichment coefficient
* average order products to merchants
+ ((1
- information enrichment coefficient)
* average demand products manufacturer)

processed backlog products manufacturer =
product to be delivered to merchants

product to be delivered to merchants =
IF THEN ELSE (stock products manufacturer before shipment
<= 0,
0,
IF THEN ELSE (stock products manufacturer before shipment
< (incoming backlog products manufacturer
+ order backlog products manufacturer) ,
stock products manufacturer before shipment ,
(incoming backlog products manufacturer
+ order backlog products manufacturer)))

stock products manufacturer after shipment =
stock products manufacturer before shipment
- product to be delivered to merchants

stock products manufacturer after shipment delay1 =
DELAY FIXED (stock products manufacturer after shipment ,1,

4e+007)

stock products manufacturer before shipment =
stock products manufacturer after shipment delay1
+ completion rate products manufacturer

ta products manufacturer = 14

target inventory products manufacturer =
4
* orders enriched manufacturer

Ti products manufacturer = 7

total demand for products manufacturer inc mistrust =
(orate products merchant 1
* (1
+ (mistrust coef 1
* mistrust value reverse products manufacturer merchant1)))
+ (orate products merchant 2
* (1
+ (mistrust coef 1
* mistrust value reverse products manufacturer merchant2)))
+ (orate products merchant 3
* (1
+ (mistrust coef 1
* mistrust value reverse products manufacturer merchant3)))
+ (orate products merchant 5
* (1
+ (mistrust coef 1
* mistrust value reverse products manufacturer merchant5)))
+ (orate products merchant 6
* (1
+ (mistrust coef 1
* mistrust value reverse products manufacturer merchant6)))
+ (orate products merchant 7
* (1
+ (mistrust coef 1
* mistrust value reverse products manufacturer merchant7)))
+ (orate products merchant 8
* (1
+ (mistrust coef 1
* mistrust value reverse product manufacturer merchant8)))
+ (orate products merchant 4
* (1
+ (mistrust coef 1
* mistrust value reverse products manufacturer merchant4)))

total products call off manufacturer =
orate products merchant 1

+ orate products merchant 2
+ orate products merchant 3
+ orate products merchant 5
+ orate products merchant 6
+ orate products merchant 7
+ orate products merchant 8
+ orate products merchant 4

Tp products manufacturer = 7

****
.Master model5
****

****
.Measure of performance
****

Absolute error inventory =
ABS (inventory error manufacturer products delay1)

Absolute error order rate =
ABS (Manufacturer order rate for houses
- order placed by the regions)

cost in stock manufacturer = 5e-006

cost in stock product merchant = 5e-006

cost out stock manufacturer = 1e-005

cost out stock product merchant = 1e-005

cost product merchant1 =
cost in stock product merchant
* stock products after shipment merchant1
+ cost out stock product merchant
* order backlog product merchant1

cost product merchant2 =
cost in stock product merchant
* stock products after shipment merchant2
+ cost out stock product merchant
* order backlog product merchant2

cost product merchant3 =
cost in stock product merchant
* stock products after shipment merchant3
+ cost out stock product merchant
* order backlog product merchant3

cost product merchant4 =
cost in stock product merchant
* stock products after shipment merchant4
+ cost out stock product merchant
* order backlog product merchant4

cost product merchant5 =
cost in stock product merchant
* stock products after shipment merchant5
+ cost out stock product merchant
* order backlog product merchant5

cost product merchant6 =
cost in stock product merchant
* stock products after shipment merchant6
+ cost out stock product merchant
* order backlog product merchant6

cost product merchant7 =
cost in stock product merchant
* stock products after shipment merchant7
+ cost out stock product merchant
* order backlog product merchant7

cost product merchant8 =
cost in stock product merchant
* stock products after shipment merchant8
+ cost out stock product merchant
* order backlog product merchant8

cost stock manufacturer =
cost in stock manufacturer
* stock products manufacturer after shipment
+ cost out stock manufacturer
* order backlog products manufacturer

cum diff in quantity product for merchant1 =
INTEG(diff deliveries product for merchant1 ,
0)

cum diff in quantity product for merchant2 =
INTEG(diff deliveries product for merchant2 ,
0)

cum diff in quantity product for merchant3 =
INTEG(diff deliveries product for merchant3 ,
0)

cum diff in quantity product for merchant4 =

INTEG(diff deliveries product for merchant4 ,
0)

cum diff in quantity product for merchant5 =
INTEG(diff deliveries product for merchant5 ,
0)

cum diff in quantity product for merchant6 =
INTEG(diff deliveries product for merchant6 ,
0)

cum diff in quantity product for merchant7 =
INTEG(diff deliveries product for merchant7 ,
0)

cum diff in quantity product for merchant8 =
INTEG(diff deliveries product for merchant8 ,
0)

cum diff in quantity product from merchant1 =
INTEG(diff deliveries product from merchant1 ,
0)

cum diff in quantity product from merchant2 =
INTEG(diff deliveries product from merchant2 ,
0)

cum diff in quantity product from merchant3 =
INTEG(diff deliveries product from merchant3 ,
0)

cum diff in quantity product from merchant4 =
INTEG(diff deliveries product from merchant4 ,
0)

cum diff in quantity product from merchant5 =
INTEG(diff deliveries product from merchant5 ,
0)

cum diff in quantity product from merchant6 =
INTEG(diff deliveries product from merchant6 ,
0)

cum diff in quantity product from merchant7 =
INTEG(diff deliveries product from merchant7 ,
0)

cum diff in quantity product from merchant8 =
INTEG(diff deliveries product from merchant8 ,
0)

days out of stock cum product Manufacturer =
INTEG(days out of stock product Manufacturer ,
0)

days out of stock cum product merchant1 =
INTEG(days out of stock product merchant1 ,
0)

days out of stock cum product merchant2 =
INTEG(days out of stock product merchant2 ,
0)

days out of stock cum product merchant3 =
INTEG(days out of stock product merchant3 ,
0)

days out of stock cum product merchant4 =
INTEG(days out of stock product merchant4 ,
0)

days out of stock cum product merchant5 =
INTEG(days out of stock product merchant5 ,
0)

days out of stock cum product merchant6 =
INTEG(days out of stock product merchant6 ,
0)

days out of stock cum product merchant7 =
INTEG(days out of stock product merchant7 ,
0)

days out of stock cum product merchant8 =
INTEG(days out of stock product merchant8 ,
0)

days out of stock product all merchants =
days out of stock cum product merchant1
+ days out of stock cum product merchant2
+ days out of stock cum product merchant3
+ days out of stock cum product merchant4
+ days out of stock cum product merchant5
+ days out of stock cum product merchant6
+ days out of stock cum product merchant7
+ days out of stock cum product merchant8

days out of stock product Manufacturer =
IF THEN ELSE (order backlog products manufacturer
> 0,

```
            1,
            0)

days out of stock product merchant1  =
        IF THEN ELSE ( order backlog product merchant1
              > 0,
            1,
            0)

days out of stock product merchant2  =
        IF THEN ELSE ( order backlog product merchant2
              > 0,
            1,
            0)

days out of stock product merchant3  =
        IF THEN ELSE ( order backlog product merchant3
              > 0,
            1,
            0)

days out of stock product merchant4  =
        IF THEN ELSE ( order backlog product merchant4
              > 0,
            1,
            0)

days out of stock product merchant5  =
        IF THEN ELSE ( order backlog product merchant5
              > 0.01,
            1,
            0)

days out of stock product merchant6  =
        IF THEN ELSE ( order backlog product merchant6
              > 0,
            1,
            0)

days out of stock product merchant7  =
        IF THEN ELSE ( order backlog product merchant7
              > 0,
            1,
            0)

days out of stock product merchant8  =
        IF THEN ELSE ( order backlog product merchant8
              > 0,
            1,
            0)
```

diff deliveries product for merchant1 =
product deliveries merchant1
- order product for merchant1

diff deliveries product for merchant2 =
product deliveries merchant2
- order product for merchant2

diff deliveries product for merchant3 =
product deliveries merchant3
- order product for merchant3

diff deliveries product for merchant4 =
product deliveries merchant4
- order product for merchant4

diff deliveries product for merchant5 =
product deliveries merchant5
- order product for merchant5

diff deliveries product for merchant6 =
product deliveries merchant6
- order product for merchant6

diff deliveries product for merchant7 =
product deliveries merchant7
- order product for merchant7

diff deliveries product for merchant8 =
product deliveries merchant8
- order product for merchant8

diff deliveries product from merchant1 =
product to be delivered from merchant1
- incoming backlog product merchant1

diff deliveries product from merchant2 =
product to be delivered from merchant2
- incoming backlog product merchant2

diff deliveries product from merchant3 =
product to be delivered from merchant3
- incoming backlog product merchant3

diff deliveries product from merchant4 =
product to be delivered from merchant4
- incoming backlog product merchant4

diff deliveries product from merchant5 =

product to be delivered from merchant5
- incoming backlog product merchant5

diff deliveries product from merchant6 =
product to be delivered from merchant6
- incoming backlog product merchant6

diff deliveries product from merchant7 =
product to be delivered from merchant7
- incoming backlog product merchant7

diff deliveries product from merchant8 =
product to be delivered from merchant8
- incoming backlog product merchant8

Integrated absolute error inventory =
INTEG(Absolute error inventory ,
0)

Integrated absolute error order rate =
INTEG(Absolute error order rate ,
0)

Manufacturer order rate for houses =
orate products manufacturer
/ coef products

mistrust value product manufacturer merchant1 =
ZIDZ (diff deliveries product for merchant1 ,
order product for merchant1)

mistrust value product manufacturer merchant2 =
ZIDZ (diff deliveries product for merchant2 ,
order product for merchant2)

mistrust value product manufacturer merchant3 =
ZIDZ (diff deliveries product for merchant3 ,
order product for merchant3)

mistrust value product manufacturer merchant4 =
ZIDZ (diff deliveries product for merchant4 ,
order product for merchant4)

mistrust value product manufacturer merchant5 =
ZIDZ (diff deliveries product for merchant5 ,
order product for merchant5)

mistrust value product manufacturer merchant6 =
ZIDZ (diff deliveries product for merchant6 ,
order product for merchant6)

```
mistrust value product manufacturer merchant7  =
        ZIDZ ( diff deliveries product for merchant7 ,
             order product for merchant7 )

mistrust value product manufacturer merchant8  =
        ZIDZ ( diff deliveries product for merchant8 ,
             order product for merchant8 )

mistrust value product merchant1  =
        ZIDZ ( diff deliveries product from merchant1 ,
             order product from merchant1 )

mistrust value product merchant2  =
        ZIDZ ( diff deliveries product from merchant2 ,
             order product from merchant2 )

mistrust value product merchant3  =
        ZIDZ ( diff deliveries product from merchant3 ,
             order product from merchant3 )

mistrust value product merchant4  =
        ZIDZ ( diff deliveries product from merchant4 ,
             order product from merchant4 )

mistrust value product merchant5  =
        ZIDZ ( diff deliveries product from merchant5 ,
             order product from merchant5 )

mistrust value product merchant6  =
        ZIDZ ( diff deliveries product from merchant6 ,
             order product from merchant6 )

mistrust value product merchant7  =
        ZIDZ ( diff deliveries product from merchant7 ,
             order product from merchant7 )

mistrust value product merchant8  =
        ZIDZ ( diff deliveries product from merchant8 ,
             order product from merchant8 )

mistrust value reverse product manufacturer merchant8  =
        DELAY FIXED ( ( mistrust value product manufacturer merchant8
                  * ( -1) ) ,1,
             0)

mistrust value reverse product merchant1  =
        DELAY FIXED ( ( mistrust value product merchant1
                  * ( -1) ) ,1,
             0)
```

mistrust value reverse product merchant2 =
DELAY FIXED ((mistrust value product merchant2
* (-1)) ,1,
0)

mistrust value reverse product merchant3 =
DELAY FIXED ((mistrust value product merchant3
* (-1)) ,1,
0)

mistrust value reverse product merchant4 =
DELAY FIXED ((mistrust value product merchant4
* (-1)) ,1,
0)

mistrust value reverse product merchant5 =
DELAY FIXED ((mistrust value product merchant5
* (-1)) ,1,
0)

mistrust value reverse product merchant6 =
DELAY FIXED ((mistrust value product merchant6
* (-1)) ,1,
0)

mistrust value reverse product merchant7 =
DELAY FIXED ((mistrust value product merchant7
* (-1)) ,1,
0)

mistrust value reverse product merchant8 =
DELAY FIXED ((mistrust value product merchant8
* (-1)) ,1,
0)

mistrust value reverse products manufacturer merchant1 =
DELAY FIXED ((mistrust value product manufacturer merchant1
* (-1)) ,1,
0)

mistrust value reverse products manufacturer merchant2 =
DELAY FIXED ((mistrust value product manufacturer merchant2
* (-1)) ,1,
0)

mistrust value reverse products manufacturer merchant3 =
DELAY FIXED ((mistrust value product manufacturer merchant3
* (-1)) ,1,
0)

```
mistrust value reverse products manufacturer merchant4  =
        DELAY FIXED ( ( mistrust value product manufacturer merchant4
                  * ( -1) ) ,1,
             0)

mistrust value reverse products manufacturer merchant5  =
        DELAY FIXED ( ( mistrust value product manufacturer merchant5
                  * ( -1) ) ,1,
             0)

mistrust value reverse products manufacturer merchant6  =
        DELAY FIXED ( ( mistrust value product manufacturer merchant6
                  * ( -1) ) ,1,
             0)

mistrust value reverse products manufacturer merchant7  =
        DELAY FIXED ( ( mistrust value product manufacturer merchant7
                  * ( -1) ) ,1,
             0)

order product for merchant1  =
        DELAY FIXED ( orate products merchant 1 ,9,
             3e+006)

order product for merchant2  =
        DELAY FIXED ( orate products merchant 2 ,9,
             500000)

order product for merchant3  =
        DELAY FIXED ( orate products merchant 3 ,9,
             1e+006)

order product for merchant4  =
        DELAY FIXED ( orate products merchant 4 ,9,
             1e+006)

order product for merchant5  =
        DELAY FIXED ( orate products merchant 5 ,9,
             300000)

order product for merchant6  =
        DELAY FIXED ( orate products merchant 6 ,9,
             2e+006)

order product for merchant7  =
        DELAY FIXED ( orate products merchant 7 ,9,
             1.2e+006)

order product for merchant8  =
```

DELAY FIXED (orate products merchant 8 ,9,
1e+006)

order product from merchant1 =
incoming backlog product merchant1

order product from merchant2 =
incoming backlog product merchant2

order product from merchant3 =
incoming backlog product merchant3

order product from merchant4 =
incoming backlog product merchant4

order product from merchant5 =
incoming backlog product merchant5

order product from merchant6 =
incoming backlog product merchant6

order product from merchant7 =
incoming backlog product merchant7

order product from merchant8 =
incoming backlog product merchant8

"Production on-costs" =
Integrated absolute error order rate
* Integrated absolute error order rate
* Integrated absolute error order rate

SC costs =
stock cost manufacturer cum
+ stock costs product for all merchants

stock cost manufacturer cum =
INTEG(cost stock manufacturer ,
0)

stock cost product merchant1 =
INTEG(cost product merchant1 ,
0)

stock cost product merchant2 =
INTEG(cost product merchant2 ,
0)

stock cost product merchant3 =
INTEG(cost product merchant3 ,

```
        0)

stock cost product merchant4  =
     INTEG( cost product merchant4 ,
        0)

stock cost product merchant5  =
     INTEG( cost product merchant5 ,
        0)

stock cost product merchant6  =
     INTEG( cost product merchant6 ,
        0)

stock cost product merchant7  =
     INTEG( cost product merchant7 ,
        0)

stock cost product merchant8  =
     INTEG( cost product merchant8 ,
        0)

stock costs product for all merchants  =
     stock cost product merchant1
        + stock cost product merchant2
        + stock cost product merchant3
        + stock cost product merchant4
        + stock cost product merchant5
        + stock cost product merchant6
        + stock cost product merchant7
        + stock cost product merchant8

sum expected deliveries product for merchant1  =
     INTEG( order product for merchant1 ,
        0)

sum expected deliveries product for merchant2  =
     INTEG( order product for merchant2 ,
        0)

sum expected deliveries product for merchant3  =
     INTEG( order product for merchant3 ,
        0)

sum expected deliveries product for merchant4  =
     INTEG( order product for merchant4 ,
        0)

sum expected deliveries product for merchant5  =
     INTEG( order product for merchant5 ,
```

```
        0)

sum expected deliveries product for merchant6  =
     INTEG( order product for merchant6 ,
        0)

sum expected deliveries product for merchant7  =
     INTEG( order product for merchant7 ,
        0)

sum expected deliveries product for merchant8  =
     INTEG( order product for merchant8 ,
        0)

sum expected deliveries product from merchant1  =
     INTEG( order product from merchant1 ,
        0)

sum expected deliveries product from merchant2  =
     INTEG( order product from merchant2 ,
        0)

sum expected deliveries product from merchant3  =
     INTEG( order product from merchant3 ,
        0)

sum expected deliveries product from merchant4  =
     INTEG( order product from merchant4 ,
        0)

sum expected deliveries product from merchant5  =
     INTEG( order product from merchant5 ,
        0)

sum expected deliveries product from merchant6  =
     INTEG( order product from merchant6 ,
        0)

sum expected deliveries product from merchant7  =
     INTEG( order product from merchant7 ,
        0)

sum expected deliveries product from merchant8  =
     INTEG( order product from merchant8 ,
        0)

********************************
  .Merchants
********************************
```

average order products to merchant 1 =
SMOOTH (order product inc mistrust merchant1 ,
Ta products merchant)

average order products to merchant 2 =
SMOOTH (order product inc mistrust merchant2 ,
Ta products merchant)

average order products to merchant 3 =
SMOOTH (order product inc mistrust merchant3 ,
Ta products merchant)

average order products to merchant 4 =
SMOOTH (order product inc mistrust merchant4 ,
Ta products merchant)

average order products to merchant 5 =
SMOOTH (order product inc mistrust merchant5 ,
Ta products merchant)

average order products to merchant 6 =
SMOOTH (order product inc mistrust merchant6 ,
Ta products merchant)

average order products to merchant 7 =
SMOOTH (order product inc mistrust merchant7 ,
Ta products merchant)

average order products to merchant 8 =
SMOOTH (order product inc mistrust merchant8 ,
Ta products merchant)

average order products to merchants =
average order products to merchant 1
+ average order products to merchant 2
+ average order products to merchant 3
+ average order products to merchant 4
+ average order products to merchant 5
+ average order products to merchant 6
+ average order products to merchant 7
+ average order products to merchant 8

call off for products merchant1 =
call off products by the site
* coef product merchant1

call off product merchant2 =
call off products by the site
* coef product merchant2

call off product merchant3 =
call off products by the site
* coef product merchant3

call off product merchant4 =
call off products by the site
* coef product merchant4

call off product merchant5 =
call off products by the site
* coef product merchant5

call off product merchant6 =
call off products by the site
* coef product merchant6

call off product merchant7 =
call off products by the site
* coef product merchant7

call off product merchant8 =
call off products by the site
* coef product merchant8

"call off to delivery delay-1" = 6

coef product merchant1 = 0.3

coef product merchant2 = 0.05

coef product merchant3 = 0.1

coef product merchant4 = 0.1

coef product merchant5 = 0.03

coef product merchant6 = 0.2

coef product merchant7 = 0.12

coef product merchant8 = 0.1

incoming backlog product merchant1 =
DELAY FIXED (call off for products merchant1 ,"call off to delivery delay-1" ,
3e+006)

incoming backlog product merchant2 =
DELAY FIXED (call off product merchant2 ,"call off to delivery delay-1" ,
500000)

incoming backlog product merchant3 =
DELAY FIXED (call off product merchant3 ,"call off to delivery delay-1" ,
1e+006)

incoming backlog product merchant4 =
DELAY FIXED (call off product merchant4 ,"call off to delivery delay-1" ,
1e+006)

incoming backlog product merchant5 =
DELAY FIXED (call off product merchant5 ,"call off to delivery delay-1" ,
300000)

incoming backlog product merchant6 =
DELAY FIXED (call off product merchant6 ,"call off to delivery delay-1" ,
2e+006)

incoming backlog product merchant7 =
DELAY FIXED (call off product merchant7 ,"call off to delivery delay-1" ,
1.2e+006)

incoming backlog product merchant8 =
DELAY FIXED (call off product merchant8 ,"call off to delivery delay-1" ,
1e+006)

incoming products merchant 1 =
DELAY FIXED (product deliveries merchant1 ,transport delay ,
3e+006)

incoming products merchant2 =
DELAY FIXED (product deliveries merchant2 ,transport delay ,
500000)

incoming products merchant3 =
DELAY FIXED (product deliveries merchant3 ,transport delay ,
1e+006)

incoming products merchant4 =
DELAY FIXED (product deliveries merchant4 ,transport delay ,
1e+006)

incoming products merchant5 =
DELAY FIXED (product deliveries merchant5 ,transport delay ,
300000)

incoming products merchant6 =
DELAY FIXED (product deliveries merchant6 ,transport delay ,
2e+006)

incoming products merchant7 =
DELAY FIXED (product deliveries merchant7 ,transport delay ,

```
        1.2e+006)

incoming products merchant8  =
    DELAY FIXED ( product deliveries merchant8 ,transport delay ,
        1e+006)

inventory error product merchant1  =
    "target inv. product merchant1"
        - stock products after shipment merchant1
        + order backlog product merchant1

inventory error product merchant1 delay 1  =
    DELAY FIXED ( inventory error product merchant1 ,1,
        0)

inventory error product merchant2  =
    "target inv. product merchant2"
        - stock products after shipment merchant2
        + order backlog product merchant2

inventory error product merchant2 delay 1  =
    DELAY FIXED ( inventory error product merchant2 ,1,
        0)

inventory error product merchant3  =
    "target inv. product merchant3"
        - stock products after shipment merchant3
        + order backlog product merchant3

inventory error product merchant3 delay 1  =
    DELAY FIXED ( inventory error product merchant3 ,1,
        0)

inventory error product merchant4  =
    "target inv. product merchant4"
        - stock products after shipment merchant4
        + order backlog product merchant4

inventory error product merchant4 delay 1  =
    DELAY FIXED ( inventory error product merchant4 ,1,
        0)

inventory error product merchant5  =
    "target inv. product merchant5"
        - stock products after shipment merchant5
        + order backlog product merchant5

inventory error product merchant5 delay 1  =
    DELAY FIXED ( inventory error product merchant5 ,1,
        0)
```

```
inventory error product merchant6  =
        "target inv. product merchant6"
             - stock products after shipment merchant6
             + order backlog product merchant6

inventory error product merchant6 delay 1  =
        DELAY FIXED ( inventory error product merchant6 ,1,
             0)

inventory error product merchant7  =
        "target inv. product merchant7"
             - stock products after shipment merchant7
             + order backlog product merchant7

inventory error product merchant7 delay 1  =
        DELAY FIXED ( inventory error product merchant7 ,1,
             0)

inventory error product merchant8  =
        "target inv. product merchant8"
             - stock products after shipment merchant8
             + order backlog product merchant8

inventory error product merchant8 delay 1  =
        DELAY FIXED ( inventory error product merchant8 ,1,
             0)

mistrust coef 1  = 1

orate products merchant 1  =
        average order products to merchant 1
             + inventory error product merchant1 delay 1
                  / Ti products merchant

orate products merchant 2  =
        average order products to merchant 2
             + inventory error product merchant2 delay 1
                  / Ti products merchant

orate products merchant 3  =
        average order products to merchant 3
             + inventory error product merchant3 delay 1
                  / Ti products merchant

orate products merchant 4  =
        average order products to merchant 4
             + inventory error product merchant4 delay 1
                  / Ti products merchant
```

orate products merchant 5 =
average order products to merchant 5
+ inventory error product merchant5 delay 1
/ Ti products merchant

orate products merchant 6 =
average order products to merchant 6
+ inventory error product merchant6 delay 1
/ Ti products merchant

orate products merchant 7 =
average order products to merchant 7
+ inventory error product merchant7 delay 1
/ Ti products merchant

orate products merchant 8 =
average order products to merchant 8
+ inventory error product merchant8 delay 1
/ Ti products merchant

order backlog product merchant1 =
INTEG(incoming backlog product merchant1
- processed backlog product merchant 1 ,
0)

order backlog product merchant2 =
INTEG(incoming backlog product merchant2
- processed backlog product merchant 2 ,
0)

order backlog product merchant3 =
INTEG(incoming backlog product merchant3
- processed backlog product merchant 3 ,
0)

order backlog product merchant4 =
INTEG(incoming backlog product merchant4
- processed backlog product merchant 4 ,
0)

order backlog product merchant5 =
INTEG(incoming backlog product merchant5
- processed backlog product merchant 5 ,
0)

order backlog product merchant6 =
INTEG(incoming backlog product merchant6
- processed backlog product merchant 6 ,
0)

```
order backlog product merchant7  =
        INTEG( incoming backlog product merchant7
                  - processed backlog product merchant 7 ,
             0)

order backlog product merchant8  =
        INTEG( incoming backlog product merchant8
                  - processed backlog product merchant 8 ,
             0)

order for products  =
        order placed by the regions
             * coef products

order product inc mistrust merchant1  =
        order product merchant 1
             * ( 1
                  + ( mistrust coef 1
                       * mistrust value reverse product merchant1 ) )

order product inc mistrust merchant2  =
        order product merchant2
             * ( 1
                  + ( mistrust coef 1
                       * mistrust value reverse product merchant2 ) )

order product inc mistrust merchant3  =
        order product merchant3
             * ( 1
                  + ( mistrust coef 1
                       * mistrust value reverse product merchant3 ) )

order product inc mistrust merchant4  =
        order product merchant4
             * ( 1
                  + ( mistrust coef 1
                       * mistrust value reverse product merchant4 ) )

order product inc mistrust merchant5  =
        order product merchant5
             * ( 1
                  + ( mistrust coef 1
                       * mistrust value reverse product merchant5 ) )

order product inc mistrust merchant6  =
        order product merchant6
             * ( 1
                  + ( mistrust coef 1
                       * mistrust value reverse product merchant6 ) )
```

order product inc mistrust merchant7 =
order product merchant7
* (1
+ (mistrust coef 1
* mistrust value reverse product merchant7))

order product inc mistrust merchant8 =
order product merchant8
* (1
+ (mistrust coef 1
* mistrust value reverse product merchant8))

order product merchant 1 =
order for products
* coef product merchant1

order product merchant2 =
order for products
* coef product merchant2

order product merchant3 =
order for products
* coef product merchant3

order product merchant4 =
order for products
* coef product merchant4

order product merchant5 =
order for products
* coef product merchant5

order product merchant6 =
order for products
* coef product merchant6

order product merchant7 =
order for products
* coef product merchant7

order product merchant8 =
order for products
* coef product merchant8

processed backlog product merchant 1 =
product to be delivered from merchant1

processed backlog product merchant 2 =
product to be delivered from merchant2

processed backlog product merchant 3 =
product to be delivered from merchant3

processed backlog product merchant 4 =
product to be delivered from merchant4

processed backlog product merchant 5 =
product to be delivered from merchant5

processed backlog product merchant 6 =
product to be delivered from merchant6

processed backlog product merchant 7 =
product to be delivered from merchant7

processed backlog product merchant 8 =
product to be delivered from merchant8

product deliveries merchant1 delay1 =
DELAY FIXED (product to be delivered from merchant1 ,1,
3e+006)

product deliveries merchant2 delay1 =
DELAY FIXED (product to be delivered from merchant2 ,1,
500000)

product deliveries merchant3 delay1 =
DELAY FIXED (product to be delivered from merchant3 ,1,
1e+006)

product deliveries merchant4 delay1 =
DELAY FIXED (product to be delivered from merchant4 ,1,
1e+006)

product deliveries merchant5 delay1 =
DELAY FIXED (product to be delivered from merchant5 ,1,
300000)

product deliveries merchant6 delay1 =
DELAY FIXED (product to be delivered from merchant6 ,1,
2e+006)

product deliveries merchant7 delay1 =
DELAY FIXED (product to be delivered from merchant7 ,1,
1.2e+006)

product deliveries merchant8 delay1 =
DELAY FIXED (product to be delivered from merchant8 ,1,
1e+006)

```
product deliveries on site =
    product deliveries merchant1 delay1
      + product deliveries merchant2 delay1
      + product deliveries merchant3 delay1
      + product deliveries merchant4 delay1
      + product deliveries merchant5 delay1
      + product deliveries merchant6 delay1
      + product deliveries merchant7 delay1
      + product deliveries merchant8 delay1

product to be delivered from merchant1 =
    IF THEN ELSE ( stock products before shipment merchant 1
          <= 0,
      0,
      IF THEN ELSE ( stock products before shipment merchant 1
            < ( incoming backlog product merchant1
              + order backlog product merchant1 ) ,
          stock products before shipment merchant 1 ,
          ( incoming backlog product merchant1
            + order backlog product merchant1 ) ) )

product to be delivered from merchant2 =
    IF THEN ELSE ( stock products before shipment merchant 2
          <= 0,
      0,
      IF THEN ELSE ( stock products before shipment merchant 2
            < ( incoming backlog product merchant2
              + order backlog product merchant2 ) ,
          stock products before shipment merchant 2 ,
          ( incoming backlog product merchant2
            + order backlog product merchant2 ) ) )

product to be delivered from merchant3 =
    IF THEN ELSE ( stock products before shipment merchant 3
          <= 0,
      0,
      IF THEN ELSE ( stock products before shipment merchant 3
            < ( incoming backlog product merchant3
              + order backlog product merchant3 ) ,
          stock products before shipment merchant 3 ,
          ( incoming backlog product merchant3
            + order backlog product merchant3 ) ) )

product to be delivered from merchant4 =
    IF THEN ELSE ( stock products before shipment merchant 4
          <= 0,
      0,
      IF THEN ELSE ( stock products before shipment merchant 4
            < ( incoming backlog product merchant4
              + order backlog product merchant4 ) ,
```

```
        stock products before shipment merchant 4 ,
        ( incoming backlog product merchant4
          + order backlog product merchant4 ) ) )

product to be delivered from merchant5  =
    IF THEN ELSE ( stock products before shipment merchant 5
        <= 0,
      0,
      IF THEN ELSE ( stock products before shipment merchant 5
          < ( incoming backlog product merchant5
            + order backlog product merchant5 ) ,
        stock products before shipment merchant 5 ,
        ( incoming backlog product merchant5
          + order backlog product merchant5 ) ) )

product to be delivered from merchant6  =
    IF THEN ELSE ( stock products before shipment merchant 6
        <= 0,
      0,
      IF THEN ELSE ( stock products before shipment merchant 6
          < ( incoming backlog product merchant6
            + order backlog product merchant6 ) ,
        stock products before shipment merchant 6 ,
        ( incoming backlog product merchant6
          + order backlog product merchant6 ) ) )

product to be delivered from merchant7  =
    IF THEN ELSE ( stock products before shipment merchant 7
        <= 0,
      0,
      IF THEN ELSE ( stock products before shipment merchant 7
          < ( incoming backlog product merchant7
            + order backlog product merchant7 ) ,
        stock products before shipment merchant 7 ,
        ( incoming backlog product merchant7
          + order backlog product merchant7 ) ) )

product to be delivered from merchant8  =
    IF THEN ELSE ( stock products before shipment merchant8
        <= 0,
      0,
      IF THEN ELSE ( stock products before shipment merchant8
          < ( incoming backlog product merchant8
            + order backlog product merchant8 ) ,
        stock products before shipment merchant8 ,
        ( incoming backlog product merchant8
          + order backlog product merchant8 ) ) )

stock product after shipment merchant1 delay1  =
    DELAY FIXED ( stock products after shipment merchant1 ,1,
```

1.2e+007)

stock product after shipment merchant2 delay1 =
DELAY FIXED (stock products after shipment merchant2 ,1,
2e+006)

stock product after shipment merchant3 delay1 =
DELAY FIXED (stock products after shipment merchant3 ,1,
4e+006)

stock product after shipment merchant4 delay1 =
DELAY FIXED (stock products after shipment merchant4 ,1,
4e+006)

stock product after shipment merchant5 delay1 =
DELAY FIXED (stock products after shipment merchant5 ,1,
1.2e+006)

stock product after shipment merchant6 delay1 =
DELAY FIXED (stock products after shipment merchant6 ,1,
8e+006)

stock product after shipment merchant7 delay1 =
DELAY FIXED (stock products after shipment merchant7 ,1,
4.8e+006)

stock product after shipment merchant8 delay1 =
DELAY FIXED (stock products after shipment merchant8 ,1,
4e+006)

stock products after shipment merchant1 =
stock products before shipment merchant 1
- product to be delivered from merchant1

stock products after shipment merchant2 =
stock products before shipment merchant 2
- product to be delivered from merchant2

stock products after shipment merchant3 =
stock products before shipment merchant 3
- product to be delivered from merchant3

stock products after shipment merchant4 =
stock products before shipment merchant 4
- product to be delivered from merchant4

stock products after shipment merchant5 =
stock products before shipment merchant 5
- product to be delivered from merchant5

stock products after shipment merchant6 =
stock products before shipment merchant 6
- product to be delivered from merchant6

stock products after shipment merchant7 =
stock products before shipment merchant 7
- product to be delivered from merchant7

stock products after shipment merchant8 =
stock products before shipment merchant8
- product to be delivered from merchant8

stock products before shipment merchant 1 =
incoming products merchant 1
+ stock product after shipment merchant1 delay1

stock products before shipment merchant 2 =
incoming products merchant2
+ stock product after shipment merchant2 delay1

stock products before shipment merchant 3 =
incoming products merchant3
+ stock product after shipment merchant3 delay1

stock products before shipment merchant 4 =
incoming products merchant4
+ stock product after shipment merchant4 delay1

stock products before shipment merchant 5 =
incoming products merchant5
+ stock product after shipment merchant5 delay1

stock products before shipment merchant 6 =
incoming products merchant6
+ stock product after shipment merchant6 delay1

stock products before shipment merchant 7 =
incoming products merchant7
+ stock product after shipment merchant7 delay1

stock products before shipment merchant8 =
incoming products merchant8
+ stock product after shipment merchant8 delay1

Ta products merchant = 14

"target inv. product merchant1" =
4
* average order products to merchant 1

```
"target inv. product merchant2"  =
      4
          * average order products to merchant 2

"target inv. product merchant3"  =
      4
          * average order products to merchant 3

"target inv. product merchant4"  =
      4
          * average order products to merchant 4

"target inv. product merchant5"  =
      4
          * average order products to merchant 5

"target inv. product merchant6"  =
      4
          * average order products to merchant 6

"target inv. product merchant7"  =
      4
          * average order products to merchant 7

"target inv. product merchant8"  =
      4
          * average order products to merchant 8

Ti products merchant  = 14

transport delay  = 1

wip products merchant 1  =
      INTEG( orate products merchant 1
              - incoming products merchant 1 ,
          2.1e+007)

wip products merchant 2  =
      INTEG( orate products merchant 2
              - incoming products merchant2 ,
          3.5e+006)

wip products merchant3  =
      INTEG( orate products merchant 3
              - incoming products merchant3 ,
          7e+006)

wip products merchant4  =
      INTEG( orate products merchant 4
              - incoming products merchant4 ,
```

```
        7e+006)

wip products merchant5  =
      INTEG( orate products merchant 5
            - incoming products merchant5 ,
        2.1e+006)

wip products merchant6  =
      INTEG( orate products merchant 6
            - incoming products merchant6 ,
        1.4e+007)

wip products merchant7  =
      INTEG( orate products merchant 7
            - incoming products merchant7 ,
        8.4e+006)

wip products merchant8  =
      INTEG( orate products merchant 8
            - incoming products merchant8 ,
        7e+006)

*******************************
  .Production allocation
*******************************

coef product merchants[merchant product 1]  =
     coef product merchant1
coef product merchants[merchant product 2]  =
     coef product merchant2
coef product merchants[merchant product 3]  =
     coef product merchant3
coef product merchants[merchant product 4]  =
     coef product merchant4
coef product merchants[merchant product 5]  =
     coef product merchant5
coef product merchants[merchant product 6]  =
     coef product merchant6
coef product merchants[merchant product 7]  =
     coef product merchant7
coef product merchants[merchant product 8]  =
     coef product merchant8

manufacturer product production allocation[Merchants product]  =
      allocate by priority ( orate product merchant[Merchants product] ,
        coef product merchants[Merchants product] ,
        8,
        0.01,
        product to be delivered to merchants )
```

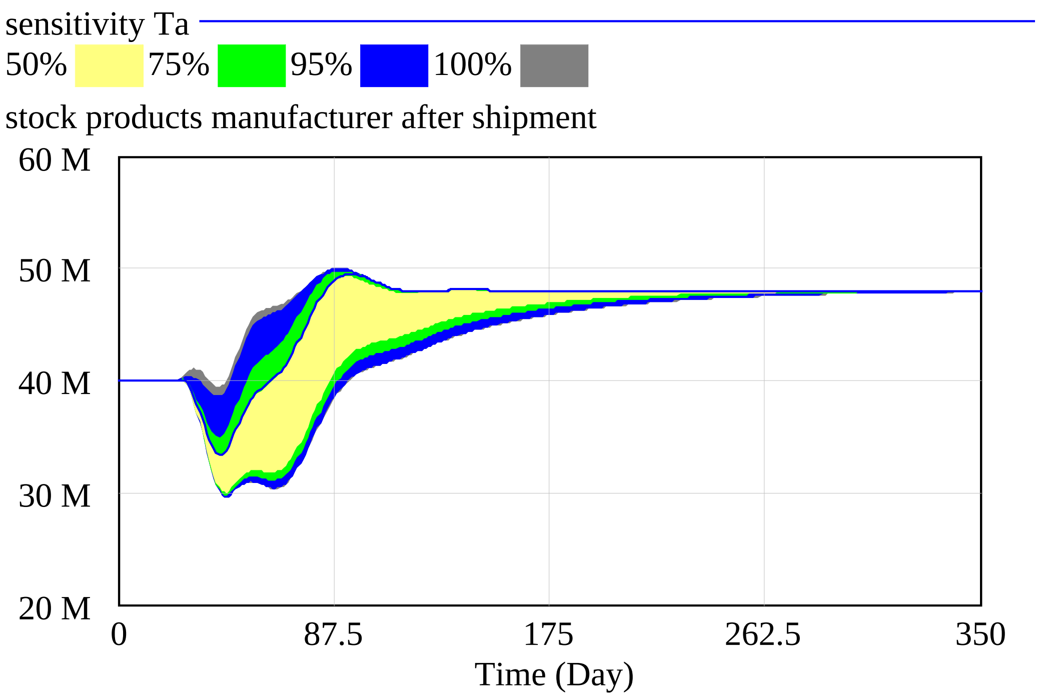
Merchants product : merchant product 1,merchant product 2,merchant product 3,merchant product 4,merchant product 5,merchant product 6,merchant product 7,merchant product 8

```
orate product merchant[merchant product 1]  =
        DELAY FIXED ( orate products merchant 1 ,6,
             3e+006)
orate product merchant[merchant product 2]  =
       DELAY FIXED ( orate products merchant 2 ,6,
            500000)
orate product merchant[merchant product 3]  =
       DELAY FIXED ( orate products merchant 3 ,6,
            1e+006)
orate product merchant[merchant product 4]  =
       DELAY FIXED ( orate products merchant 4 ,6,
            1e+006)
orate product merchant[merchant product 5]  =
       DELAY FIXED ( orate products merchant 5 ,6,
            300000)
orate product merchant[merchant product 6]  =
       DELAY FIXED ( orate products merchant 6 ,6,
            2e+006)
orate product merchant[merchant product 7]  =
       DELAY FIXED ( orate products merchant 7 ,6,
            1.2e+006)
orate product merchant[merchant product 8]  =
       DELAY FIXED ( orate products merchant 8 ,6,
            1e+006)

product deliveries merchant1  =
        manufacturer product production allocation[merchant product 1]

product deliveries merchant2  =
        manufacturer product production allocation[merchant product 2]

product deliveries merchant3  =
        manufacturer product production allocation[merchant product 3]

product deliveries merchant4  =
        manufacturer product production allocation[merchant product 4]

product deliveries merchant5  =
        manufacturer product production allocation[merchant product 5]

product deliveries merchant6  =
        manufacturer product production allocation[merchant product 6]

product deliveries merchant7  =
        manufacturer product production allocation[merchant product 7]

product deliveries merchant8  =
```

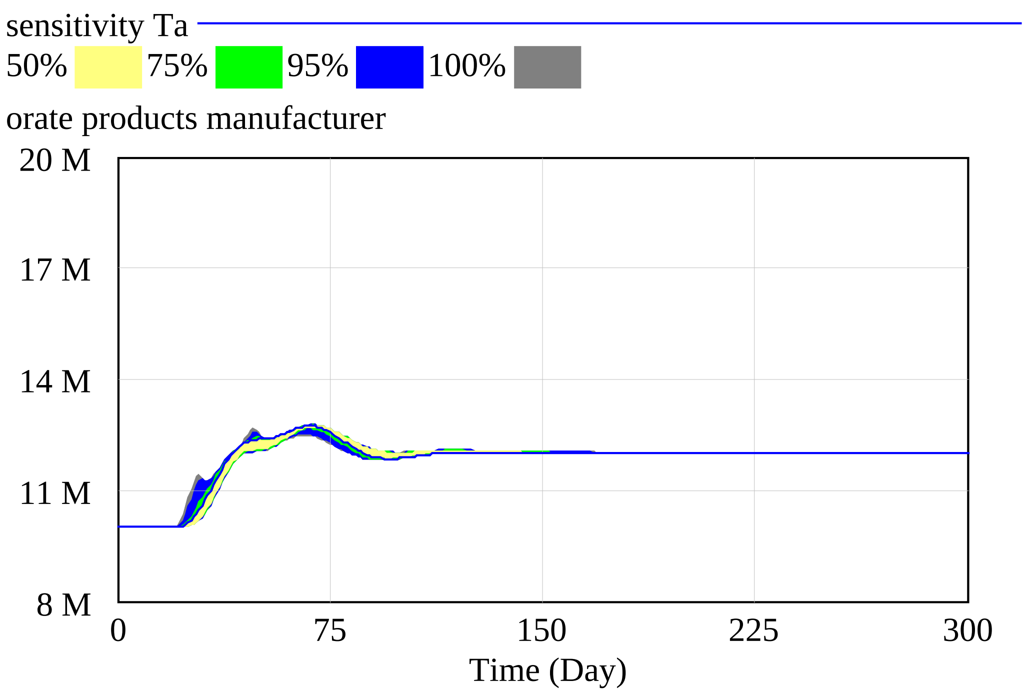
```
        manufacturer product production allocation[merchant product 8]

********************************
   .Site construction
********************************

coef labour  = 3

construct house  =
        MIN ( INTEGER ( stock of products to be used
                  / coef products ) ,
             INTEGER ( stock of labour to be used
                  / coef labour ) )

construction time delay  = 63

demand for labour  =
        DELAY FIXED ( ( call off products by the site
                / coef products )
                * coef labour ,call off to delivery delay ,
             300)

free labour  =
        water proofed house
             * coef labour

incoming call off for labour  =
        demand for labour

labour backlog  =
        INTEG( incoming call off for labour
                - processed call off for labout ,
             0)

labour to be used  =
        IF THEN ELSE ( subcontractor available before used
                <= 0,
             0,
             IF THEN ELSE ( subcontractor available before used
                  < ( incoming call off for labour
                      + labour backlog ) ,
                subcontractor available before used ,
                ( incoming call off for labour
                  + labour backlog ) ) )

labour used  =
        construct house
             * coef labour

processed call off for labout  =
```

```
    labour to be used

products delivered on site  =
    product deliveries on site

products used  =
    construct house
      * coef products

stock of labour to be used  =
    INTEG( labour to be used
        - labour used ,
      300)

stock of products to be used  =
    INTEG( products delivered on site
        - products used ,
      1e+007)

sub contractor available after used  =
    subcontractor available before used
      - labour to be used

subcontractor available after delay1  =
    DELAY FIXED ( sub contractor available after used ,1,
      5000)

subcontractor available before used  =
    free labour
      + subcontractor available after delay1

total weather proofed houses built  =
    INTEG( water proofed house ,
      0)

water proofed house  =
    DELAY FIXED ( construct house ,construction time delay ,
      100)
```

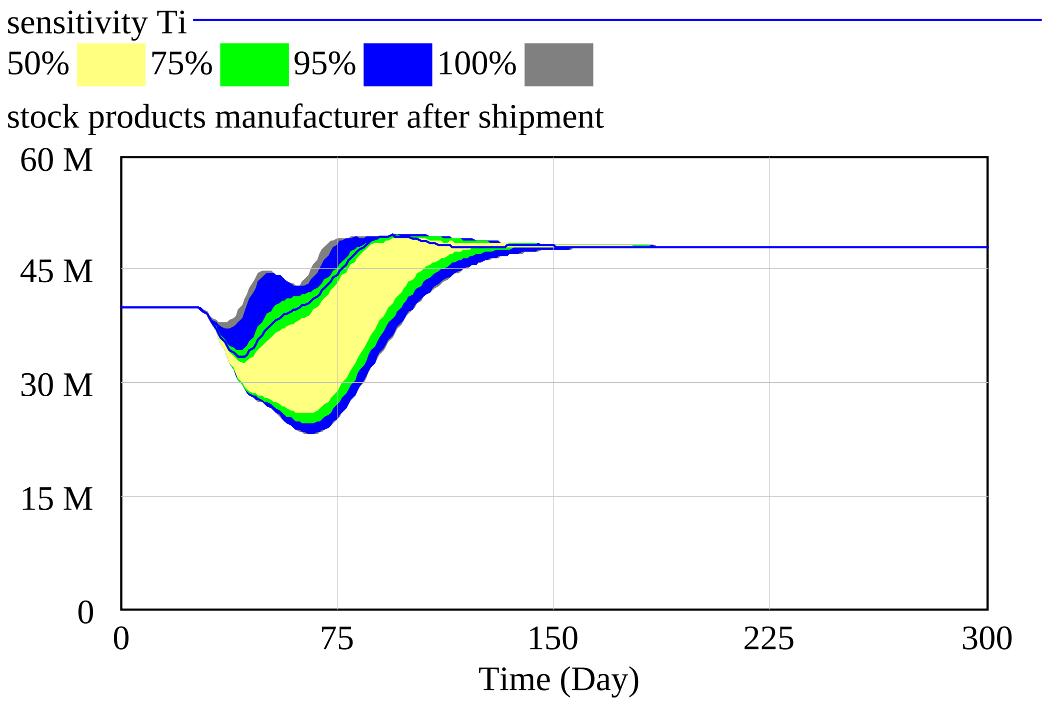
Appendix 4 – Sensitivity analysis



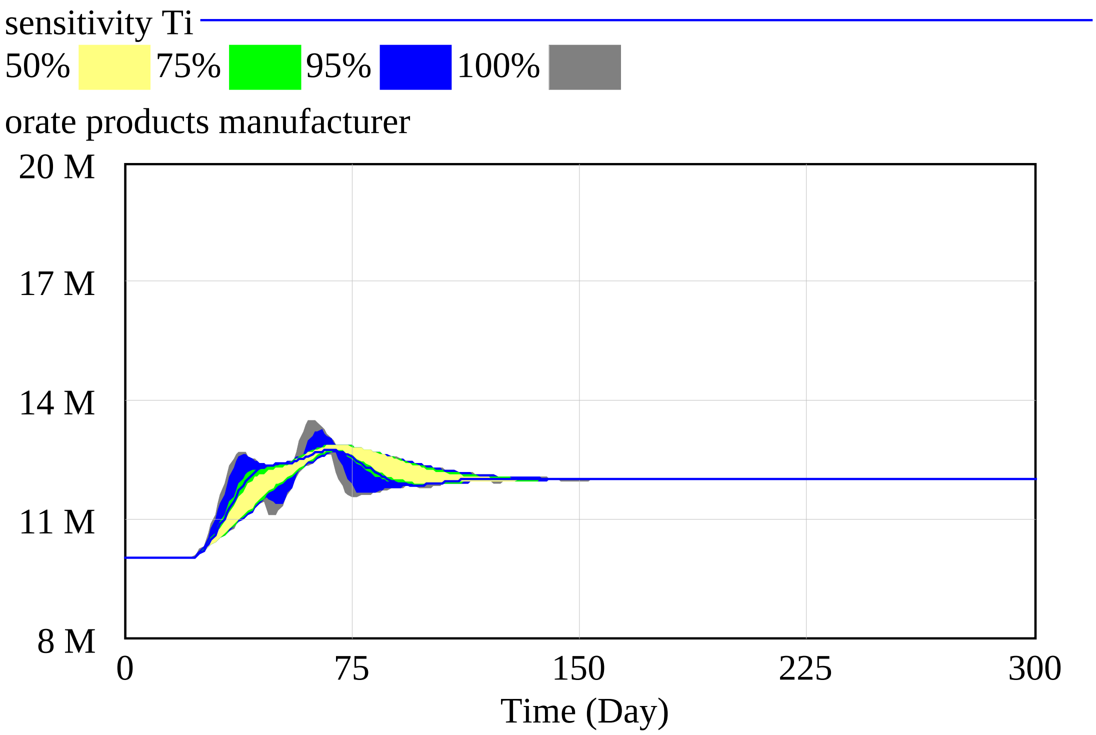
Sensitivity analysis for T_a (time to average consumption)(1 to 60) on the manufacturer's inventory level



Sensitivity analysis for T_a (time to average consumption)(1 to 60) on the manufacturer's order rate



Sensitivity analysis for T_i (time to adjust inventory)(2 to 30) on the manufacturer's inventory level



Sensitivity analysis for T_i (time to adjust inventory)(2 to 30) on the manufacturer's order rate