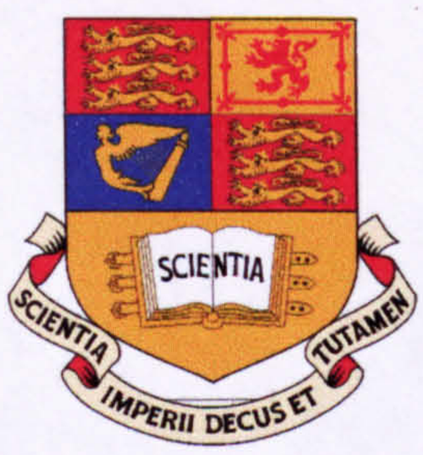
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Agility in Supply Chain Networks

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A thesis submitted for the degree of Doctor of Philosophy in Engineering
of the University of London and for the Diploma of Imperial College

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ABSTRACT

With the emergence of a new business era, characterised by continuous changes and tough global competition, there is now a widespread recognition of agile supply chains as a strategy for companies to compete in the rapidly changing markets. Key to an agile supply chain is fast material, information and decision flows across the supply network, which can be achieved through the integration of business processes both within and outside an organisation in the network.

Based on the IST Project Co-OPERATE, this thesis proposes a system that enhances agility in supply chain networks by managing the supply chain execution process in an exception-focused way. Starting from the literature review of supply chain management and business requirements analysis, a framework for improved coordination of production planning and control activities in a distributed supply network is conceptualised. Following the top-down design approach, the decentralised system architecture is chosen based on the discussion and evaluation of three reference models for network coordination. Guided by the overall design principles, the high-level design of the four focused business processes is accomplished and the Exception Handling process is chosen for further design and development, which is embedded in a broader process entitled exception-focused supply chain execution management (ESCEM).

To validate the proposed concepts and methodology and to demonstrate the potential benefits of the developed solution, a pilot system for ESCEM is implemented in a collaborative supply chain environment and evaluated by industrial partners in the Co-OPERATE project, which is based on studies of some typical real business cases. The novel results of the presented work are then summarised and finally possibilities for further research identified.

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Chapter 1

INTRODUCTION

1.1 AGILITY AND SUPPLY CHAIN NETWORKS

The idea of supply chain can be traced back to the beginning of the Industrial Revolution, when work division was established for improved efficiency and productivity. However, it was not until the early 1980s that the term supply chain management (SCM) was introduced by consultants. From the literal meaning, supply chain has a linearity which conceals some non-linear characteristics of inter-company relationship, e.g. loop relationship where the customer is also a supplier to the supplier (Cox and Lamming, 1997). Meanwhile, a company can simultaneously participate in several supply chains. This has led to a more comprehensive concept – supply chain network, or simply supply network. Therefore, a supply chain can be defined as:

A network of business entities co-operatively developing, purchasing, manufacturing and distributing products or delivering service to the end customer (Figure 1-1).

During the last five years, much of the research on supply chain strategies has been focused on how lean and agile manufacturing paradigms can be adopted in the supply chain (Fisher, 1997; Naylor et al., 1999; Mason-Jones et al., 2000; Christopher, 2000 and Lamming et al., 2000). Gunasekaran (1999) states that the key difference between them is that agility places a higher priority on responsiveness over cost-efficiency and leanness compromises responsiveness over cost-efficiency. Naylor et al. (1999), Christopher (2000) and Mason-Jones et al. (2000) argue that lean does not necessarily imply agile, however, agile and lean are complementary within the correct supply chain strategy. They suggest that leanness and agility can be combined with a strategic use of a decoupling point, aiming to reap the benefits of both paradigms as illustrated in Figure 1-2.

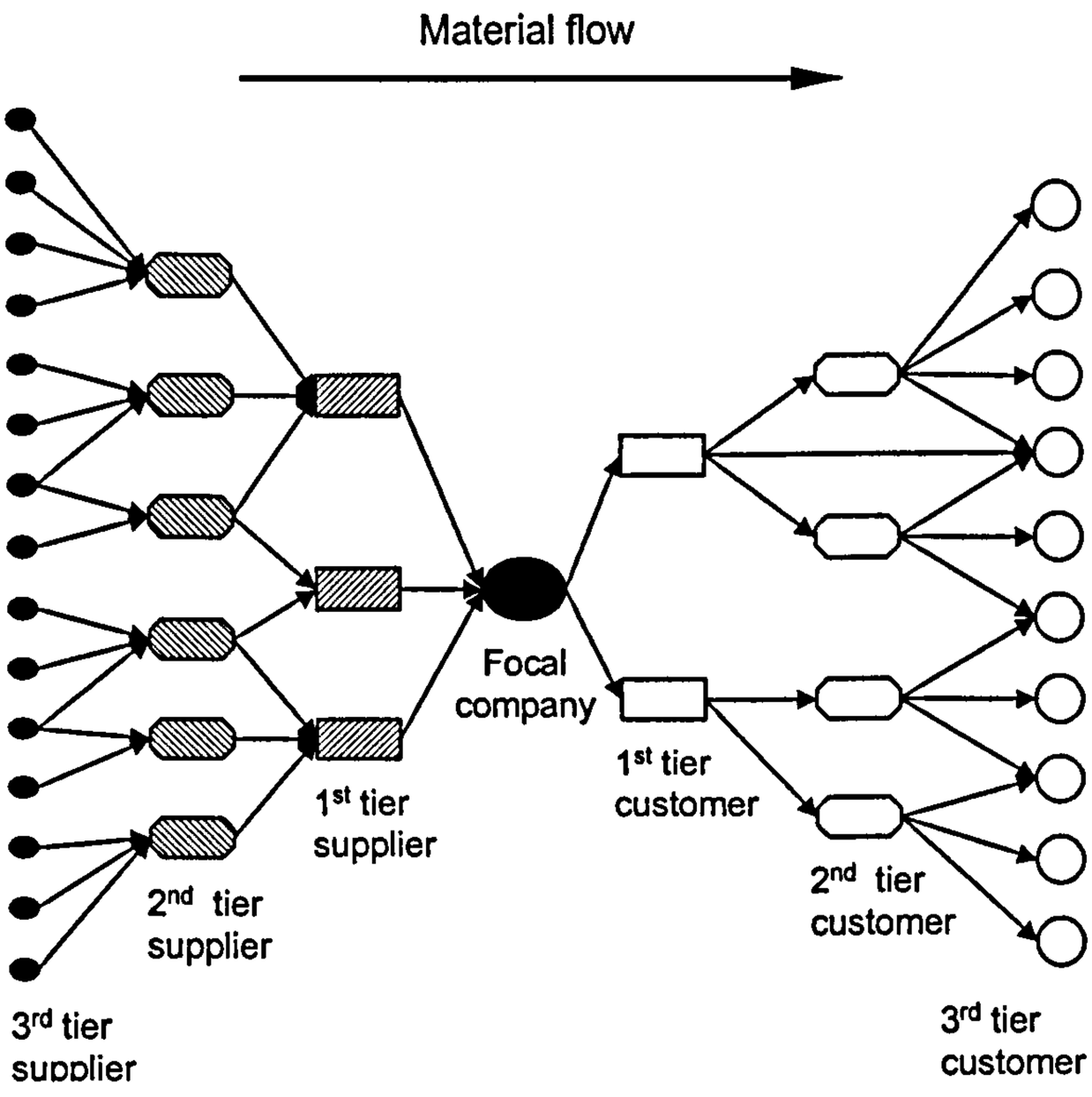


Figure 1-1: A complex supply chain

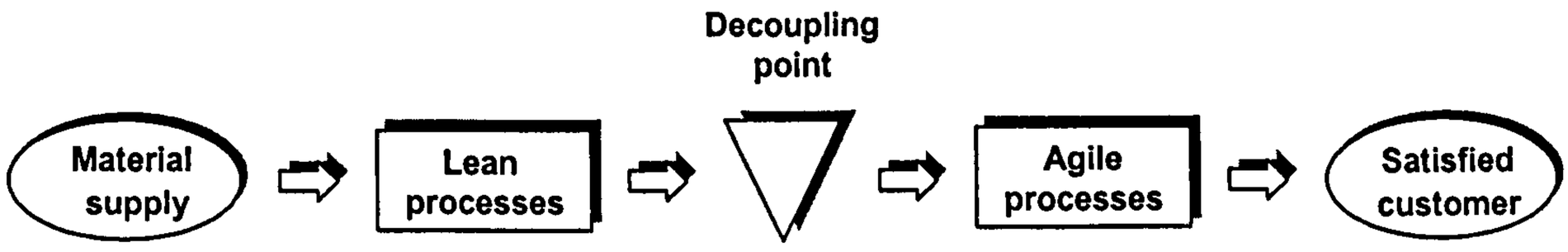


Figure 1-2: Block diagrams representing leagile supply (after Mason-Jones et al., 2000)

Fisher (1997) concludes that supply chains must be managed according to the nature of the product being supplied. He observes that products primarily fall into two categories: "functional" and "innovative" products. Functional products (e.g. stationary items) usually have relatively stable, easy-to-forecast demand and long product life cycles, and thus cost minimisation is the primary target, while innovative products are characterised by unstable, hard-to-predict demand and shorter product life cycles, and thereby need to focus on speed and flexibility, or agility, in order to win orders.

Lamming et al. (2000) support and develop Fisher's argument. Based on a survey including 16 major firms from a variety of industries in Europe and their suppliers and customers, they conclude that Fisher's argument can be extended from chains to net-

works, and product uniqueness should be coupled with product innovativeness as a feature of the product. They also conclude that product complexity should be used as a second differentiator since complex products usually have large numbers of components, making supply networks more difficult to manage.

It can be concluded that at any node in a supply network, the supply chain strategy to be pursued is primarily customer-driven, including demand variability, product complexity and customisation and delivery lead-time. Meanwhile, network culture, which is sometimes a reflection of the ability of the focal company to influence the rest of the supply network, also has a considerable impact on the supply chain strategy of the company.

1.2 SUPPORTING AGILE SUPPLY CHAIN BY THE INTERNET

For a supply chain to be agile, it must obtain some key characteristics as depicted in Figure 1-3.

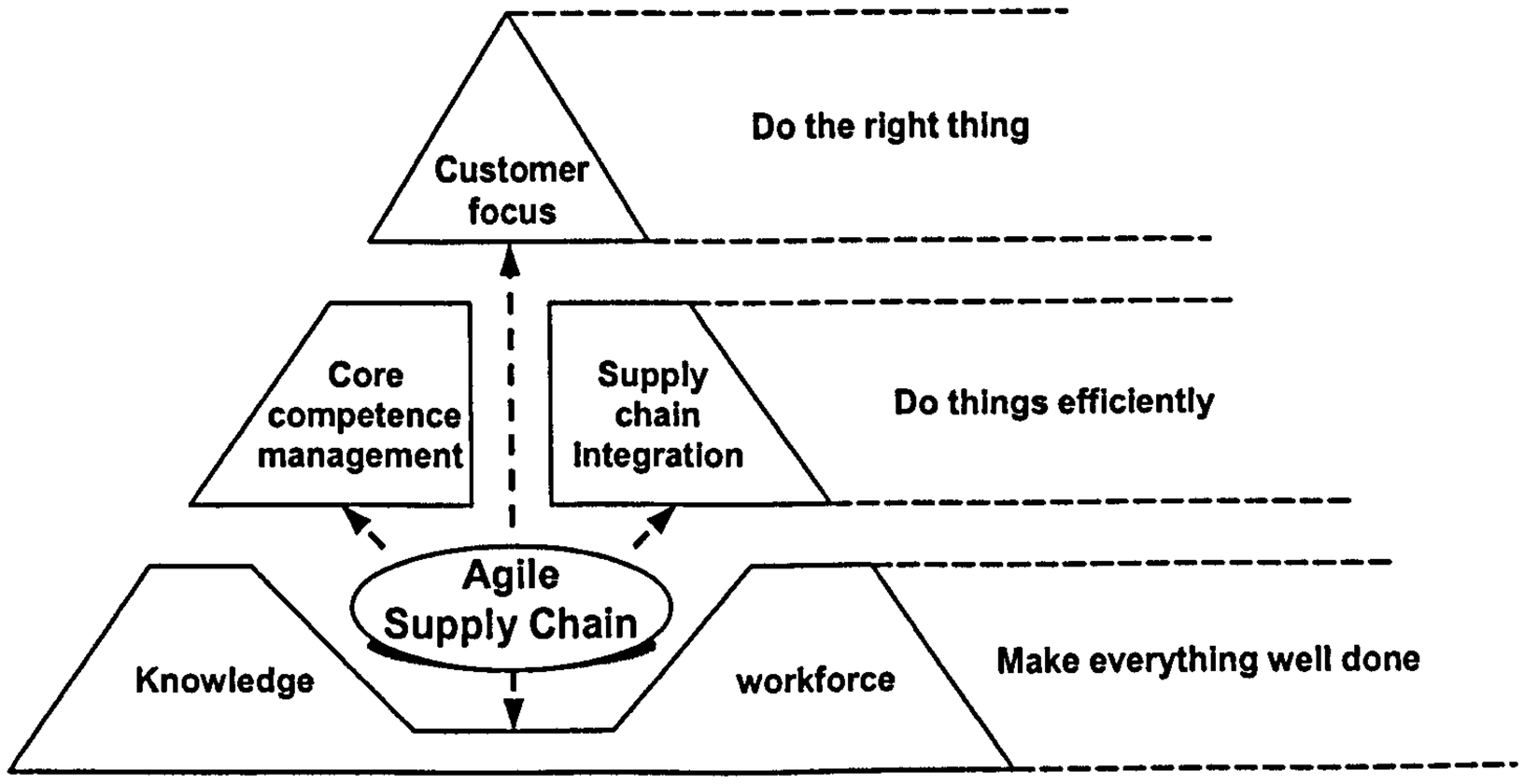


Figure 1-3: A conceptual model of agile supply chain

Firstly, an agile supply chain should be customer focused through the anticipation and response to the total need of the customer, in terms of product specification, variety, volume and delivery requirements, etc (Korhonen et al., 1998; Katayama and Bennett, 1999). Secondly, each company should focus on its own core competence to achieve maximum efficiency and cost-effectiveness (Sharp et al., 1999; Yusuf et al. 1999).

Thirdly, core competence focus necessitates a greater reliance on suppliers and business partners, and thus an integrated supply chain (Stevens, 1989; Maloni and Benton 1997; Frohlich and Westbrook, 2001). Finally, core competence management and supply chain integration ultimately depend on motivated, knowledgeable workforce to convert their skills, knowledge and expertise into workable solutions (Sheridan, 1993; Yusuf et al., 1999).

Though agility is a multidimensional competence with different meanings for different operational environments (Narasimhan and Das, 1999), it is generally agreed that the essence of agility is the ability to respond to changes in a fast and cost-effective way (Goldman and Nagel, 1993; Mason-Jones and Towill, 1999; Gunasekaran, 1998, 1999; Yusuf et al., 1999; Sharifi and Zhang 1999). In the supply chain execution process, the response time is basically the time it takes to close the gap from when an event occurs until actions are taken, which will rely not so much on equipment, but on information and knowledge workforce (Sheridan, 1993; Goldman and Nagel, 1993; Gunasekaran, 1998, 1999; Yusuf et al., 1999; Schönsleben, 2000) as shown in Figure 1-4.

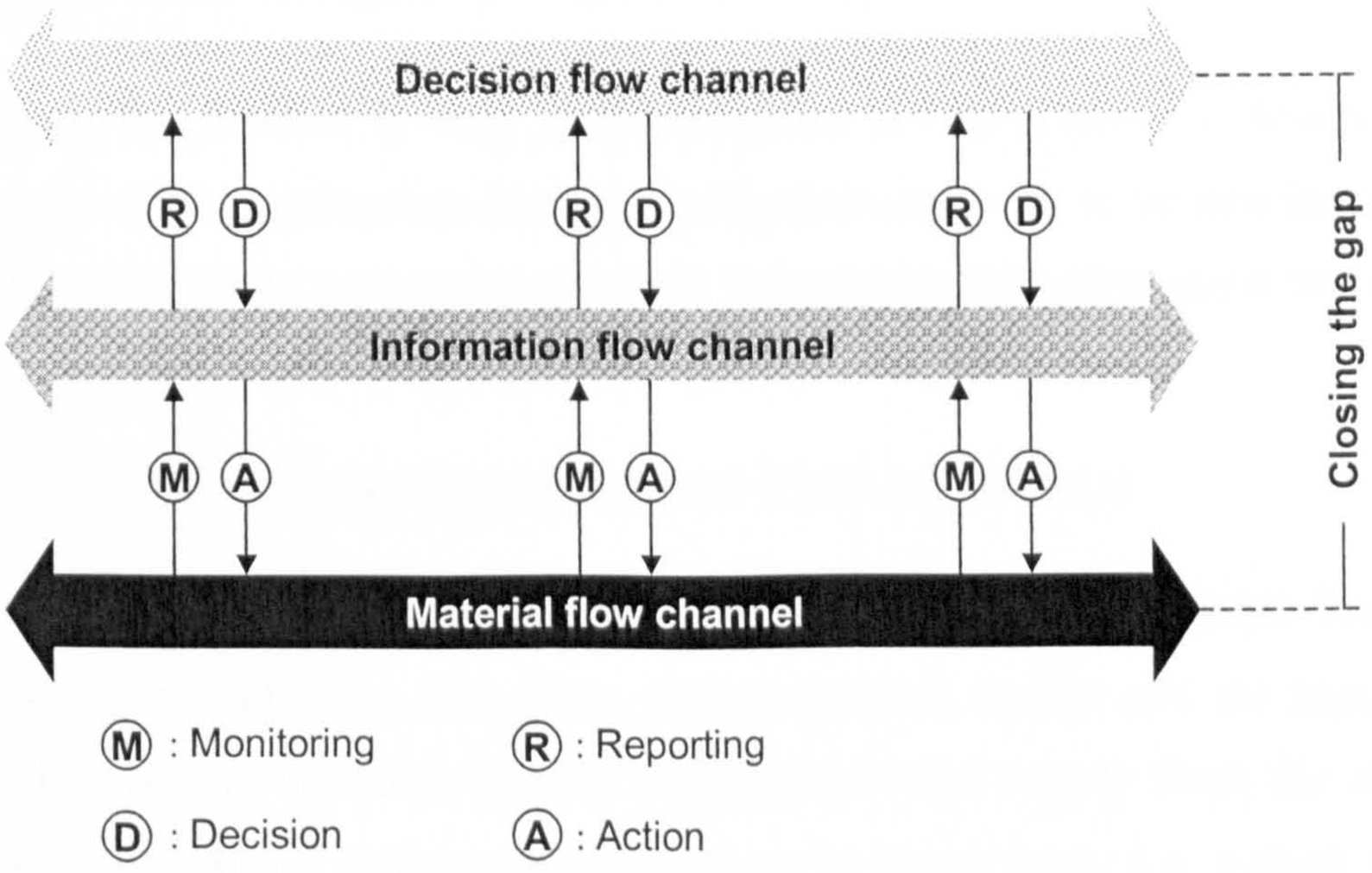


Figure 1-4: Closing the gap – the MRDA cycle in an agile supply chain

It is thus recognised that effectiveness and efficiency of any supply chain relies on the visibility of demand, inventories and material flows throughout the pipeline. Time lapses in information flows are directly translated into inventory (Korhonen et al.,

1998). These problems tend to be larger at the interfaces between companies where more disparities and uncertainties exist. Therefore, it is paramount to facilitate fast, accurate information exchange and efficient coordination between companies to achieve the synchronisation of material and information flows.

The Internet has some compelling characteristics over traditional means of communication, such as electronic data interchange (EDI) – the application-to-application transfer of business documents using the ANSI X.12 or UN/EDI-FACT standards, which makes it the most attractive platform for supply chain integration and coordination.

- Global availability makes information accessible world-wide.
- Low operating cost and fast information transfer.
- Multi-type data support (transactional data and non-transactional data, e.g. pictures, hyperlinks) promotes supply chain collaboration.
- Standardisation (e.g. a common communication protocol: TCP/IP) lowers integration costs.
- Many-to-many configuration reflects the real network nature of a supply chain.

Nevertheless, the Internet is only a technological infrastructure. To achieve an integrated supply chain, appropriate business methodologies have to be developed and supporting IT tools must be put in place to meet its business and information requirements.

1.3 Motivation and objectives of PhD research

Generally, supply chain challenges and solutions vary across industries. This research targets two capital-intensive industries: the automotive supply and the semiconductor industries because the research focus is on the electronics supply chain for the automotive industry. In spite of different characteristics between them, e.g. a short fixed planning horizon in the automotive supply industry and a high yield loss in the semiconductor manufacturing process, supply chains in these two industries face three major common problems.

- **Distorted demand**

Demand information for a product tends to become distorted as the information moves upstream in the supply chain. This phenomenon, also called "the bullwhip effect", could lead to excessive inventories, unstable production plans and poor customer service due to unavailable products or long backlogs (Lee et al., 1997).

- **Missed delivery**

With just-in-time delivery widely adopted in industries, especially in the automotive industry, fast, reliable delivery has become a demanding requirement for suppliers. An international study shows that European auto components suppliers have significantly higher percentage of late deliveries and shipments than their Japanese counterparts (Oliver et al., 1996). The negative effect of missed deliveries could cascade quickly forward through the supply chain, causing bloated inventories, expanded lead-times and unsatisfied customers.

- **Poor responsiveness**

Due to lack of information on real customer demand and of decision-support tools for handling unforeseen or exceptional events, a supply chain usually takes too long to respond to new or changing customer requirements. This is also the case on the supply side when suppliers have delivery problems and try to minimise the knock-on effect on their customers and even further downstream in the supply chain.

Despite all research work and industrial efforts, the problems stated above are still rife within many supply chains. The most effective approach to address them is to integrate the entire supply chain and to coordinate inter-company activities by information technology (Levary, 2000). EDI helps to promote information sharing and reduce the amount of data entry, however, its high cost, perceived technical complexity and required organisational changes prevent small and medium-sized enterprises (SMEs) from participation (Raymond and Blili, 1997). On the other hand, ERP systems help companies get "their own house in order", but this inward-looking approach has impeded inter-company integration and coordination in supply networks (Zheng et al., 2000).

The Internet and Web-enabled SCM tools have provided great opportunities for supply chain managers to tackle the above issues. Some companies, such as Honeywell Aerospace, have started to unleash the potential benefits of Web-enabled supply chain management (Small, 2001). Yet, learning how to take advantage of the new possibilities is likely to take some time.

Currently, the supply chain community has concentrated on the optimisation of manufacturing plans and best practices in the supply chain, such as vendor managed inventories (VMI) whereby the supplier assumes the responsibility for managing the replenishment of stock. However, even perfect plans cannot avoid unforeseen or exceptional events, or "exceptions" in the supply chain execution process, such as late deliveries. In both academia and industries, little attention has been paid in developing the methodology and standard business processes for handling such exceptions in the supply chain execution process after customer orders being placed.

The main objective of this PhD research is to develop new concepts, methodology, business processes and communication tools for improved visibility of supply information and enhanced exception handling capability in the supply chain execution process. Specifically, the research topic covers:

- identifying business and system requirements for manufacturing coordination in complex supply networks.
- developing a framework of key collaborative business processes for improved coordination of supply chain planning and execution activities.
- developing new concepts and methodology for holistic control and exception-focused management of the supply chain execution process.
- designing and developing business processes for improved supply information visibility and enhanced exception handling capability in the supply chain execution process.
- designing and implementing an exception-focused supply chain execution management tool to demonstrate the developed concepts, methodology and business processes.

The research work is based on an IST project entitled Co-OPERATE, which is outlined in the next section.

1.4 THE CO-OPERATE PROJECT

The full name of the Co-OPERATE project is "Co-operation in Dynamic Networked Organisations", which aims to develop a set of new concepts, methodologies and communication tools for improved coordination of production planning and control activities in the supply network.

The Co-OPERATE project started in January 2000 and was completed in April 2002. The project targeted the automotive supply and the semiconductor industries, which are representative of cross-industry supply networks. Companies in these industries usually get involved in complex supply networks to produce highly customised products, and thus require fast, accurate information exchange and close collaboration and coordination between companies in the network. There are three major innovative elements for the Co-OPERATE system as follows.

- Concentration on short- to medium-term supply chain planning and execution processes in a supply network. This focus pinpoints the essential business processes that can reap considerable immediate benefits with minimum investment.
- A modular, fully decentralised system architecture compatible with the distributed and independent nature of individual network nodes, which promotes flexibility and reconfigurability in the network.
- Low cost of ownership suitable for SMEs, whose involvement in the collaboration processes will benefit the whole network.

The project work was carried out in eight work packages (WP) as outlined in Figure 1-5, which were led by the different partners in the project according to their greatest competence.

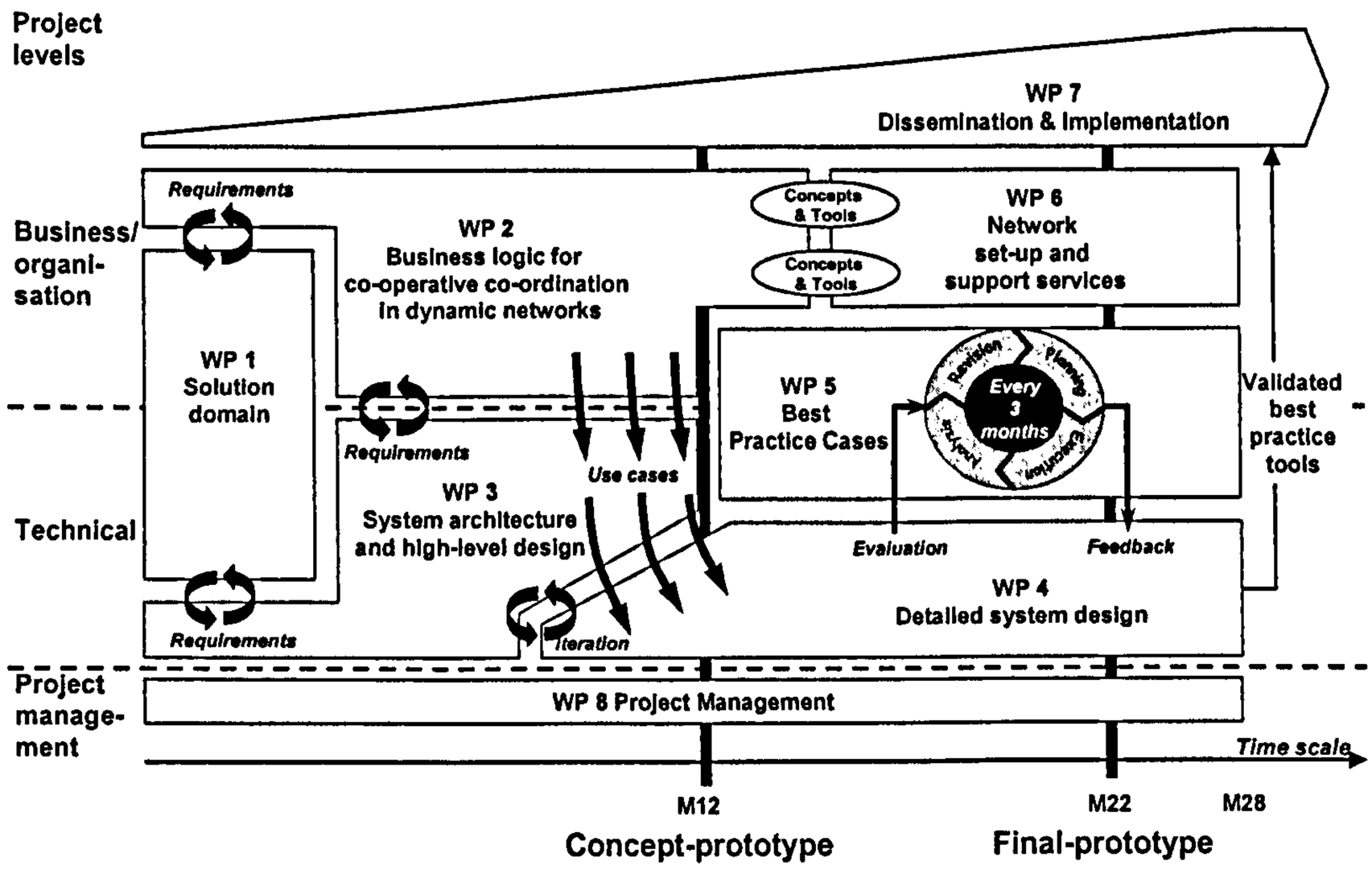


Figure 1-5: Co-OPERATE Project structure (Co-OPERATE project proposal, 1999)

The project partners are:

- Alcatel Microelectronics, a semiconductor manufacturer with locations in Oudenaarde and Brussels, Belgium. They produce components for telecommunication, automotive electronics and other markets and supply Siemens VDO with customised integrated circuits. Alcatel was the leader of WP8, which coordinated activities in all aspects of the project. In the meantime, Alcatel was also involved in WP1, 2, and 5.
- Siemens VDO, a 1st-tier automotive supplier with main business on electronic systems, such as engine electronics, safety systems and driver information systems, which are customised for different car models. Its headquarter in Regensburg, Germany participates in the Co-OPERATE project. During the project life cycle, Siemens VDO mainly contributed to WP 1, 2 and 5.
- MEMC Electronic Materials in Novarra, Italy, the world's second largest silicon wafer manufacturer. They supply Alcatel Microelectronics with wafer material, which has limited customisation. Similar to Siemens VDO, MEMC was involved in WP1, 2 and 5. However, the scope of involvement of MEMC was smaller than that of Siemens VDO.

- Xansa, a management and information technology consultancy based in Reading, UK. They were involved in WP1, 2 and 6.
- INESC Porto, a research institution in electronics and information technology in Portugal. They contributed to WP1, 2, 3, and 4, particularly to the Request and Feasibility Study (ReFS) process as a medium- to long-term business solution for network coordination (Refer to Chapter 3 and 4).
- Imperial College, the Computer Aided Systems Engineering (CASE) section in the Department of Mechanical Engineering. As the original project proposer, Imperial College were involved in all the tasks of the project, particularly in the detailed design and implementation of Operational Ordering and Planning (OOP), Visibility of Order Progress (VOP) and Exception Handling (eXH) processes as business solutions for improved coordination of short- to medium-term supply chain planning and execution activities (Refer to Chapter 3 and 4).

The main industrial partners in the project constitute a small part of a real supply network. Additionally, there are also five SMEs affiliated to the project, who were involved in the business requirements analysis stage of the Co-OPERATE project.

The research work presented in this thesis was an important part of the Co-OPERATE project. During the system design stage, the author contributed to WP1, 2 and 3, in co-operation with other two colleagues: Hermann Löh and Thomas Rupp (Löh, 2000, Rupp, 2001, Co-OPERATE deliverables: D3, D5, D8, D9 and D10). In the later stage of system implementation and evaluation, the author contributed to WP4 and 5, particularly to the eXH process and its interface with the VOP process (Xu et al., 2003), in collaboration with other two colleagues: Ihab Olama and Lale Ulku, who were involved in OOP and VOP (Co-OPERATE deliverables: D14, D19 and D21).

1.5 THESIS OUTLINE

Chapter 1 gives an introduction to the research domain and presents the motivation and objectives of the PhD research. In Chapter 2, current development and issues concerning ERP systems and supply chain management are described, and commercial solutions for network coordination are reviewed.

Chapter 3 describes the industrial context and business requirements derived from that. Based on this, a framework for supply chain coordination is proposed. In Chapter 4, discussion and evaluation of possible forms of network coordination architectures for the proposed framework leads to the choice of the fully decentralised system architecture. This is followed by the scope identification of the eXH process and the high-level design of four focused business process. Finally, the Co-OPERATE system is compared with other solutions.

Chapter 5 focuses on detailed design of exception-focused supply chain execution management. Firstly, the need for exception-focused supply chain execution management is introduced. Secondly, a holistic control, exception-focused methodology for supply chain execution management is developed. Thirdly, detailed design for the eXH process is presented, including process description, function modelling and scenario analysis.

In Chapter 6, business processes designed in Chapter 5 are implemented in a pilot system to demonstrate the developed concepts and methodology. The implementation environment is first introduced and then the pilot system database is presented. This is followed by the description of the functionality implemented in the pilot system.

Chapter 7 evaluates the developed concepts, methodology and business processes by a typical real case study. This is followed by the description of the evaluation method for Co-OPERATE and the evaluation results for the case study through the comparison between the traditional and the proposed processes. Then, the results of evaluation for the Co-OPERATE system are summarised and strengths and weaknesses of the evaluation are discussed. Finally, the thesis is concluded in Chapter 8 by bringing out the novelty of the presented work, recapturing the main contributions of the PhD research and indicating future work.

Chapter 2

REVIEW OF SUPPLY CHAIN MANAGEMENT

This chapter provides a literature review of several topics that are relevant to this research. The first section gives an overview of enterprise requirements planning (ERP) as the backbone of the supply chain. As the logical next step, some major issues in supply chain management are discussed in the second section of the chapter. The relevant literature on methods for supply chain integration and coordination is reviewed in the third section. The fourth section depicts current commercial solutions in network coordination. Finally, discussion is provided on the previous literature reviewed and lessons learnt are summarised.

2.1 ERP: THE BACKBONE OF THE SUPPLY CHAIN

2.1.1 Historic overview

The term "enterprise resources planning" was coined by the Gartner Group (a research and advisory firm with its headquarter in Stamford, Connecticut, USA) in the early 1990s to describe a set of applications that integrate and automate some core business processes within an organisation, such as manufacturing, accounting and human resources (Mabert et al., 2001). With its roots in manufacturing, the ancestry of ERP was material requirements planning (MRP), which was extended into manufacturing resources planning (MRP II) to support the shop floor and distribution management (Zheng et al., 2000).

ERP represents the application of the client/server technology and relational database management systems to the MRP II model and extends it to cover additional areas, such as accounting, human resources, etc (Gumaer, 1996). These large integrated systems provide instant access to timely information and better visibility of operational information in an organisation, leading to improved efficiency of resources. During the 1990s,

ERP systems achieved tremendous commercial value. SAP, Oracle, Peoplesoft, Baan, and JD Edward are currently among leading ERP software vendors.

2.1.2 Backbone of the supply chain

Figure 2-1 presents the general architecture of an ERP system. The Gartner Group defines ERP as follows.

A collection of applications that integrate sales, manufacturing, human resources, logistics, accounting and other enterprise functions based on a common architecture that links the enterprise to both customers and suppliers.

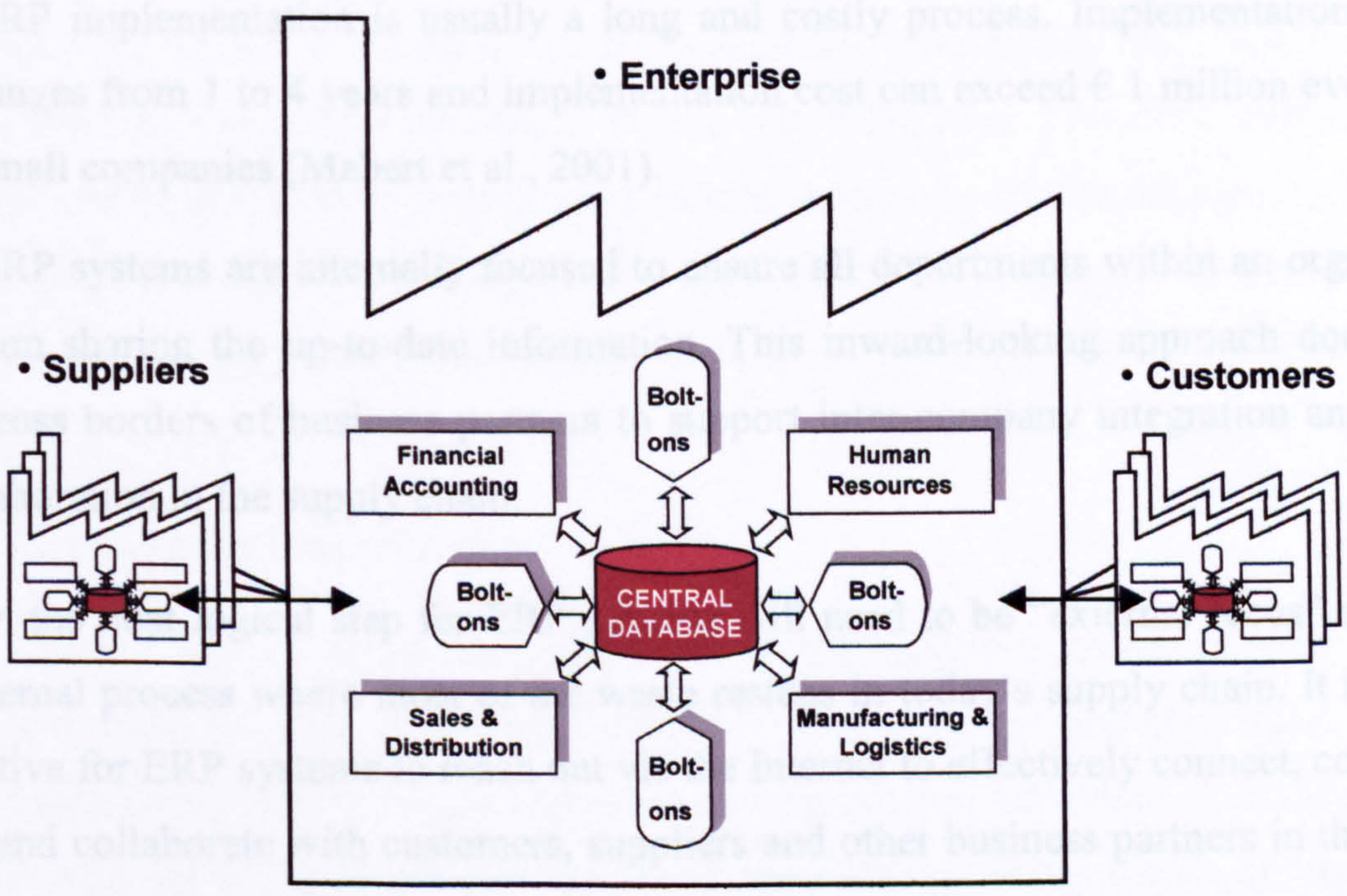


Figure 2-1: Generic system architecture of an ERP system

As an integrator linking together such back-office operations as manufacturing, accounting and distribution, ERP is actually the information hub of the enterprise with spokes to other "bolt-on" (or application-specific) systems that provide specialised functionalities such as customer relationship management. It embraces an IT infrastructure that facilitates the information flow between all supply chain processes within an organisation, and also provides a platform for people across different departments to share

information and to work effectively. From a broad view of the supply chain, ERP means getting a company's internal systems integrated so that they can participate in the integration of the entire supply chain. Therefore, ERP is actually the backbone of the supply chain.

2.1.3 Major issues and future trends

Despite all the merits indicated above, ERP has some major drawbacks:

- The system components related to manufacturing planning still use the same basic model as MRP II with some unrealistic assumptions, such as infinite capacity, fixed lead-times, etc (Gumaer, 1996).
- ERP implementation is usually a long and costly process. Implementation time ranges from 1 to 4 years and implementation cost can exceed € 1 million even for small companies (Mabert et al., 2001).
- ERP systems are internally focused to ensure all departments within an organisation sharing the up-to-date information. This inward-looking approach does not cross borders of business partners to support inter-company integration and collaboration in the supply chain.

Clearly, the next logical step for ERP systems will need to be "external focus" as it is the external process where most of the waste resides in today's supply chain. It is thus imperative for ERP systems to reach out via the Internet to effectively connect, communicate and collaborate with customers, suppliers and other business partners in the supply chain. The Gartner Group has coined a new term to describe the new outward-facing, Internet-based enterprise system: ERP II (Michel, 2001). Hence, in the foreseeable future, among others, one major trend of the ERP market is extending beyond the core functionality of ERP systems to include the supply chain management capabilities (Zheng et al., 2000).

2.2 ISSUES IN SUPPLY CHAIN MANAGEMENT

With the focus of ERP systems shifting from inward-facing to outward-facing, SCM has become the most important new issue to be addressed (Stein, 1998). Though there exists

no commonly accepted definition of SCM (Mabert and Venkataramanan, 1998; Wisner and Tan, 2000), the broadest vision of the concept is to integrate and manage business processes across inter-organisational boundaries to meet the end customer's needs. The following five major issues are critical in SCM.

2.2.1 Creating time-based competitive advantage

During the 1980s, with a considerable research and studies on the secret of Japanese manufacturing industry, time-based competitive advantage was found to be the key for business success (e.g. Stalk, 1988; Womack et al. 1990). Generally, traditional manufacturing requires long lead-time to resolve conflicts between various jobs or activities requiring the same resources. The long lead-time requires sales forecasts to guide planning, which are usually inaccurate, leading to increased inventories, more unscheduled jobs and thus to even longer lead-times for the scheduled jobs. Therefore, competitive advantage can be achieved by breaking the vicious loop of the traditional manufacturing planning (Stalk, 1988). This strategy is also applicable to the entire supply chain when business processes are extended beyond the confines of one organisation.

2.2.2 Reducing the bullwhip effect

This is a major issue in the automotive supply and the semiconductor industries, which will be discussed in more details in Section 3.2. Basically, the bullwhip effect is the amplification of real customer demand caused by the rational behaviour of supply chain members who are trying to achieve their local optimisation within their own organisations. The causes of the bullwhip effect and its possible solutions are well documented and will be reviewed in Section 3.2.2.1. Generally, lack of inter-organisational communication coupled with large time delays in information exchange are at the root of the problem (Metters, 1997). Therefore, the problem can be most effectively addressed through information sharing between a company and its customers and suppliers in the supply chain (Lee, 2000).

2.2.3 Establishing appropriate inter-company relationship

Studies suggest that great benefits could be achieved by establishing strategic partnership between the customer and the supplier. Contrary to traditional supply relationship, supply chain partnership emphasises long-term relationship and reduced number of suppliers, enhanced information sharing to reduce uncertainties, and better cooperation to improve cost-effectiveness and customer service (Maloni and Benton, 1997). On the other hand, true strategic partnerships are costly to develop and maintain. Therefore, it would be advisable for a company to build appropriate relationships with their customers and suppliers at different levels of cooperation (Heikkila, 2002).

2.2.4 Synchronising demand and supply

It can be argued that today's supply chain is actually an integration of three distinct chains: supply chain, demand chain and value chain as indicated in Figure 2-2.

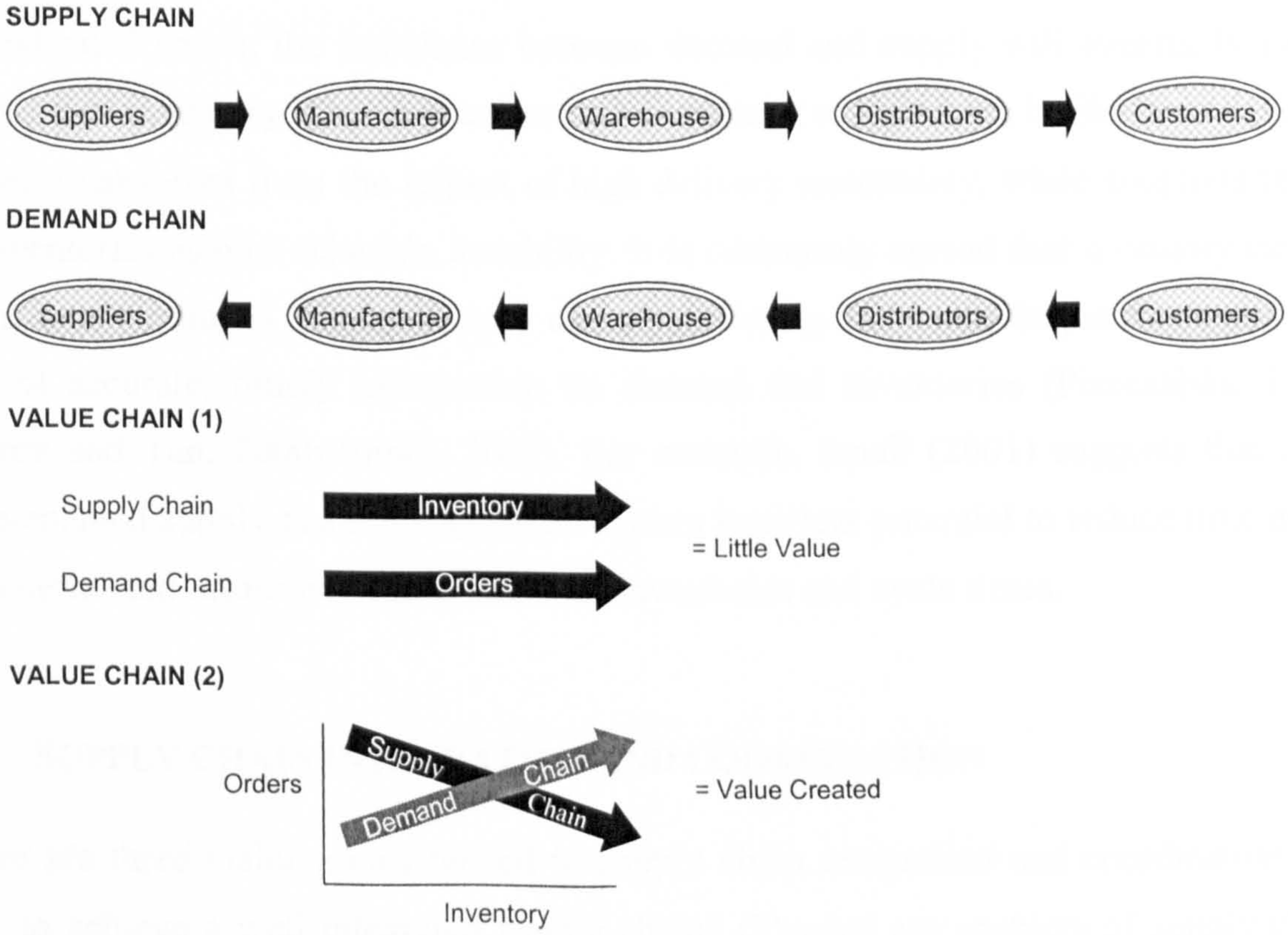


Figure 2-2: Supply chain, demand chain and value chain (after Modern Materials Handling, 2001)

The supply chain includes all the activities involved in producing, storing and delivering manufactured goods from the original supplier to the end customer. The demand chain operates in the opposite direction of the supply chain, which is a series of events driven by customer orders.

The value chain is the end result of the interaction between the supply chain and the demand chain. When supply does not match demand, too much inventory sits in warehouses with little value for the customer. Conversely, when supply most equals demand, inventory moves fast and value is created, which benefits the entire supply chain.

The ultimate objective of today's supply chain management is to create a value chain through the synchronisation of the demand flow and the material flow and to achieve a balance between high customer service, improved lead-time and low cost (Vokurka and Lummus, 2000).

2.2.5 Substituting information for inventory

As indicated above, the imbalance between demand and supply will eventually cause excesses of inventory. This is because customers tend to keep high buffer stock level to protect themselves from the impact of high delivery uncertainty, while suppliers resort to inventories against schedule instability. It is commonly agreed that inventory can be significantly reduced through supply chain partnership and more frequent communication of accurate, timely information on demand and inventories (Piszczalski, 1998; Wisner and Tan, 2000; Small, 2001). For example, Small (2001) suggests that their Web-enabled supply chain management system has clear potential to reduce time delay of material and information flow and thus inventories and cycle times.

2.3 SUPPLY CHAIN INTEGRATION AND COORDINATION

There are three major issues related to supply chain integration and coordination: (1) how to achieve a well integrated supply chain? (2) what are enablers of supply chain integration and coordination? (3) is there a clear positive relationship between supply chain integration and performance improvement?

2.3.1 Achieving supply chain integration and coordination

One of the pioneering works by Stevens (1989) classifies supply chain integration into three categories: functional integration, internal integration and external integration as illustrated in Figure 2-3, which has laid a foundation for later work (e.g. Morash and Clinton, 1998; Ballou et al., 2000). Mabert and Venkataramanan (1998) proposed a five-phase hierarchical approach for supply chain integration: supply chain design, aggregate supply planning, material flow planning, order fulfilment and scheduling and dispatching. These five phases should be integrated and coordinated across different planning and control levels and various time frames ranging from daily to 2 – 5 years. Clearly, this hierarchical approach is mainly internally focused and emphasises information integration, which is the foundation of broader supply chain integration.

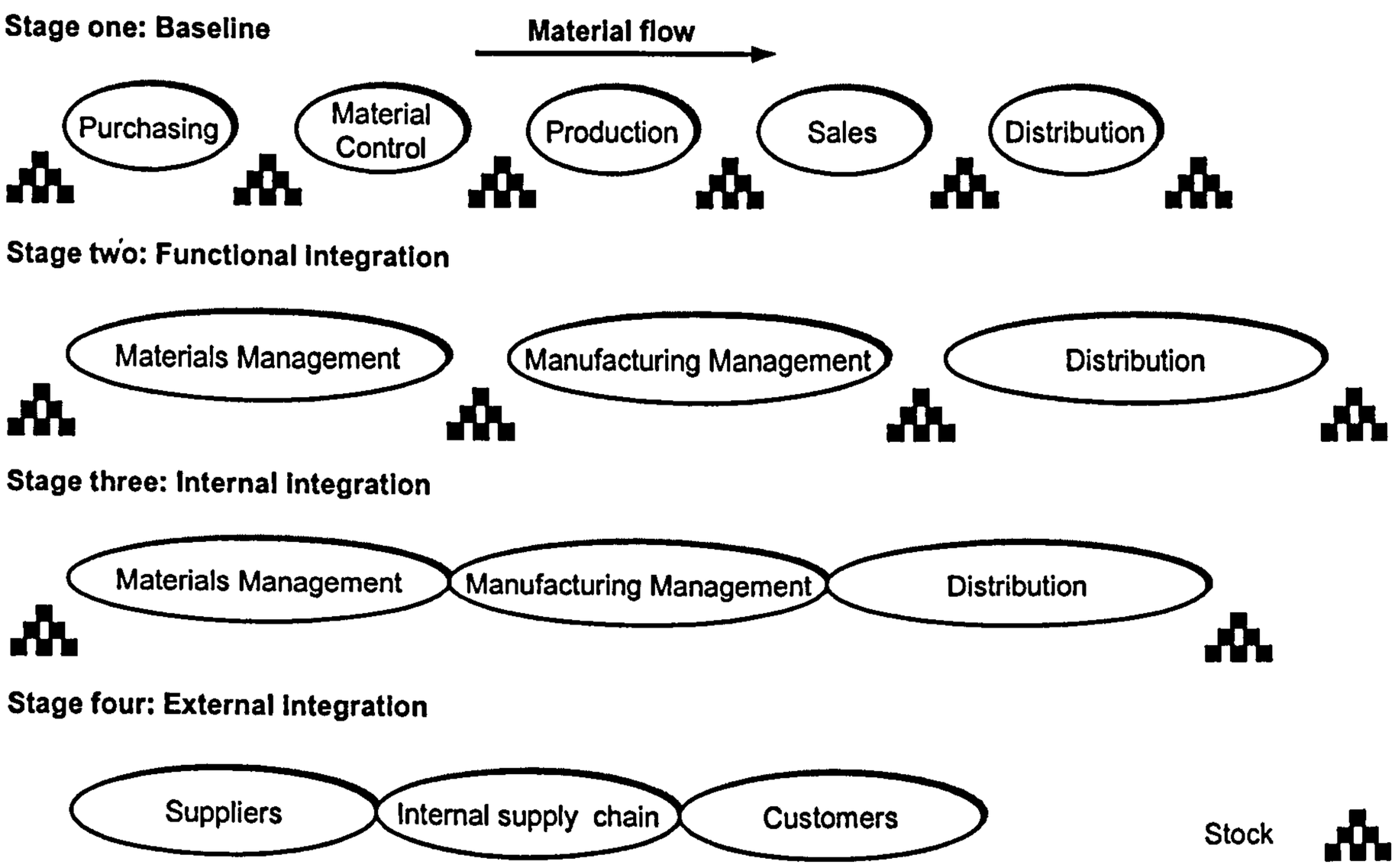


Figure 2-3: Achieving an integrated supply chain (after Stevens, 1989)

Recently, Lee (2000) claims that there are three key dimensions in supply chain integration: information integration, coordination and resource sharing, and organisational relationship linkage. While "integration" is generally regarded as the means of bringing information together, "coordination" is usually viewed as the means of involving higher human decision support. In this sense, supply chain integration and coordination has

gone beyond information integration to cover behavioural, operational and organisational collaboration between business partners.

2.3.2 Enabling supply chain integration and coordination

To achieve inter-organisational integration, corresponding organisational capabilities have to be built and technical enablers have to be put in place. There exist several technologies enabling inter-organisational integration and coordination along the supply chain, which include EDI and extensible markup language (XML). While EDI is a proven technology for the electronic exchange of business-related documents (e.g. purchase orders, invoices) among business partners, XML is a newly defined markup language that allows users to define their own meaningful tags that wrap the data. A comparison between the two technologies is given in Table 2-1.

Criteria	EDI	XML
Translation protocol	ANSI X.12 predominantly in America or UN/EDI-FACT in the rest of the world.	The XML technology itself is now the translation protocol.
Flexibility in content definition	EDI standards have complete control over the content within transaction sets.	Users have some flexibility in defining custom content.
Infrastructure for data transmission	Value-added network (VAN).	Internet.
Timing for data transmission	Batched data transmission; not in real time.	Designed for real-time data transmission in support of dynamic supply chain collaboration.

Criteria	EDI	XML
Communications cost	High because it requires specialized equipment, software, training, etc.	Low as it only needs access to the Internet.
Security	EDI provides document tracking, security and reliable access for important business documents.	There are concerns about the security of the Internet.

Table 2-1: Comparison of EDI and XML

Due to its high cost and technical complexity, traditional EDI using VANs has not reached SMEs to any significant extent. However, Internet-based EDI replaces the VAN with the Internet and Web browsers to reduce transaction costs significantly while reaching SMEs. It is generally recognised that EDI and XML will co-exist within the supply chain in the foreseeable future (e.g. Galaz and Carlson, 2000; Douglas, 2001; Cooke, 2002).

From the technical point of view, although Internet-based EDI combines the advantages of traditional EDI with the advantages the Internet has brought, it does not improve the underlying translation protocol (Small, 2001). In contrary, XML provides a much more flexible and universal mechanism for information exchange between supply chain members. Considering a great number of XML-based e-business initiatives underway, it is likely that XML will eventually replace EDI (Galaz and Carlson, 2000).

2.3.3 Evaluating supply chain integration and coordination

Growing evidence suggests that a higher level of integration with suppliers and customers is expected to result in a greater potential benefit (e.g. Stevens, 1989; Lee and Whang, 2000; Wei and Krajewski, 2000). Empirical results indicate that enterprise logistics, characterised by high levels of both internal and external integration, is a necessary tool for the coordination of supply chain operations which are dispersed around the world (Stock et al., 2000), Recently, studies by Frohlich and Westbrook (2001) suggest

that the greatest degree of integration with both suppliers and customers has strong association with higher levels of performance. Clearly, there is a positive relationship between supply chain integration and improvement on supply chain performance, which are supported by the findings of all these research and studies.

2.4 COMMERCIAL SOLUTIONS FOR NETWORK COORDINATION

The main purpose of supply chain management is to focus on true customer demand and coordinate supply chain activities to meet the demand of the end customers. Yet, a typical supply chain is often a sequence of disconnected activities, manifested especially across the inter-organisational boundaries due to poor information visibility and supply chain coordination. ERP did little to address the need for elimination of the barriers between business partners as it was mainly focused internally (White, 1999). This has led to a significant amount of industrial effort to develop workable solutions for information exchange between business partners. The following five industrial initiatives are critical for network coordination.

2.4.1 Supply chain planning

Supply chain planning (SCP) is the generic term for software application used by manufacturers to decide what to build and when – based on current orders, forecasts and available resources (Anderson, 2002). Originally, SCP was focused on planning and scheduling of shop floor operations, and thus was called advanced planning and scheduling (APS), which allows for production planning and scheduling to take into account constraints of capacity, materials and human resources. A comparison between manufacturing resources planning (MRPII), which is one of the key modules of any ERP system, and APS systems is illustrated in Table 2-2. As APS engines overcome many limitations of MRP II engines, it is widely held that the APS engine will eventually replace the MRP II engine (Parker, 2000).

Criteria	MRP II / ERP	APS
Assumptions	• Infinite resources (materials, capacity, etc.). • Fixed internal and external lead-times. • Using the same priority for all customer orders.	• There are constraints for different resources. • Dynamic internal lead-times based on shop loading and other factors. • Customer orders can have different priorities.
Input data	• Customer orders and forecasted demand from master production schedule (MPS). • Inventory data. • Bill-of-materials (BoMs).	• Static data: BoMs, process routings, production rules (e.g. order prioritization), etc. • Dynamic data: customer orders, WIP, finished goods inventories, etc. • Constraints on materials and capacity and business rules (e.g. customer/supplier relations).
Planning logic	• Starting from MPS and through the BoMs and backward scheduling, MRP II planning engines generate a set of purchasing and production orders with start and due dates and required quantities, which is followed by capacity checks.	• APS planning engines employ operations research methods (e.g. linear programming), heuristics, discrete-event simulation and other methods to consider multiple constraints in one planning run, giving optimized planning results.

Criteria	MRP II / ERP	APS
Advantages	• Simple and easy-to-understand planning logic. • Well developed by hundreds of MRPII / ERP vendors and vastly implemented in a variety of industries. • ERP systems have formed the information backbone of enterprises.	• APS systems can be run at any time (e.g. daily or event-driven). • Considering multiple constraints simultaneously generates optimal and feasible manufacturing plans. • Fast execution time allows multiple simulations to keep execution plans constantly feasible.
Disadvantages	• Re-planning weekly often brings about considerable differences between plan and reality. • Infinite capacity models lead to the inability of MRPII / ERP systems in tackling the problems on the shop floor. • Primarily a transaction system with limited decision support information.	• Fast, constraint-based planning requires high volume of accurate information. • With an industry-specific orientation, an APS planning engine cannot easily be transferred to another industry. • Integration between APS and ERP systems is a considerable effort.

Table 2-2: Comparison of MRPII / ERP and APS

With the scope of planning expanded from within a single enterprise to the entire supply chain, SCP software suites are emerging to tackle different planning and scheduling problems at different levels with different goals. According to AMR Research – a Boston, Massachusetts-based market analyst and consulting firm for the manufacturing

industry, the scope of SCP can be generally depicted in Figure 2-4 (Parker, 2000). In reality, most supply chain planning software vendors make a distinction between supply chain planning and manufacturing production planning. For example, i2 Technologies has separate software modules for supply chain planning, factory planning and master planning.

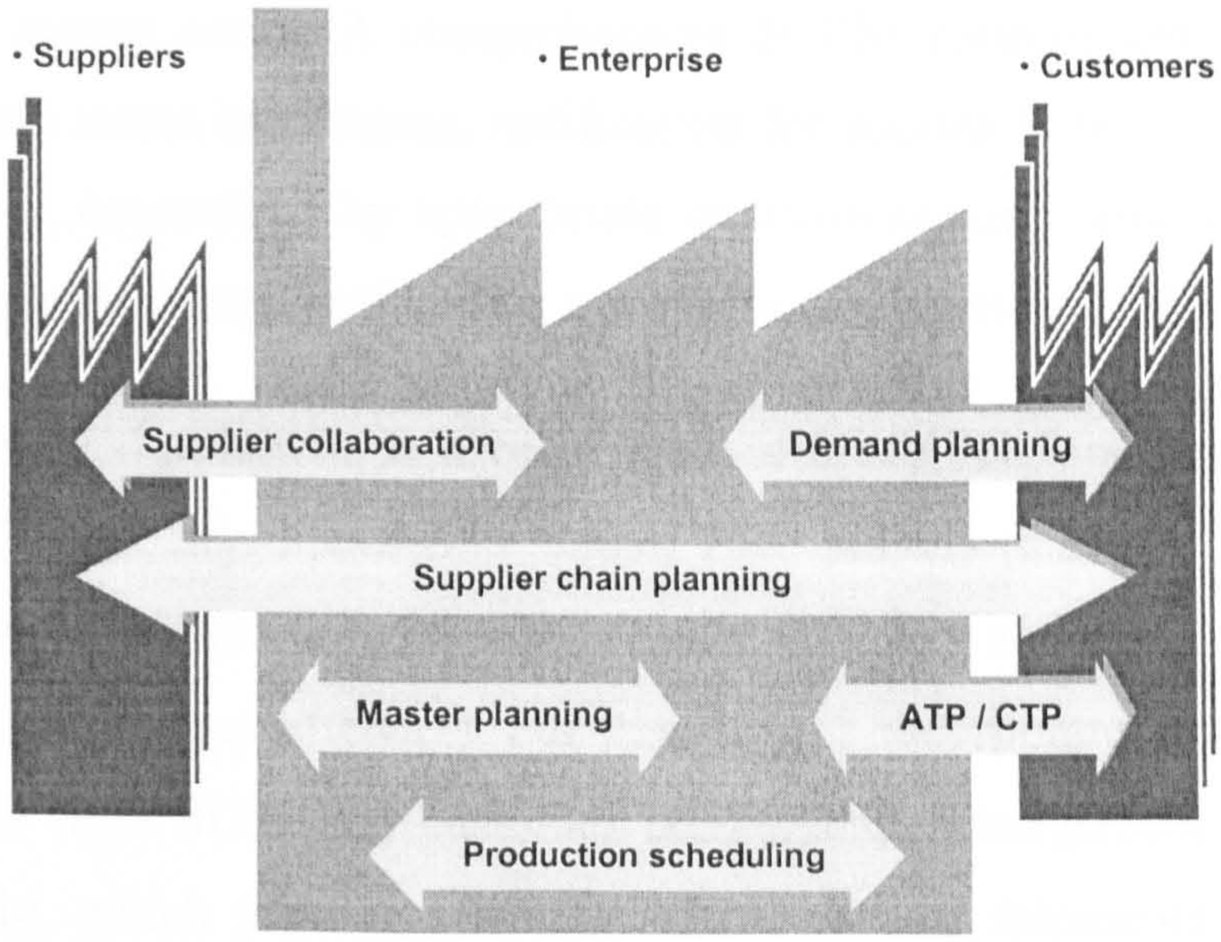


Figure 2-4: The scope of supply chain planning

Recognising the tremendous benefits APS could bring and difficulty of integrating SCP packages with ERP systems, leading ERP vendors are now incorporating supply chain planning functionality into their offerings, either by developing this capability in house or acquiring it. For example, SAP has developed its own SCP solution called advanced planner and optimiser (APO), which uses a centralised planning engine for a manufacturing network with ERP systems for local production planning. Considering their fast response time and improved planning quality over traditional planning and ERP systems, SCP systems are very desirable and can be used as local planning systems for network coordination. However, the Co-OPERATE system cannot assume the availability of SCP systems since SMEs are usually not affordable to such systems.

2.4.2 Supply chain event management

In the real world, even perfect supply chain planning is not sufficient. Today's business challenges require that each supply chain member has visibility of what is going on inside and outside the organisation. This is where supply chain event management (SCEM) fits into the whole picture of SCM. Basically, SCEM is an application that monitors the supply chain based on business rules and automatically alerts individuals when important events occur. A comprehensive SCEM solution embodies five functions: supply chain status monitoring, notification for actions to be taken, simulation of alternative actions, controlling by appropriate decision making, and ongoing performance measurement. However, until today, no vendor can provide all these functions.

The market for SCEM solutions is diverse. Best-of-breed vendors include Tilion, See-Commerce and Viewlocity. Meanwhile, major ERP players (e.g. SAP) and SCM vendors (e.g. i2) have also incorporated supply chain visibility and event management capabilities into their product offerings. For instance, i2 incorporates event management functionality into their SCM and customer relationship management (CRM) applications respectively, which provide visibility of orders and shipments across a supply chain.

According to AMR Research, SCEM is forecasted to be the highest growth sector of all supply chain applications by 2005 (Tilion, 2002). In the foreseeable future, SCEM will go beyond promoting visibility and delivering alerts to provide a solution that triggers appropriate actions. The Co-OPERATE system can adopt the methodology of SCEM to provide solutions for more effective and efficient coordination of supply chain planning and execution activities.

2.4.3 Business-to-business electronic marketplaces

Business-to-business (B2B) electronic marketplaces are Web sites where buyers and sellers can conduct a variety of business transactions, e.g. auctions, reverse auctions and request for quote, and perform inter-company collaboration, e.g. fast access to business partners' orders and collaborative product design. The most basic form of B2B marketplaces is simply online catalogues, or e-catalogues, where sellers advertise their prod-

ucts with related product information, such as price, specifications, etc. Buyers can browse the e-catalogue to find appropriate suppliers and place orders with them.

B2B marketplaces can be horizontal or vertical. Horizontal marketplaces provide a broad spectrum of products from different industries. Such products include office supplies, hand tools and spare parts – the so-called MRO (materials, repair and operations) products. This type of marketplaces is usually public to attract as many participants as possible. For example, e-Bay is a typical horizontal marketplace that targets a wide range of clients and businesses. In contrast, vertical marketplaces usually form around a specific industry and can be public as well as private. E2open.com for the high-tech and electronics industry and Covisint for automotive supply in the USA are examples of vertical marketplaces (Dai and Kauffman, 2002).

Major marketplace software vendors include Ariba, CommerceOne, SAP's mySAP.com Marketplace, i2 Technology's TradeMatrix and Manugistic's bstreamz. The complexity of implementing a B2B marketplace depends on the type of the marketplace and how much functionality for it. For an e-catalogue-style marketplace, its technical implementation is relatively simple. Marketplace software (e.g. IBM's WebSphere Commerce Suite, Marketplace Edition) is usually employed for generating the e-catalogue, and the trading mechanisms (e.g. auctions) are linked to the catalogue. In a large catalogue with many attributes per product, a search engine is usually attached to the catalogue, which helps the buyer narrow the number of products based on attribute values (Sairamesh et al., 2002).

For private B2B marketplaces, marketplace software also provides an integration infrastructure for integrating the marketplace with trading partners' back-end systems (e.g. ERP systems) through messaging services. Therefore, the technical structure of B2B marketplaces may be adapted for supply chain collaboration. However, it is still not clear how B2B marketplaces will organise business processes and intelligence to achieve comprehensive manufacturing coordination in a complex supply network (e.g. the automotive supply network).

2.4.4 Business-to-business portals

If B2B marketplaces can be defined as Web sites that seek to facilitate business transactions and collaboration among business partners, portals are actually Web-based user interfaces that aggregate most relevant information from internal and external sources and present it in a personalised way to end users. As users can be internal users, suppliers or customers, portals are classified into enterprise portals and business-to-business (B2B) portals. At their simplest, B2B portals are just Web pages that are directly linked to internal systems. For example, a semiconductor subcontractor can build such a B2B portal that allows its customers to have on-line view of the production progress of their respective lots on the shop floor.

The technical implementation and deployment of a B2B portal can be very simple. It only needs a Web server within a company and Web browsers for its customers or suppliers that are electronically linked to the server via the Internet. With this technical set-up, customers can log into a special Web site to check the status of their respective orders and suppliers to view the latest orders or production schedules from the company. Recent development in portal technology includes the employment of an application server for hosting business logic, an integration server as an infrastructure for application integration and a set of adapters for communicating with internal and external systems and for translating data from its native format into a format that can be displayed through the portal user interface (Rosen, 2000).

As Web-based portals can bring together most relevant information on a task, company users can find useful information more quickly and make decisions more efficiently. Nearly all the major SCM-system and ERP-system vendors have developed their own portal products. For example, SAP has developed its portal product called mySAP.com Workplace. However, current commercial implementations for B2B portals are still limited to transaction-style interactions and some may be in their early stages of development towards more advanced business processes.

2.4.5 Business-to-business standards

The need for business-to-business (B2B) communication standards is apparent – enabling low-cost B2B connectivity through a common language for online information

sharing and collaboration. Due to its flexibility in data description and identification, XML has become a base protocol for data exchange among different Web applications or business partners. There have been more than 100 different XML-based B2B standards, e.g. the simple object access protocol (SOAP), the universal description, discovery and integration standard (UDDI), commercial XML (cXML), Microsoft's BizTalk and RosettaNet, to name but a few. Many are designed for serving specific industries (e.g. RosettaNet for the computer and electronics industries) or for facilitating B2B transactions and collaboration (e.g. SOAP and UDDI). Nonetheless, two of the most important initiatives for establishing B2B standards are RosettaNet (2002) and BizTalk (2002).

RosettaNet is a pioneer to the field of open B2B electronic commerce standards for the computer and electronics industries, which are complementary to many SCM applications including i2's. Unlike standards that focus only on specific business elements (e.g. UDDI) and/or proprietary solutions (e.g. cXML), RosettaNet provides a complete business process architecture including data dictionaries, an implementation framework and process specifications. Its partner interface processes (PIPs) are specialised system-to-system, XML-based dialogues that define business process between business partners and are applied to eight core processes, including administration, order management, etc. The activities and interactions of RosettaNet's PIP 3A8: Request Purchase Order Change are illustrated in Figure 2-5 and Figure 2-6 respectively.

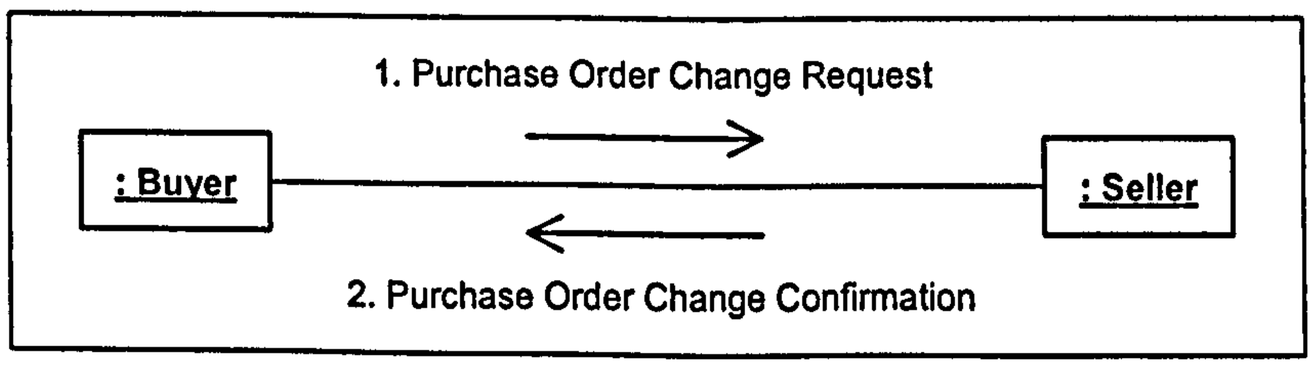


Figure 2-5: Request purchase order change activities (RosettaNet, 2002)

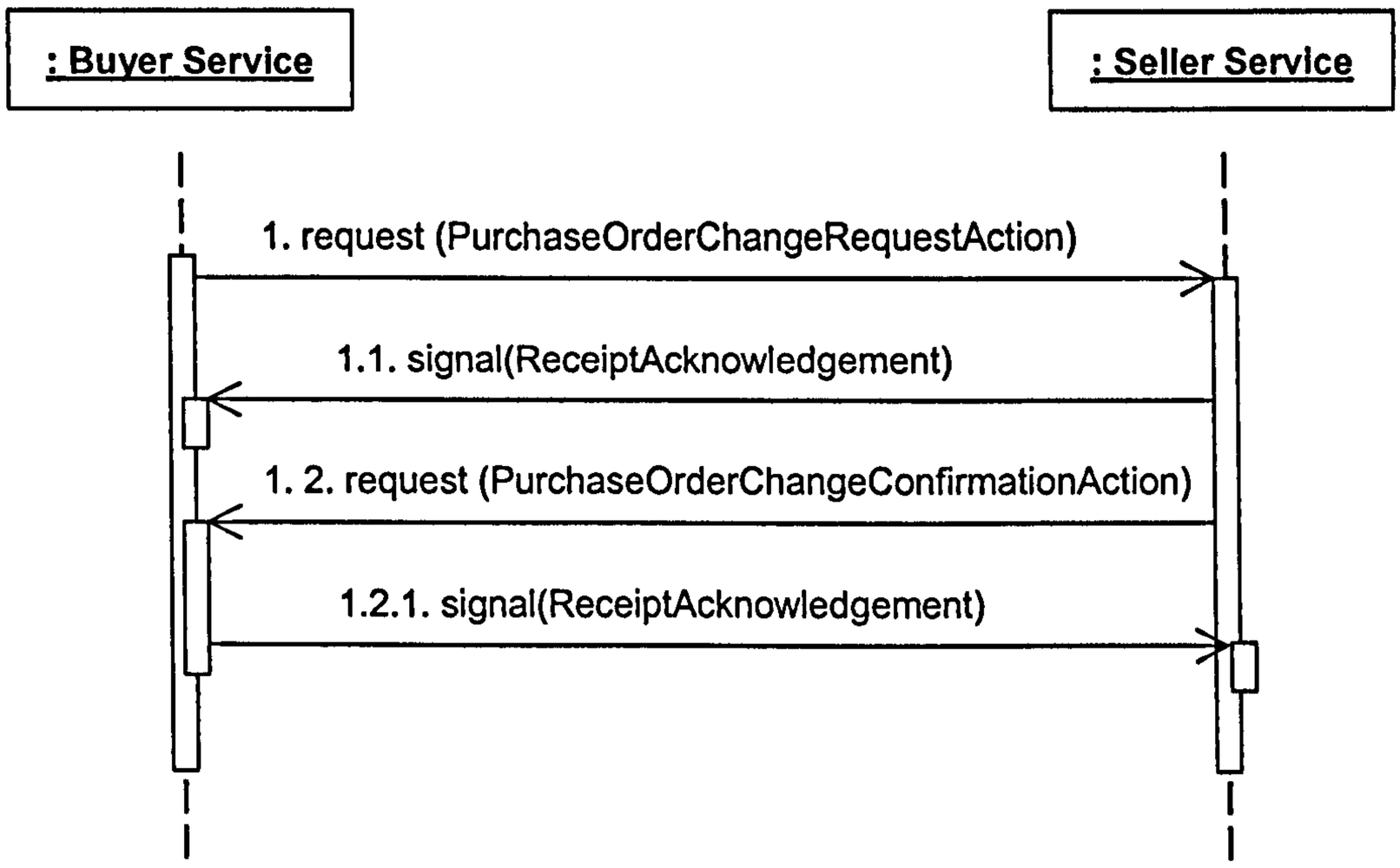


Figure 2-6: Request purchase order change interactions (RosettaNet, 2002)

From the industry and business process perspectives, as RosettaNet is currently focused on the computer and electronics industries, it is still a starting point and is not defining very complex business processes (Booker, 1999). Therefore, RosettaNet's process standards are still evolving and leave some gaps between defined standards and comprehensive industry requirements (Olson and Williams, 2001).

BizTalk is an e-business framework that provides a set of specifications for the design and development of XML-based messaging solutions for communication between applications and organisations. The specifications build upon standard and emerging Internet technologies such as Hypertext Transfer Protocol (HTTP), XML and SOAP which employs XML documents for the exchange of binary data between independent applications. This data-focused approach is supposed to allow businesses to easily interchange BizTalk documents (e.g. purchase orders) with online trading partners regardless of the platform or operating system of their existing systems.

Based on BizTalk Framework 2.0, Microsoft has introduced integration software on the enterprise application integration (EAI) market: BizTalk Server 2000 and its current release BizTalk Server 2002 – an XML-based product for enabling disparate software to communicate in B2B processes. The two main advantages of the BizTalk server are less expensive and easier to use than traditional EAI tools, such as IBM's MQ Series. There-

fore, it is suitable for SMEs that usually lack the financial and IT resources necessary for many EAI tools currently on the market.

2.5 DISCUSSION AND LESSONS LEARNT

With the increased growth of outsourcing and supply chain complexity, there is a growing awareness that today's business success depends more and more on the integration and coordination of the diverse activities across the supply chain. The problems of ERP systems as described in Section 2.1 have led to the emergence of APS engines, which lie at the heart of the so-called SCM systems, led by i2 and Manugistics.

Though SCM systems support constraint-based planning and decision making, a great advantage over ERP systems, they still have some important drawbacks:

- Most of SCM systems are based on sophisticated forecasting methods for demand planning and APS for supply planning, and hence do not manage the supply chain outside individual companies.
- They are limited in helping companies to detect and solve supply chain issues in a timely manner, which might impact other business partners in the supply chain.
- The cost for acquisition and implementation of a SCM system is prohibitive for SMEs, e.g., SCM application package from i2 Technologies will easily cost £2 – £3 million (Zheng et al., 2000).

Currently, i2 Technologies (2002) offers supply chain planning functionality as part of their Five.Two software suite, which features multi-enterprise, multi-tier visibility, planning and execution capability. However, it is not clear how it would deal with the complexity of a multi-tier network set-up and how it would balance the expenses and benefits of all the business partners in the supply network when it comes to optimising all the supply chain process simultaneously. Core to Manugistics (2002) offering is its enterprise profit optimisation (EPO) solution, which aims to match supply with demand through differential pricing strategies. The solution may work very well in such industries as consumer goods industry. Nevertheless, it has limitations for partnership supplier chains, which promote trust, collaboration and long-term relationship.

E-marketplaces and portals are newly emerged tools that can be used to promote e-business. However, most of these tools are still in their early stages towards supply chain coordination. For example, e-marketplaces have the potential to facilitate supply chain integration. However, it is still not clear how to achieve the goal of full network coordination in terms of business process changes and technical arrangement. Portals are naturally restricted to rather simple interactions. Therefore, it is highly desirable to develop a more innovative coordination framework which captures key business processes in the supply chain.

Based on the literature research as reviewed in this chapter, some lessons have been learnt as follows:

- Despite its limitations, ERP remains the backbone for most large- and medium-sized companies. Key to supply chain coordination is using Internet technologies to make quick, secure access to business partners' enterprise information.
- Effective communication with accurate information and close coordination are regarded to reduce one of the industry's biggest problems: the bullwhip effect.
- Just as a chain can only be as strong as the weakest link, it is an imperative to develop a supply chain management system with low cost ownership so that SMEs can participate in the coordination process.
- The methodology for supply chain event management can be applied to the supply chain coordination process to achieve better customer service and improved supply chain performance.
- Focusing on some critical coordination processes can bring in maximum cost-effectiveness.

Chapter 3

BUSINESS REQUIREMENTS AND SOLUTIONS

This chapter presents business requirements analysis and solutions for the automotive supply and the semiconductor industries. The first section describes the characteristics of the two target industries. This is followed by an analysis of their unique supply chain challenges, which are directly translated into business and technical requirements. The last section of this chapter presents a conceptual framework for improved coordination of production planning and control activities in a distributed supply network, which consists of a set of interrelated business processes. The business processes were then prioritised for high-level and detailed design and implementation.

3.1 INDUSTRIAL SETTING

The automotive supply industry and the semiconductor industry share some common characteristics, such as heavy investment and complex, dynamic business environments, which have driven the increasing adoption of B2B e-commerce in these industries. Statistics indicates that the computer and electronics industry rank first, followed by the automotive industry in the use of B2B e-commerce (Morcott, 2000). On the other hand, there also exist some different features between the two target industries, such as high scrap rates in the semiconductor industry and a short fixation horizon in the automotive supply industry.

It is therefore a prerequisite to understand the characteristics of each of the target industries, so that their business requirements can be identified and appropriate solutions being developed. The details on the characteristics of the automotive supply and the semiconductor industries are addressed respectively in the following two sections.

3.1.1 The automotive supply industry

The automotive industry is a highly competitive mature industry with a global market. The supply chain process for a complete vehicle usually involves engineering and production of around 10,000 discrete parts, which are then assembled into about 100 major assemblies as illustrated in Figure 3-1. The major characteristics of the automotive supply industry can be epitomised as follows.

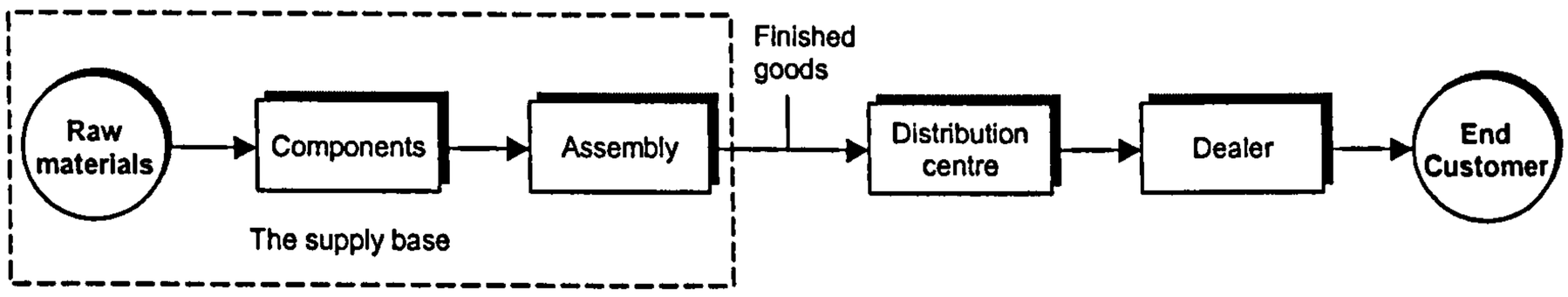


Figure 3-1: The automotive supply chain

- **Mass customisation**

The conundrum faced by the automotive industry is that a large volume make it suitable for mass production while a broad range of choices driven by customer demand in terms of models, colours and other options require small-lot, make-to-order mode of production. This means that the automotive industry must pursue mass customisation – providing such variety that nearly everyone can find what they want at a price they can afford. Consequently, automotive suppliers have to produce highly customised products for their customers, e.g. all end products manufactured by Siemens VDO are customised according to individual customers' specifications.

- **Tightened supplier relationships**

From the early 1990s, following the Japanese just-in-time practices, the automotive industry, especially in the US and Europe, has undergone a dramatic restructuring of their supplier relationships. In Europe, large automobile manufacturers, or original equipment manufacturers (OEMs), have slashed the number of direct suppliers, or 1st tier suppliers from between 1,000 and 2,500 in the 1980s to a few hundreds while building single or dual sourcing and collaborative partnership with them. Now, a 1st tier sup-

plier is in charge of delivering a whole component or a module (e.g. seat assembly) to the automobile assembly plant.

- **Multi-tier structure**

The move towards modularisation has made it easier for the OEMs to manage and coordinate their manufacturing processes, while landing the 1st tier supplier in a more difficult situation. As a survival strategy, many 1st tier suppliers have responded the challenge by merging or acquisition. The merger between Siemens Automotive and VDO is an example in point. In the process of restructuring, a multi-tier structure has emerged in which 1st tier suppliers rely on many SMEs as second tier suppliers and so on.

- **Network coordination**

Typically, the multi-tier network structure in the automotive industry does not simplify or speed the supplier chain, rather, it makes information more diffuse, and thus coordination more difficult as there are more interfaces between tiered suppliers (Cookson and Delattre, 2001). On the other hand, mass customisation requires the entire supply chain to be customer focused. Hence, suppliers need to become extremely flexible, i.e. more frequent deliveries in small batches to their customers and more adaptable production and logistics to schedule changes at short notice. They usually cope with this demanding situation by holding high buffer stock level, which is apparently contrary to the "lean" spirit. It is therefore paramount to coordinate customer demand and the order fulfilment process across the supply network.

- **Order schedules**

Customer demand is mainly conveyed by order schedules, which cover 6 – 12 months, typically with required quantities per week for the first 2 – 3 months and forecasts for the months ahead. While these schedules are updated weekly, call-offs can be changed daily. To maintain a certain degree of schedule stability, usually, the schedule for the beginning weeks (1 – 10 weeks) is fixed, called the fixation horizon. The schedule for the following weeks can be changed to a certain extent, depending on the product, contractual agreements and the flexibility of the supplier, e.g. up to 5% for week 3. However, these rules can be overridden in case of exceptions, e.g. material shortage bringing down a customer' production line.

3.1.2 The semiconductor industry

The semiconductor industry has become the foundation of the new information economy as semiconductor devices (or "chips") are used in a broad variety of products, e.g. motor vehicles, computers, mobile phones, even toys. Meanwhile, since chips are small, highly valuable, quick to become obsolete, and globally produced and distributed, speed and flexibility (or agility) are absolutely vital for production and logistics. For instance, air freight is normal and supplying customers overnight is a routine challenge for logistics (Maltz et al., 2000). '

The major forces in the industry have been the manufacturers of standard products (e.g. memory devices) in fairly high volume (Uzsoy et al., 1992). In this case, the balance between throughput and customer service is achieved by setting a decoupling point. However, the application specific integrated circuit (ASIC) market where small lots of custom circuits are designed and manufactured on a one-time basis is growing rapidly. In these facilities, a much broader variety of products – from automotive electronics to telecom devices – are produced, and each manufacturing lot is often clearly associated with a specific customer order.

The semiconductor manufacturing process is typical of complexity and dynamics. The product flow is extremely complicated. Particularly, the manufacturing steps amount to the hundreds and the wafer flow is highly re-entrant, passing through each equipment up to a dozen or more times. Besides, process yields vary significantly due to environmental, equipment or material factors, and the production equipment is subject to difficult-to-predict downtime.

It is therefore very important to understand the semiconductor manufacturing process and its challenges and opportunities for network coordination. Generally, the process can be divided into five basic steps: wafer manufacturing, wafer fabrication, probe test, assembly and final test as illustrated in Figure 3-2.

1. Wafer manufacturing: The process begins at an operation called crystal pulling, by which the single crystal is pulled and cut into wafers with various diameters (e.g. 100mm, 125mm, 150mm). These wafers are then polished to form the mirror-finish surfaces that are defect-free.

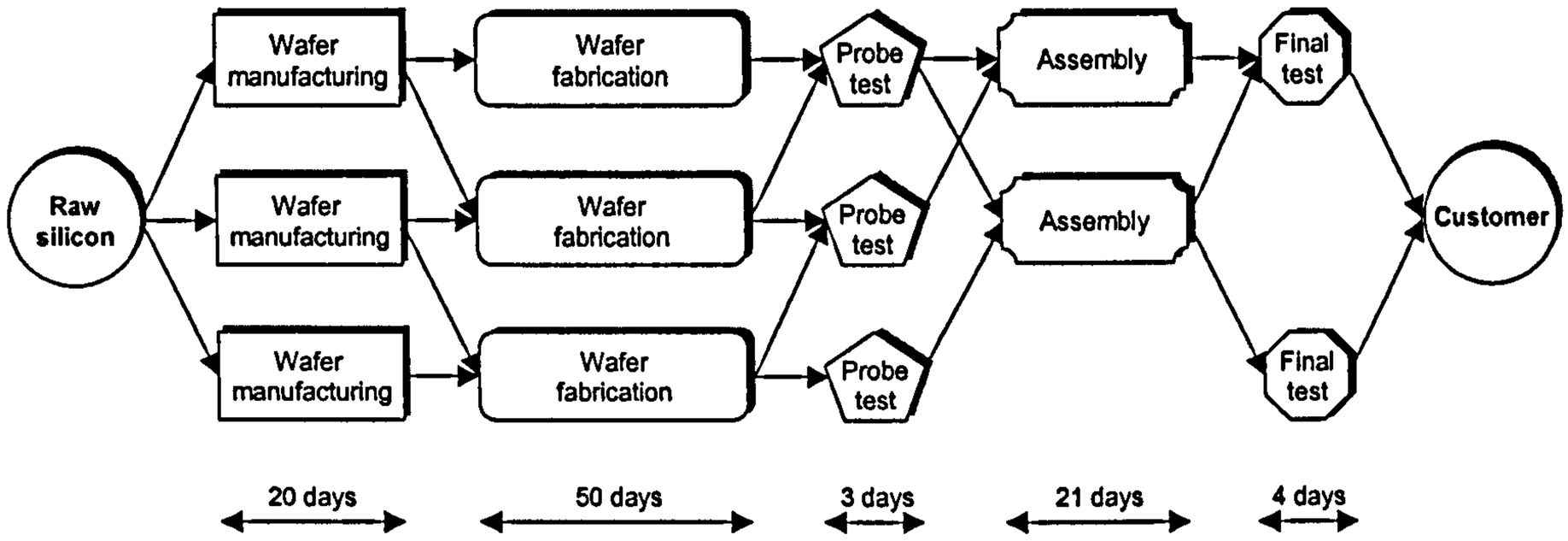


Figure 3-2: The semiconductor manufacturing process

2. Wafer fabrication: This is the highly repetitive, most costly and time consuming process, wherein the specific patterns are created in many different layers of the base wafer. The number of operations can be well into hundreds for a complex component such as a microprocessor. Products move through the fab in lots of a constant size (typically 25 wafers).

3. Probe test: In this step, the individual circuits on each wafer are tested electronically to detect any problems and avoid the further processing of defective circuits. The wafers are then cut up into individual circuits.

4. Assembly: In assembly, the circuits are placed in plastic or ceramic packages that protect them from the environment. There are a broad variety of product types at this stage as a result of many different types of packages. Then, the leads are attached to the products and the packages sealed and tested for leaks and other defects.

5. Final test: A final test is performed using sophisticated and automatic test equipment to interrogate each integrated circuit and determine whether it operates according to the specifications.

Among the above five steps, wafer manufacturing, wafer fabrication and probe testing are usually called "front-end" while assembly and final test are viewed as "back-end".

3.2 SUPPLY CHAIN CHALLENGES IN THE TARGET INDUSTRIES

Understanding the unique characteristics of the two target industries is the first step towards identifying the business requirements in these industries. In this section, major supply chain issues in these industries are first generalised, then their root causes analysed, and the business requirements derived.

3.2.1 The fundamental supply chain issue

Despite their differences in industrial characteristics, the automotive industry and the semiconductor industry have a fundamental supply chain issue in common: shortages and excesses of inventory. For a company producing highly customised products, the consequence of a stock-out is not just lost sales but rather the whole factory brought to a halt. On the other hand, for high-volume, short-product-life-cycle products, holding excessive inventories not only means capital investment tied in them, but rapid decline of potential return from the investment.

There are many possible causes for shortages and excesses of inventory such as schedule changes, quality problems. However, the fundamental problem behind them is the lack of synchronisation between demand and supply. On the demand side, the most detrimental factor that can create excesses or shortages of inventories is the "bullwhip effect", which in extreme cases may even cause some small suppliers to go out of business, or to be acquired (Baliga, 2001) and is rife in the automotive and semiconductor supply chains. On the supply side, unreliable execution processes, which often incur late deliveries, can be the primary cause of inventory shortages and can also be another reason for holding excessive inventories.

However, even if the bullwhip effect were completely eliminated, demand variations are inevitable in today's volatile markets. On the other hand, one-hundred-percent reliable execution processes can never be achieved. This means that industries' supply chains must be flexible and responsive. Here, time for response is the key. If the time is sufficient, e.g. longer than the manufacturer's lead-time, buffer stock is no longer needed or can be dramatically reduced and the risk of stock-outs can be minimised.

3.2.2 Supply chain challenges and solutions

The industrial partners in the Co-OPERATE project played a very important role in the analysis and identification of business and technical requirements for network coordination. An extensive analysis of the current business processes and practices was performed in six companies of the industries concerned, covering 1st, 2nd and 3rd-tier suppliers as well as SMEs. The requirements analysis was conducted on the basis of over 30 face-to-face interviews with managers and operational personnel from different departments, covering various business processes, which include customer relations management, marketing, procurement, order fulfilment, production planning and information systems management.

Based on the requirements analysis as described above, it is clear that numerous benefits can be reaped if current business processes are improved in the three areas: control of the bullwhip effect, execution process reliability, and supply chain responsiveness. This is verified through multiple communications with the Co-OPERATE industrial partners and supported by relevant literature survey.

3.2.2.1. Reducing the bullwhip effect

The concept of the bullwhip effect can be traced back to as early as 1958 in the work of Forrester (Taylor, 1999, 2000). He primarily attributed the effect of demand distortion to rational behaviour of demand managers over-responding to increases and decreases in quantities ordered by their immediate customers. Since then, there have been a considerable number of articles addressing various aspects of the bullwhip effect (e.g. Sterman, 1989; Lee et. al., 1997; Taylor, 1999, 2000).

Most of these papers have devoted a lot of efforts in describing and/or simulating the phenomenon and identifying its causes. For example, Lee et al. (1997) suggest the following sources of the bullwhip effect: demand signal processing, rationing game, order batching and price variations. While all the research adds depth to the understanding of the causes of the bullwhip effort, the coordination framework developed in this thesis aims to attack the root causes of the effect by streamlining the information flow process. In particular, the most important requirements are:

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- **Immediate information flow coupled with knowledge sharing**

Immediate information flow will reduce time lags in sharing any changes in demand with suppliers. Nevertheless, the internal planning process must be fast enough such that the time interval between the receipt of demand changes and the transfer of the actual supply requirements can be minimised. Besides, knowledge about the market, internal plant arrangement and other related information should be shared to better gauge demand.

- **Consumption driven supply management**

Probably the best way to avoid the problematic, though rational, behaviour within supply chain member is to give visibility of the actual and planned consumption of components to their suppliers. Consequently, the supplier enjoys the freedom to optimise their internal production and delivery arrangement, while keeping the lowest level of echelon inventory. With the development of supply chain partnership, the supplier can take over the customer's inventory, leading to supplier-managed inventory.

- **Collaborative learning processes**

By working together, supplier chain partners can identify what information is causing the biggest ripples in the bullwhip and learn how that information can be translated without distortion.

3.2.2.2. Enhancing supply chain reliability

Even if the bullwhip effect were completely erased from the supply chain, it doesn't mean that the customer can always get their orders delivered on time. This is because disturbances (e.g. machine breakdown) can happen and disrupt the supply chain execution process. In fact, the reliability of the supply chain execution process remains a serious problem both in the automotive supply industry and in the semiconductor industry. The study by Oliver et al. (1996) indicates that the average percentage of late deliveries in European auto components industry is higher than 5%. For understandable reasons (e.g. random yields and unpredictable equipment downtimes), the situation in the semi-

conductor industry is much worse, with only two-thirds on-time delivery (Maltz et al., 2000).

Though network coordination in itself can not contain the poor performance of the supply chain execution process, it will be a great advantage to the entire supply chain if the supplier can develop an alert mechanism to detect problems early and report them to the affected partners in a timely manner. This allows the customer and the supplier to work together and have more (hopefully sufficient) response time to address the problems. Hence, the following requirements are critical in supporting more reliable supply chain execution processes:

- **Feasible order quotation**

In a make-to-order manufacturing environment, the shop floor works based on the promised due dates and quantities of orders. Therefore, a realistic order quotation based on current backlog, capacity constraints and material availability is critical to internal throughput, production lead-time and external delivery performance.

- **Order progress visibility**

With the Internet facilitating fast and inexpensive communication between business partners, increasingly, customers want near-real-time visibility into the status of their orders, such as on schedule, partially available, severely delayed, etc. If there is a clear message that an order cannot be fulfilled as promised, the customer can take actions proactively, or propagate it to the affected partners in the supply network.

3.2.2.3. Improving supply chain responsiveness

Matching supply to demand is key for successful management of the supply chain with long lead-times and short life cycles. It requires a more responsive supply chain that is reactive to actual customer demand and disturbances in the supply chain execution process. In current practices, inventories act as a buffer to contain surges in demand and variations in the execution process. However, challenged by increasing pressure to reduce inventories and simultaneously improve customer service, the supply chain needs to be even more flexible and responsive.

Clearly, to create a responsive supply chain, flexible and adaptive facilities that can handle the increased speed must be in place as a "hardware", which includes various types of process flexibilities and adequate buffers. As an important part of the solution, the process developed in this PhD thesis focuses on improving the supply chain responsiveness through standard exception handling processes, Web-based communications and consistent user interfaces. To achieve this, some key requirements are:

- **Standard exception handling processes with human support**

In today's business environment, people in the logistics department are constantly fire fighting to get things to the right path – customer satisfaction, because customer demand can change at a short notice and the execution processes are often unreliable. This enormous pressure is very often related to informal communications between partners primarily based on telephone, fax and email. To alleviate this situation, the critical point is having a Web-based solution that streamlines the communication process and ties together key information to support better decision making in case of exceptions.

- **Trust and cooperation**

Trust is the basis of supply chain coordination, which will be fostered through timely communications between partners and increased transparency of sensitive information, such as costs. Enhanced trust leads to better supply chain cooperation and coordination.

3.2.3 System requirements for network coordination

Besides their business requirements, supply chain networks in the automotive supply and the semiconductor industries have their structural and organisational requirements, which must be met by the coordination system under consideration. Some major system requirements are depicted as follows.

- **Heterogeneous and distributed environment**

Supply chain networks in the target industries are highly heterogeneous. Companies from diverse industries participate in a supply network. Alcatel Microelectronics supplying Siemens VDO in the same network is an example in point. Moreover, individual companies within the network might have different local systems for production plan-

ning and control. Meanwhile, distribution, in terms of subcontracting or separation of manufacturing functions, has increasingly become companies' long-term competitive strategy, especially in the semiconductor industry. A coordination system should address the requirements demanded by such a heterogeneous and distributed environment.

- **Scalable and re-configurable structure**

Business partners participate in a supply network to exploit market opportunities. On one hand, the network can grow quickly with the booming of the market, the system must easily scale to cater for the growth of the network. On the other hand, the structure of the network changes over time. The system must be quickly reconfigurable to reflect the up-to-date network structure.

- **High human support**

Although automation is highly desirable in most ordinary business processes, it could bring about disastrous consequences in unexpected or exceptional cases. This is because knowledge, experience and judgement of human users are most important factors in handling these exceptional events, and cannot be replaced by computers. Therefore, a coordination system must actively get human users involved and provide decision-support information and user-friendly interfaces whenever desired.

3.3 A FRAMEWORK FOR SUPPLY CHAIN COORDINATION

In this section, the business and system requirements described above are first translated into a number of interrelated business processes, which have the potential to improve network coordination. This is followed by the prioritisation of the business processes by all project partners for further development and implementation.

3.3.1 Business processes for network coordination

To achieve the coordination of production planning and control activities in a distributed supply network, seven interrelated business processes were identified, which have formed a research framework and potential scope for the Co-OPERATE project. The focus of each business process is epitomised as follows:

1. Long-term production planning for the supply network
   - Communication of long-term forecast of demand and associated risks.
   - Communication of new product introduction, product variants, product engineering changes and other events which significantly influence the future demand or the trend of demand of products.
   - Capacity checking and related decision making for the affected nodes in the supply network (e.g. purchasing of new machinery or hiring of new employee).

2. Operational ordering and planning
   - Visibility of order schedules, consumption schedules and single orders to the upstream companies in the supply network.
   - Visibility of the current buffer stock levels and delivery schedules of certain products to the downstream companies in the supply network.
   - Detection and resolution of planning problems early through feedback loop in the regular operational planning process.

3. Request and feasibility study
   - Fast check for capacity and material availability across the supply network when new orders or large order changes are expected.

4. Visibility of order progress
   - Visibility of orders in supply fulfilment of the upstream companies to their immediate customers.
   - Production monitoring and early detection of production disturbance in the upstream companies.
   - Early warning of delivery problems from the upstream companies to their immediate customers.

5. Exception handling
   - Rush order handling through the fast request – quotation – review – order confirmation process.

- Resolution of delivery problems (e.g. partial delivery, delayed delivery) through fast information exchange and negotiation process to solve the problems quickly.
- Establishment of containment rules and escalation routes for disturbances to reduce their negative effects to the minimum and to enhance schedule stability in the supply network.

6. Multi-sourcing coordination
   - Medium- or long-term coordination of new orders or large order changes to enhance the capability of the whole supply network in filling the gap.
   - Short-term coordination of urgent demand to increase the success rate of order fulfilment and to enhance the delivery reliability of suppliers.
7. Network performance management
   - Agreement on a common set of network performance indicators (e.g. forecast accuracy, delivery reliability).
   - Evaluation and analysis of network performance indicators and consequent action programs.

Figure 3-3 depicts the positioning of the seven business processes and their relationship to one another. According to the diagram, long-term production planning (LTP), operational ordering and planning (OOP) and request and feasibility study (ReFS) work on the planning level addressing issues before actual orders are placed. At this level, LTP is a strategic production planning process, OOP is mainly focused on regular ordering and planning processes, and ReFS is actually an efficient planning tool for LTP and OOP when new orders or large order changes are expected in the medium or long term.

On the execution level, visibility of order progress (VOP) and exception handling (eXH) address issues after actual orders are placed. Basically, VOP is focused on monitoring the supply chain execution process, providing the up-to-date information on order fulfilment and giving early warnings to the affected customers in case of anticipated problems in delivery. Accordingly, eXH mainly deals with various delivery problems (e.g. partial delivery, delayed delivery).

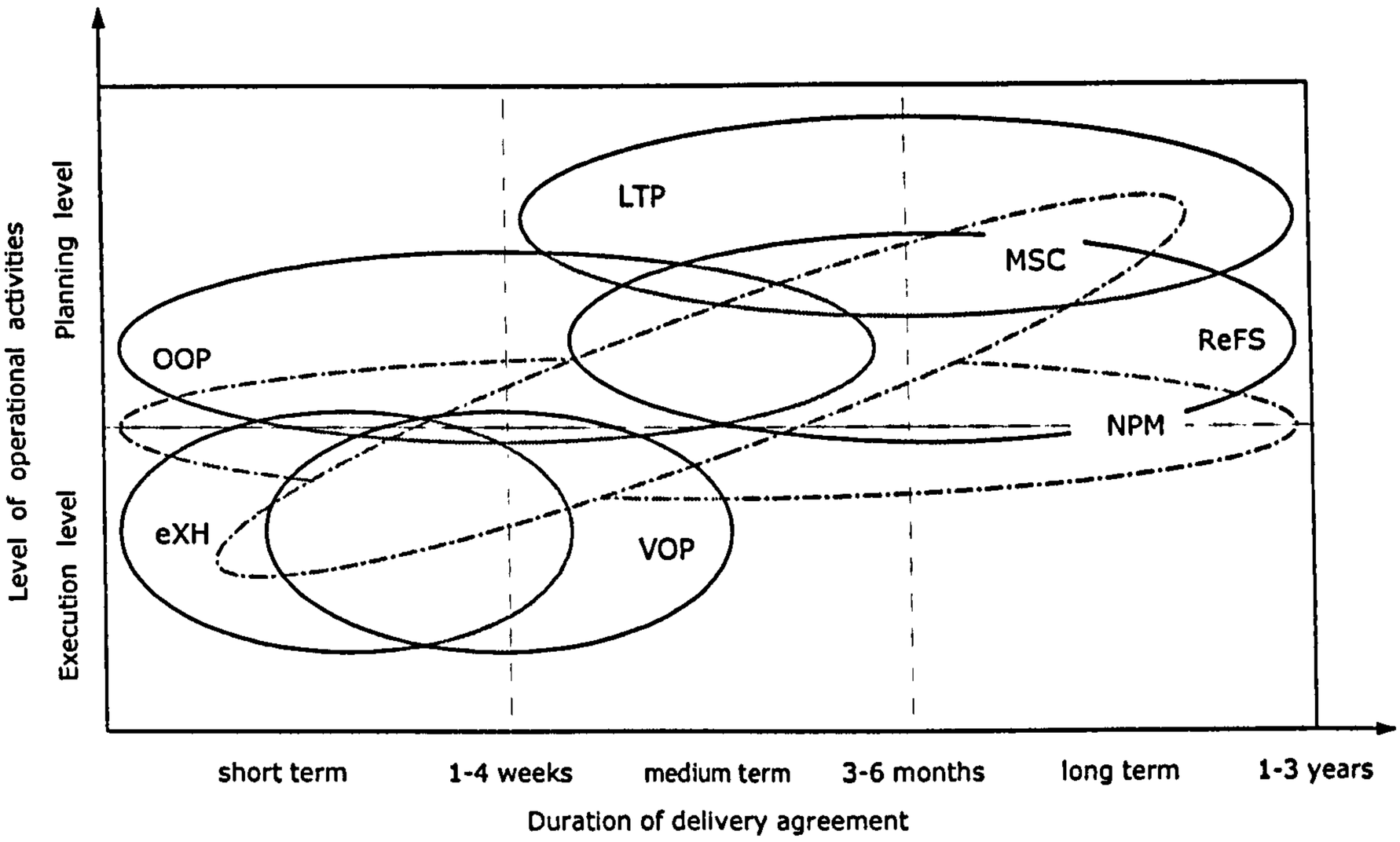


Figure 3-3: Positioning of the seven proposed business processes

Different from LTP, OOP, ReFS, VOP and eXH, multi-sourcing coordination (MSC) and network performance management (NPM) work both on the planning level and on the execution level, and cover the entire time horizon. Actually, LTP, OOP and ReFS can employ MSC for medium- or long- term coordination of new orders or large order changes, while eXH can utilise MSC for short-term coordination of urgent demand. NPM is based on a predefined set of network performance indicators (e.g. forecast accuracy, delivery reliability).

3.3.2 Prioritisation of coordination business processes

Clearly, each of the seven business processes has its own business domain and specific functionality in network coordination. Nevertheless, the importance and potential benefits of each business process differ in the target industries. Therefore, to achieve maximum possible results with available resources, the seven business processes were prioritised by all Co-OPERATE project partners based on the following criteria:

- Improved information visibility
- Improved supply chain responsiveness
- Reduced cycle times

- Improved flexibility in the supply chain
- Reduced inventory levels
- Enhanced capability in handling problems
- Early warning of disturbances in the supply chain
- Improved supply chain synchronisation
- Enhanced collaborative planning in the supply chain

Each business process was weighted according to its potential contribution to the above nine objectives, which were graded into three levels: 9 (high), 3 (average) and 0 (little) in order to differentiate the priorities of the different business processes. The result of the prioritisation clearly indicates that Operational Ordering and Planning, Visibility of Order Progress, Exception Handling and Request and Feasibility Studies are the business processes that have the largest potential benefits for network coordination in the target industries.

Based on the understanding of Figure 3-3, it is clear that ReFS complements OOP for coordinating supply chain planning activities from the short to long term, while eXH complements VOP for enhancing the reliability and responsiveness in the supply chain execution process. By integrating VOP as an exception identification mechanism with eXH as the standard exception handling process, this PhD research contributes to the development of the exception-focused methodology and corresponding business processes for supply chain execution management, which constitutes an important part of the Co-OPREATE system.

Chapter 4

THE OVERALL CO-OPERATE SYSTEM

Following the top-down design approach as depicted in Figure 4-1, three basic system architectures for network coordination are discussed. The completely decentralised system architecture is chosen after the evaluation of the three alternatives. This is followed by the description of the overall guiding design principles. While the system architecture stipulates the way network coordination is organised, the overall guiding design principles direct the high-level business process design. In the third section, the business scope for the Exception Handling process is identified through boundary investigation. The fourth section describes the high-level design for each of the four chosen business processes. Lastly, the Co-OPERATE system is compared with other solutions.

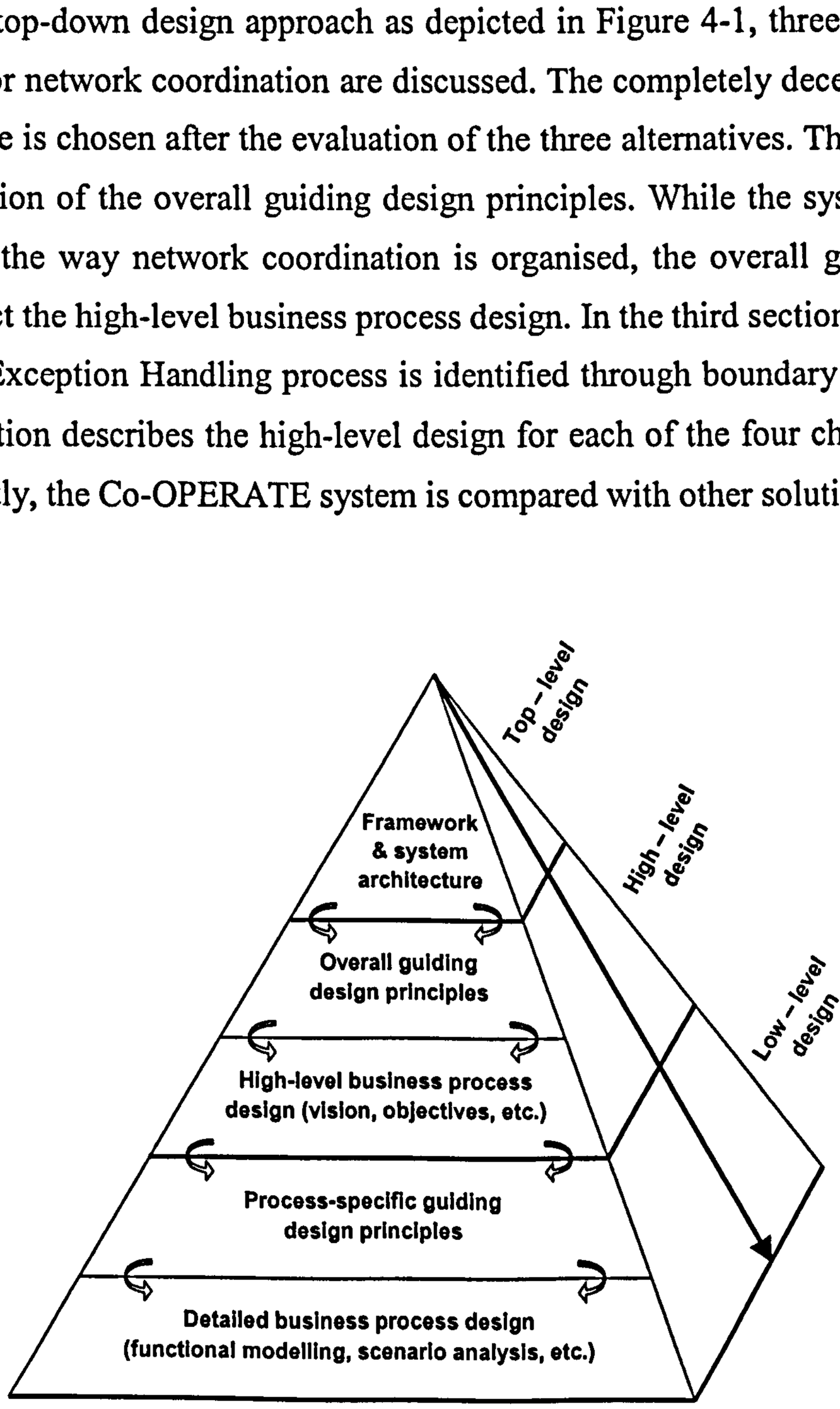


Figure 4-1: The top-down system design approach

4.1 NETWORK COORDINATION ARCHITECTURE

According to current research (e.g. European research projects: X-CITTIC and PRODNET II) and existing software systems, such as ERP and SCM systems, there are three reference models for network coordination (Co-OPERATE deliverable D9, 2000):

- Centralised coordination system with local data access.
- Hybrid coordination system with some distributed local functionality and a central coordination module.
- Completely decentralised coordination system without central coordination.

As each architecture has specific characteristics, the strategic choice can be made through the evaluation of strengths and weaknesses of each reference model and matching them with the target industrial setting.

4.1.1 Centralised coordination architecture

This traditional architecture has been extensively used in all kinds of enterprise systems (e.g. MRPII and ERP systems). As illustrated in Figure 4-2, the central coordination module runs a global coordination algorithm for the whole supply network. Users get access to the central module through thin clients which have very limited functionality. Generally, the central module is usually accompanied by a central database, and is managed by a responsible department or an appropriate partner. This architecture is typically adopted by ERP systems such as SAP R/3. Besides, most SCM systems such as Manugistics's EPO have a similar architecture though they may extract data from more than one source.

Advantages

- Simple system structure providing fast information processing.
- Easy to achieve a wide range of integration covering major business processes.
- A central database rendering data readily accessible and maintained.

Disadvantages

- Global control compromising local decision autonomy.

- Possible overlap in functionality with existing enterprise systems.
- Central database incurring data security issues.
- Central coordination preventing partners from participating more than one supply network.
- Central coordination algorithms making it difficult to incorporate the differential specifics of individual business partners.

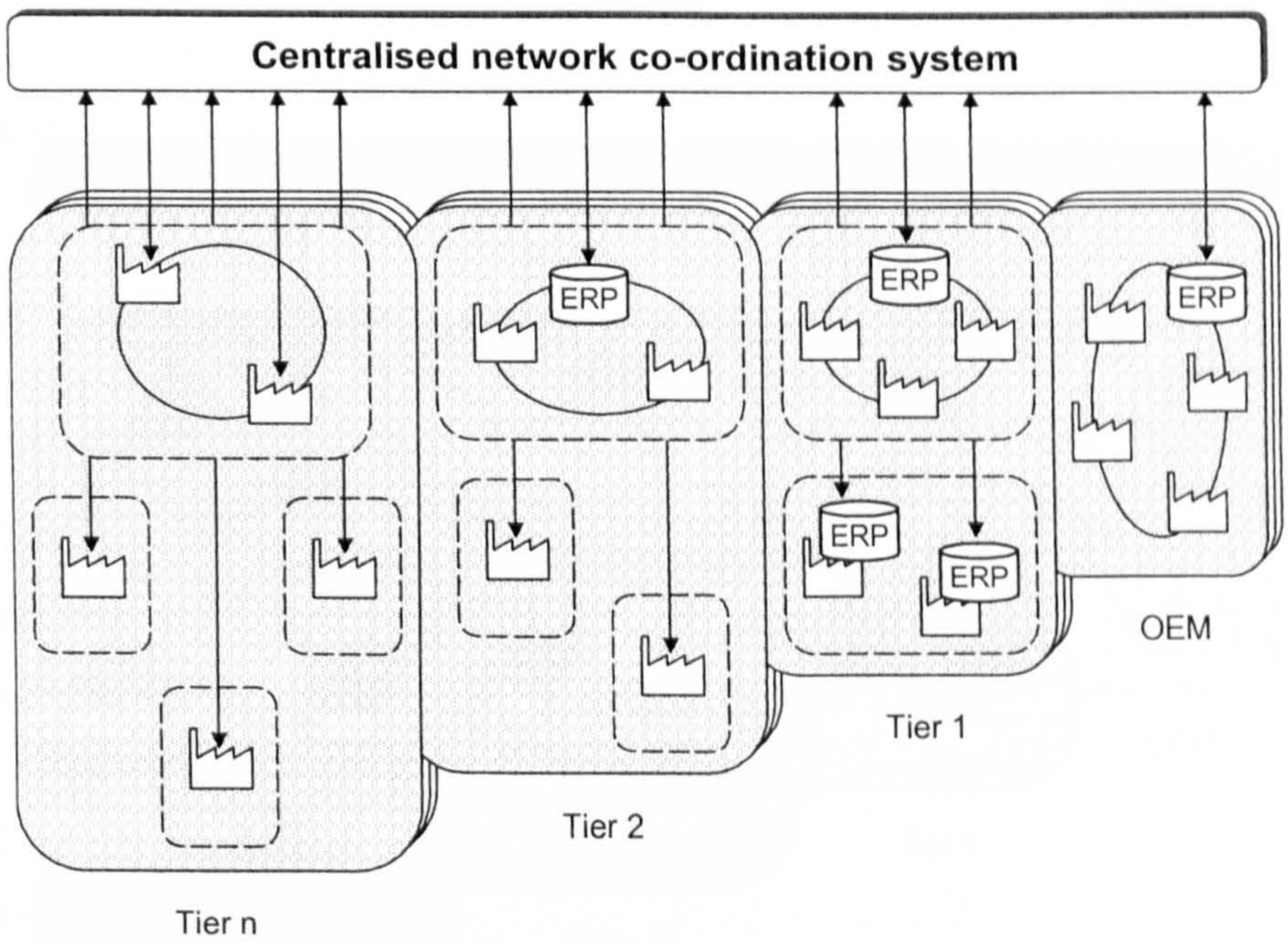


Figure 4-2: Centralised system architecture

Conclusions

Though the centralised architecture has been widely employed by ERP and SCM systems due to its attractive benefits and available information technologies, it is inherently unsuitable for the development of a network coordination system simply because no partner would agree to give up all their decision making autonomy. Moreover, it is technically extremely difficult, if not impossible, to achieve information synchronisation especially in a complex supply network.

4.1.2 Hybrid coordination architecture

The hybrid coordination architecture divides the whole task of coordination into two levels, i.e. the global level and the local level as illustrated in Figure 4-3. While the central coordination module on the global level performs the similar coordination task as in the completely centralised coordination architecture, it has less input information from each local module and performs less complicated optimisation, leaving each company primarily independent. Hence, each local planning module (LPM) provides local planning and control functionality for its own company.

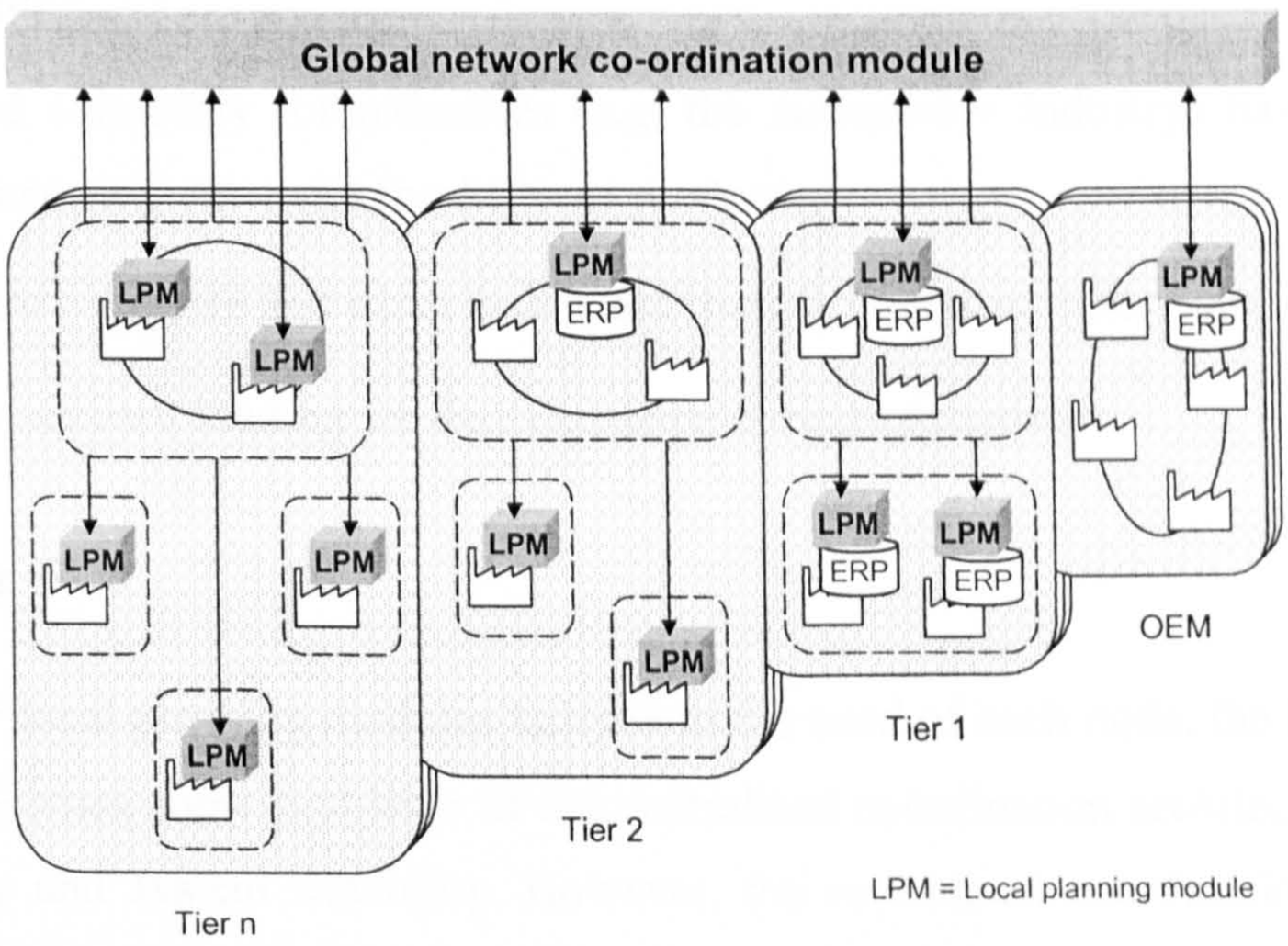


Figure 4-3: Hybrid system architecture

In a sense, this hybrid architecture is an evolution of the completely centralised architecture and combines local decision making with global optimisation. It seems that this hybrid architecture has been adopted in the current SCM systems such as SAP's APO and i2's SCM application. For example, i2's SCM in its Five.Two software package offers multi-enterprise, multi-tier visibility, planning and execution capability, which could use this hybrid system architecture. However, it is not clear whether it is actually hybrid or completely centralised.

Advantages

- Local planning modules allowing local decision making autonomy within individual companies.
- Local modules can be in principle plugged into several central coordination modules for different supply networks if they use compatible communication standards.
- Overlap in functionality can be avoided through an interface between the local module and existing local enterprise systems.

Disadvantages

- Limited suitability for industries (e.g. the automotive industry) having varying manufacturing networks for different products.
- Need for complete and exact BoMs and routing information for complex products.
- Heavy network loading for data exchange during run times.

Conclusions

By virtue of local planning modules tailored to the need of each node, the hybrid architecture overcomes some problems of the centralised coordination architecture, such as data privacy and system flexibility. However, the centralised coordination still poses some difficult problems, such as the ownership of the central module. Additionally, heavy network loading may cause the delay of information flow. Therefore, the hybrid architecture is well suitable for industries with close, long-term relationships, such as the semiconductor industry, but much less for the automotive, machinery and telecommunications equipment industries.

4.1.3 Decentralised coordination architecture

Distinguishing from the centralised and hybrid architecture, the decentralised architecture has no central coordination module. As illustrated in Figure 4-4, this architecture consists of a self-coordinating unit, called unit coordination module (UCM), for each local unit which can be a company or a plant within a company. If a company has its

own local planning system, it can perform local planning for the company while connecting via a coordination module to other companies in the supply network. If there is no local planning system in a company, the network coordination can also work on the plant level. This flexibility makes network coordination suitable for companies with local planning systems, especially for SMEs without large-scale integrated ERP systems.

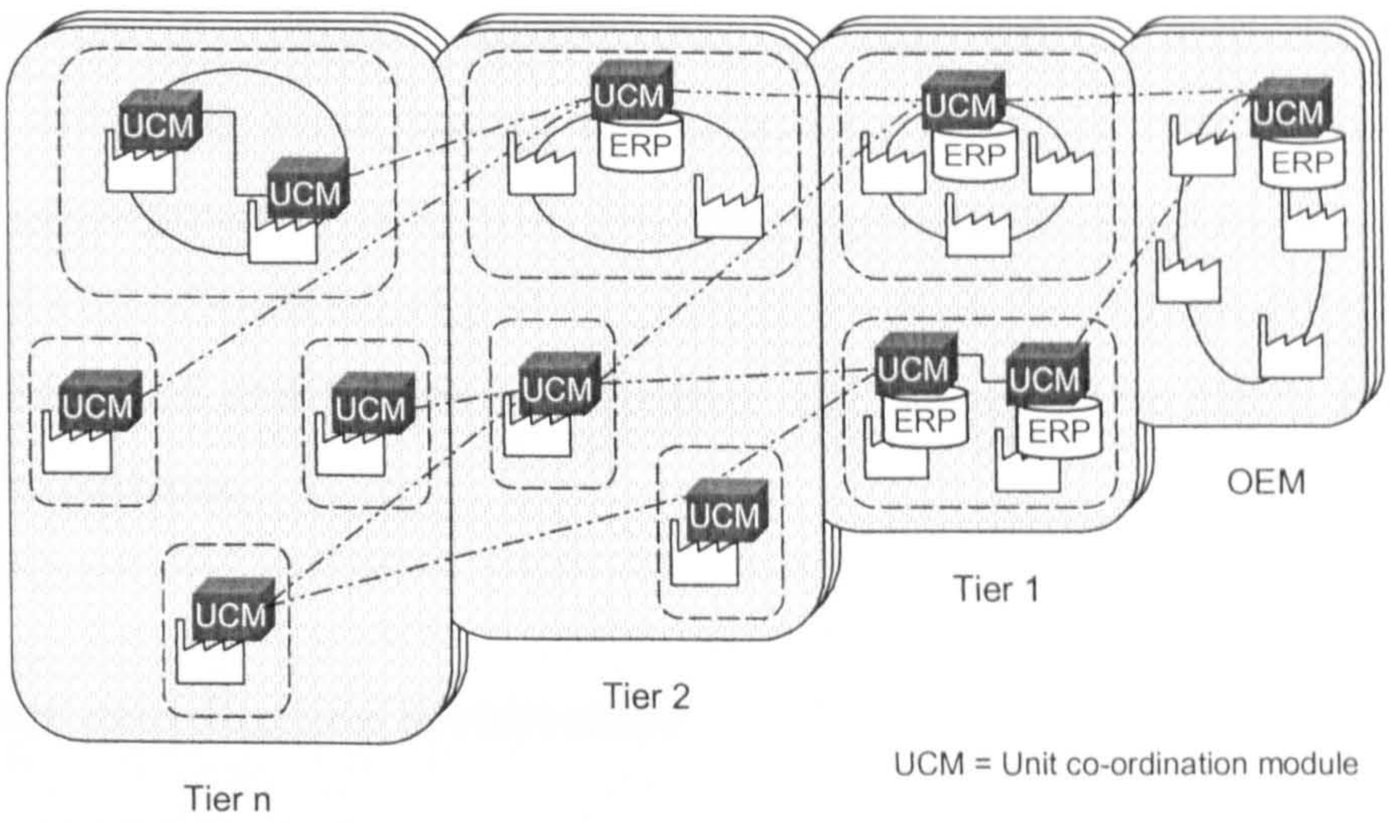


Figure 4-4: Decentralised system architecture

The UCM coordinates the company for which it performs coordination and its immediate suppliers and customers. This architecture seems to have been employed in the latest development of commercial e-business marketplaces. For example, the recent development of i2' Tradematrix Open Commerce Network (OCN) implies a similar decentralised architecture. However, it may take some time for these marketplaces to add full-blown collaborative planning and execution functionality.

Advantages

- Each partner has complete control of its local planning function and thus maintains intact local decision making autonomy.
- Each partner can easily participate in several networks with compatible communication standards.

- Highest data protection and process integrity.

Disadvantages

- New and potentially complex coordination algorithms to be developed.
- Possible heavy network loading for data exchange between network members.

Conclusion

From the network coordination perspective, the decentralised architecture with self-coordinating units has some unique characteristics from the two previous reference models as it corresponds directly with the many-to-many structure of the network. This makes the network coordination pattern compatible with the current coordination practices well established and proven in industries and hence can be easily accepted by all partners in the network.

4.1.4 Chosen coordination architecture

From the above description and evaluation, it can be seen that the completely centralised architecture is most suitable for a single company as it provides a simple and a relatively quick way for the synchronisation of information and processes. The hybrid architecture is best suited for large and diverse companies or for networks with long-lasting relationship between partners. For both types of architecture, their similar central coordination modules make them unsuitable for varying products with differing network configurations, which features the automotive supply industry.

Consequently, the fully decentralised architecture was chosen as the network coordination architecture for the Co-OPERATE system. Its highest flexibility and versatility mirror the nature of the real supply network. The architecture also complies with modern management principles such as delegation of decision making to the same level as operative responsibility. Nevertheless, as this coordination architecture has been much less explored in comparison with the other two, it still needs to prove its suitability for manufacturing coordination in complex distributed supply networks.

4.2 OVERALL GUIDING DESIGN PRINCIPLES

As with engineering design, it is logically the first step to conceive how the system should work based on its requirements. The results of this conception forms a number of overall guiding design principles, which will direct the high-level business process design.

4.2.1 Demand and supply information visibility

Traditionally, companies try to optimise their manufacturing processes with inaccurate demand and supply information, resulting in long lead-times. On the other hand, they tend to keep high inventory levels to protect themselves against demand variations and supply uncertainties. Demand and supply information visibility aims to reduce lead-times and inventory levels across the supply chain.

From the demand perspective, the supplier needs to get access to accurate, up-to-date customer demand (e.g. daily consumption or orders) so that they can make precise production plans, ensure the availability of goods in demand and at the same time minimise inventories at all levels. From the supply perspective, the customer wants to view on line the status of their orders and to check whether they are on schedule or delayed. Such information is critical for operational decision making. For instance, a customer is expecting the full quantity of goods ordered to make a production run. However, they are informed in advance by the supplier that the order can only be partly filled. In this case, the customer can take actions proactively to prevent production from disruption.

4.2.2 Exception-focused supply chain planning and execution

Making information visible across the supply chain is only one step forward, but not enough. The next logical step is using information to improve the supply chain efficiency. However, companies cannot handle every piece of information with equal management attentions simply because there is too much information in the supply chain and each kind of information has different implications for different management units. This means that management should focus on unforeseen or exceptional events or "ex-

ceptions" in the supply chain, such as rush orders and lost shipments, which usually have heavier impact on the supply chain than do normal activities.

The exceptions in the supply chain planning and execution processes can come in the short or medium to long term, and on the demand or supply side as illustrated in Table 4-1. In the short term, suppliers need to be informed of any demand changes immediately so that they can have enough time to respond to customers' new requirements. On the other hand, customers want to know any delivery problems of critical components sufficiently early so that they can take actions proactively to prevent production from disruption. In the medium to long term, it is very important for suppliers to know new orders or large order changes at the earliest time, and it may also be valuable to get the customer informed of capacity shortage or other order fulfilment problems.

Aspects \ Time / Exceptions	Short term	Medium to long term
Demand side	Rush orders and/or changed due date and / or quantity	New orders and / or large order changes
Supply side	Delivery problems	Capacity shortage

Table 4-1: Exceptions in supply chain planning and execution

To achieve responsiveness and efficiency in the supply chain, it requires not only focusing on exceptions, but identifying and reporting them early enough so that they can be addressed in a timely manner, minimising their knock-on effects. When exceptions are detected through business rules, expeditors or production planners in the affected companies need to be alerted immediately and supported by most relevant information and standard business processes to maximise the efficiency in exception handling.

4.2.3 Rule-based supplier/customer responsibility

While exception-focused supply chain planning and execution aims to achieve simplicity in supply chain management, too many demand exceptions will keep suppliers con-

stantly fire fighting and result in poor delivery performance. On the other hand, too many supply exceptions will reduce the customer service level, compromising the customer-supplier relationship. It is thus practically necessary for the customer and the supplier to pre-negotiate their individual responsibilities based on certain business rules. This is especially important for supply chain partnership, where contracts are typically negotiated for a given price and total quantity over a certain period.

In practice, customers usually provide their suppliers with a schedule of requirements (e.g. order schedules) that includes a fixation horizon. For example, the schedule for week 1 is fixed, week 2 may be changed by a small amount (e.g. up to 5%), week 3 may allow up to 10% quantity variation for an automotive electronic supplier with a lead-time of one week. This has formed a funnel for allowed demand variation. It is the supplier's responsibility to follow the demand variation within the hatched area as illustrated in Figure 4-5. Outside the hatched area, the responsibility is with the customer. On the supply side, the supplier has to provide near-real-time visibility on order progress from the initial stage of the process and to alert the customer on delivery problems of critical parts some time in advance (e.g. at least one week). Thus, it is the supplier's responsibility to meet the customer's requirements if they fail to alert their customer early enough.

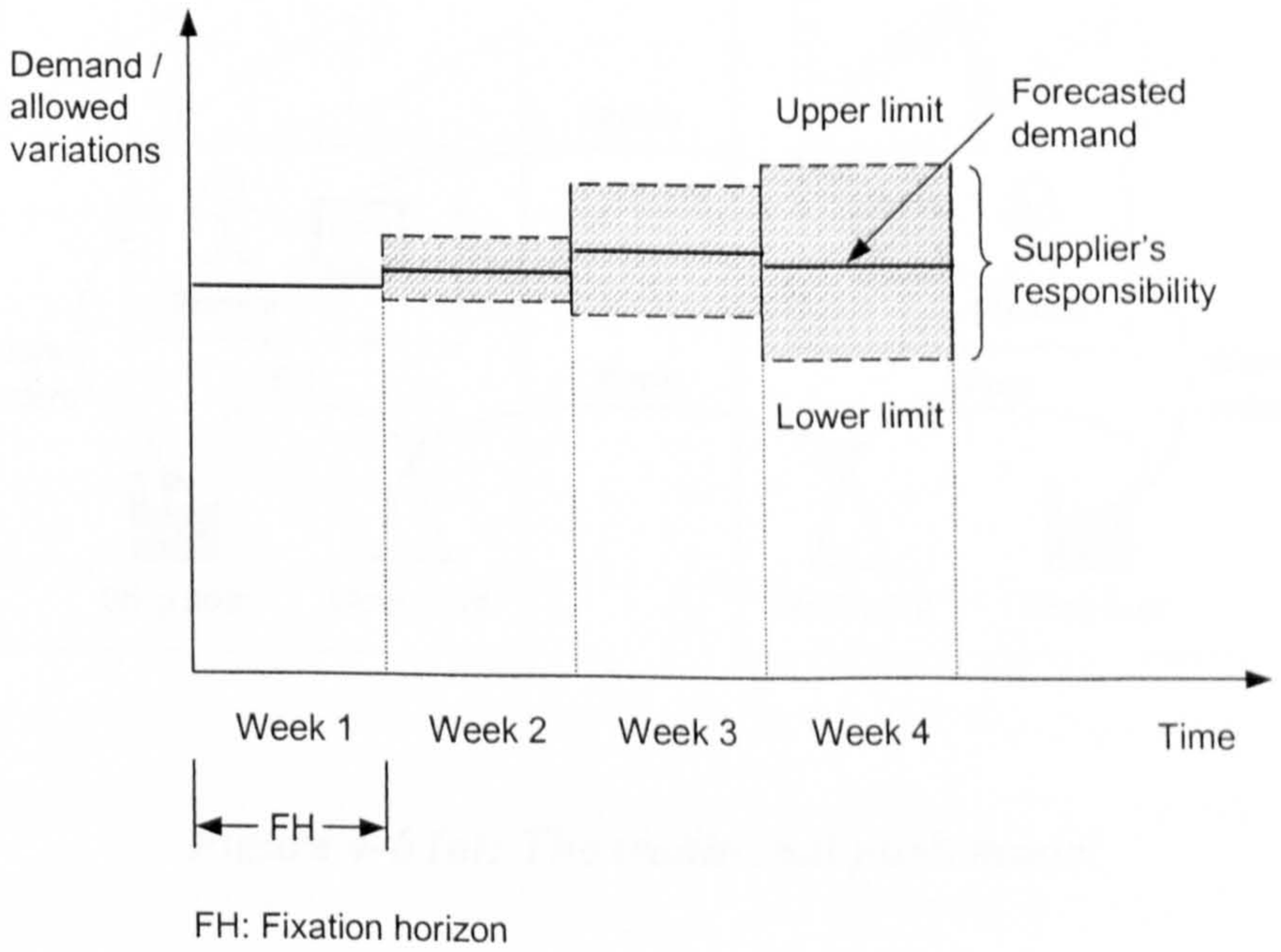


Figure 4-5: Rule-based supplier/customer responsibility

In case of exceptions (e.g. rush orders, late deliveries), however, the customer and the supplier should collaboratively resolve problems through fast, effective negotiations by employing buffer stocks or flexibility in production. This mutual commitment and collaborative problem solving approach will certainly promote closer customer/supplier partnership.

4.2.4 Consumption-driven supply management

Traditionally, the production planning process in a supplier company is usually driven by batched customer orders and forecasts, which are transmitted by EDI, fax or email as shown in Figure 4-6 (a). Orders from the customer are then processed by the supplier's production planning system (e.g. an ERP system) generating production orders, which are converted into work orders when released to the shop floor. The produced goods are first pushed into a stock point on the supplier side and then into a stock point on the customer side, which are then pulled and consumed by the shop floor of the customer. This is primarily a push process driven by the material supply.

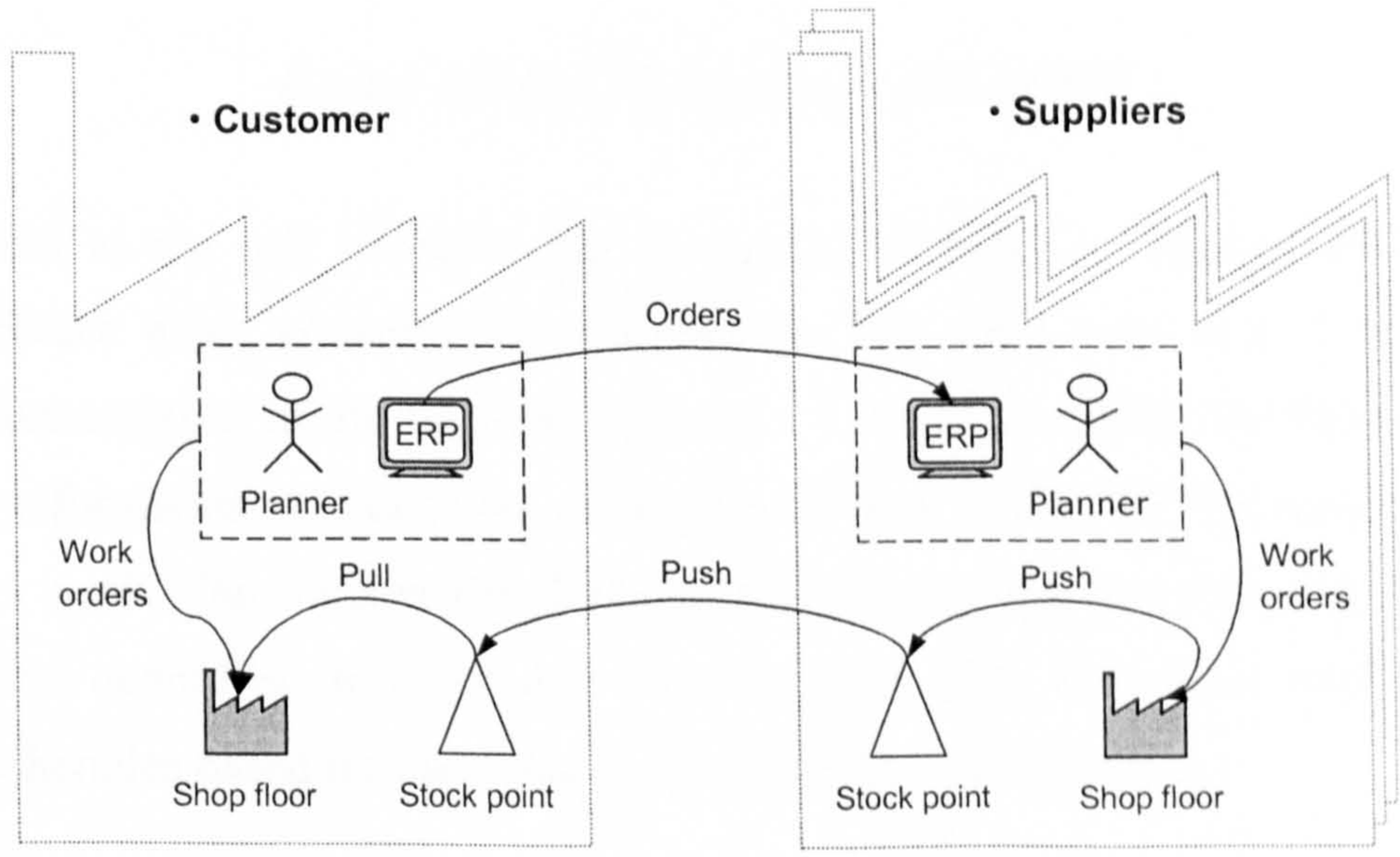


Figure 4-6 (a): The traditional push model

The traditional push model has many drawbacks including the bullwhip effect, which can be incurred by demand signal processing, order batching, rationing game or a com-

bination of them. While the unwanted parts are overstocked, urgently needed components are often out of stock bringing the whole production line to a halt. The main reason for the problems is that the supplier does not have the immediate visibility of true customer demand. The solution lies in the move towards a pull model as illustrated in Figure 4-6 (b).

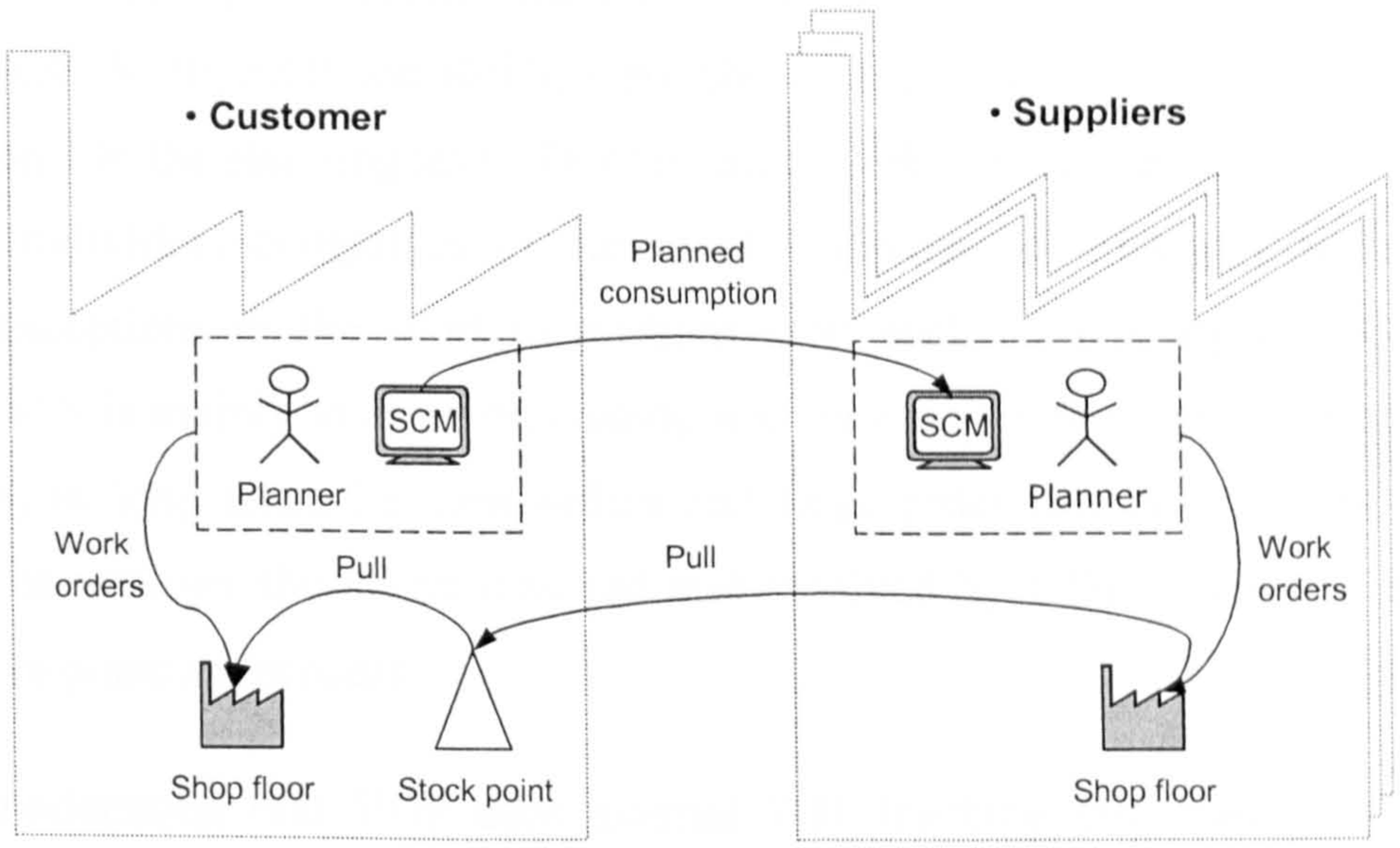


Figure 4-6 (b): The proposed pull model

Fundamental to the pull model is the immediate visibility of planned consumption, which includes exact consumption quantities in the short term (e.g. 3 weeks) and planned consumption in the medium term (e.g. 2 months). While the short-term consumption information is ideally on a daily basis, time bucket for the medium term is normally a week. The supplier can then generate their production plan with the weekly consumption quantities, whereas they can fine-tune their short-term production and delivery schedules based on the actual daily demand of the customer.

Currently, most companies have their own buffer stocks to accommodate any short-term demand or supply variations. This kind of double buffering does not make sense in the pull model as it incurs more wasted inventory space, associated costs and management attentions. Preferably, the management of buffer stock should be assigned to the supplier so that they can optimise their internal production and delivery schedules while meeting the customer's consumption requirements and maintaining the buffer stock at

practically the lowest level. In practice, the buffer stock should be located or at least near the customer site. However, both the customer and the supplier should have the up-to-date information on the current stock level for operational decision support.

4.3 SCOPE OF EXH

In Section 3.3, among the seven interrelated business processes, four most important ones, i.e. OOP, VOP, eXH and ReFS, were chosen for detailed process design and implementation. On the planning level, OOP interacts with the regular production planning process in individual companies of the supply network, addressing planning-related issues or exceptions in the short to medium term such as quantity and/or due date changes. ReFS is mainly focused on dealing with two major demand-side exceptions in the medium to long term, i.e. new orders and large order changes. Clearly, most demand-side exceptions should be detected and resolved by OOP and ReFS during the collaborative planning process.

It is also understood that VOP uses internal WIP tracking information and finished goods inventory information to derive customer order status, and eXH concentrates on addressing exceptions in the supply chain execution process such as late deliveries. Yet, the scope of eXH has not been clearly defined. In this section, exceptions for manufacturing systems are first categorised. Then the term "exception" for eXH is defined by stipulating some principles. Finally, the scope of eXH is clarified.

4.3.1 Taxonomy of exceptions for manufacturing systems

As an exception can be defined in many ways, here, it is confined to an unplanned operational change. Therefore, substantial structural changes (e.g. product engineering changes, process reengineering) are out of the scope. Based on this understanding, according to the different stages of a manufacturing system, exceptions can be classified into the three categories as follows (Figure 4-7):

- **Output-related exceptions**: order changes from customers (e.g. rush orders, changed order quantity and/or due date).

- **Process-related exceptions**: disturbances occurring within the manufacturing system (e.g. machine breakdown, high scrapping).
- **Input-related exceptions**: delivery problems from suppliers (e.g. partial delivery, delayed delivery).

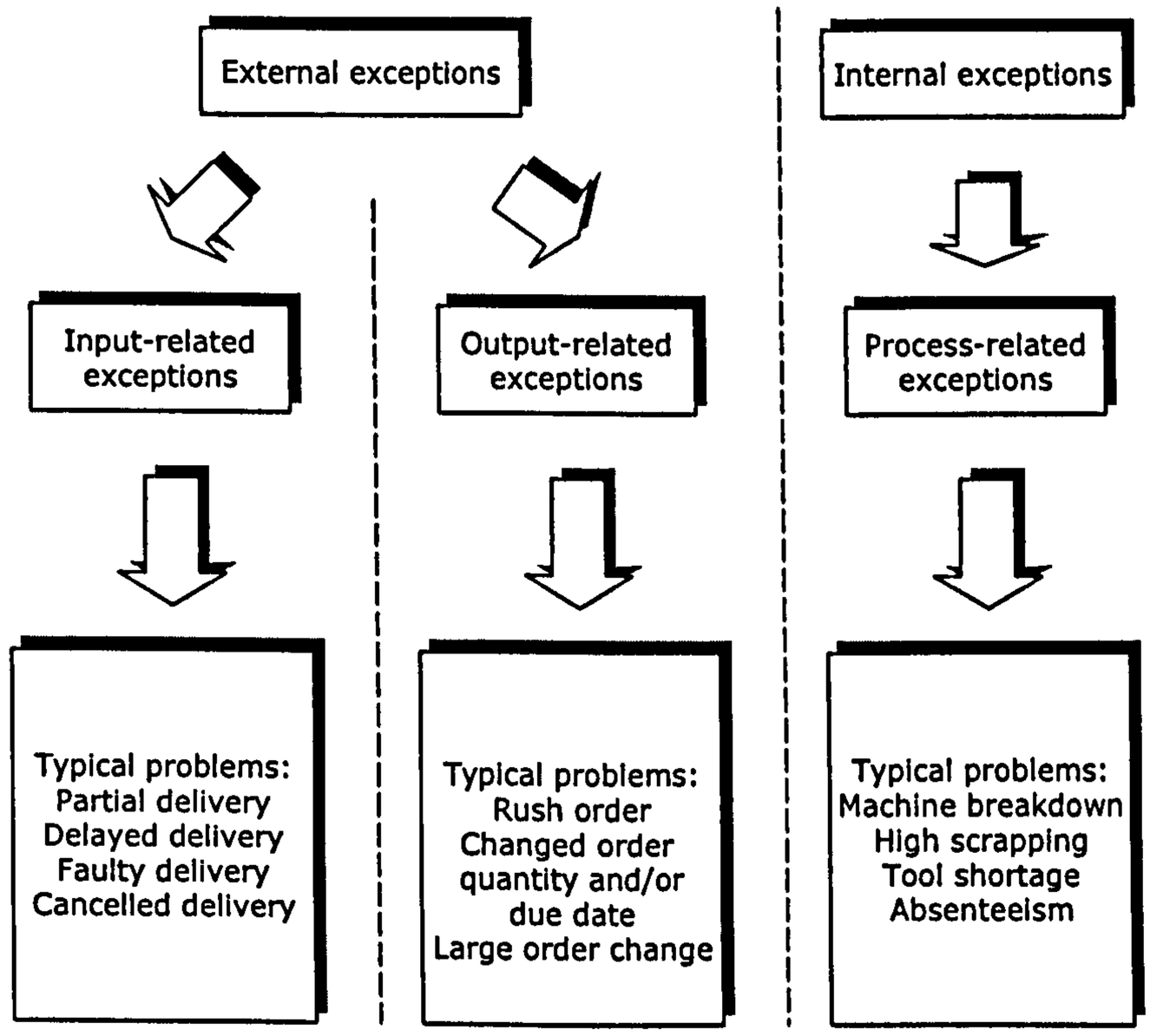


Figure 4-7: Taxonomy of exceptions for manufacturing systems (Xu et al., 2003)

4.3.2 Definition of exceptions for eXH

To clarify the scope of eXH, the first step is to define the exceptions to be handled by eXH. According to Webster's Dictionary, exception is "...a case to which a general principle or rule does not apply". Therefore, in order to define the contents of exceptions to be handled by eXH, some principles or rules should be stipulated in advance. The following principles have been established to help define the scope of the term "exception":

- From the disturbance scope perspective, exceptions must affect at least two business partners in the supply network.

- From the handling requirements perspective, exceptions need to be handled collaboratively by all business partners affected or to be affected in the supply network.
- From the consequence severity perspective, only the exceptions which would have a severe consequence on part of the supply network are to be handled by eXH.
- Demand-side and supply-side exceptions in the medium to long term should be resolved through the collaborative planning process.

By applying the above principles to Co-OPERATE, exceptions for eXH can be defined as follows:

Unexpected operational changes which need to be handled collaboratively by at least two business partners in the supply network, and would have severe consequence if not dealt with appropriately.

4.3.3 Contents of eXH

Based on the understanding of the above principles and the definition of exception for eXH, it is clear that the focus of eXH is primarily on dealing with short-term demand and supply issues, i.e. urgent demand from the customer side and delivery problems from the supplier side. Specifically, according to the origin of stimuli, fundamentally, there are two kinds of exceptions for eXH:

- **Customer-raised exception**: rush order (with the requested lead-time less than the normally quoted lead-time).
- **Supplier-raised exception**: missed delivery (e.g. partial delivery, delayed delivery).

4.4 HIGH-LEVEL BUSINESS PROCESS DESIGN

This section describes the functional relationship between the four focused business processes, i.e. OOP, VOP, eXH and ReFS, and high-level design for each of them. Detailed process design for eXH will be described in Chapter 5.

4.4.1 Functional relationship between business processes

Figure 4-8 presents the functional relationship between OOP, VOP, eXH and ReFS. The Co-OPERATE system starts with OOP, which extracts short- to medium-term planned consumption and forecasts in the form of order schedules, consumption schedules and single orders from the ERP system or local planning system (LPS) in an individual company. The demand information is communicated to the upstream companies. Based on the consumption information from the customer, detailed delivery schedule for the immediate coming weeks with time buckets per week, or per day or per shift for JIT cases is generated by the supplier and transmitted to the customer. The delivery schedule has to be checked and approved by the customer before being accepted.

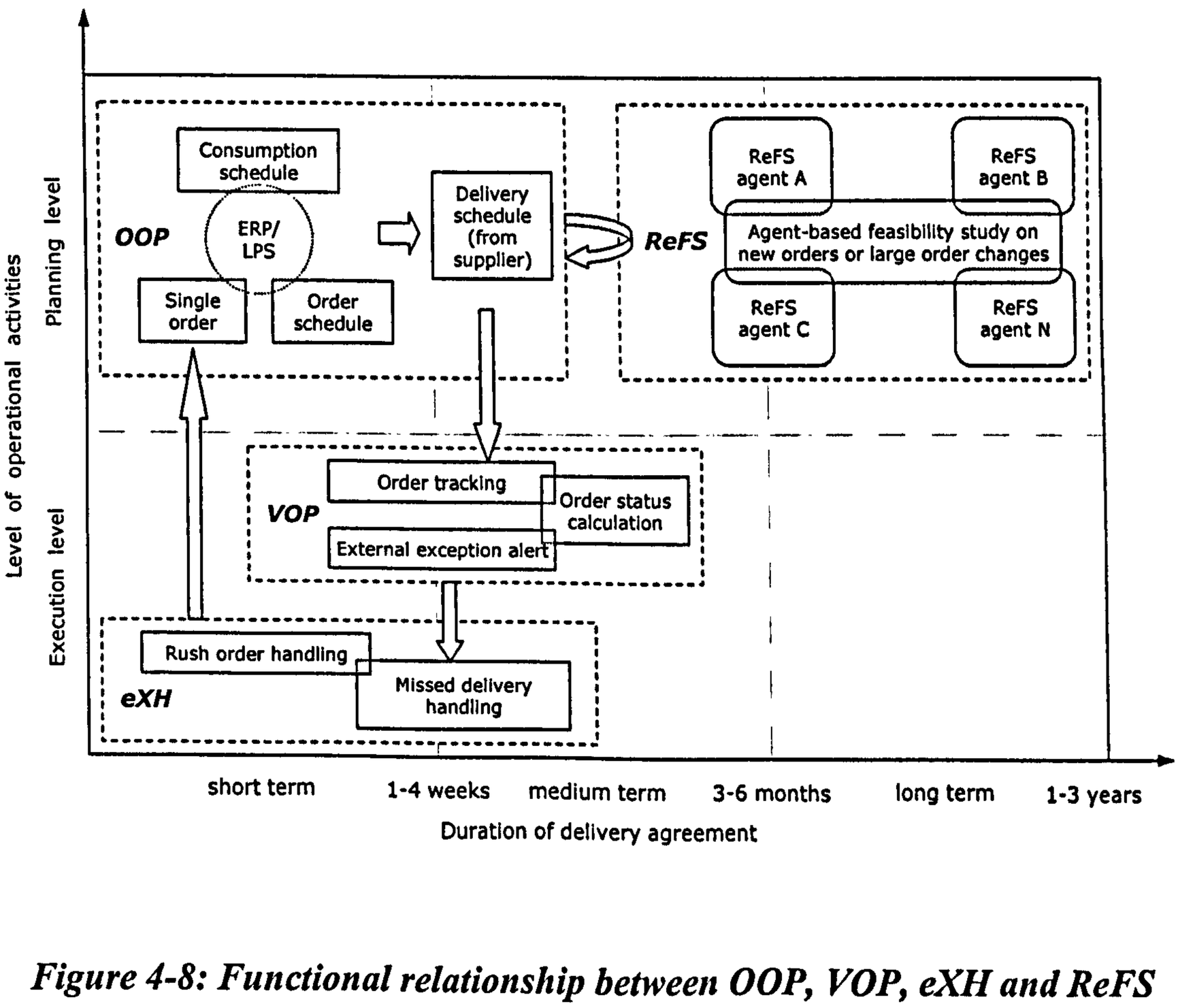


Figure 4-8: Functional relationship between OOP, VOP, eXH and ReFS

The planning process described above assumes that customer demand evolves over time and fluctuates only to certain predefined limits. In reality, however, there are two major issues complicating the planning process in the medium to long term: (1) new orders unforeseen in the previous demand plan, and (2) large order changes in a planned order according to predefined business rules, e.g. over 30% quantity change in month 2. In

such cases, it is desirable to have a fast feasibility check across the relevant part of the network within a short time period (e.g. 1 – 2 days) before actually placing new orders or initiating large order changes. Therefore, ReFS complements OOP in functionality for supply chain planning. As the process entails the propagation of request on demand and quotation on delivery capabilities across the relevant part of the network, an agent-based approach has been adopted to facilitate the desired fast system response.

Once the plans are established, the focus of manufacturing coordination in the network shifts from the demand side to the supply side. It is the supplier' responsibility to provide the customer with meaningful, formalised information on the status of their orders. VOP achieves this purpose by continuously monitoring the production process in the upstream company and alert the customer to exceptions when certain delivery cannot be fulfilled as promised in the delivery schedule. In this case, it triggers the exception handling process, which focuses on resolving unexpected demand and supply problems in the short term, i.e. rush orders and missed deliveries. Essentially, a rush order is a special single order, which requires less than the standard delivery lead-time.

4.4.2 Operational ordering and planning

Vision

To create feasible and synchronised manufacturing plans across the supply network while resolving planning-related problems through fast feedback loops (Figure 4-9).

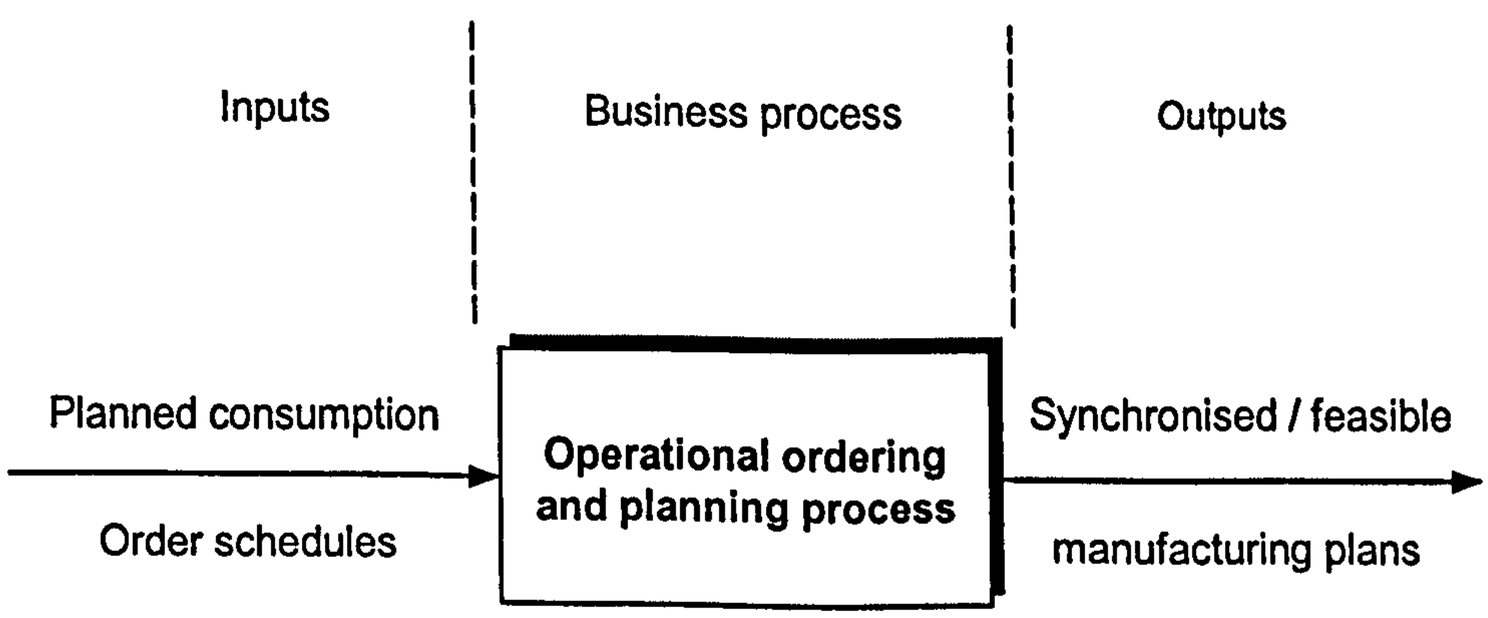


Figure 4-9: Basic diagram of the OOP process

Objectives

- Reduce the bullwhip effect in the supply network through the provision of planned consumption to the upstream companies and feedback of delivery schedules to the downstream companies.
- Detect and resolve order fulfilment issues early at the collaborative planning stage.
- Improve customer service through the creation of mutually agreed delivery schedules.

Performance indicators

- Percentage of parts managed through consumption driven supply management.
- Average buffer stock levels at different locations in the network.
- Percentage of planning-related problems undetected and/or unresolved.

Process outline

The process aims to reduce the bullwhip effect in the network through the transition from the traditional push model to the pull model based on consumption driven supply management as depicted in Section 4.2.4. Figure 4-10 presents the basic operational ordering and planning process in a three-tier business case. To avoid the tendency for high buffer levels and over-ordering, the downstream company communicates to the upstream company their planned consumption in the coming week(s) with a time bucket per day or even per shift in JIT cases, together with the on-hand inventory levels. The planned consumption can be updated on a daily basis. Meanwhile, forecasts in the form of order schedule with time bucket per week or per month reaching up to 6 months into the future coupled with some qualitative information (e.g. prediction of market changes and capacity variations) are also transferred to the upstream company for strategic or tactic decision making.

Based on the accurate demand and inventory information, the upstream company can create the delivery schedule for a specific part taking into account their current production and inventory status and manufacturing capabilities. This delivery schedule is fed

back as a response to the downstream company. In case of difficulties, the upstream company should indicate how much they can fulfil and solutions for the remaining quantities and reasons for difficulties. In such cases, it triggers a negotiation process between the upstream and the downstream companies. Predefined business rules such as the fixation horizon, standard workflow structure and formalised information exchanges will improve the negotiation process.

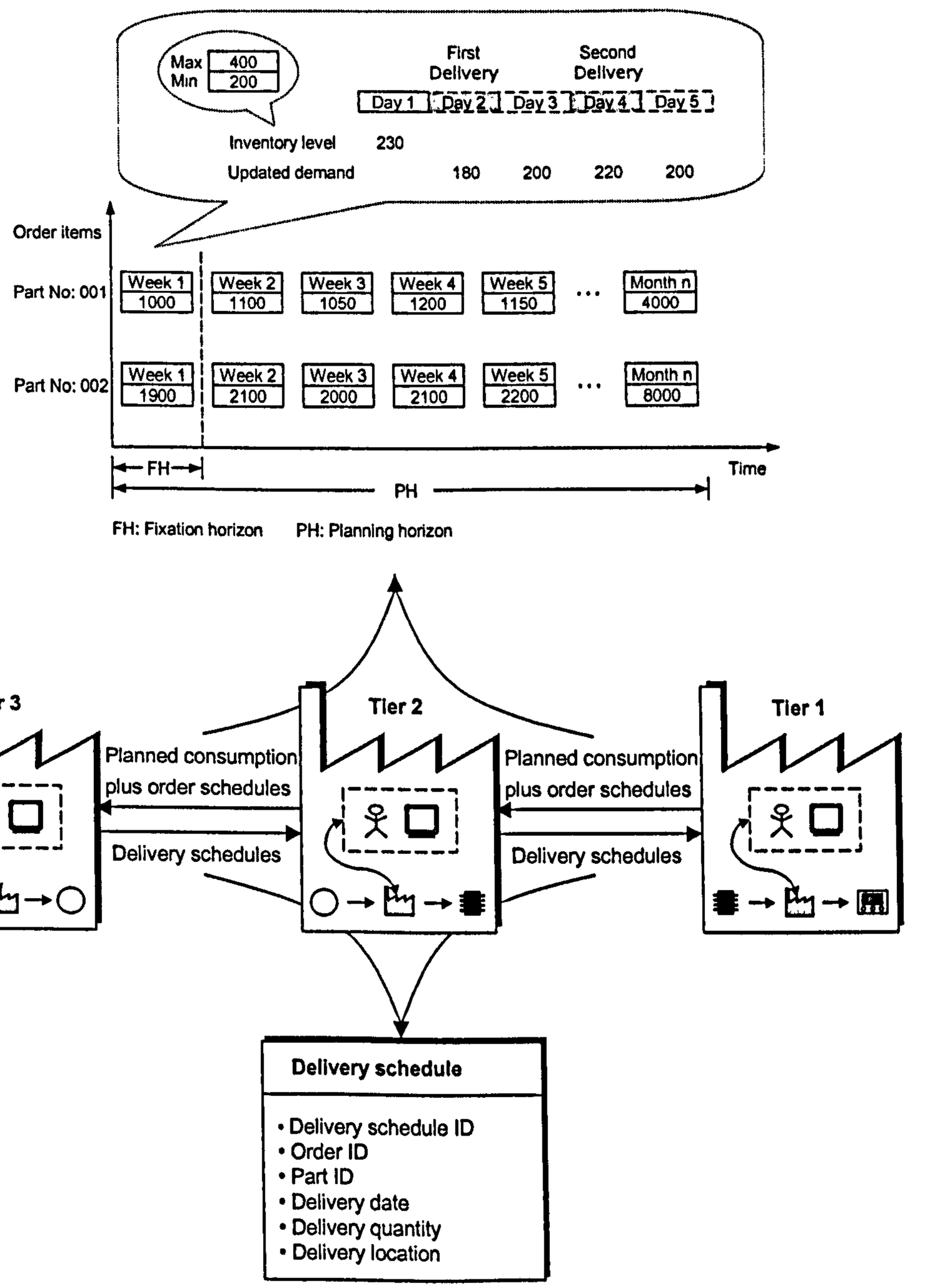


Figure 4-10: OOP process outline

It should be noted that the collaborative planning process does not intend to replace the internal production planning systems (e.g. ERP systems) within individual network companies. Instead, it takes advantage of local planning systems and communicates with them by extracting and writing back relevant data, which accords with the decentralised coordination architecture for the Co-OPERATE system.

4.4.3 Visibility of order progress

Vision

To enhance the visibility of order progress by continuously monitoring the production process and immediately providing meaningful, formalised information on order status, while alerting customers in case of exceptions (Figure 4-11).

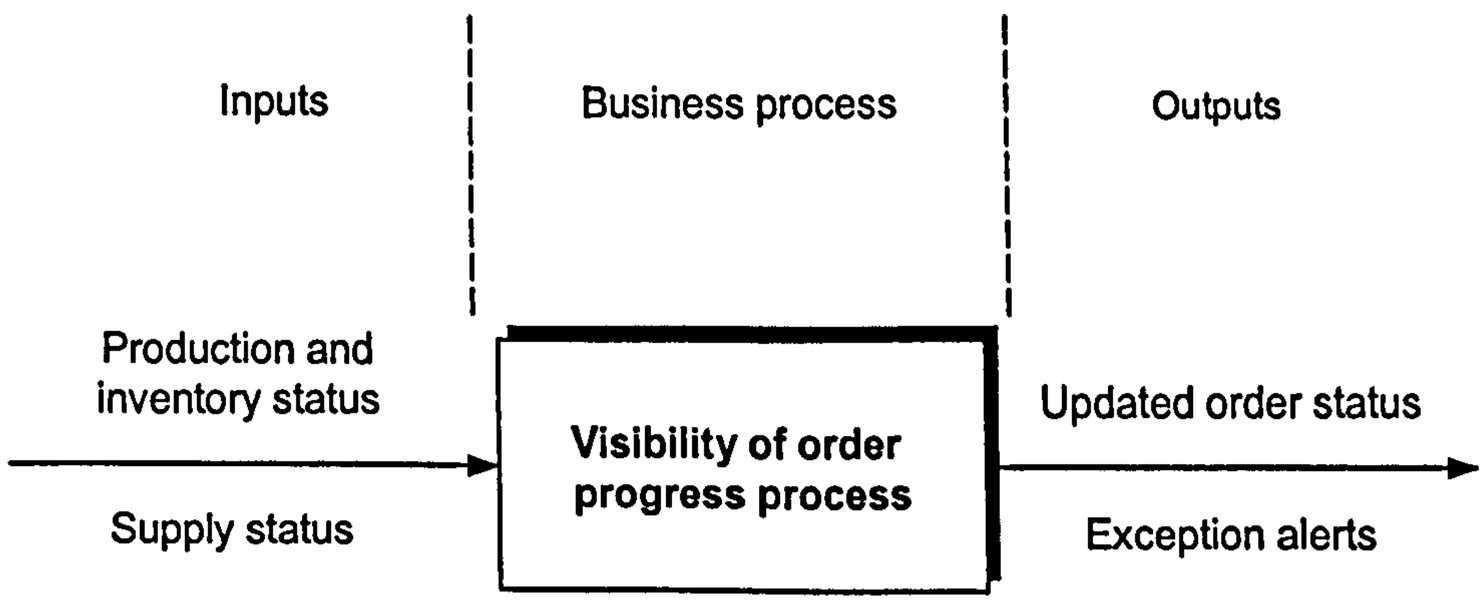


Figure 4-11: Basic diagram of the VOP process

Objectives

- Improve customer service (fulfilled deliveries) by monitoring and providing order status in near real time across the network.
- Increase the length of time for response through early detection and alerting of delivery problems.
- Reduce manual work by providing a formalised way of reporting order status.

Performance indicators

- Percentage of early warnings sent to customers for delivery problems.
- Average length of advance time of early warnings for delivery problems.
- Percentage of fulfilled deliveries.

Process outline

If the Operational Ordering and Planning process is to make customers' demand clearer to their suppliers, the main objective of the Visibility of Order Progress process is for suppliers to provide their customers with near-real-time, formalised supply information. The combination of these two processes makes demand and supply information visible across the supply network as depicted in Section 4.2.1. Figure 4-12 outlines the VOP process, which is mainly for the supplier to provide the customer with up-to-date order status information and to alert the customer in case of delivery problems.

To make supply information visible in near real time, the supplier needs to continuously track work orders and inventory levels to provide relatively accurate and up-to-date production and inventory information. The production information is usually extracted from local shop floor management systems such as manufacturing execution systems or other internal tracking systems or even a manual system in case of a few production stages, while inventory information is pulled out of local ERP systems or warehouse management systems.

However, tracking work orders and inventory levels is not sufficient for the supplier to provide meaningful information on the progress of their customer orders. To achieve this, there are two major issues to be addressed by the supplier. The first one is how to dynamically match external customers' orders with internal manufacturing batches, which is especially critical in a consumption driven supply network. Generally, an external customer order does not correspond directly to a manufacturing batch since the supplier may have several customers ordering the same or a functionally compatible product with similar requirements on delivery time. In such cases, a matching table between external customer orders and internal inventory and manufacturing batches coupled with corresponding rules will automate or at least significantly improve the alloca-

tion process. Nevertheless, for highly customised products (one product for only one customer), the automation of the matching process is quite straightforward.

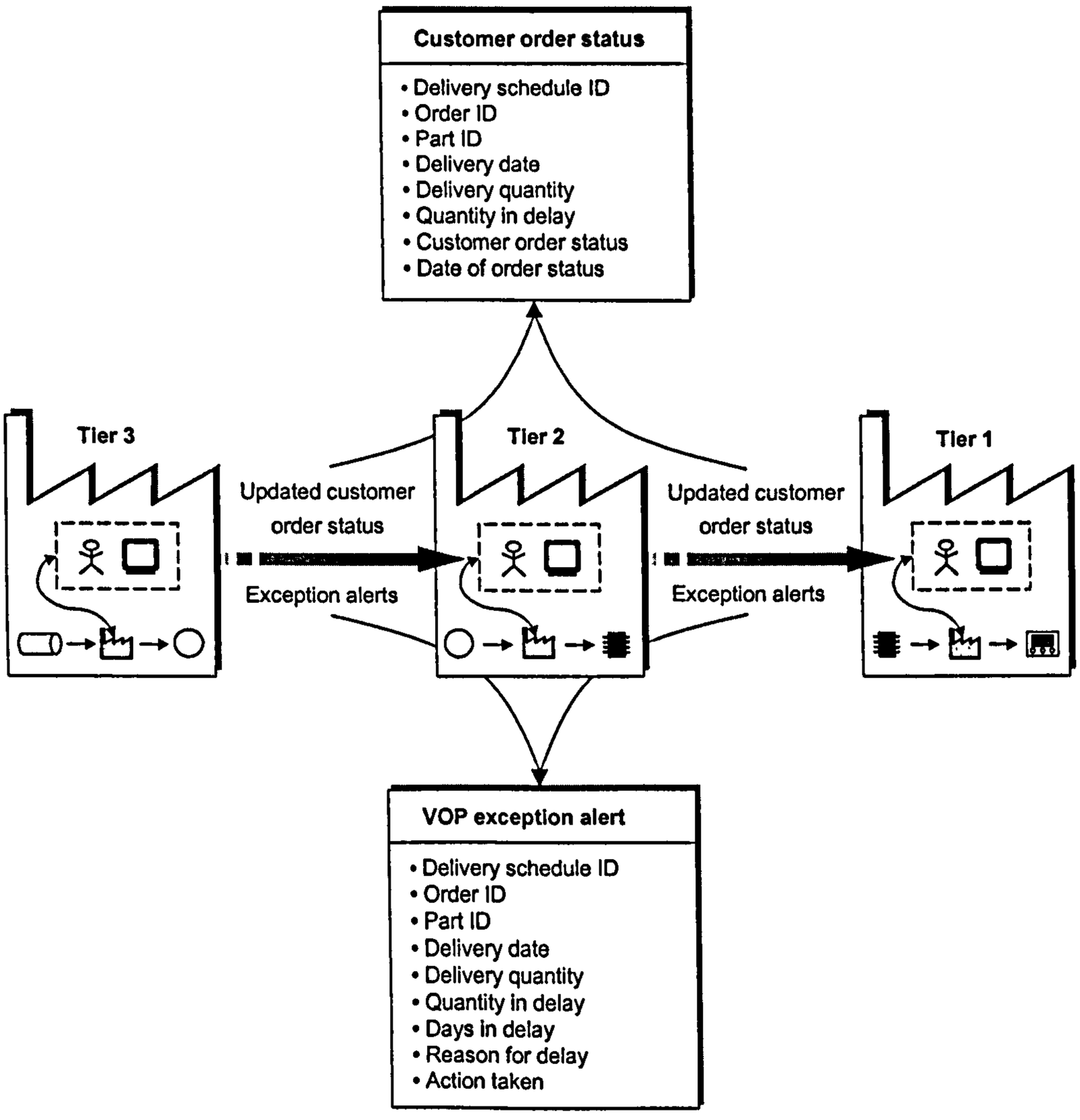


Figure 4-12: VOP process outline

Once this dynamic matching process has been established, the second issue is how to detect the delay of order progress early enough and give an "early" warning (e.g. at least one week before the due date) to the affected customer whenever warranted. Thus, a milestone approach has been employed to track the internal progress against standard lead-times of the milestones, which are determined according to the local production process for a specific product and the criticality of the product. If the actual order progress is detected lagging behind the standard process, an internal exception alert is first generated so that the production manager can analyse the consequence of the delay. If

the results of analysis indicate that the delay cannot be recovered at the later stages of production and/or be complemented by available buffers, an external exception alert is to be sent to the customer, which triggers the eXH process.

Compared with current order tracking practices in industries, which mainly focus on the logistics process, such as Dell computers and Amazon.com. This process emphasises the holistic view of a manufacturer's delivery capability including their own suppliers' delivery capabilities. On the other hand, instead of requiring the customer to understand the supplier's internal processes in detail, it provides simplified, meaningful information on order progress. Hence, the traffic light approach is employed to signal the general status of order progress as shown in table 4-2.

Colour	Meaning	Actions to be taken
Green	The customer order is progressing normally.	No actions need to be taken by the supplier or the customer.
Yellow	The customer order is slightly delayed or the quantity falls short, but can be recovered at the later stages of production or can be accommodated by buffer stock.	The supplier needs to take some internal actions to recover the delayed customer order (e.g. by expediting the order), but the customer does not need to take actions.
Red	The customer order is severely delayed, and can neither be recovered at the later stages of production nor accommodated by buffer stock.	In this case, the customer order status needs to be reviewed by the supplier expeditor before an external exception alert is sent to the customer, which triggers the collaborative exception handling process.

Table 4-2: Traffic light approach to express customer order status

4.4.4 Exception handling

Vision

To provide both customer and supplier expeditors an efficient, robust and formalised tool when dealing with rush orders and missed deliveries (Figure 4-13).

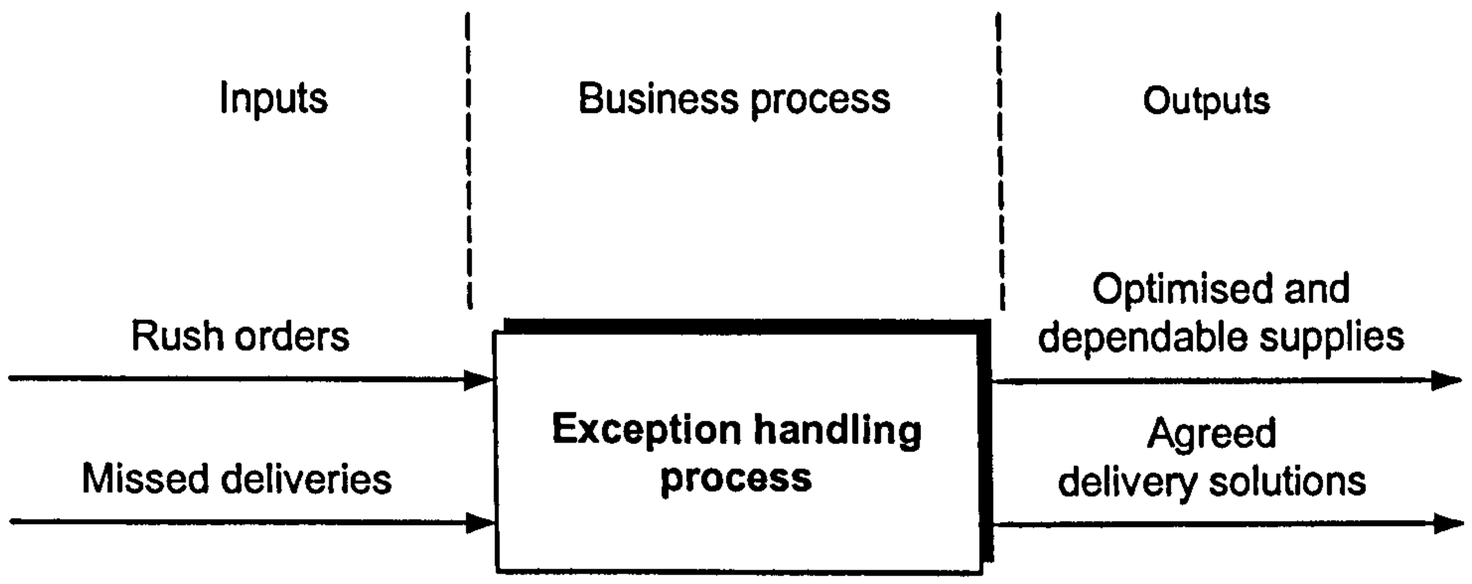


Figure 4-13: Basic diagram of the eXH process

Objectives

- Reduce the "fire fighting" pressure and the handling time by providing formalised ways of information exchange, including information transferring and processing and negotiation.
- Optimise the delivery lead-time, cost and success rate of rush order fulfilment by considering current stock levels, costs and locations of available suppliers.
- Reduce the frequency of material shortages and the associated costs with them by resolving missed deliveries as early as possible.

Performance indicators

- Frequency of material shortages.
- Percentage of rush orders which are successfully fulfilled.
- Percentage of missed deliveries which are successfully resolved.

Process outline

The Visibility of Order Progress process performs only the production monitoring functionality for production control. To achieve the full production control of the network, it needs a clear route to resolve delivery problems detected and reported by VOP. Therefore, the Exception Handling process is logically the next step of the VOP process to

close the control loop. The detailed process design for eXH is described in Chapter 5. Therefore, here is just a brief overview as illustrated in Figure 4-14.

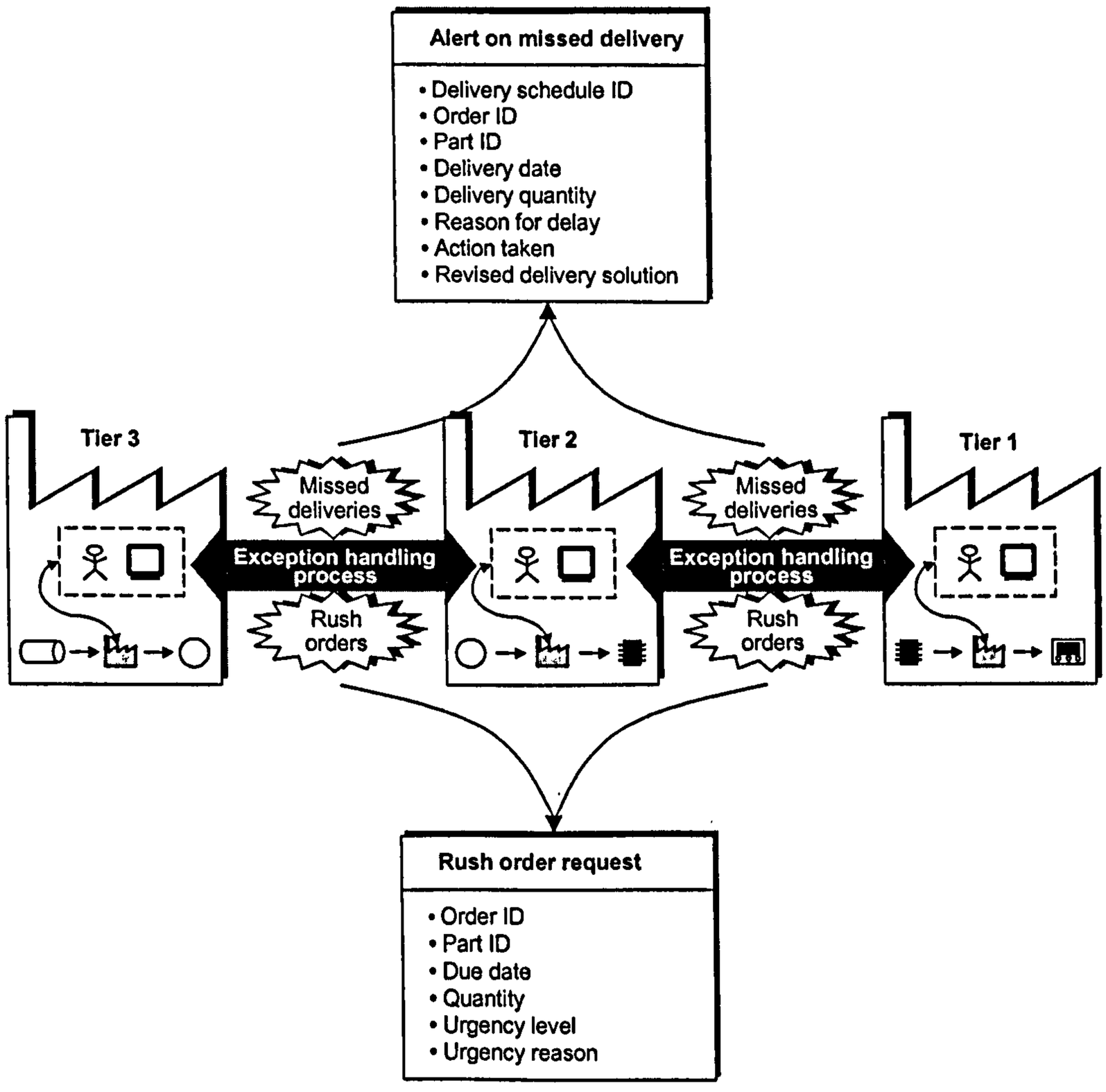


Figure 4-14: eXH process outline

According to the overall guiding principle specified in Section 4.2.2, supply chain planning and execution processes have to be managed by exceptions, allowing more management attention focused on handling unforeseen or exceptional events. This is also in line with the idea of supply chain event management as reviewed in Section 2.4.2. As illustrated in Table 4-1 in Section 4.2.2, exceptions in the supply planning and execution process can be in the short term or medium to long term, and on the demand or the supply side. To minimise their negative effects, exceptions should be detected and resolved at the planning stage. In other words, demand and supply exceptions in the medium to

long term should be identified and resolved by OOP and ReFS during the collaborative planning process. Therefore, the eXH process should focus on handling short-term demand and supply exceptions, i.e. rush orders and missed deliveries.

There are two major issues in handling exceptions in the supply network. One is that there is a need to establish standard exception handling processes via fast and effective communications, which facilitate quick and correct decision making. The other one is that clear escalation routes for alerting the affected business partners should be established to allow fast propagation of exception alerts across the relevant part of the network. Nevertheless, exceptions should be contained at the lowest level to minimise their negative effects on the network level. For example, if an internal exception alert signals that certain demand fulfilment has slipped behind schedule, the node should take internal measures (e.g. expediting late batches) to contain the problems. Only when internal efforts are not sufficient to recover the problem can the node alert the affected customer.

4.4.5 Request and feasibility studies

Vision

To provide a fast response to request on new orders or large order changes across the relevant part of the supply network (Figure 4-15).

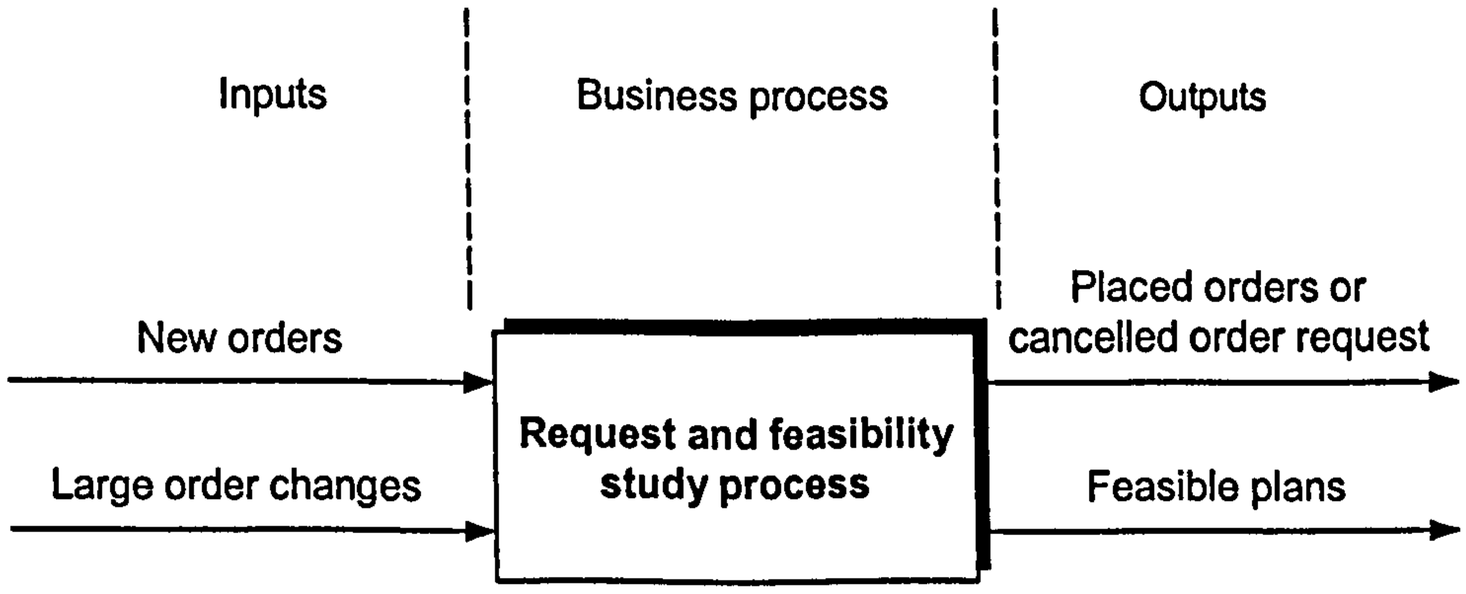


Figure 4-15: Basic diagram of the ReFS process

Objectives

- Reduce the response time to request on new orders or large order changes.
- Facilitate more feasible and dependable plans in the operational ordering and planning process.

Performance indicators

- The average response time for an incoming inquiry from a customer.
- The average response time for the network answering an inquiry from the OEM.

Process outlines

The Request and Feasibility Studies process is complementary in functionality to the Long-term Production Planning and the Operational Ordering and Planning process. Actually, it is a helpful planning tool which helps to make more feasible plans especially in the medium or long term. Within a node, this process is in correspondence with available-to-promise (ATP), which determines if a customer's order request can be met from existing inventory and production orders, and capable-to-promise (CTP), which checks if a customer's request date can be met from available plant capacity. However, ReFS focuses more on a fast feasibility check on the network level than on the node level. Figure 4-16 illustrates the ReFS process.

The process starts with a node in the network which is very often an OEM or a 1st-tier supplier. It sends a request to its immediate suppliers for a new order or large order changes on due dates and/or qualities that override business rules stipulated in contractual agreements. Each node that has received a request breaks down the request into internal and external requirements using the BoMs and checks its internal capacity availability and other capabilities. The external supply requirements are transferred to their own suppliers who in turn perform the same process of internal material requirements planning and external supply requests. This way, each node queries its internal capacity model and production plans and then gives a quotation quickly to its direct customer, who consolidates the quotations from their suppliers to create a quotation for their own customer until a final answer is achieved. If the request is probably to be fol-

lowed by the placement of an order, ReFS can reserve the capacity for the relevant part of the supply network.

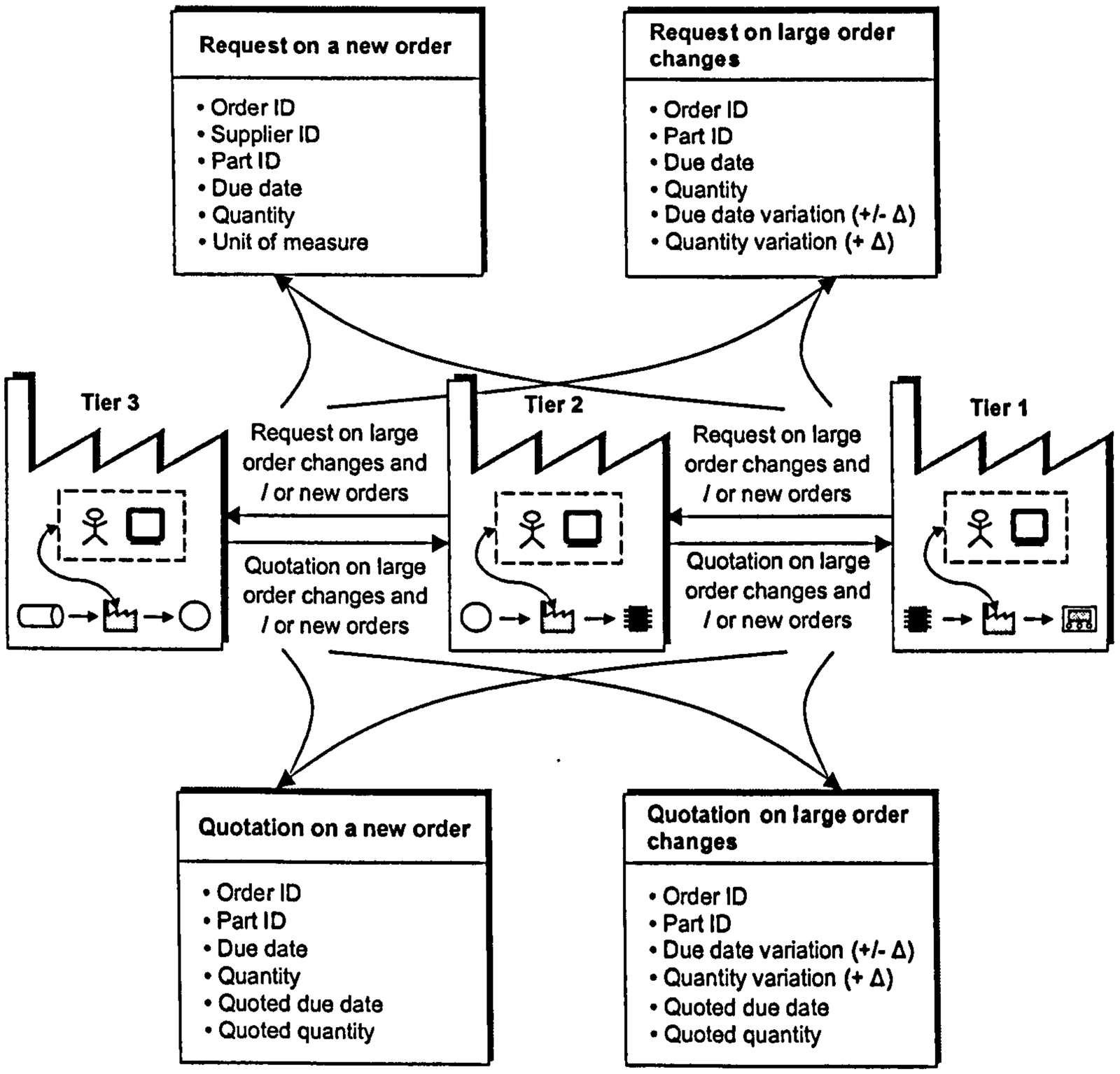


Figure 4-16: ReFS process outline

As the ReFS process often entails the propagation of request on demand and quotation on delivery capability across the relevant part of the network, an agent-based approach has been adopted so that the result of the ReFS process can be obtained in a reasonably short period. Among others, one key issue is how to construct a capacity model for a specific node, which should be configurable to capture the specificity of each node in the network. A practical, efficient way to do this is through an algorithm repository which contains flexible and user-configurable algorithms for capacity modelling. These configurable algorithms should consider specific business scenarios, level of detail of

capacity models and the extent to which users' knowledge can be incorporated in the capacity models (Co-OPERATE deliverable D10, 2000).

4.5 Comparison of Co-OPERATE with other solutions

The decentralised coordination architecture for the Co-OPERATE system has two important aspects: (1) there is no central optimisation for the total supply network in view of incommensurate decision variables (e.g. cost, delivery lead-time) and loss of local decision autonomy for each node in the supply network, (2) Co-OPERATE supports existing local planning systems (e.g. ERP systems) as local business processes are extremely heterogeneous and so are local planning systems. By focusing on the inter-company planning and execution coordination processes, it is expected to get SMEs involved in the supply chain coordination process that are normally not affordable to expensive EDI or ERP systems.

Therefore, while i2 provides business process optimisation across multiple tiers of suppliers and customers, Co-OPERATE is mainly focused on planning and execution coordination processes between a company and its immediate customers and suppliers. Meanwhile, as Co-OPERATE targets complex supply networks where companies have partnerships based on long-term contracts, it does not take pricing optimisation into account, which is a key feature of Manugistics EPO.

From the business process perspective, there is some overlap, for instance, between RosettaNet's Notify of Purchase Order Update (PIP 3A7) and Request Purchase Order Change (PIP 3A8) and Co-OPERATE's eXH. However, as Co-OPERATE is primarily targeted towards complex supply networks with highly customised products, its eXH focuses on providing expeditors with relevant local planning, inventory and production status information for decision making and streamlining eXH processes through fast, effective negotiations, which differs Co-OPERATE significantly from RosettaNet.

Chapter 5

DESIGN OF EXCEPTION-FOCUSED SUPPLY CHAIN EXECUTION MANAGEMENT

Following the high-level business process design in Chapter 4, this chapter focuses on detailed business process design for the Exception Handling process, which is embedded in a broader process entitled exception-focused supply chain execution management (ESCEM). The need for ESCEM is introduced in the first section of the chapter. The second section proposes a holistic control paradigm for supply chain execution management, which is the foundation of the methodology for ESCEM described in the third section. The process design for eXH is further detailed through function modeling and scenario analysis, which are presented respectively in the fourth and fifth sections of the chapter.

5.1 INTRODUCTION

The supply chain performance is ultimately measured by how well supply chain execution systems, which include warehouse management system (WMS), manufacturing execution system (MES) and transportation management system (TMS), can fulfill the demand of the end customer. However, customers are not concerned with routine orders and normal supply chain processes. Key to supply chain execution management is how to handle exceptions, such as rush orders, last-minute changes, etc, which creates the greatest opportunities for a supplier to differentiate itself from its competitors. Therefore, exception-focused supply chain execution management is imperative.

To manage exceptions effectively and efficiently, each node in a supply network needs near-real-time visibility of supply chain activities both within and outside the node so that the exceptions can be detected sufficiently early. While supply chain execution systems contain most of the information for immediate visibility into the execution

process, the supply chain is often out of control. This is not because the information is not there, but because it is locked away in different databases or data stores. Consequently, to provide immediate visibility and effective control of the supply chain, it is essential to bring together information from various enterprise systems, present it in a timely, meaningful way and act on it in case of exceptions.

The objective of ESCEM is to contain exceptions at the lowest level and, if they cannot be contained within a node, to minimize their negative effects on the network level. To achieve this, there is a need to detect the exceptions as early as possible, which is the main task of VOP. On the other hand, it is of vital importance to resolve them via standard business processes and formalised communication, which is the focus of eXH. Through the integration of VOP and eXH, it is expected that ESCEM can be used to achieve better control of the supply chain execution process. The methodology for ESCEM is based on a holistic control paradigm for supply chain execution management, which integrates feedforward, concurrent and feedback control across different business boundaries and is described in the next section.

5.2 PROPOSED CONTROL PARADIGM

In today's industrial environment, customers seldom receive an early warning on delivery problems before the planned delivery date and often realise a delay by goods not having arrived as planned. In other words, companies usually take feedback control after the delivery problem has occurred. The major drawback for feedback control is that by the time the customer has the information, the negative effect has taken place. To tackle the problem, feedforward control for preventing anticipated delivery problems, and concurrent control for correcting delivery problems as they happen need to be integrated into the current feedback control to improve supply chain performance.

Figure 5-1 presents the scope of feedforward, concurrent and feedback control for supply chain execution (SCE). In this proposed control paradigm, feedforward and concurrent control play the primary role in managing the supply chain execution process. Via feedforward control, it means that progress deviations from the standard process are detected early enough to permit correction before these slips eventually cause delayed deliveries. In such cases, internal exception warnings are first generated to alert respon-

sible personnel that progress deviations are occurring and corresponding actions need to be taken to correct the situation so that the delay can be recovered at the later stages of production.

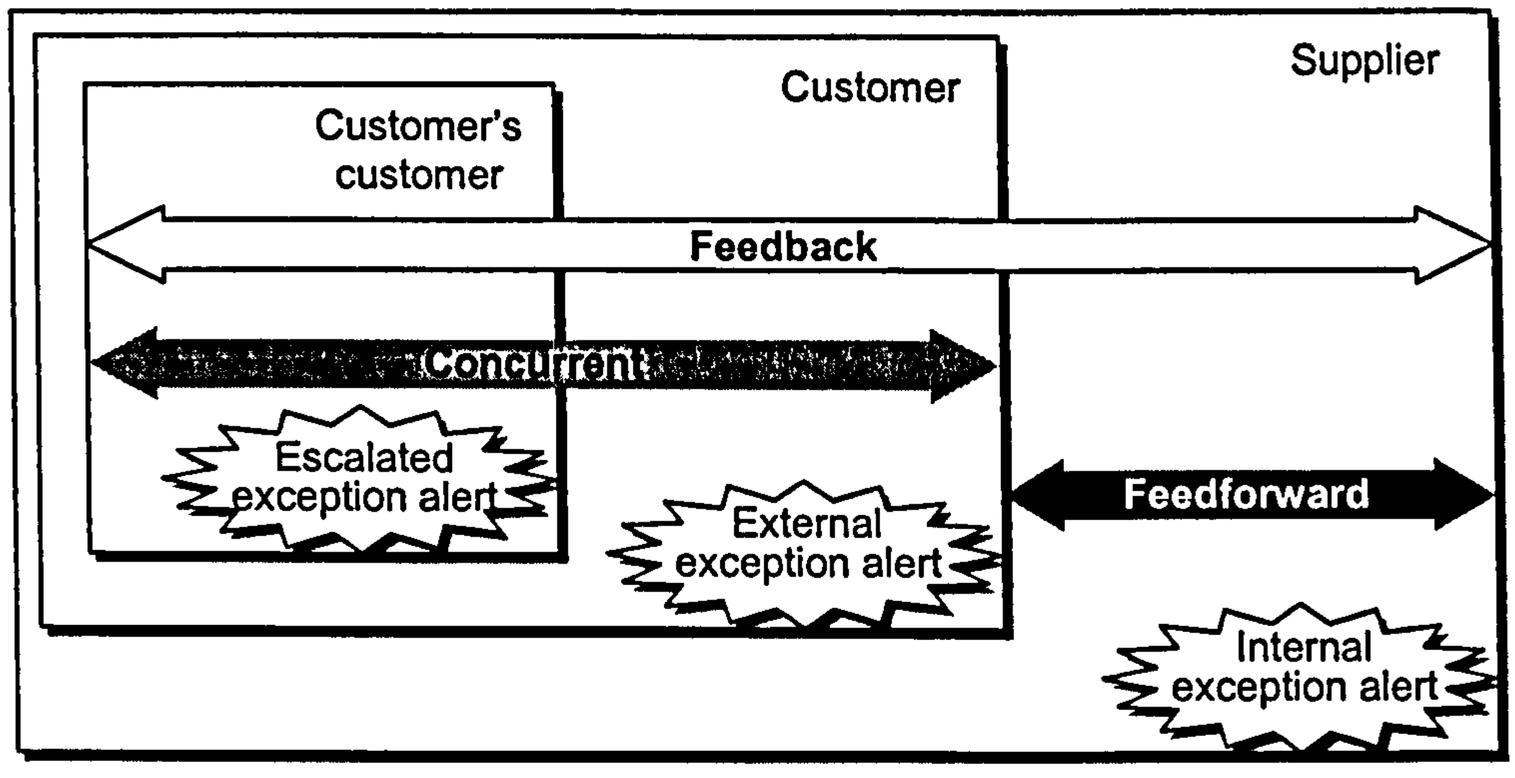


Figure 5-1: Scope of feedforward, concurrent and feedback control for SCE

Feedforward control is an ideal situation. However, in a real industrial environment, this is not always the case. Very often, the delay generated at the earlier stages of production can not be recovered at the later stages for some practical reasons. For example, there is a bottleneck at the later stages, which constrains the throughput time of the entire production process. Under such conditions, although feedforward control is impossible, concurrent control is much better than the traditional feedback control because the customer and the supplier can collaboratively deal with delivery problems before they become too costly.

While feedback control is usually the simplest form of control, it is undesirable and should play a minor role in supply chain control as it is not responsive and often incurs much higher costs than concurrent control. Sometimes, the negative effect propagates beyond the direct customer to the second tier customer. This ripple effect can increase the overall cycle time and incur rapid degradation of the network performance.

On the whole, feedforward control is most desirable. Nevertheless, this type of control requires not only timely, accurate information, but efficient decision support on judging the current situation and choosing the appropriate actions. Therefore, there is always a

trade-off between conflicting factors such as customer service, technical investment and associated risks when considering the form of control of order fulfillment for a specific product. Generally, the feedforward and concurrent control need to be simplified to take care of major exceptions in terms of criticality of product, importance of customer, etc, while the feedback control can be used to handle minor exceptions which have less significance to management than do major ones.

5.3 METHODOLOGY FOR ESCEM

The last two sections have introduced the necessity for exception-focused supply chain execution management and proposed a holistic control paradigm for supply chain execution management, which integrates feedforward, concurrent and feedback control across different business boundaries. This section extends this idea by exploring the methodology behind it for improved coordination of supply chain execution activities.

Traditionally, the conflicts between demand and supply are resolved through telephone-based negotiations between the customer and the supplier, which can involve a significant amount of manual work, incurring lots of "fire fighting" pressure on expeditors in the logistics department. Enabled by the Internet and other IT tools, the exception-focused methodology provides a standard workflow structure and corresponding Web-based tools for the above-mentioned negotiation process, which tries to resolve the conflicts taking into account constraints on both the customer and the supplier sides.

5.3.1 Mechanism for ESCEM

When exceptions arise, generally, the first measure to absorb their negative effect is naturally the flexibility of the manufacturing system because of its implicitly available accommodating character (Newman et al., 1993). Swamidass (1988) divides manufacturing flexibility into two levels: machine-level flexibility and plant-level flexibility. Here, manufacturing flexibility is meant at the total manufacturing system level (i.e. at the plant level), embracing four main types of flexibilities: product, mix, volume and delivery (Slack, 1987). As the negative effects of exceptions are always changing, and manufacturing flexibility is usually a long-term decision, a dynamic equilibrium be-

tween the negative effects of exceptions and measures to absorb them must be achieved and maintained. Figure 5-2 shows a systematic model for ESCEM.

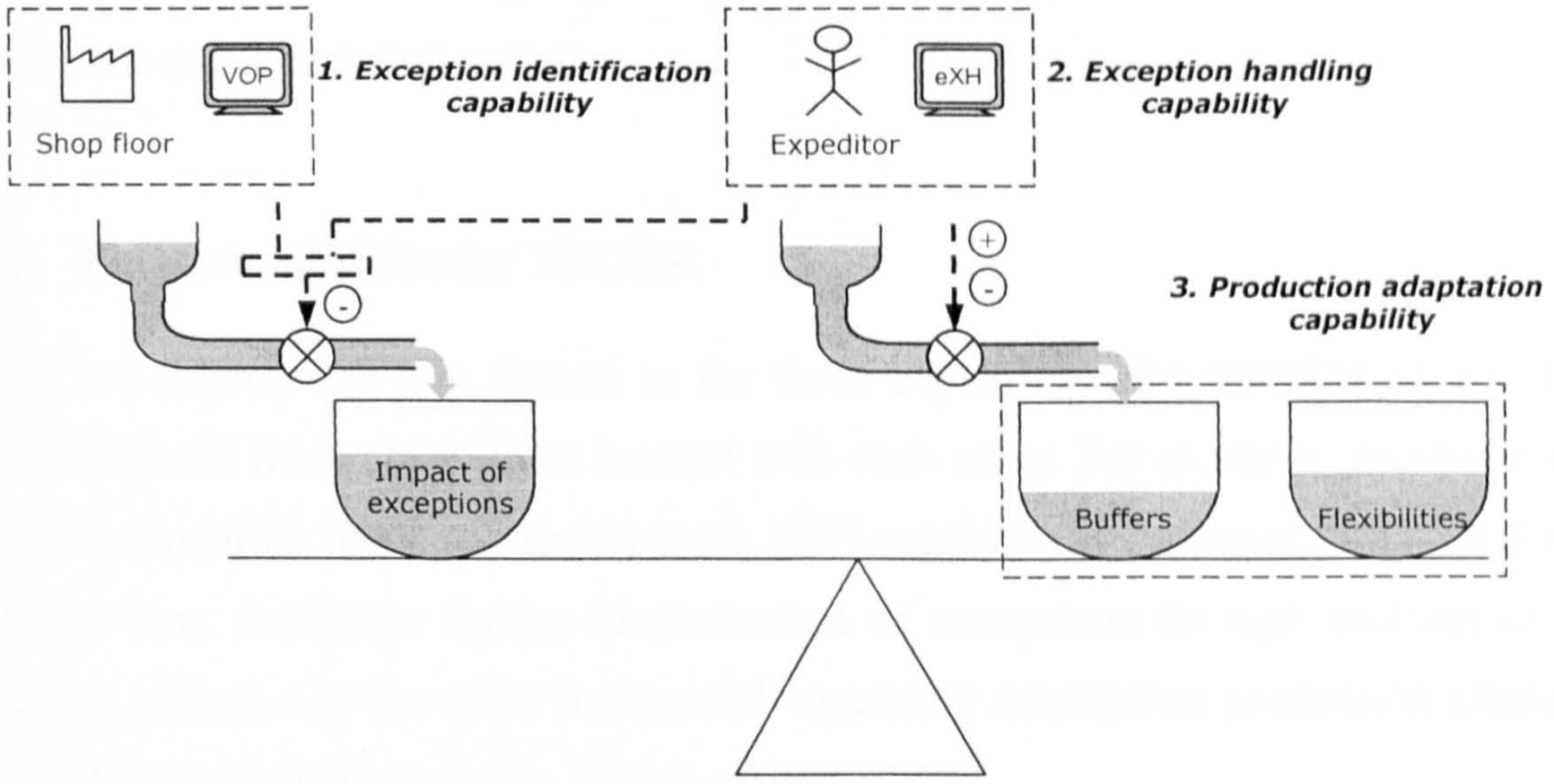


Figure 5-2: A systematic model for ESCEM

In practice, if the aggregate negative effect of exceptions tends to increase, manufacturers usually use buffers, in the forms of buffer stock, time buffer and/or reserved capacity, to maintain balance (Ho et al., 1995). Essentially, manufacturing flexibility with the compensation of buffers has constituted the production adaptation capability of a manufacturing system. Although raising buffer levels is a short-term expediency, it has some disadvantages which make it an unattractive solution. First, buffers are usually costly. Second, excessive use of time buffers can aggravate the congestion of the manufacturing system (Whybark and Williams, 1976; Kanet 1982). Finally, using reserved capacity can be very costly, which makes reserved capacity seldom used intentionally in a typical industrial practice. All these disadvantages indicate that while any manufacturing system will have some buffers, they should be minimised.

In fact, a strategic and more advisable solution for tackling exceptions is through supply chain integration and coordination, which helps to detect exceptions early enough so that uncertainties associated with the exceptions can be reduced dramatically. On the other hand, helps solve problems effectively and efficiently by providing useful and up-to-date information and standard handling processes. Generally, there are three factors

influencing eXH capability: (1) information, (2) environment, and (3) decision-maker. Compared with the systematic model for ESCEM described in Figure 5-2, correspondingly, there are three capabilities for ESCEM, i.e. exception identification capability from VOP, exception handling capability from eXH, and production adaptation capability from the manufacturing system.

5.3.2 Three capabilities for ESCEM

Figure 5-3 depicts the key factors in the three capabilities for ESCEM. It should be noted that these three capabilities interact with each other. For example, exception identification capability helps to ease the work eXH capability is supposed to do. eXH capability, in turn, facilitates further identification of exceptions through analysis of their knock-on effects. On the other hand, eXH capability determines production adaptation capability and its deployment to a large extent.

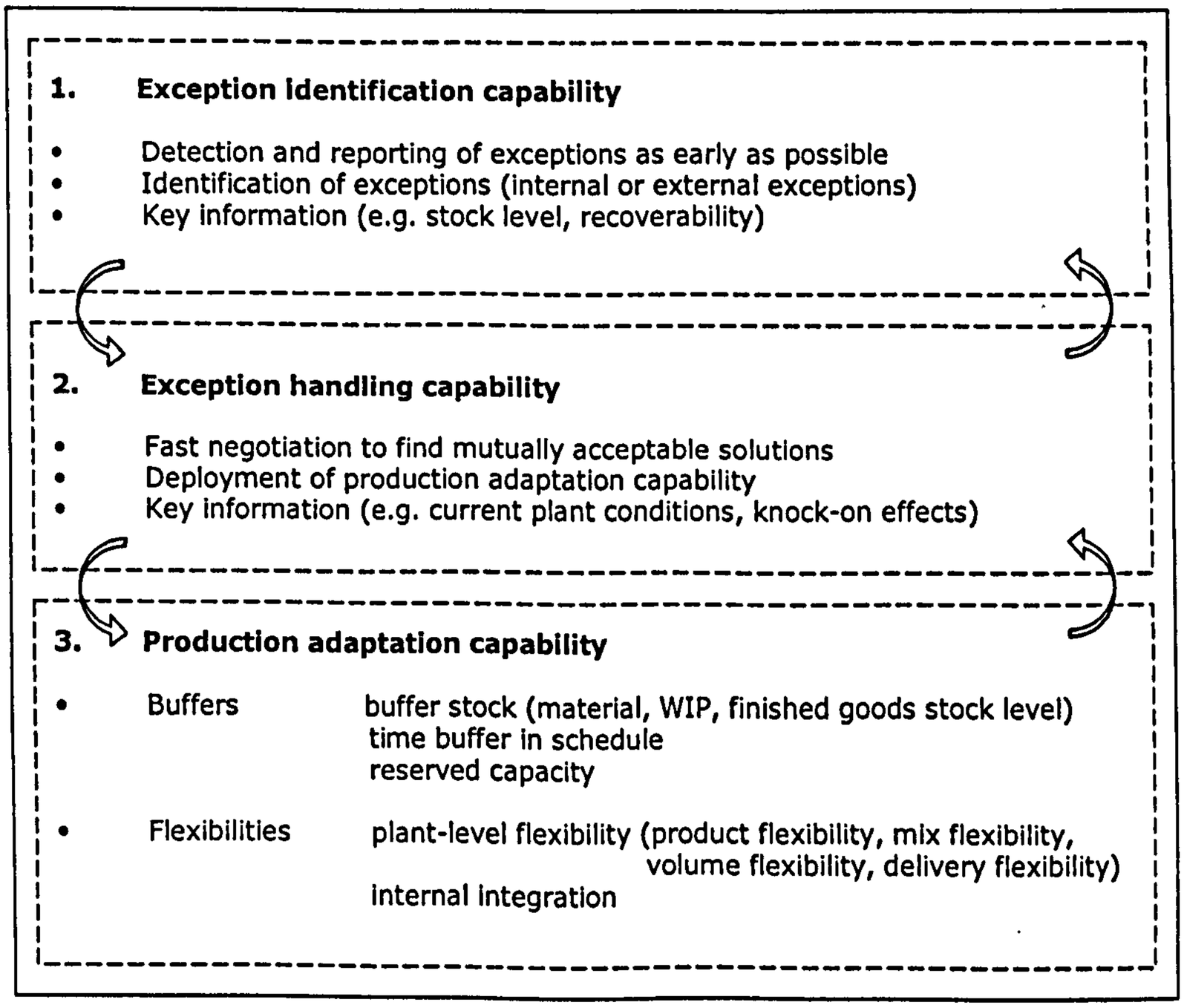


Figure 5-3: Three capabilities for ESCEM

5.3.2.1. Exception identification capability

As shown in Figure 5-3, the exception identification capability is embodied in the VOP process. Key to VOP is to detect and report exceptions in a timely, meaningful manner. To detect deviations in the order fulfillment process, it is essential to track inventory levels and work orders. The progress of work orders is measured against the predefined milestones. However, there is no direct link between customer orders and finished goods inventories and production orders in local planning systems (e.g. ERP systems). In practice, it is a dynamic mapping process, which can be automated based on certain criteria (e.g. due date, importance of customer) and business rules using the criteria (e.g. key customers are satisfied first) as illustrated in Figure 5-4.

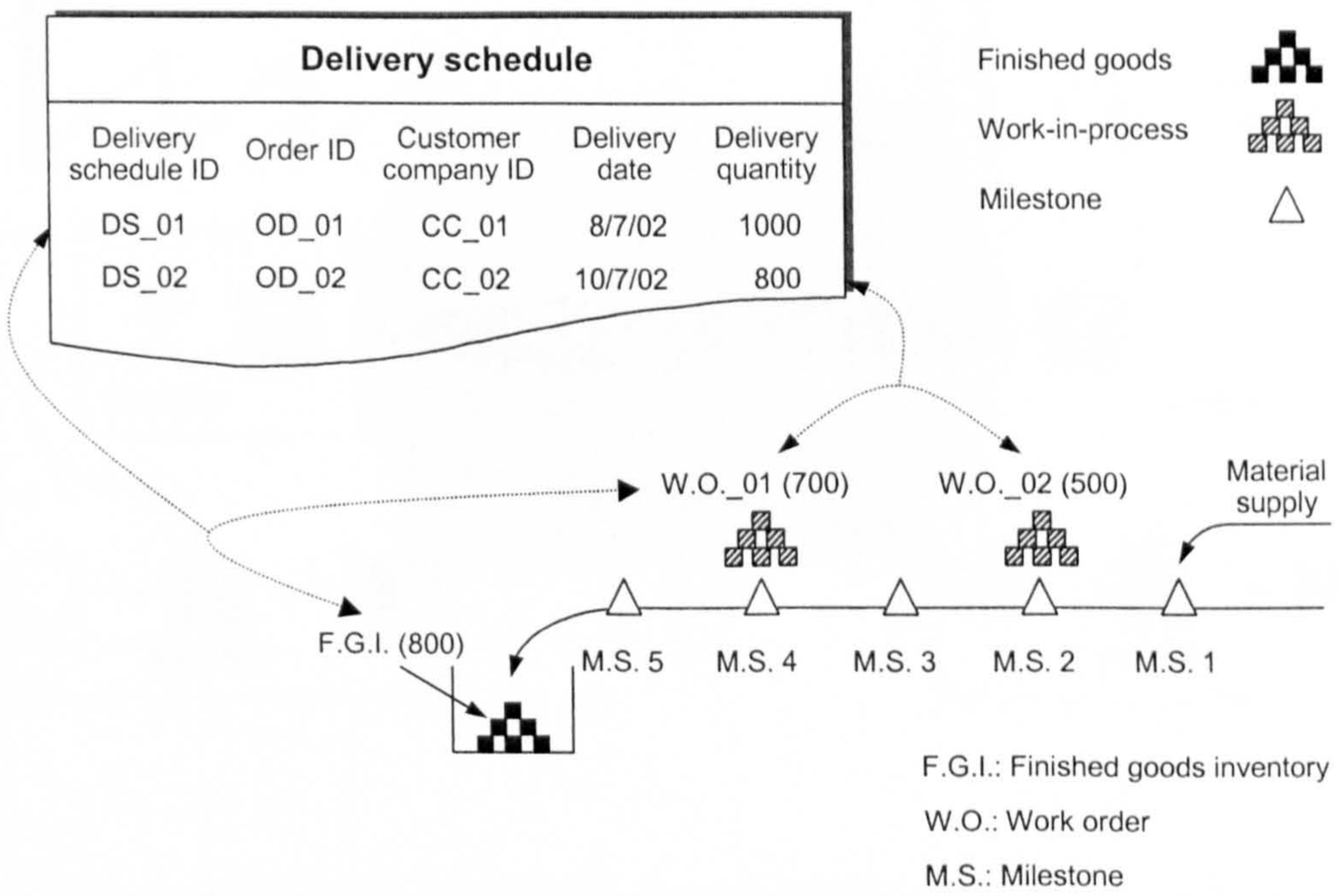


Figure 5-4: Mapping customer orders with WIP

To maintain the stability of the supply chain execution process, information on external exception alerts to the customer should be certain and meaningful. Otherwise, the customer might become confused by constantly changing order status. This requires that exception alerts from VOP have to be checked and judged by the supplier expeditor based on his or her knowledge and experience on current inventory and production status and recoverability of delayed work orders.

5.3.2.2. Exception handling capability

The exception identification capability, i.e. VOP in this context, addresses only one side of the problem. The advantage of early detection of problems can be reduced or offset by the delay and ineffectiveness in the exception handling process. Therefore, it is indispensable to establish Web-based, effective negotiation channel by which both the customer and the supplier can collaborate to find mutually acceptable solutions as illustrated in Figure 5-5. This can be achieved through standard exception handling processes, which are described in the fourth and fifth sections of this chapter.

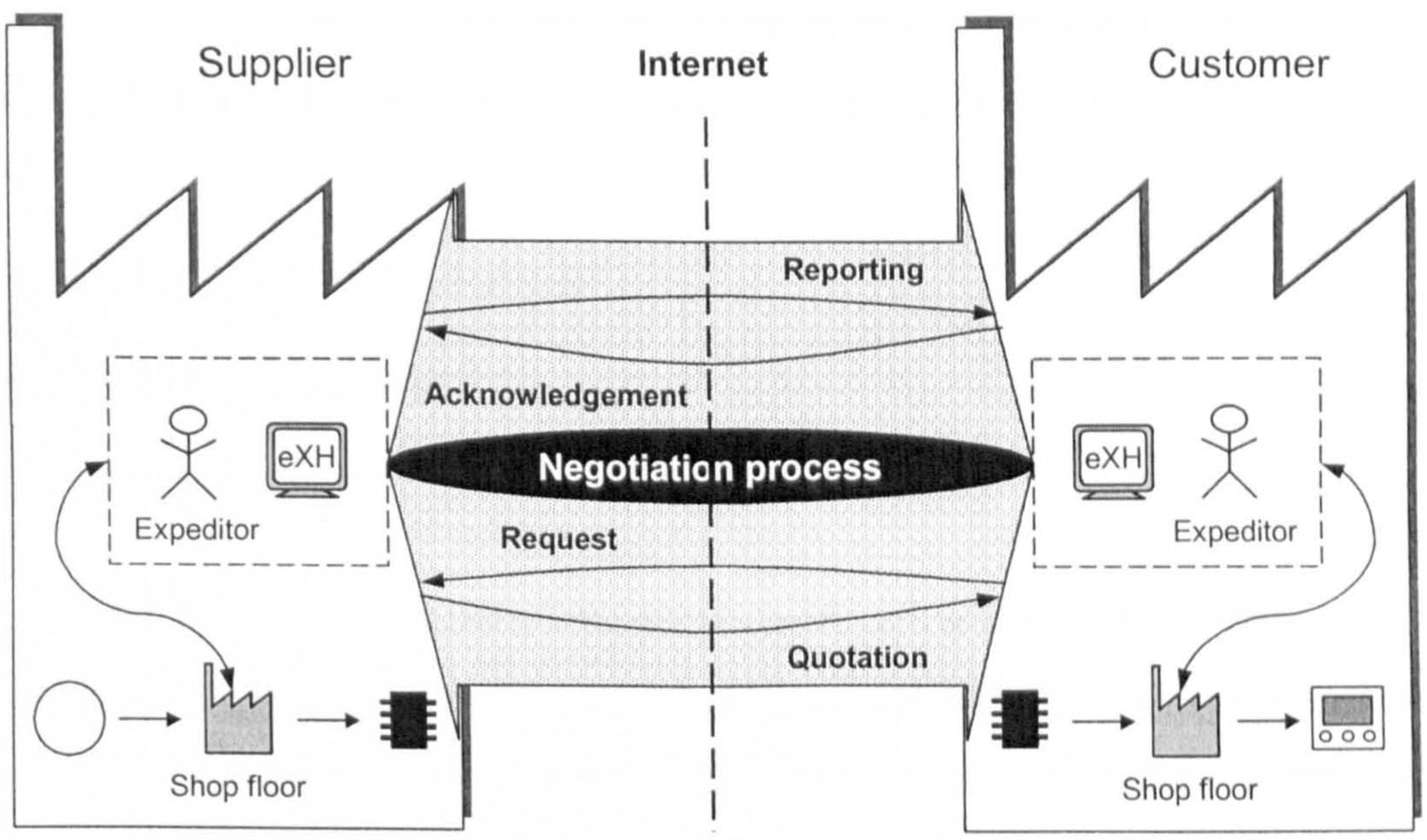


Figure 5-5: Exception handling through fast, effective negotiations

To effectively combat exceptions, expeditors at both the customer and the supplier sides inevitably employ production adaptation capability (i.e. buffers and flexibilities). Based on the details of exceptions, current plant status and production adaptation capability, expeditors can judge the severity of the knock-on effects incurred by the exceptions, and take appropriate actions. As a result, smart deployment of the production adaptation capability is critical to the cost-effectiveness of exception handling and can lead to improved performance of the entire supply chain.

5.3.2.3. Production adaptation capability

During the last three decades, buffers and manufacturing flexibility have been hot research topics with a significant number of articles addressing each of them and relationships between them (e.g. Slack, 1987; Newman et al., 1993; Ho et al., 1995). It would go beyond the scope of this thesis to provide an extensive review and discussion on these two topics. The remaining part of this section hence confines itself to key issues in the two domains in relation to the deployment of production adaptation capability.

- **Buffers**

Buffers in terms of buffer stock, time buffer and reserved capacity have long been used to protect manufacturing systems against uncertainties. Since the 1970s, there has been a considerable amount of research around three key issues related to the deployment of buffers:

- Which buffering method to use?
- Where to place buffers?
- How much buffer?

Some general but limited results have been achieved. For example, safety (or buffer) stock may be used at the end item level, and safety lead-time at lower levels (New, 1975). However, there are no general guidelines to help practitioners to make strategic buffering decision. On the other hand, there are methods to calculate the necessary amount of buffer stock based on statistical data (e.g. Krupp, 1982, 1999; Sandvig 1998, 2000; Hung and Chang 1999). However, planners or expeditors may not have the information nor the time to do statistical calculations for hundreds of purchased parts.

In practice, the decisions on how much buffer stock to be held are often based on the experience and knowledge of planners and expeditors. For example, if a supplier seldom exceeds five days overdue, then five day's worth of material is a reasonable amount of buffer stock (Dillon, 1990). Although safety lead-time is not recommended or even strongly objected by some practitioners, conservative purchasing planners still practice time buffers 'unconsciously' just to protect themselves against stock-outs (Ho et al., 1995). Reserved capacity may help to reduce finished goods buffer stock, however, it is rarely used because of potentially high cost.

- **Flexibilities**

There have been various taxonomies to categorize the different types of flexibility (Gupta and Goyal, 1989). This is mainly because flexibility clearly possesses both a strategic and an operational dimension and can manifest itself in different forms at different levels. At the manufacturing system level, an observation by Slack (1987) points out that managers identify four main types of flexibility: product, mix, volume and delivery. Meanwhile, it is generally agreed that internal integration in terms of information systems and flexible organizational structure underlies each type of the flexibilities. Basically, there are two key issues related to the understanding and deployment of an enterprise's flexibility:

- What relationships exist between each type of flexibility?
- How to measure flexibility?

Some qualitative relationships between different types of flexibilities have been found, e.g. volume flexibility and delivery flexibility have some degree of interchangeability determined by the types of manufacturing systems (Slack, 1987). However, quantitative relationships between them have proved difficult to establish. On the other hand, measurement of flexibility is essential for understanding the current status of an enterprise's manufacturing flexibility and also for identifying the requirements of each type of flexibility and making the trade-offs between them.

As an example, delivery flexibility is one of the flexibility types production controllers are interested in, which is defined as the ability to move planned delivery dates forwards (Beamon, 1999). This ability allows the supply chain to accommodate rush orders and can be expressed as the percentage of the delivery time which can be reduced. Assume T_c is the current time period, and there are $s = 1 \cdots S$ jobs in the system at this moment. For job J, it has N operations and each operation has a normal lead-time L_{ni} ($i = 1 \cdots N$) and a shortest lead-time L_{si} ($i = 1 \cdots N$). If job J is currently in operation M ($M<N$), then the instantaneous delivery flexibility for job J is:

$$DF_J = \sum_{i=M}^{N} (L_{ni} - L_{si}) \; / \sum_{i=M}^{N} L_{ni}$$

5.4 DETAILED PROCESS DESIGN FOR EXH

In this section and the following, the eXH process is further detailed, which is guided by process-specific design principles for eXH, modeled with IDEF0 and analyzed based on typical business scenarios.

5.4.1 Design principles for eXH

Besides the overall guiding design principles for high-level business process design which are described in Section 4.2, each business process should have some process-specific guiding principles for detailed process design. Major design principles for the eXH process are summarized as follows.

- Treating the shop floor as an equal communication partner because it actually serves as an internal supplier and often plays a critical role in handling exceptions.
- Following the request-quote-review-confirm process for rush order handling, and following the alert-request-quote-comment process for missed delivery handling.
- Taking buffer stock as the first choice in fulfilling rush orders and taking buffer stock and time buffer as the first choice in case of missed delivery handling.

5.4.2 Process description for eXH

Figure 5-6 presents the missed delivery handling process with the shop floor as an independent communication unit. It follows the alert – request – quote – comment process. An internal exception alert from VOP is first judged by the supplier expeditor before an external exception alert is sent to the customer. After receiving the supplier' exception alert, the customer expeditor may request a minimum delivery from the supplier if the revised delivery solution proposed by the supplier does not meet the customer's production schedule. Then, the supplier expeditor readjusts the delivery solution trying to satisfy the customer' minimum delivery requirements.

Once receiving the supplier's readjusted delivery solution, the customer expeditor can make some comment on it and may send a rush order to another alternative supplier in a multi-sourcing case if the customer's requirements are still not fully met.

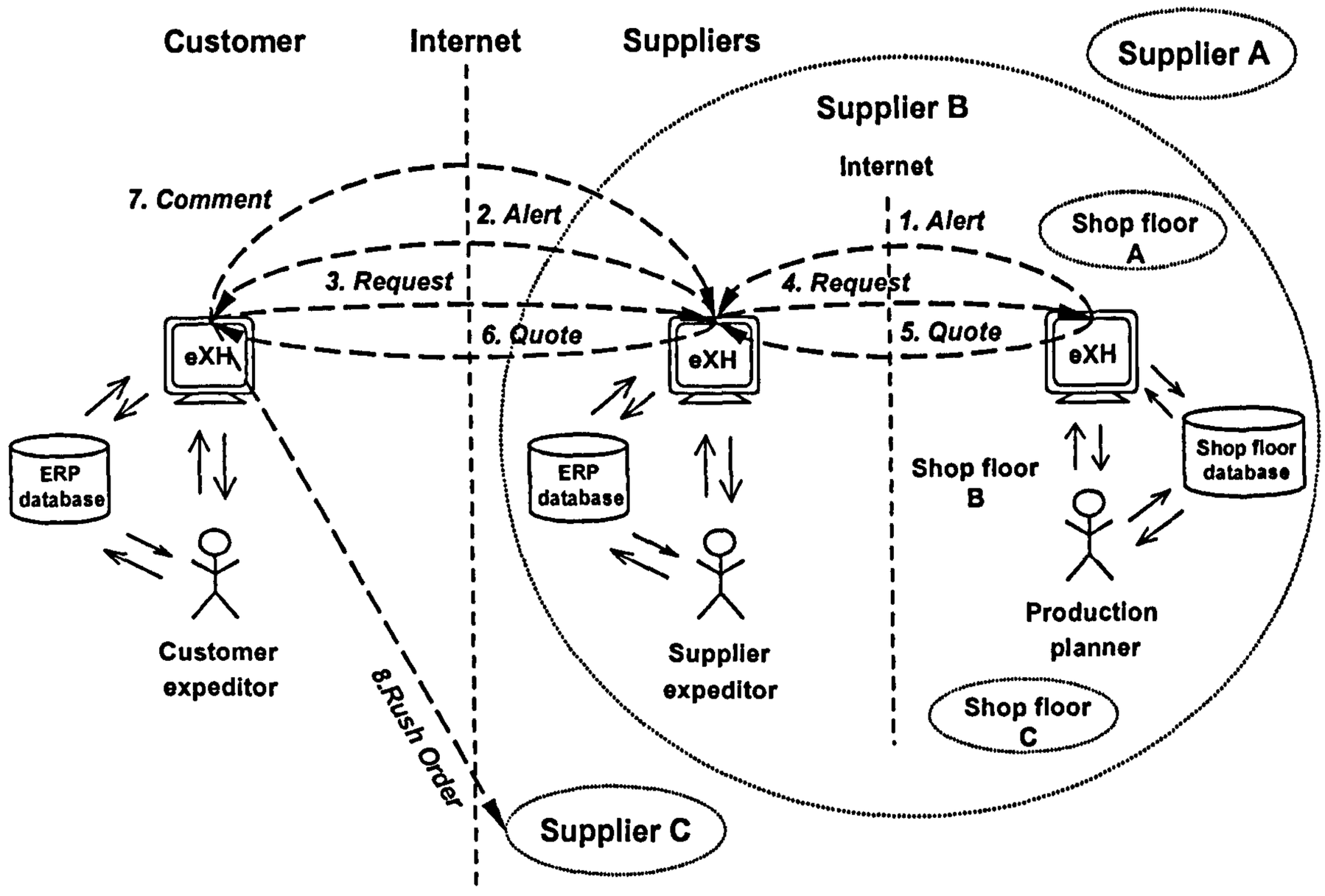


Figure 5-6: Schematic business process for missed delivery handling

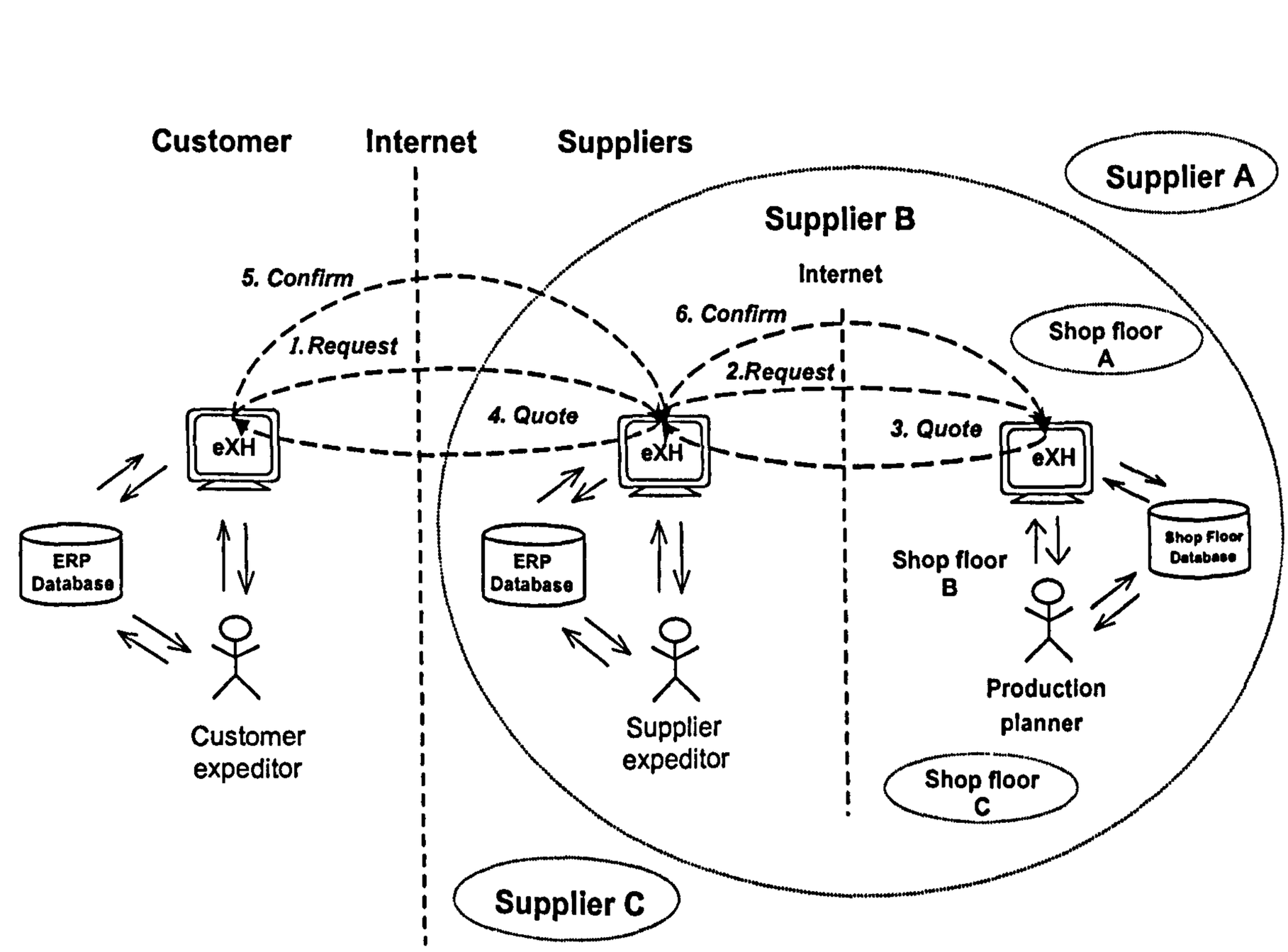


Figure 5-7: Schematic business process for rush order handling

The rush order handling process is depicted in Figure 5-7. It follows the request – quote – review – confirm process. In a generic multi-sourcing case, the customer expeditor selects some of available suppliers to send rush order requests and gets quotations from them. After consolidating all the quotations from the chosen suppliers, the customer expeditor decides which suppliers to place rush orders and how much for each of them. In case the supplier wants to get an existing order delivered earlier than planned delivery date, the process is simpler and has some similarity to the missed delivery handling process.

5.4.3 Function modeling

The eXH process is modeled with IDEF0. In alignment with the top-down design approach, the IDEF0 modeling technique uses a hierarchical approach for functional decomposition, whereby the model starts by representing the whole system as a single box at the highest level labeled A0. The A0 box can be decomposed into a set of activities at level A1. This process repeats until the system is described in the necessary detail as illustrated in Figure 5-8.

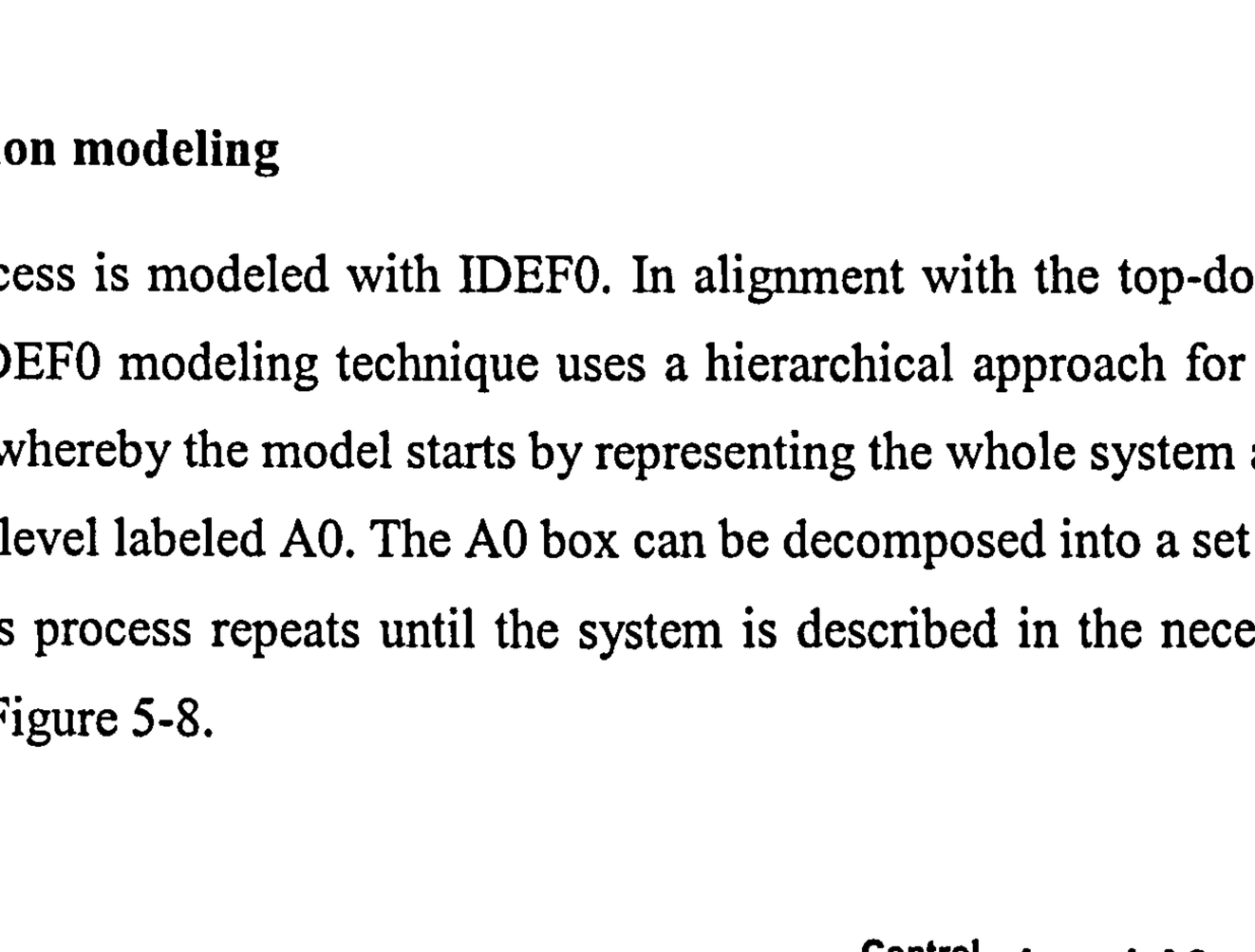


Figure 5-8: Hierarchical structure of IDEF0 modeling approach

In this hierarchical structure, each activity (or process step) is represented as a box. Inputs are information and/or materials which are transformed by the activity to outputs. Controls are the information and/or materials used to constrain the activity. Resources are people, facilities or systems that perform or provide the energy to the activity.

The process model for eXH is presented in Appendix A, and the description for each process step of the missed delivery handling process and the rush order handling processes is summarized in Appendix B.

5.5 SCENARIO ANALYSIS

While function modeling using IDEF0 provides a detailed process view of the system through functional decomposition, scenario analysis tries to describe what the system should achieve from the user's point of view, which bridges the gap between business process design and software development. The scenarios described here have been extensively discussed with expeditors and production planners from industrial partners of the Co-OPERATE project. The result of scenario analysis is sequence diagrams that show interactions between local planning systems (e.g. ERP systems), the eXH process, customer expeditor, supplier expeditor and supplier production planner in a time sequence.

5.5.1 Handling a delayed delivery

Handling a delayed delivery is the most common and important scenario in missed delivery handling. Figure 5-9 (Page 103) illustrates the sequence diagram of "Handling a delayed delivery".

The scenario starts with an exception alert from VOP, which reports how much in quantity is going to be delayed, how long is the delay, reason for the delay and actions that have been or will be taken. The supplier expeditor views the alert and checks the available finished goods inventory from the supplier's ERP system simultaneously. If the inventory is not sufficient to cover the delayed quantity, an external exception alert will normally be sent to the customer, which includes a revised delivery solution.

While receiving the exception alert, the customer expeditor checks buffer stock and time buffer in the production schedule from their ERP system and available stock of material on the shop floor. If the totality of buffer stock plus time buffer is not sufficient to prevent production from disruption, a minimum delivery requirement in terms of minimum delivery quantity and latest delivery date is calculated by the system as the default value and subject to the adjustment of the expeditor.

The minimum delivery requirement is reviewed by the supplier expeditor, who re-accesses the supplier ERP system to get the up-to-date information on buffer stock. If the buffer can cover the required minimum quantity, the expeditor responds the customer directly; otherwise, sends an urgent delivery request to production planner for the remaining part of the quantity together with a priority (very high, high) for it. In the latter case, after receiving the response from the production planner, the supplier expeditor adjusts the revised delivery solution and sends a readjusted delivery solution back to the customer.

The readjusted delivery solution is then reviewed by the customer expeditor, who feeds back the supplier with some comment and/or suggestions. Finally, the supplier expeditor notes the production planner regarding the immediate delivery and the customer's demand in the near term.

5.5.2 Placing a new rush order

Placing a new rush order covers the whole range of the rush order handling process. Figure 5-10 (page 104) presents the sequence diagram of "Placing a new rush order".

The scenario begins with a new rush order request giving part number, required quantity and due date, price, urgency level (very urgent, urgent) and reason for urgency (e.g. out of stock). In a multi-sourcing case, the customer expeditor can select some of available suppliers to send order requests. A rush order request can be generated by the customer's ERP system or by an expeditor, and transmitted by the Co-OPERATE system to the supplier.

When receiving the rush order request, the supplier expeditor views order information and available buffer stock from the supplier's ERP system on the same web page. If the

buffer is sufficient to fulfill the order, the expeditor responds the customer immediately; otherwise, sends an order request to the production planner for the remaining part of the quantity with a priority for it. In the latter case, based on the assigned finished goods inventory and the response from the production planner, the supplier expeditor sends a quotation to the customer, which can be the full quantity or partial quantity with the remaining part of the quantity coming a few days later.

Having received quotations from the requested suppliers, the customer expeditor consolidates all the quotations and decides which suppliers to place rush orders and how much for each of them, i.e. a rush order request is either confirmed or cancelled.

5.6 Conclusions

In this chapter, a holistic control paradigm for supply chain execution management is proposed. By extending this control paradigm, the methodology for ESCEM has been developed, which includes a systematic model and three capabilities for ESCEM.

As the core of ESCEM, the eXH process is further detailed through process description, function modeling and scenario analysis. The implementation of a pilot system for ESCEM is described in the next chapter.

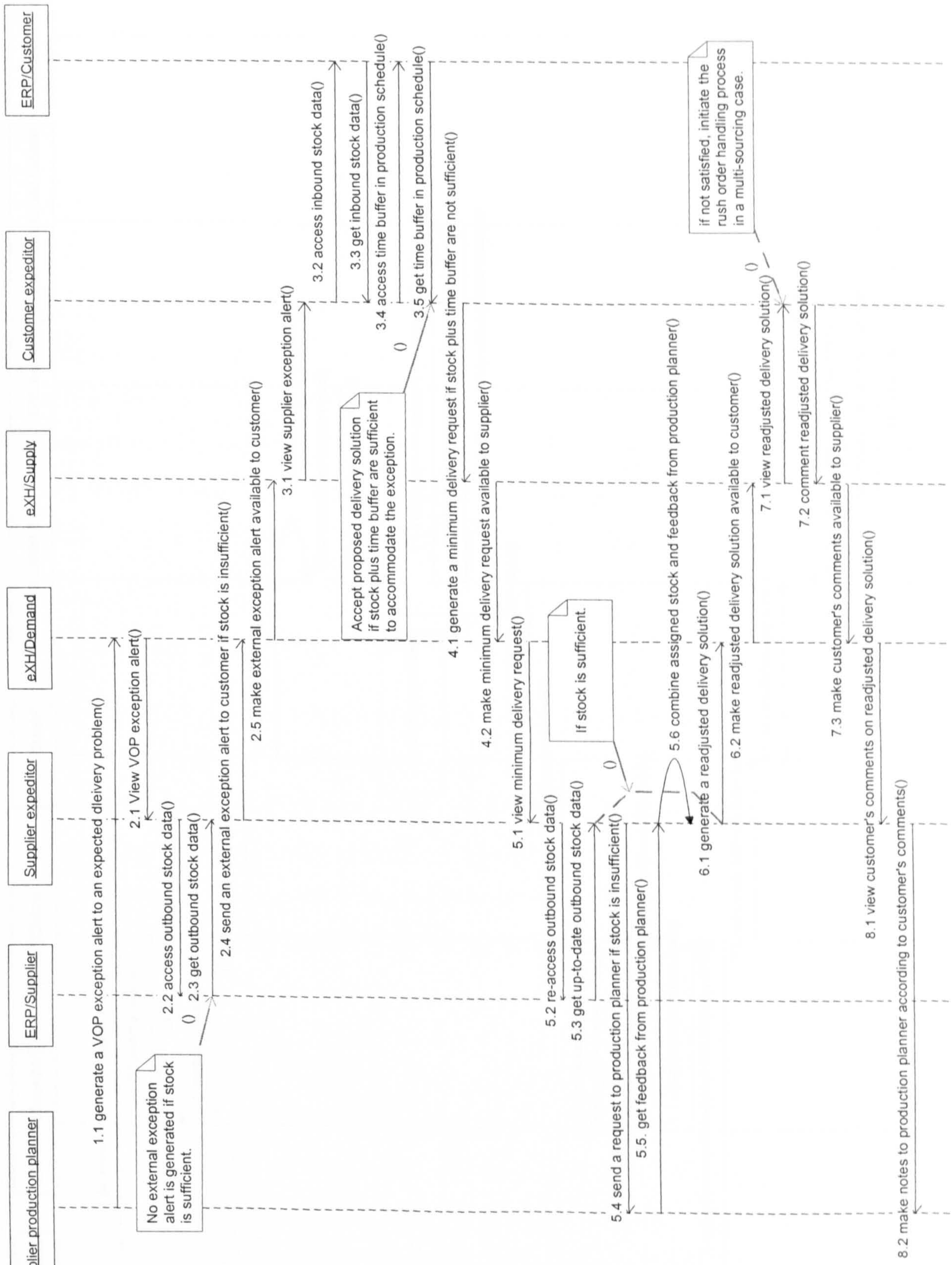


Figure 5-9: Sequence diagram of handling a delayed delivery

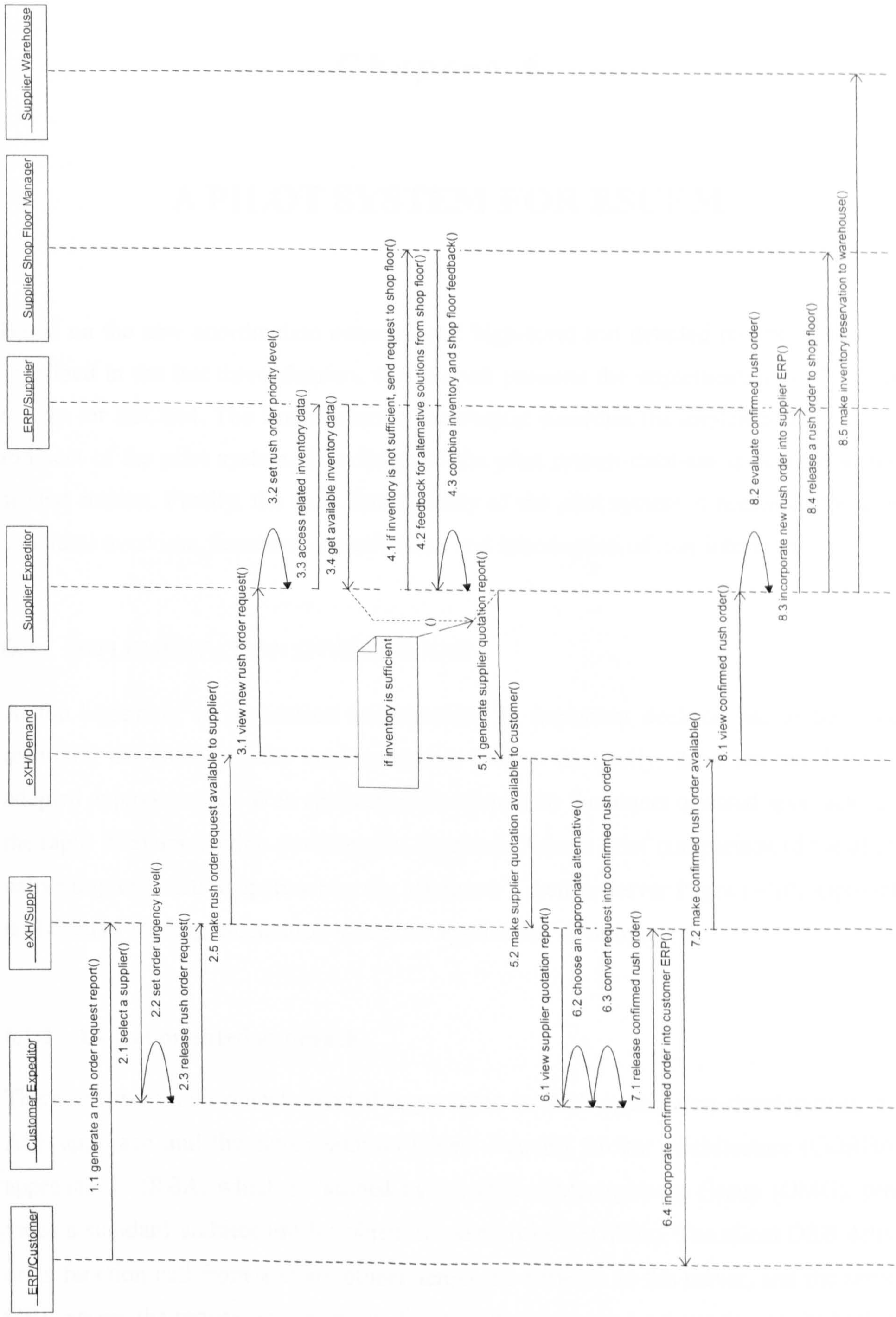


Figure 5-10: Sequence diagram of requesting a new rush order

Chapter 6

A PILOT SYSTEM FOR ESCEM

Based on the new coordination concepts and high-level and detailed process design as described in the last three chapters, this chapter presents the implementation of a pilot system for ESCEM. The first section of the chapter describes the implementation environment of the pilot system. The design of the pilot system database is detailed in the second section. Finally, the main functionality of the pilot system is presented through structural overview, functional specification and introduction of user interfaces.

6.1 IMPLEMENTATION ENVIRONMENT

At the beginning of application development, an important decision has to be made regarding the choice of the implementation toolset. Generally, there are two broadly adopted approaches for Web application development: the object oriented approach and the rapid Web application development approach. After a brief comparison of the alternative implementation approaches, the Microsoft's Active Server Pages (ASP) approach is chosen as the implementation model for application development.

6.1.1 Object oriented approach

There are two main object-oriented approaches in Web application development: the ASP approach and the Java/Common Object Request Broker Architecture (CORBA) approach. CORBA, which is defined by the Object Management Group (OMG), provides a standard architecture for object request brokers (ORBs). The client ORB delivers a function call from a client object across the network to the server, and the server ORB passes the request to the target object on the server and returns the results back to the client object. The client ORB communicates with the server ORB using the Internet interoperable object request broker protocol (IIOP).

Java and CORBA are complementary. Java allows portable objects to be created and distributed across multiple platforms, while CORBA complements Java by linking Java objects together and integrating them with the rest of the server environment, such as databases and objects or applications written in other languages (Michalas et al., 2000). The integration of Java and CORBA allows programmed objects to communicate with each other in a platform-independent distributed network.

On the ASP model, the ASP technology provides a set of built-in server objects, which manage interactions between the client and the server. There are six such objects: request, response, server, application, session and object context. Figure 6-1 presents how these objects fit together.

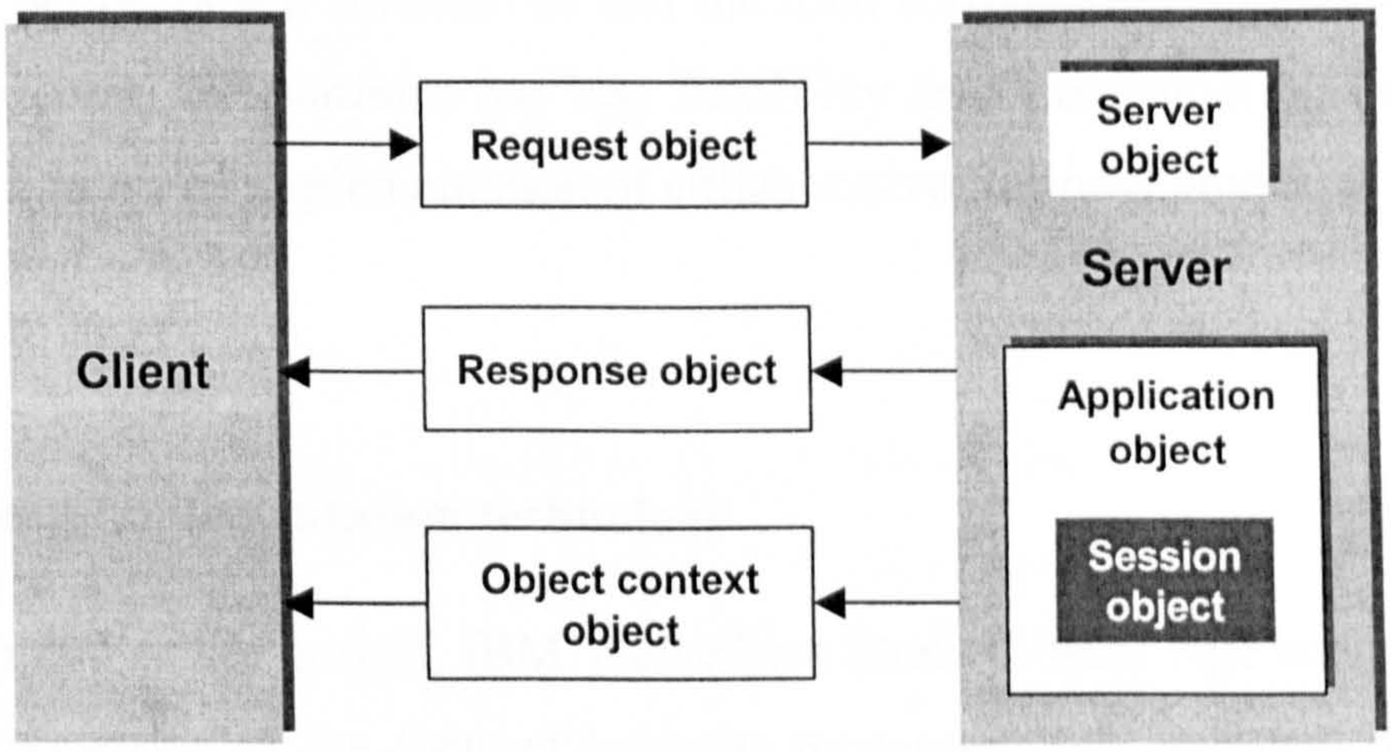


Figure 6-1: The ASP object model

The request object deals with a request that a user might make of a site or an application. The server retrieves information from the request object and put it into the server object. The response object is used to deal with the server's response back to the browser. The application and session objects manage information about the currently running application and the instances of it, i.e. sessions. The object context object is used to either commit or abort transactions, which are managed by Microsoft's Transaction Server. Additionally, another standard server component supplied with ASP, the activeX data objects (ADO), is specially designed to provide a high performance interface to databases (Michalas et al., 2000).

Compared with the ASP approach and other programming languages such as C++, the primary advantage of the Java/CORBA approach is its portability, which makes the Java approach most suitable for Web application development. However, its high complexity entails a long learning curve.

6.1.2 Rapid Web application development approach

A rapid Web application development platform provides the infrastructure that facilitates quick and easy development of Web applications. A predominant feature of the platform is the readily configurable and secure infrastructure, upon which application developers can build a prototype quickly with relatively little coding. Hence, the main advantage of the platform is that applications can be prototyped, tested and modified in a very short period (a few months) so that the total software development cycle can be reduced. However, the platform has less flexibility than programming languages (e.g. C++, Java) in terms of implementation of collaborative business processes and access of databases.

6.1.3 Chosen implementation technology

At the beginning of the project, IBM Websphere Studio/Visual Age was used to implement basic scenarios of the focused business processes. The technical difficulties encountered and the long learning cycle rendered the use of the software toolset inadequate. For prototyping the new concepts developed, EQOS, a rapid Web application development platform was adopted. Although the EQOS platform did help to demonstrate the concepts and the basic business processes to the project partners in a couple of months, it was very difficult to access the structure of the database and was thus not suitable for further implementation.

After encountering technical difficulties in the Java approach in the initial technical trial and subsequently in accessing the database structure of the EOQS platform in developing the concept prototype, the Co-OPERATE partners re-evaluated the most popular implementation tools for Web application development. The Microsoft's ASP approach was ultimately chosen for the development of the whole application.

Generally, the implementation environment of the ESCEM pilot system could be described as follows.

- Hardware: PC.
- Operating systems: Microsoft's Windows 2000 Server and Window 2000 Professional.
- Tool for user interface design: Microsoft's FrontPage 2000.
- Scripting language: Visual Basic Script.
- Database systems: Microsoft Access 2000 or Microsoft SQL Server 7.0.

6.2 TECHNICAL ARCHITECTURE

A three-tier client/server architecture was adopted to run the pilot system as illustrated in Figure 6-2. The major components of the architecture are described as follows.

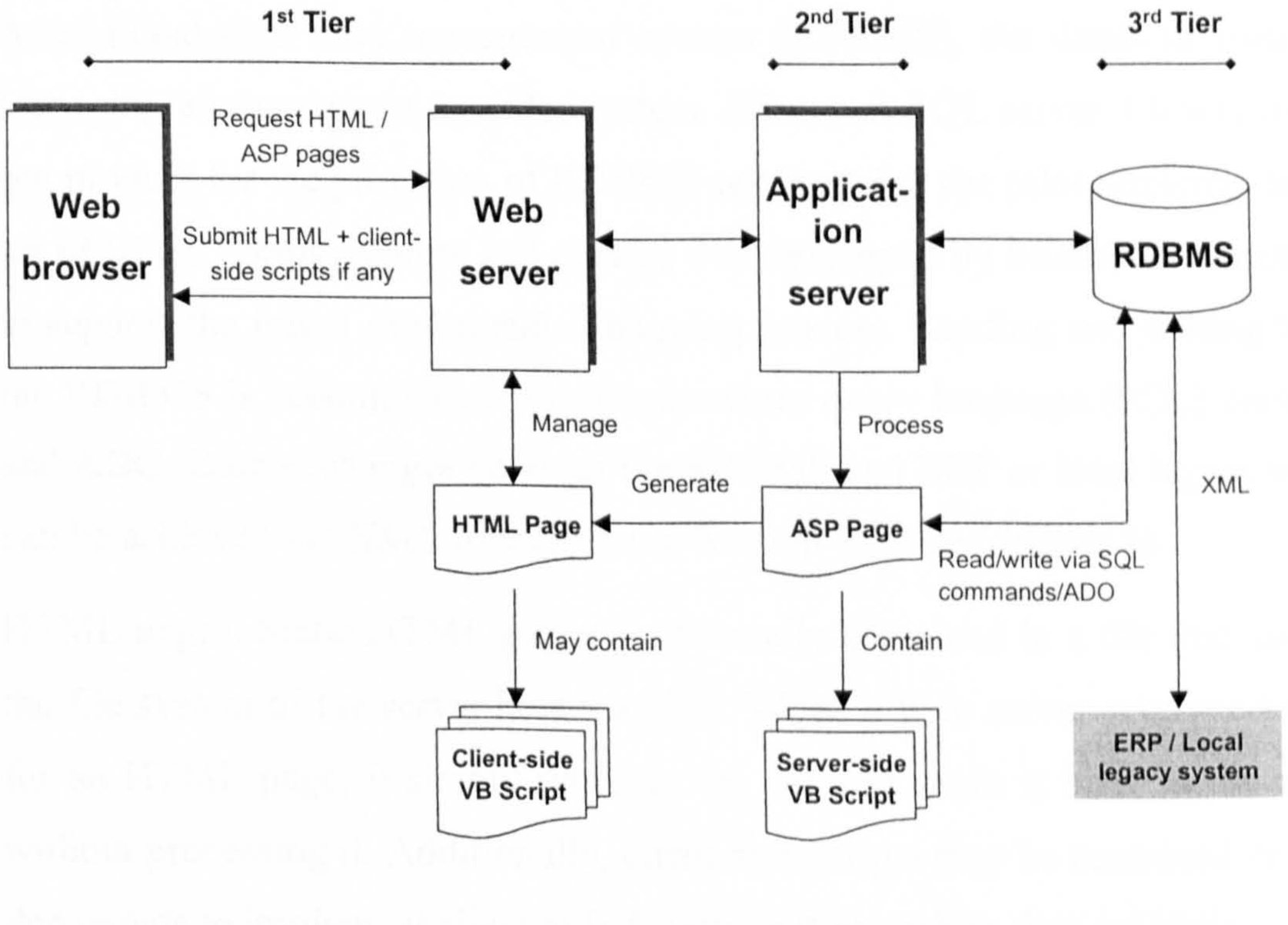


Figure 6-2: Technical architecture for the pilot system

- Web browser: any standard forms-capable HTML browser. For the pilot implementation, Microsoft's Internet Explorer was the preferred Web browser. The

main responsibility of the Web browser includes presenting Web content, issuing requests to the Web server and handling any results generated by the request.

- Web server: a program running on the server that listens incoming requests from Web browsers and services those requests as they come in, which can be either to HTML or ASP pages. While the Web server deals with the requests from the Web browsers and page rendering, business logic executes on the application server. Microsoft's Internet information server (IIS) was chosen to implement the Web server.

- Application server: While the Web browser and the Web server comprise the first tier (the presentation layer) of a three-tier Web architecture, the application server consists of the second tier (the application layer), which represents the business logic of the application. The main responsibilities of the application server include the access to the database and the execution of server-side business logic. Microsoft's IIS and ASP engine implement this functionality and the integration between the Web server and the application server.

- A relational data base management system (RDBMS), the database system for managing all the data in the pilot system. Microsoft SQL server 7.0 was the chosen product for the provision of RDBMS services. For the pilot implementation, a set of tables, forms, reports and queries was developed by Microsoft Access 2000 to support the initial design and debugging process. Reading and writing back to the RDBMS is accomplished through structure query language (SQL) commands and ADO. Data exchanges between the RDBMS and ERP or local legacy systems can be achieved via XML files (Refer to Section 8.2.1 in Chapter 8).

- HTML pages: Static HTML pages are normally contained in a file that resides in the file system of the server host machine. When a Web server receives a request for an HTML page, it simply retrieves the file and sends it back to the browser without processing it. Additionally, client-side scripts may be contained in HTML documents to implement client-side functionalities such as data validation.

- ASP pages: An ASP page usually consists of the static HTML code and server-side scripts. When a user requests an ASP page, server-side scripts are first assigned by IIS to appropriate script engines (VB script in this context) for interpretation and execution. Script output and the static HTML code in the ASP page are

then merged and sent back to the browser. On the other hand, ASP pages have access to all server-side resources such as ADO and data managed by the RDBMS.

6.3 PILOT SYSTEM DATABASE

Database design is logically an initial stage towards the implementation of business logic of a Web application as performing any system functionality usually involves interactions with databases. An integrated Co-OPERATE database was designed for managing all essential data required for network coordination. This necessitates identification of data sources, design of database structure and formulation of effective SQL commands for data query, which are described below.

6.3.1 Data sources

To manage the supply chain execution process by exceptions, only relevant data essential for manufacturing coordination in a distributed supply network are extracted from local enterprise systems and transferred into the integrated Co-OPERATE database. These data can be classified into five different sources:

- Administration data: includes some basic information about each company in the network, e.g. company ID, name, address. For each company, it also includes some key information about each user, e.g. user name, password, contact information.
- Product data: contains key attribute information for both supplied and purchased products in a company, e.g. part ID, description, unit of measure.
- Order data: provides some essential information on each of three types of orders (i.e. order schedule, consumption schedule and single order), e.g. order ID, order type, due date and quantity for a certain period.
- Stock data: supplies some aggregate information on both inbound and outbound stock in a company, e.g. on-hand stock, allocated stock, control limits.
- Manufacturing data: is mainly about information on the shop floor. Key information includes production order ID, current milestone, produced quantity and planned due date.

The above data can be stored in a large enterprise database (e.g. an ERP database) or more often in multiple databases for different enterprise applications, such as ERP, WMS, and MES. At SMEs, these data may be contained in files (e.g. spread sheets and text files) or in popular PC database programs (e.g. dBASE and Paradox) and in many other forms of databases.

With all the above data available in the database, manufacturing coordination processes can take place whenever needed, generating some derived data for coordination, e.g. delivery schedules, customer order status, revised delivery solutions from suppliers, minimum delivery request from customers. Figure 6-3 illustrates the five data sources and the derived coordination data in the pilot system database.

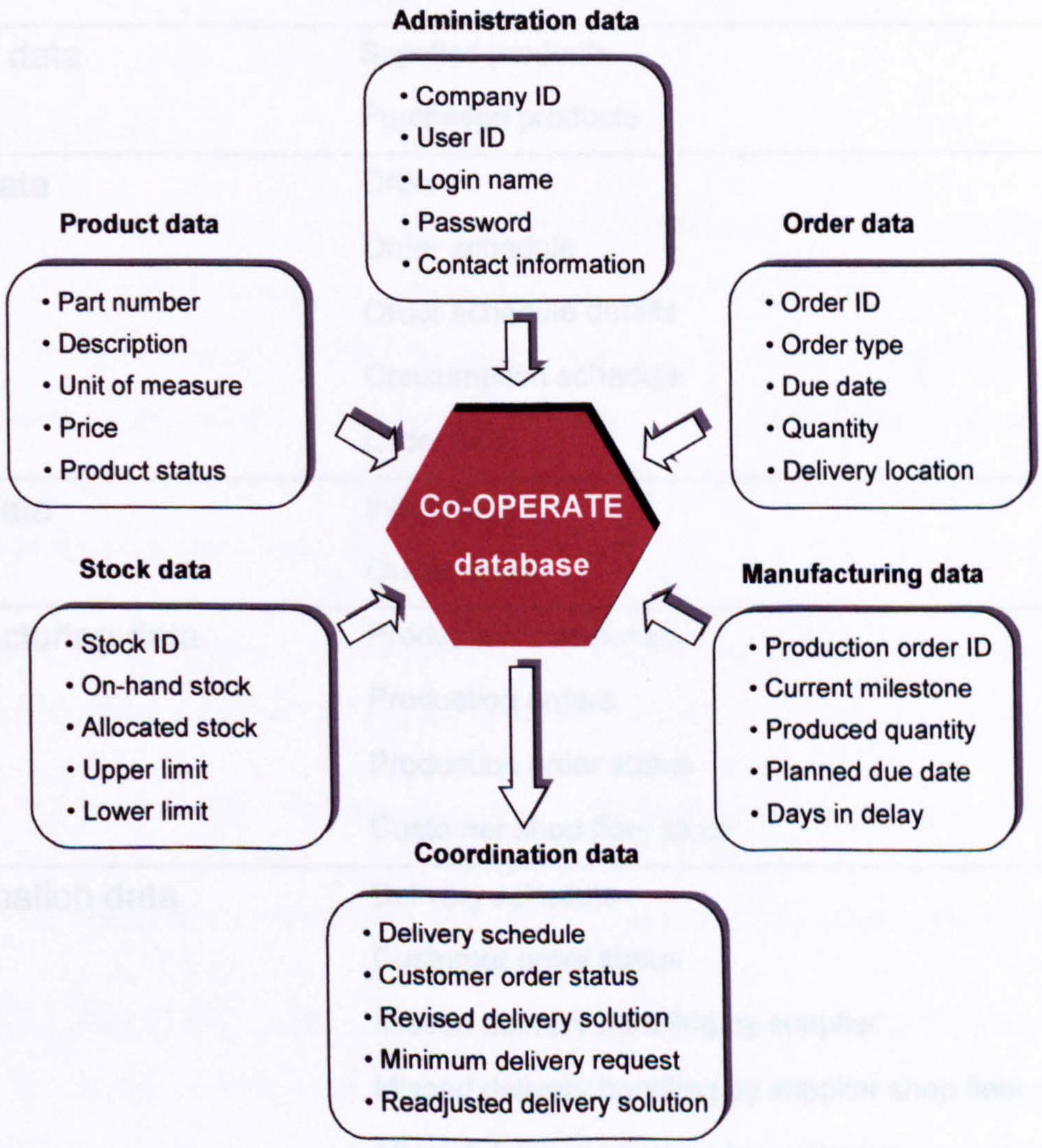


Figure 6-3: Data sources and derived data of the pilot system database

6.3.2 Database structure

Microsoft Access 2000 was chosen for the initial design of the pilot system database mainly because it is a powerful, flexible and easy-to-use relational database management system. Based on general guidelines for relational database design (Whitehorn and Marklyn, 2001), 32 tables were created for capturing data from the five different sources and for storing the derived coordination data as shown in Figure 6-3. Among others, Table 6-1 lists 26 tables that were essential for the pilot system implementation.

Categories	Tables
Administration data	Company
	User
Product data	Supplied products
	Purchased products
Order data	Order
	Order schedule
	Order schedule details
	Consumption schedule
	Order item
Stock data	Input stock
	Output stock
Manufacturing data	Production milestones
	Production orders
	Production order status
	Customer shop floor stock
Coordination data	Delivery schedule
	Customer order status
	Missed delivery handling by supplier
	Missed delivery handling by supplier shop floor
	Missed delivery handling by customer
	New rush order handling by customer
	New rush order handling by supplier
	New rush order handling by supplier shop floor

Earlier delivery handling by customer
Earlier delivery handling by supplier
Earlier delivery handling by supplier shop floor

Table 6-1: Classification of tables in the pilot system database

By analysing the relationships between the tables listed in Table 6-1, we proposed the structure of the pilot system database as illustrated in Appendix C. In each table, primary keys are highlighted. The relationships between any two tables are indicated by lines connecting them. For example, the primary key "Order ID" in the "Order" table has a one-to-many relationship with the attribute "Order ID" in tables "Order schedule", "Consumption schedule", "Single order", and "Delivery schedule". Each table shown in Figure C-1 is described in detail in Appendix D.

6.3.3 Data query

The database described previously captures all the essential data for manufacturing coordination in the supply chain execution process. To provide users with useful information via Web pages to support their decision making, it is critical to extract relevant data from different tables, which is considered as a query to the database. Data query is implemented in SQL commands, which are extensively used in the pilot system to provide the contents for user interfaces.

For example, to write a readjusted delivery schedule back into the database, the record can be identified by using the following SQL statement.

StrSQL = "SELECT * FROM MD_SuppEXH WHERE DelScheduleID = " &
Request.Form ("TDSID") & " ORDER BY SuppExhDate DESC; "

Where "MD_SuppEXH" is the table for recording all the coordination data input by the supplier expeditor during the missed delivery handling process. "Request.Form ("TDSID")" stands for the delivery schedule ID shown on the current user interface, and "SuppExhDate" is an attribute representing the date on which the exception is handled by the supplier expeditor.

6.4 PILOT SYSTEM FUNCTIONALITY

Based on the high-level and detailed business process design described in Chapter 4 and 5, this section gives an overview of functional structure, functional specifications and user interfaces of the pilot system.

6.4.1 Functional Structure

Figure 6-4 illustrates the functional structure of the pilot system. It simplifies the missed delivery handling and the rush order handling processes as depicted in Figure 5-6 and Figure 5-7 respectively, and extends the customer – supplier case to a suppliers – manufacturer – customers scenario. This is because an exception may be propagated to a relevant third-tier company downstream if it can not be contained by the immediate two companies in the supply chain.

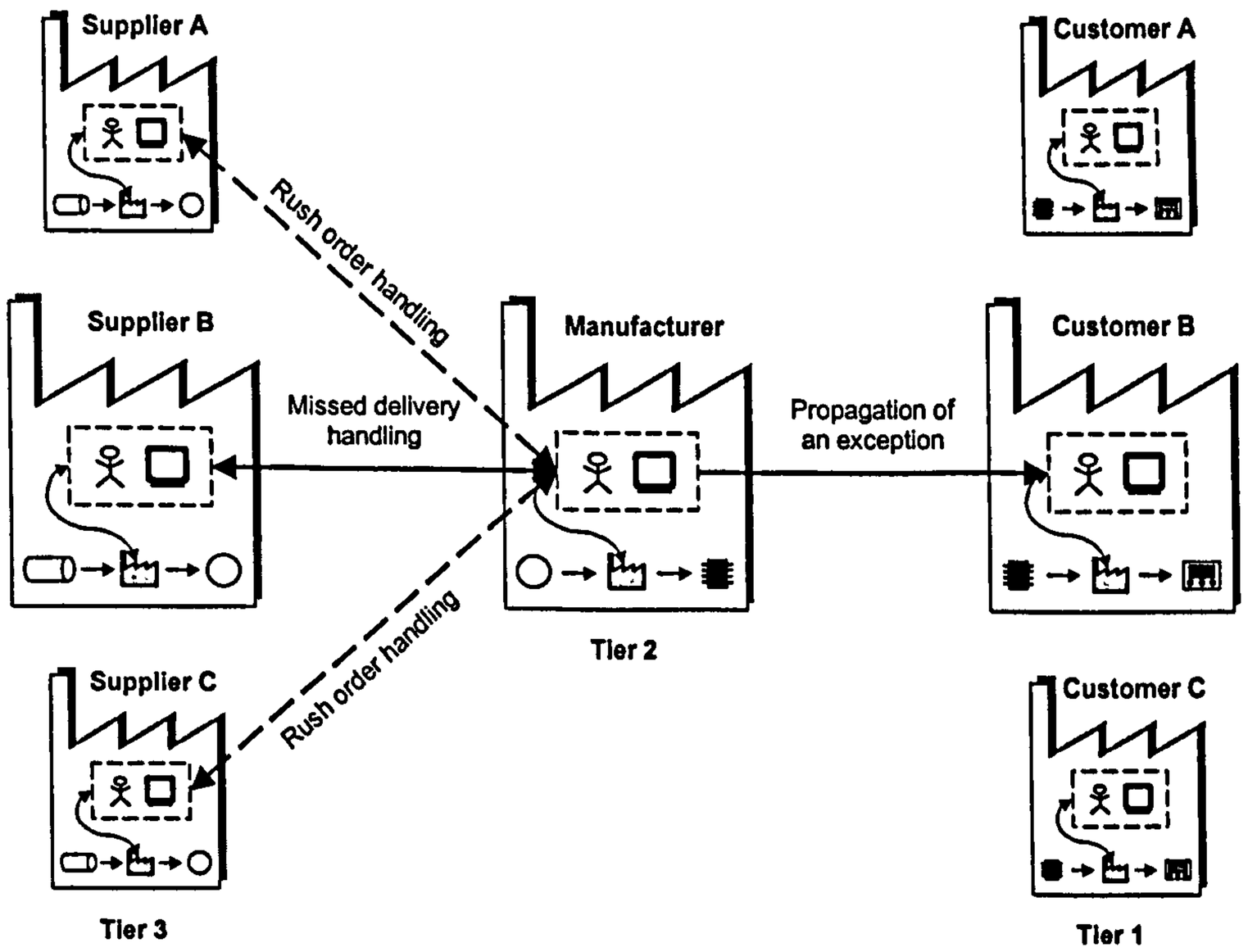


Figure 6-4: Functional structure of the pilot system

The functional structure can be best understood by referring to the generic business process of the pilot system as described in Figure 6-5. Generally, the rush order han-

dling process can be executed independently of the missed delivery handling process. However, these two processes can be coupled if the part encountering a missed delivery is multi-sourced.

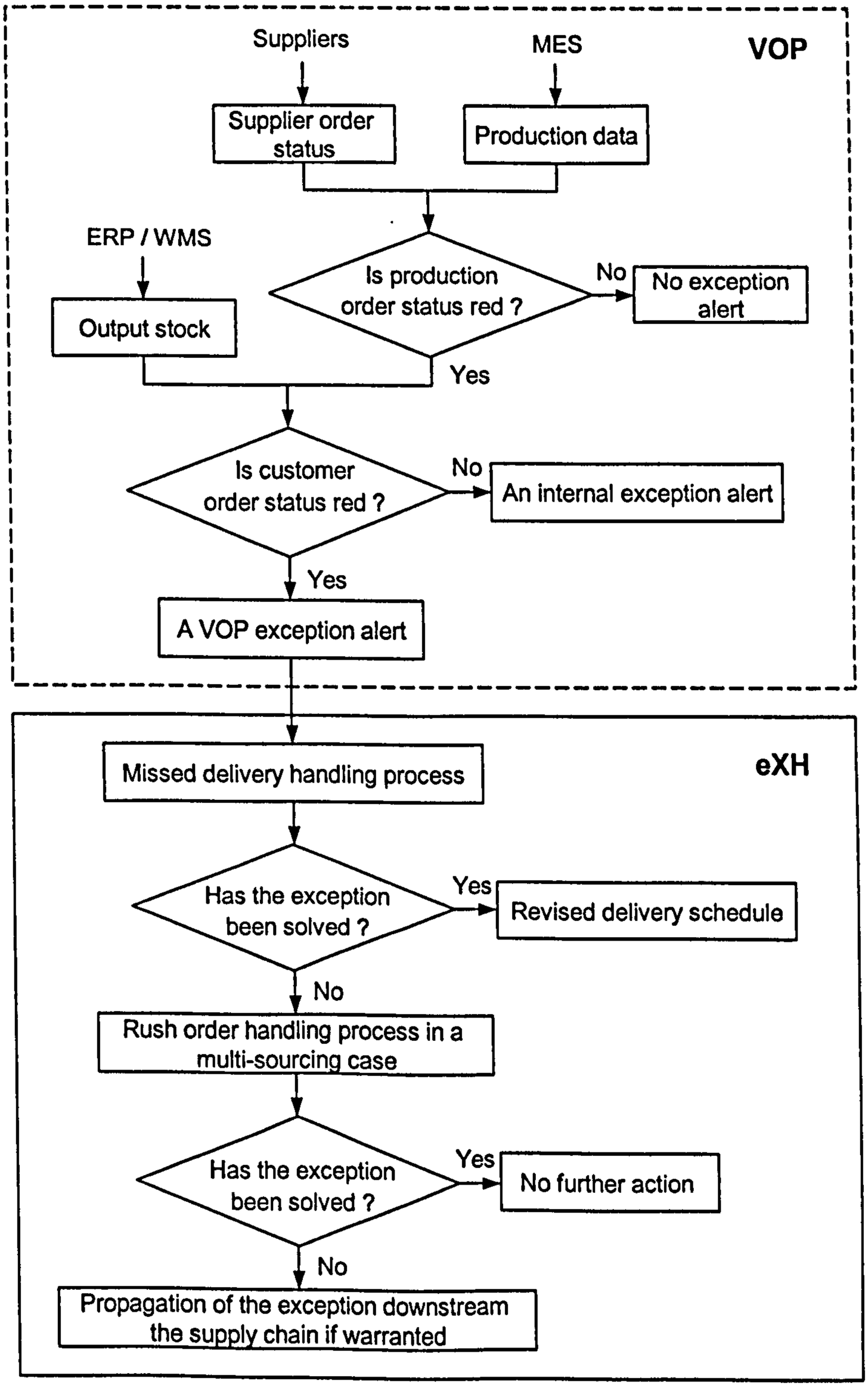


Figure 6-5: Generic business process of the pilot system

The process starts with the internal check of the production order status of a product through comparison of the production data captured from MES with the predefined milestones. If the production is severely delayed and the time left for production is less than the minimum time for the remaining processing, the progress status for the product is set to "RED". In this case, it is necessary to review the status of the related customer order by checking whether output stock is sufficient to accommodate the delayed production. If not, the customer order status is set to "RED" and a VOP exception alert is then generated, which triggers the missed delivery handling process.

The customer order with "RED" status is first reviewed by the supplier expeditor before an external exception alert is sent to the customer. If the problem is solved during the missed delivery handling process, the planned delivery schedule is revised. Otherwise, it initiates the rush order handling process with alternative suppliers in a multi-sourcing case. An exception alert may be propagated further downstream in the supply chain if the exception can not be contained by the above process.

6.4.2 Functional specifications

The implementation of pilot system functionality is based on a workflow model which consists of multiple process steps on both the supply and the demand sides. Table 6-2 and Table 6-3 give a brief overview on functional specifications of the pilot system.

Module	Functional specifications
Visibility of order progress	This module provides the updated information on the progress of customer orders: • Extract order progress information from internal manufacturing execution system; • Determine production order status by comparing production data with predefined milestones; • If production order status is "RED", support the determination of customer order status with the up-to-date information on output stock;

Module	Functional specifications
	• Generate a VOP exception alert if the status of a customer order is "RED"; • Publish the updated information on order status to customers.
Missed delivery handling	This module supports the supplier expeditor to handle all the tasks in case of a missed delivery: • Receive a VOP exception alert and propose a revised delivery solution to the customer; • Receive the customer's reminder on an overdue delivery generated automatically by the system and propose a revised delivery solution to the customer; • Receive the customer's minimum delivery request and request the shop floor for an urgent delivery if buffer stock is not sufficient to meet the request; • Support the expeditor to respond to the minimum delivery request with a readjusted delivery solution; • Receive the customer's comment on the readjusted delivery solution; • Support the expeditor to make a note to the shop floor.
Rush order handling	This module supports the supplier expeditor to handle all the tasks in case of a rush order: • Receive a customer's request on earlier delivery of an existing order; • Receive a customer's request for a new rush order; • Support the expeditor to request the shop floor for an urgent delivery in case of insufficient buffer stock; • Support the expeditor to feedback the customer with a revised (for an existing order) or proposed (for a new order) delivery solution; • Receive the customer's confirmation on their previous

Module	Functional specifications
	request for a new rush order; • Support the expeditor to confirm the request to the shop floor.
Exception handling	This module supports the supplier's production planner to handle all the tasks in case of an exception: • Receive the expeditor's request on an urgent delivery; • Support the production planner to feedback the expeditor with the expected delivery date and quantity; • Receive the expeditor's confirmation on his or her previous request for a rush order or note on the customer's requirements.

Table 6-2: Supply-side functional specifications

Module	Functional specifications
Visibility of order progress	This module manages order progress information from suppliers: • Receive the updated information on order progress from suppliers; • Generating VOP exception alerts to existing or expected delivery problems.
Missed delivery handling	This module supports the customer expeditor to handle all the tasks in case of a missed delivery: • Receive an exception alert from the supplier and support the expeditor to determine the minimum delivery request if buffer stock plus time buffer is insufficient to accommodate the revised delivery solution; • Receive the supplier's response on an overdue delivery and support the expeditor to determine the minimum

Module	Functional specifications
	delivery request if warranted; • Support the expeditor to comment the readjusted delivery solution posed by the supplier expeditor.
Rush order handling	This module supports the customer expeditor to handle all the tasks in case of a rush order: • Support the expeditor to request earlier delivery of an existing order; • Support the expeditor to request a new rush order; • Receive the supplier's feedback on the request for earlier delivery of an existing order; • Receive the supplier' quotation on a new rush order request; • Support the expeditor to confirm the request for a new rush order.

Table 6-3: Demand-side functional specifications

6.4.3 User interfaces

At each step of a business process, user interfaces provide the platform for users to execute and interact with the system. Generally, user interfaces in the pilot system can be grouped in two categories: user reference screens and user/system interaction screens.

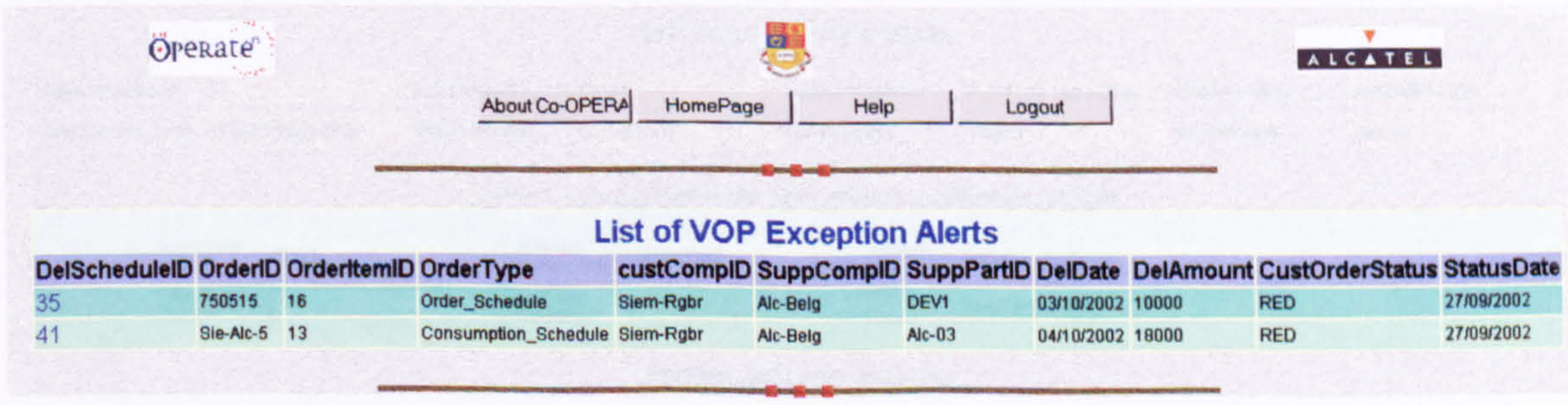
6.4.3.1. User reference screens

User reference screens include menus, reports and tables, which provide guidance or decision support information for users, but do not need any input from them. A report can be a piece of administrative information, user support information hyperlinked to a user/system interaction screen, or a notification from a business partner. A table is often used to list all the tasks for a process step, which are hyperlinked to the corresponding user/system interaction screens to perform these tasks. Therefore, tables are heavily

used in the eXH process. Figure 6-6 illustrates the menu screen for the missed delivery handling process, and Figure 6-7 illustrates a table listing Alcatel's VOP exception alerts to Siemens VDO.



Figure 6-6: Menu screen for missed delivery handling



DelScheduleID	OrderID	OrderItemID	OrderType	custCompID	SuppCompID	SuppPartID	DelDate	DelAmount	CustOrderStatus	StatusDate
35	750515	16	Order_Schedule	Siem-Rgbr	Alc-Belg	DEV1	03/10/2002	10000	RED	27/09/2002
41	Sie-Alc-5	13	Consumption_Schedule	Siem-Rgbr	Alc-Belg	Alc-03	04/10/2002	18000	RED	27/09/2002

Figure 6-7: Table listing VOP exception alerts

6.4.3.2. User/system interaction screens

User/system interaction screens provide decision support information and also require users to enter some data to complete specific tasks. This type of screens is core to the exception handling process. An example is given below to illustrate how it works in the pilot system.

- ***Screen name: Supplier expeditor reviews a VOP exception alert***

When the manufacturing process on the shop floor is severely delayed and the status of the affected customer order is set to "RED" because of insufficient buffer stock, a VOP exception alert is generated for internal attention, which must be reviewed by the supplier expeditor before an external exception alert is sent to the customer. Figure 6-8 illustrates the screen whereby a VOP exception alert is reviewed by an expeditor in Alcatel.

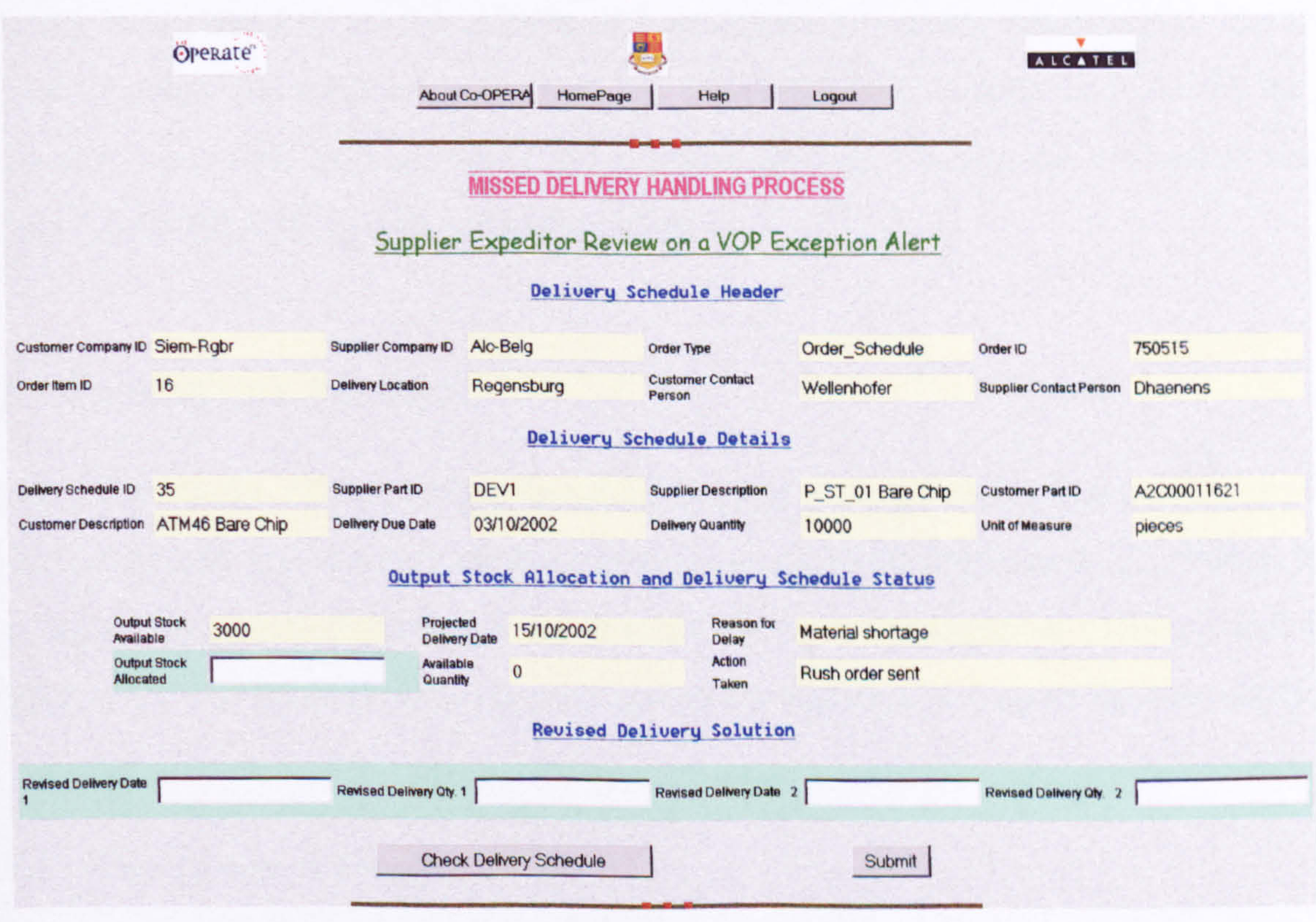


Figure 6-8: Supplier expeditor review on a VOP exception alert

After checking some key information related to the delayed production order, the available amount of output stock and the updated delivery schedule, the expeditor decides how much stock to be assigned to the customer order and proposes a revised delivery solution, which can be one delivery at a later date or two split deliveries.

6.5 CONCLUSIONS

The implementation of the pilot system for ESCEM has been described in this chapter, which comprises the selection of the implementation environment, the design of the pilot system database and the detailing of the pilot system functionality.

As an important step in system development, the implemented pilot system for ESCEM was tested and evaluated through studies of real business cases. The evaluation work is presented in the next chapter.

Chapter 7

CASE STUDY AND SYSTEM EVALUATION

By running the ESCEM pilot system with typical real business cases, this chapter presents a case study – handling a missed delivery, which embodies the core business process in the pilot system. The purpose of the case study is to illustrate how the proposed process can improve customer service (delivery performance in this context) in comparison with the current process.

The first section of this chapter gives a brief overview of the case study, which includes the introduction of a subset of a real supply chain involved and the focus and set-up of the case study. The second section describes the details of the business case and how it is going to be handled by the current and proposed processes respectively. The third section presents the evaluation method for Co-OPERATE, which is followed by the evaluation results for the case study in the fourth section. Finally, the evaluation results for the Co-OPERATE system are summarised.

7.1 CASE STUDY PROFILE

To do a case study, two important decisions have to be made in the first place: the scope of the case study and the way the case study is going to be performed. To address these two issues, this section gives a brief description on the companies involved and their relationships, the focused business process and the technical set-up of the case study.

7.1.1 The supply chain case

Figure 7-1 illustrates the supply chain case for the case study in this chapter, which is actually part of a real supply chain in the larger context of a complex supply network. The supply chain case comprises three companies: Siemens VDO, Alcatel Microelectronics and MEMC Electronic Materials.

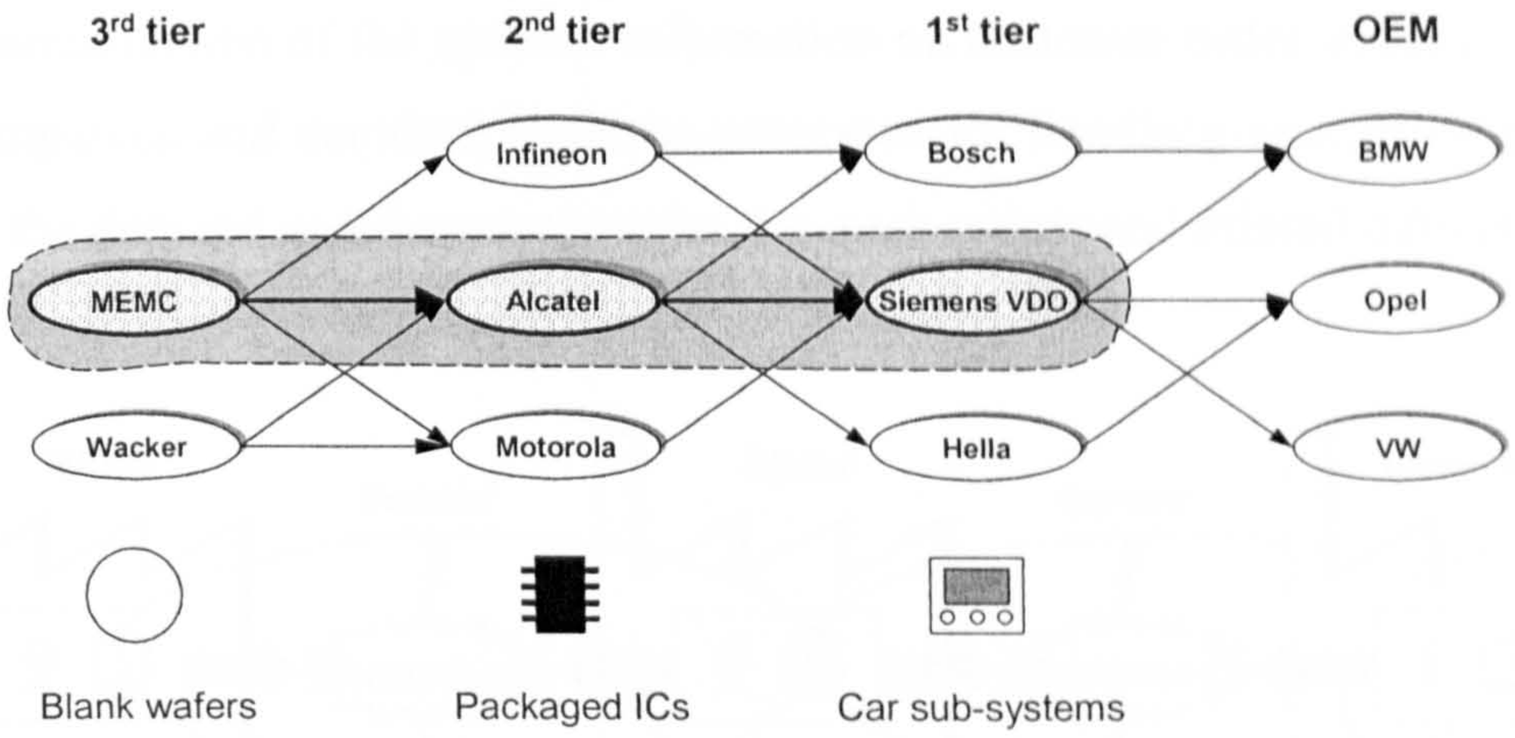


Figure 7-1: The supply chain case

MEMC produces blank silicon wafers according to exacting specifications of their customers, among which Alcatel is one such customer. Alcatel transforms blank silicon wafers into silicon "chips" through a series of photolithographic steps, which are then shipped to a subcontractor who separates the individual chips found on a silicon wafer and mounts them into special packages. The packaged integrated circuits (ICs) are returned to AME, where they are tested according to specifications provided by individual customers before delivered to them. Based on the customised devices provided by their suppliers such as AME, Siemens VDO supplies specific car sub-systems to OEMs, e.g. BMW, Opel, VW.

It must be noted that all the three companies in the supply chain case produce highly customised products for their own customers. For example, each type of silicon chips produced by AME has a unique customer and may not be delivered to any other customers. Siemens VDO produces car sub-systems conditioned to the specific needs of individual OEMs.

7.1.2 Case study focus

As can be seen from Figure 7-2, the purpose of the pilot system is to demonstrate how the system can improve delivery performance and responsiveness of the supply chain through Web-enabled visibility of order progress and enhanced exception handling capability as a contingency solver. Specifically, the pilot system mainly concentrates on

timely communication of the updated information on customer order status to the down-stream companies and standard business processes for handling exceptions popped up from both the demand and the supply sides, i.e. rush orders and missed deliveries.

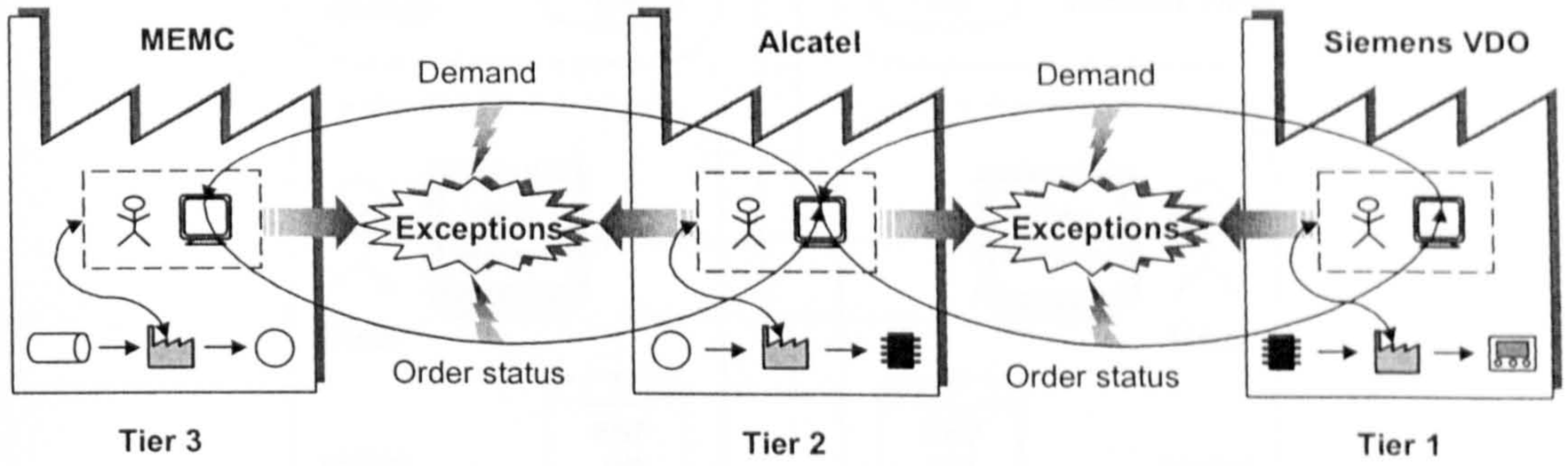


Figure 7-2: Case study profile of the pilot system

For the case study in the following section, it is focused on how the supplier and the customer can collaboratively handle a missed delivery when an exceptional alert from the supplier signals that a scheduled delivery will not arrive on the planned delivery date and will be delayed for a number of days because certain exceptional event has occurred (e.g. machine breakdown).

7.1.3 Case study set-up

To do the case study in question, logistics experts from the three companies involved in the system evaluation used standard PC as Web browsers that were connected to the pilot system on a server at Imperial College. The case study set-up is illustrated in Figure 7-3.

The base data from local planning systems (for some companies also from MES) were entered manually. In the future the input data can be extracted from these systems and transferred to the pilot system via XML files, which will be discussed in the concluding chapter.

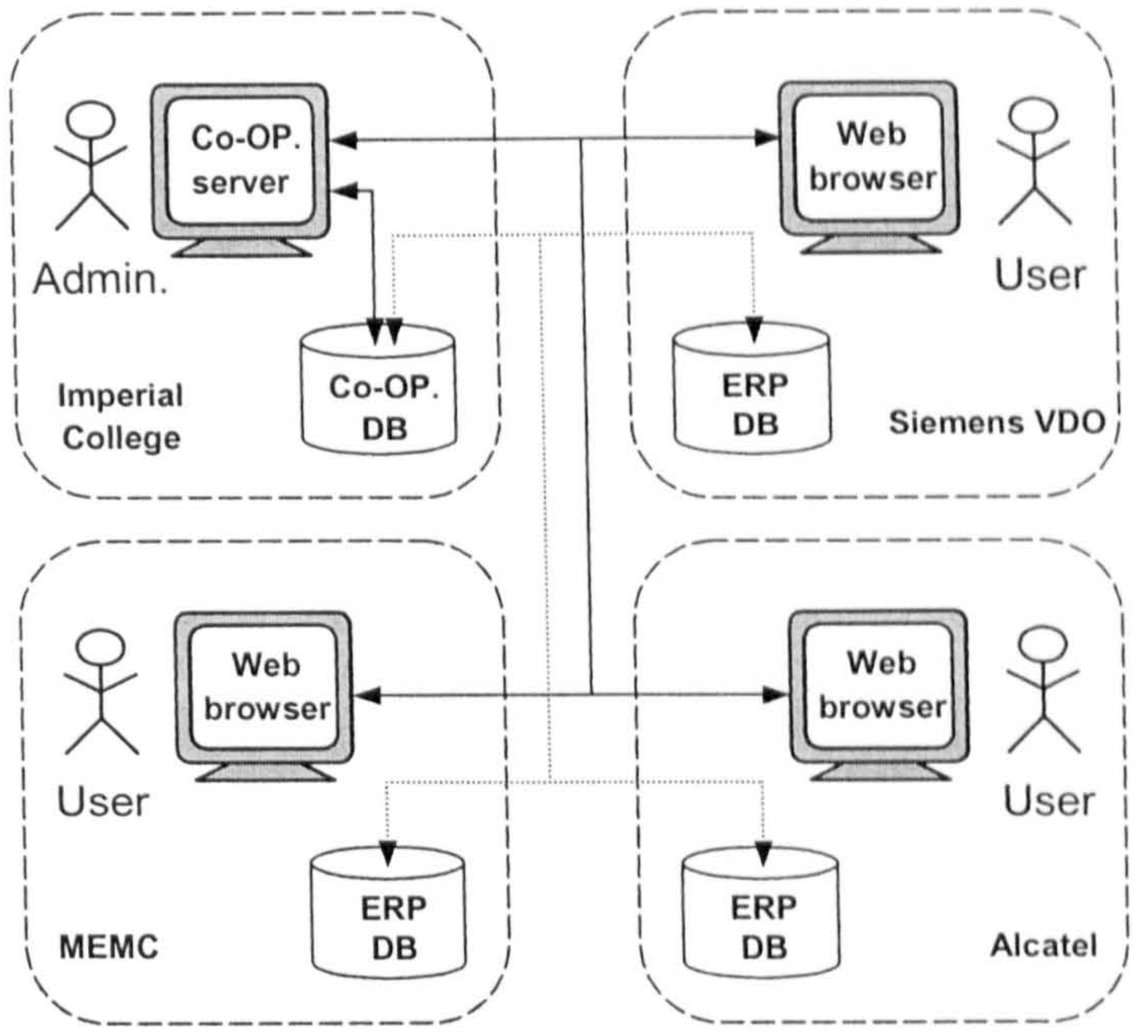


Figure 7-3: Case study set-up

7.2 CASE STUDY: HANDLING A MISSED DELIVERY

After the focused business process for the case study is defined, the next step is for the industrial partners to prepare a typical real business case to make the emulation of the business case as realistic as possible. Based on the historic but real business case provided by the industrial partners, this section describes in detail how the business scenario of a missed delivery is going to be handled in the current and the proposed processes respectively. The evaluation results of the case study are summarised in the form of a comparison table between the current and the proposed processes, and will be given in the fourth section of this chapter.

7.2.1 Case description

Siemens VDO is a 1st-tier supplier to major car manufacturers, supplying complex assemblies, e.g. electronic engine management systems, navigation systems. With their end customers (i.e. OEMs) pursuing just-in-time practices, the company must satisfy their customers' needs for more frequent, on-time delivery of products. To achieve this end, it is paramount that they synchronise their production processes with those of their suppliers.

Alcatel is one of Siemens VDO's suppliers providing packaged integrated circuits. Generally, Alcatel's manufacturing process consists of seven serial manufacturing processes: wafer fabrication (fab), wafer probe, die conversion, assembly, test, pack and transport as illustrated in Figure 7-4. Like other semiconductor manufacturers, Alcatel's manufacturing processes feature high complexity (hundreds of manufacturing steps with re-entrant process flows), long cycle times (6-12 weeks) and unexpected yield loss, leading to high uncertainty in order fulfilment. As a common industrial practice, the high delivery uncertainty has to be buffered by a relatively high level of buffer stock, which is in conflict with the mentality of "lean production" predominant in the automotive industry.

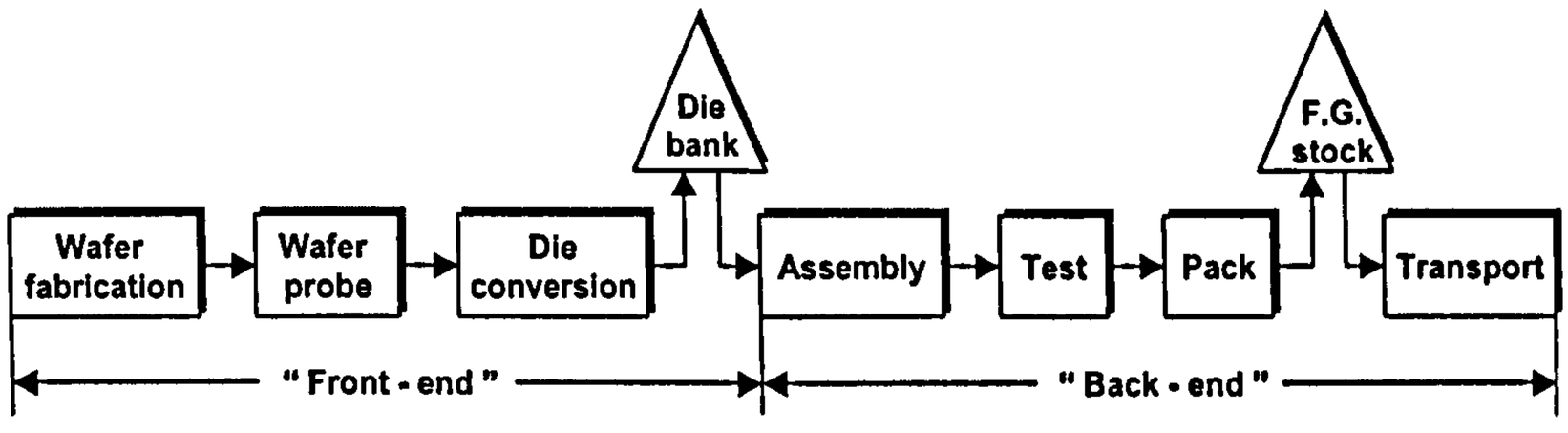


Figure 7-4: Generic manufacturing process in Alcatel Microelectronics

In a real industrial environment, large companies like Siemens VDO try to push inventories upstream in the supply chain to their suppliers to keep themselves as "lean" as possible, which lands the suppliers such as Alcatel in a very difficult situation. Short product life cycle (usually 6-12 months), rapid price decline and relatively high value renders inventories extremely expensive. On the other hand, capacity constraints and mass customisation make it practically infeasible to maintain high levels of inventories. Consequently, in practice, only a limited level of buffer stock is held for some critical products against uncertainties.

Actually, buffer stock does not necessarily prevent the customer from material shortages because customers' demand may increase significantly in a short time (e.g. a few weeks). On the supply side, the supplier's delivery capability may be severely impaired by an unexpected event in the supply chain execution process, e.g. the delayed delivery of a subcontracted part. The following case is typical of logistics management in Siemens VDO.

On a typical work day, say, 12/09/2002, an expeditor in Siemens VDO received a message via EDI from Alcatel indicating that a scheduled delivery, with order ID: 750515, part ID: DEV1, delivery due date: 12/09/2002, and delivery quantity: 12000, would not arrive on the planned date because a critical machine for the final test of packaged ICs broke down on an earlier date, and the expected delivery date would be 17/09/2002.

7.2.2 Current practice and process

Currently, neither Siemens VDO nor Alcatel can give a regular update on the status of order progress to their own customers or an early warning to them in case of delivery problems. In most cases, Siemens VDO realise a delay in supply delivery by the goods not having arrived as planned. For major suppliers such as Alcatel, a message on a missed delivery is transmitted by EDI, while for SMEs, who can not afford EDI, the message is usually communicated via an email or fax, or directly by a phone call.

Generally, after receiving a message on a missed delivery, the supplier expeditor needs to manually check their enterprise systems for the up-to-date information on input stock and production schedule to assess the possible consequence of the delay. In a tight situation, the expeditor may go to the shop floor and discuss with the production planner on the impact of the missed delivery. If not critical, a message that informs the supplier the latest date when the customer need the delivery is usually sent to the supplier via an email or fax. However, in case of urgencies, the expeditor usually needs to call their counterpart to discuss the situation and find a solution acceptable to both sides.

In the missed delivery case as described in Section 7.2.1, upon receiving the message from Alcatel that the planned delivery on 12/09/2002 was postponed to 17/09/2002, an expeditor in Siemens VDO manually checked their ERP system for available quantity of input stock and up-to-date production schedule to see if the delay could cause material shortage. Unfortunately, as the shop floor was scheduled to launch a manufacturing lot of 6000 pieces on 12/09/2002, and currently there was no input stock of part "DEV1" either in the warehouse or on the shop floor, the unexpected delay in delivery did cause a severe shortage of material, which shut down the whole production line.

Clearly, the main cause for the costly consequence at Siemens VDO was that Alcatel did not give an early warning on their highly potential delay in delivery and on the other hand Siemens VDO did not expect the missed delivery. When it came to the planned delivery date, it was already too late to do anything to avoid the shutdown of the production line. In reality, expeditors in both Siemens VDO and Alcatel spend most of their time reacting to exceptional events, such as the missed delivery case described above, in their routine work. It involves lots of fire fighting work, which imposes much pressure on the expeditors.

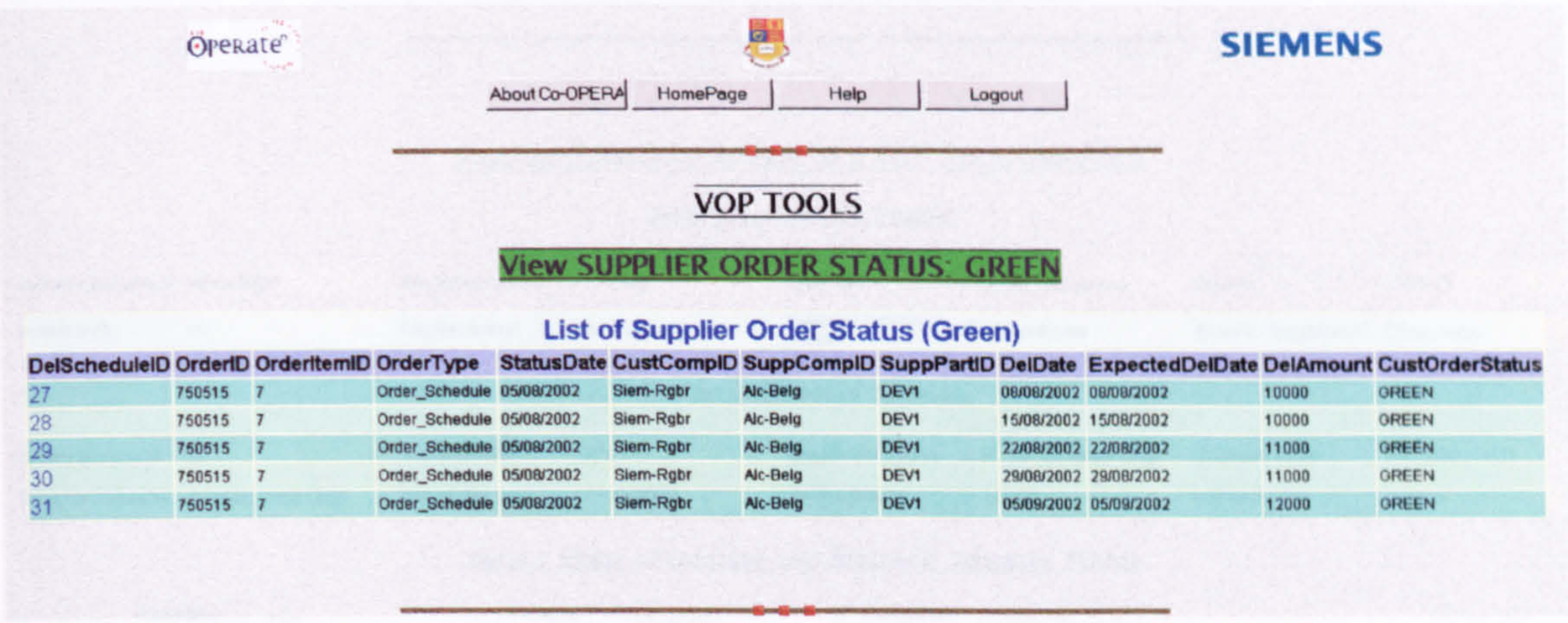
To address the problem proactively, Siemens VDO need improved visibility (hopefully in near real time) of their order status and reasonably early warnings on delivery problems (e.g. one week before the planned delivery date). Meanwhile, instead of using informal communication tools such as phone, fax and email, which create lots of paper work and are error-prone, it is desirable to develop a Web-based SCM system with standard exception handling processes and user interfaces, which is what the proposed process is intended to provide.

7.2.3 The proposed process

In an ESCEM environment, the progress of a product being manufactured is continuously monitored by Alcatel's WIP tracking system. Customer orders are typically matched against WIP in the manufacturing process. According to the quantities of manufacturing lots on current milestones and standard lead-times for the milestones, the status of a customer order is calculated and updated whenever it changes. If a manufacturing process step is subcontracted, the subcontracted process is considered as a milestone. Figure 7-5 illustrates one of Siemens VDO's orders which has "GREEN" status.

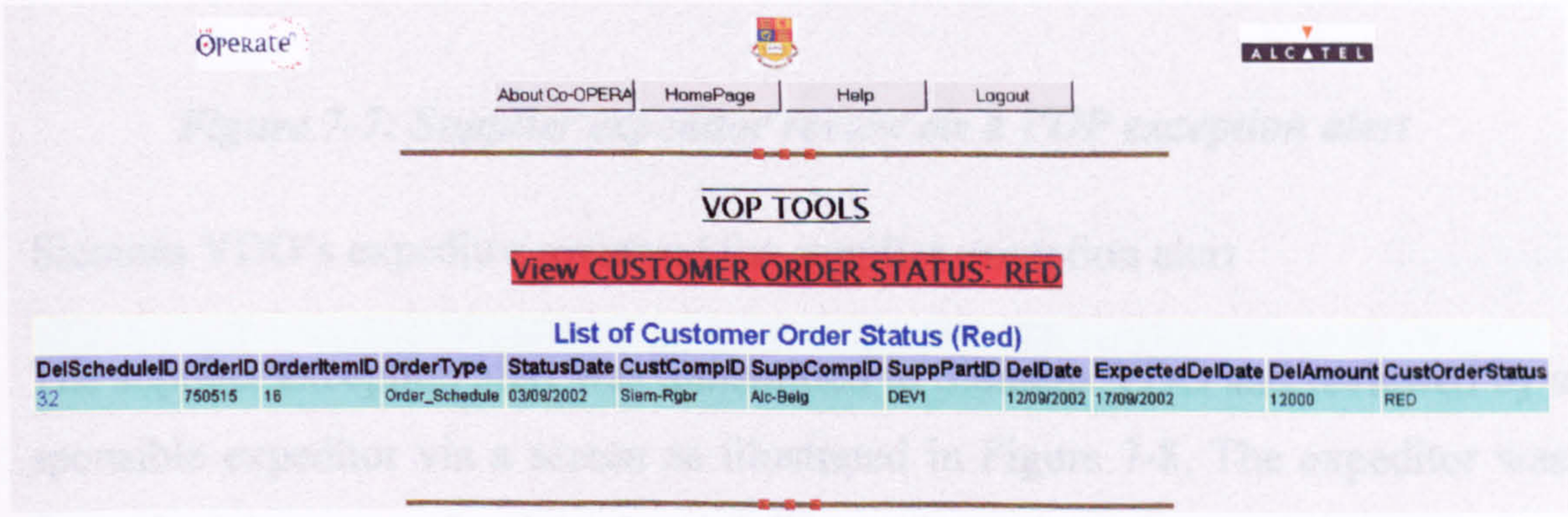
By virtue of the WIP tracking system, the delivery problem described in Section 7.2.1 could be detected and reported earlier via VOP, and resolved through the eXH process. Suppose that, on 03/09/2002, the device "DEV1" got stuck at the stage of final test because a critical machine broke down, which entailed repair of the facility. It was estimated that it would incur a severe delay in delivery. To assess the impact of the unexpected event on the next delivery to Siemens VDO, the available quantity of output stock for DEV1 was checked and found insufficient to cover the next delivery. In this

case, the customer order status for DEV1 was set "RED" as shown in Figure 7-6, and a VOP exception alert being generated, which would trigger the following missed delivery handling process.



DelScheduleID	OrderID	OrderItemID	OrderType	StatusDate	CustCompID	SuppCompID	SuppPartID	DelDate	ExpectedDelDate	DelAmount	CustOrderStatus
27	750515	7	Order_Schedule	05/08/2002	Siem-Rgbr	Alc-Belg	DEV1	08/08/2002	08/08/2002	10000	GREEN
28	750515	7	Order_Schedule	05/08/2002	Siem-Rgbr	Alc-Belg	DEV1	15/08/2002	15/08/2002	10000	GREEN
29	750515	7	Order_Schedule	05/08/2002	Siem-Rgbr	Alc-Belg	DEV1	22/08/2002	22/08/2002	11000	GREEN
30	750515	7	Order_Schedule	05/08/2002	Siem-Rgbr	Alc-Belg	DEV1	29/08/2002	29/08/2002	11000	GREEN
31	750515	7	Order_Schedule	05/08/2002	Siem-Rgbr	Alc-Belg	DEV1	05/09/2002	05/09/2002	12000	GREEN

Figure 7-5: An order from Siemens VDO with "GREEN" status



DelScheduleID	OrderID	OrderItemID	OrderType	StatusDate	CustCompID	SuppCompID	SuppPartID	DelDate	ExpectedDelDate	DelAmount	CustOrderStatus
32	750515	16	Order_Schedule	03/09/2002	Siem-Rgbr	Alc-Belg	DEV1	12/09/2002	17/09/2002	12000	RED

Figure 7-6: An order from Siemens VDO with "RED" status

1. Alcatel's expeditor reviewed the VOP exception alert.

   Before an external exception alert was sent to Siemens VDO, the VOP exception alert was first checked by an expeditor in Alcatel via a screen as illustrated in Figure 7-7. The expeditor checked the available quantity of output stock for DEV1, assigned a certain amount of the inventory to the order if warranted and proposed a re-

vised delivery solution to Siemens VDO, which constituted an external exception alert to Siemens VDO.

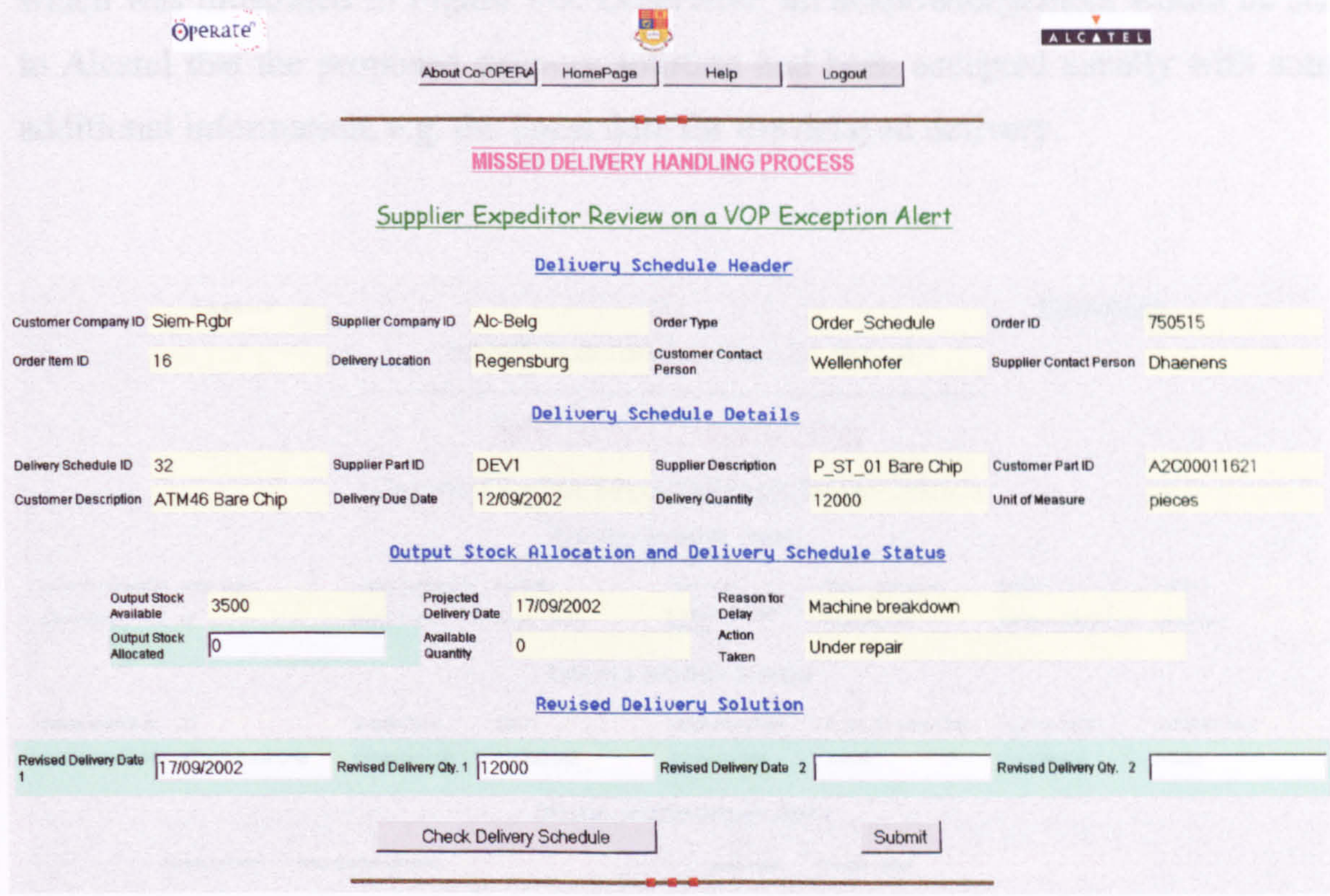


Figure 7-7: Supplier expeditor review on a VOP exception alert

2. Siemens VDO's expeditor reviewed the supplier exception alert

The supplier exception alert was transmitted to Siemens VDO and reviewed by a responsible expeditor via a screen as illustrated in Figure 7-8. The expeditor was informed of the reason for the missed delivery, the action taken and the revised delivery solution proposed by Alcatel. Meanwhile, the system showed the available quantities of input stock for DEV1 both in the warehouse and on the shop floor and the up-to-date production schedule. By matching the available input stock (stock in the warehouse + stock on the shop floor + expected deliveries according to the revised delivery solution) with the current production schedule, the system would indicate if a minimum delivery was necessary.

In this case, as the total quantity of input stock (available plus expected) was insufficient to meet the production schedule, a minimum delivery was required so that pro-

duction would not be disrupted. The system thus automatically calculated the latest delivery date and the minimum delivery quantity as the default value subject to the expeditor's modification according to his or her own experience and judgement, which was illustrated in Figure 7-9. Otherwise, an acknowledgement would be sent to Alcatel that the proposed delivery solution had been accepted usually with some additional information, e.g. the latest date for the delayed delivery.

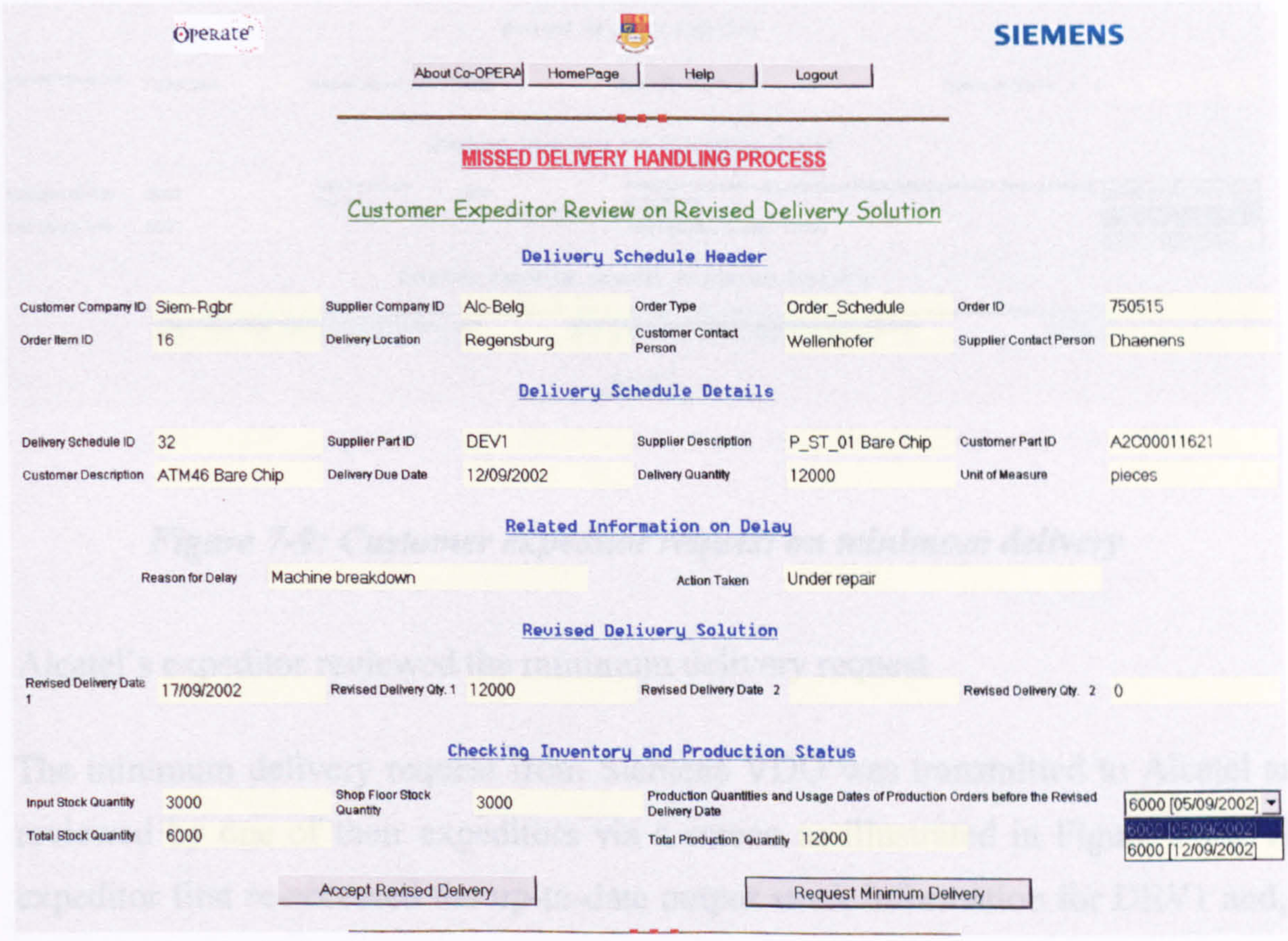


Figure 7-8: Customer expeditor review on revised delivery solution

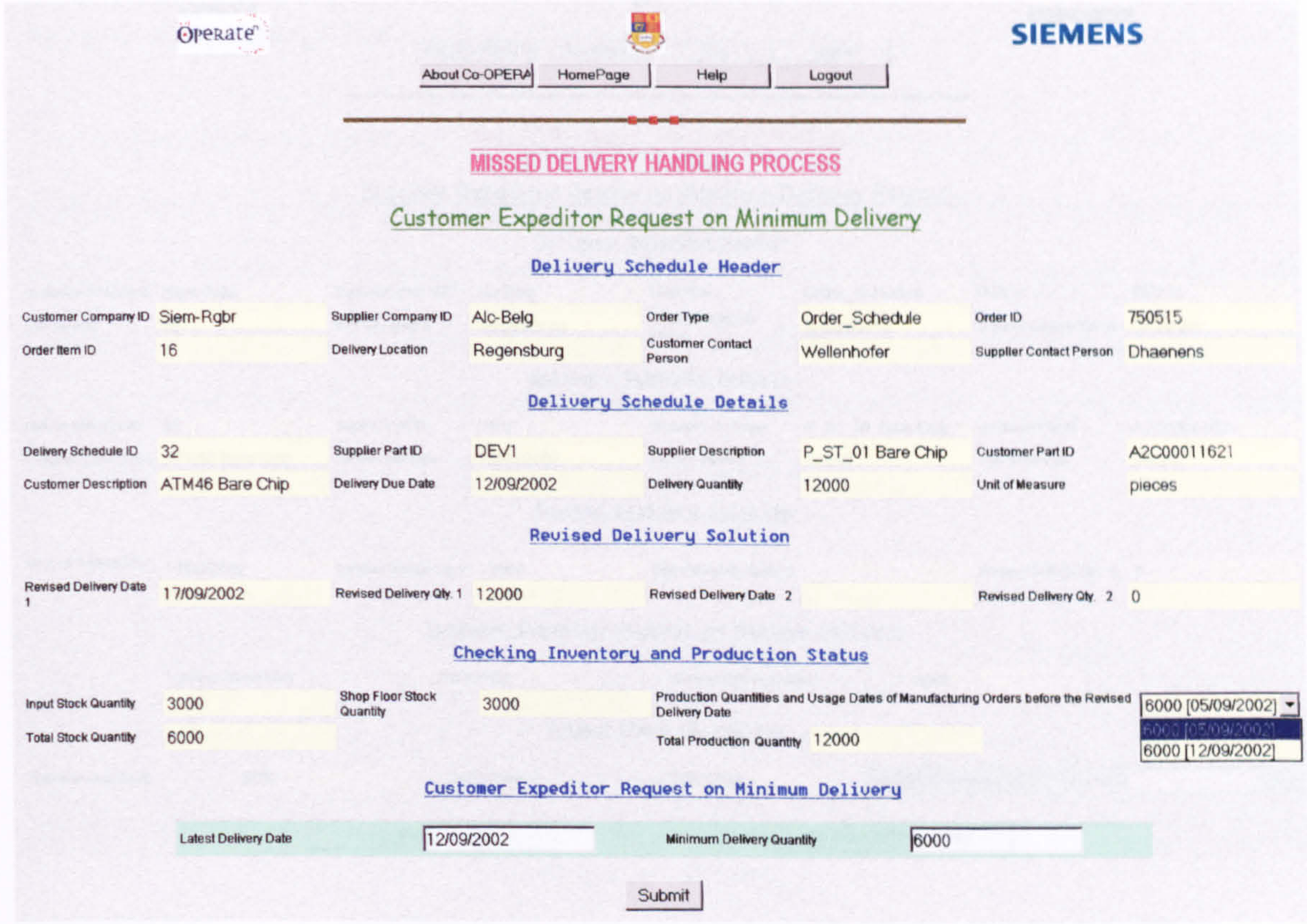


Figure 7-9: Customer expeditor request on minimum delivery

3. Alcatel's expeditor reviewed the minimum delivery request

The minimum delivery request from Siemens VDO was transmitted to Alcatel and reviewed by one of their expeditors via a screen as illustrated in Figure 7-10. The expeditor first re-accessed the up-to-date output stock information for DEV1 and, if available, assigned a certain amount of the stock to the request. If the assigned output stock met the minimum delivery request, the expeditor could respond the customer directly. In this case, as the assigned quantity was insufficient to cover the minimum delivery request, it proceeded to another screen as illustrated in Figure 7-11 to make a delivery request to the shop floor.

Based on the minimum delivery request, the assigned quantity of output stock and other related information, the system automatically calculated the required delivery date and quantity for the shop floor as default value subject to the expeditor's modification. Besides, some qualitative information was added in terms of the priority of the request (very high or high) and the reason for that.

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ALCATEL

MISSED DELIVERY HANDLING PROCESS

Supplier Expeditor Review on Minimum Delivery Request

Delivery Schedule Header

Customer Company ID	Siem-Rgbr	Supplier Company ID	Alc-Belg	Order Type	Order_Schedule	Order ID	750515
Order Item ID	16	Delivery Location	Regensburg	Customer Contact Person	Wellenhofer	Supplier Contact Person	Dhaenens

Delivery Schedule Details

Delivery Schedule ID	32	Supplier Part ID	DEV1	Supplier Description	P_ST_01 Bare Chip	Customer Part ID	A2C00011621
Customer Description	ATM46 Bare Chip	Delivery Due Date	12/09/2002	Delivery Quantity	12000	Unit of Measure	pieces

Revised Delivery Solution

Revised Delivery Date 1	17/09/2002	Revised Delivery Qty. 1	12000	Revised Delivery Date 2		Revised Delivery Qty. 2	0

Customer Expeditor Request on Minimum Delivery

Latest Delivery Date	12/09/2002	Minimum Delivery Quantity	6000

Output Stock Allocation

Output Stock Available	3500	Last Updated	03/09/2002	Output Stock Allocated	3000

Feedback to Customer | Request to Shop Floor

Figure 7-10: Supplier expeditor review on minimum delivery request

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ALCATEL

MISSED DELIVERY HANDLING PROCESS

Supplier Expeditor Request to Shop Floor

Delivery Schedule Header

Customer Company ID	Siem-Rgbr	Supplier Company ID	Alc-Belg	Order Type	Order_Schedule	Order ID	750515
Order Item ID	16	Delivery Location	Regensburg	Customer Contact Person	Wellenhofer	Supplier Contact Person	Dhaenens

Delivery Schedule Details

Delivery Schedule ID	32	Supplier Part ID	DEV1	Supplier Description	P_ST_01 Bare Chip	Customer Part ID	A2C00011621
Customer Description	ATM46 Bare Chip	Delivery Due Date	12/09/2002	Delivery Quantity	12000	Unit of Measure	pieces

Revised Delivery Solution

Revised Delivery Date 1	17/09/2002	Revised Delivery Qty. 1	12000	Revised Delivery Date 2		Revised Delivery Qty. 2	0

Customer Expeditor Request on Minimum Delivery

Latest Delivery Date	12/09/2002	Minimum Delivery Quantity	6000	Output Stock Allocated	3000	Transportation (days)	1

Shop Floor Request

Shop Floor Due Date	11/09/2002	Shop Floor Quantity	3000	Shop Floor Priority	Very High	Priority Reason	Prime customer

Submit

Figure 7-11: Supplier expeditor request to shop floor

4. Alcatel's shop floor fed back to their expeditor

The expeditor's request was transmitted to the corresponding shop floor in Alcatel and reviewed by their production planner via a screen as illustrated in Figure 7-12. While the requested delivery date and quantity was set by the system as the default value for shop floor feedback, the production planner could modify the value based on his or her own knowledge and judgement on current production status, such as backlogs, WIP, bottlenecks and capacity utilisation.

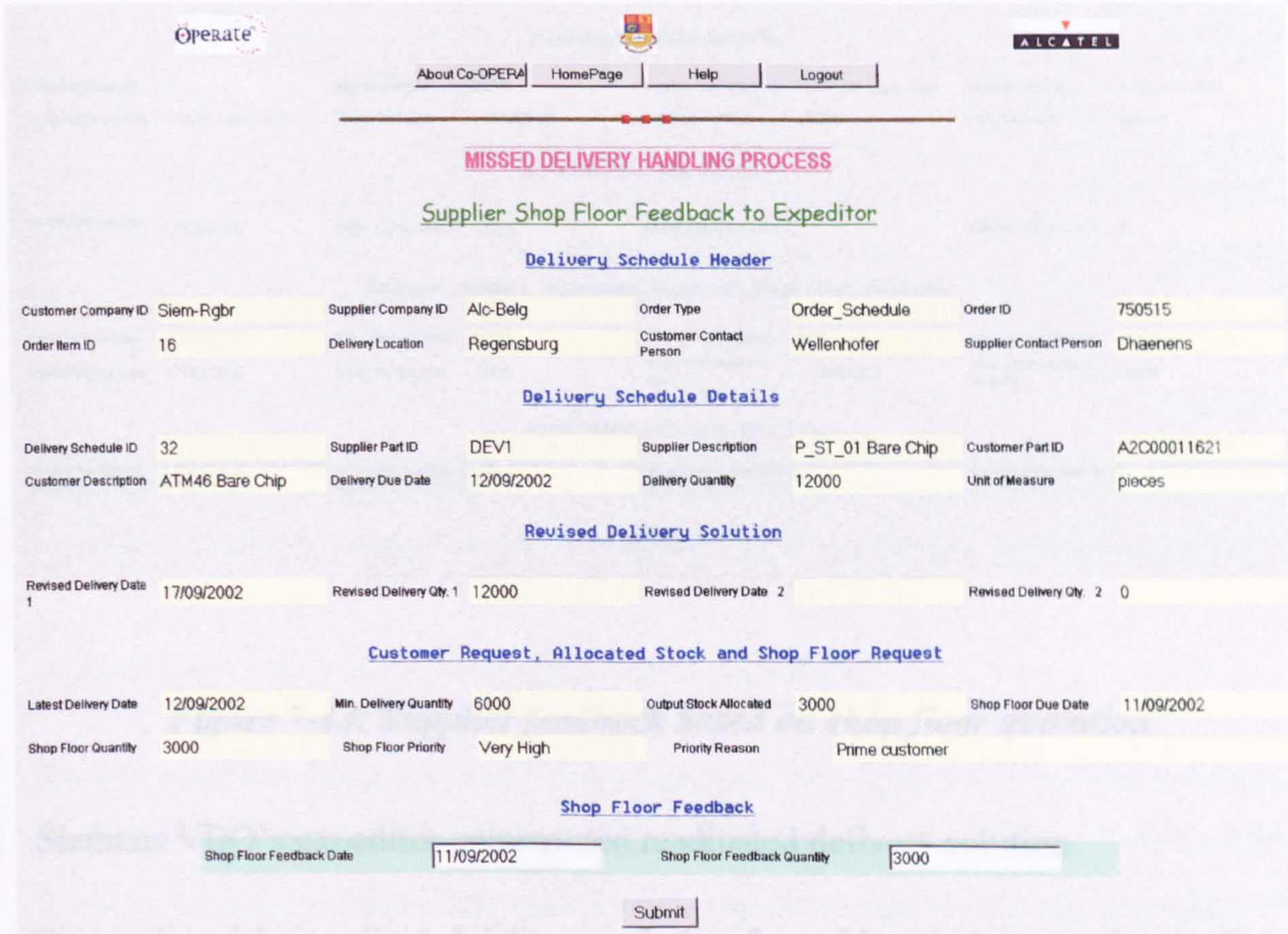


Figure 7-12: Supplier shop floor feedback to expeditor

5. Alcatel's expeditor fed back to Siemens VDO

Upon receiving the response from the shop floor, the expeditor in Alcatel fed back to Siemens VDO via a screen as illustrated in Figure 7-13. By checking the updated output stock information for DEV1 and the response from the shop floor, the expedi-

tor modified the revised delivery solution and proposed a readjusted delivery solution, aiming to satisfy the minimum delivery request to the maximum.

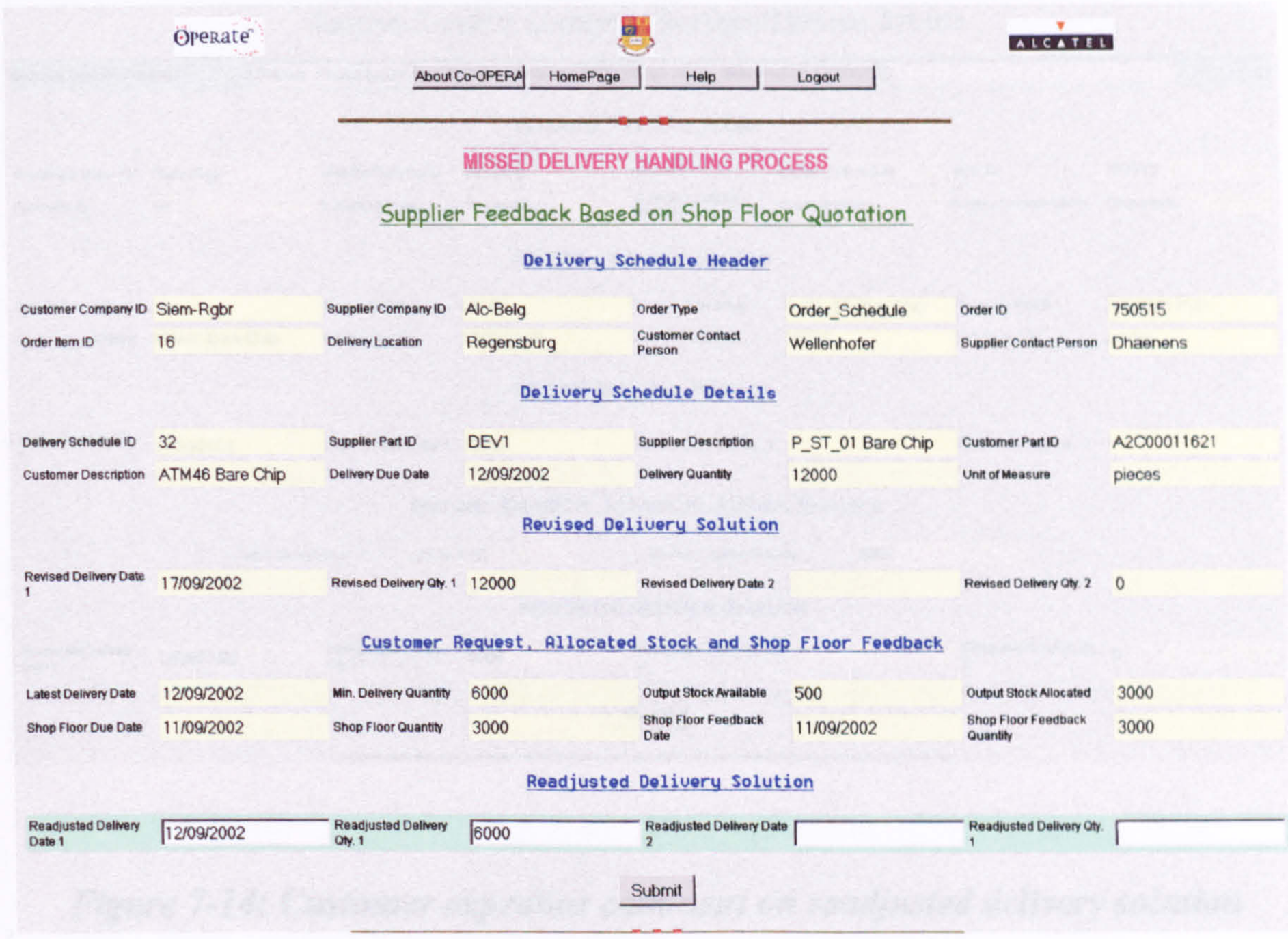


Figure 7-13: Supplier feedback based on shop floor quotation

6. Siemens VDO's expeditor commented readjusted delivery solution

On receipt of the readjusted delivery solution from Alcatel, the expeditor in Siemens VDO could view it via a screen as illustrated in Figure 7-14. In the first place, the expeditor might want to know if the minimum delivery request had been fully met. In this case, the minimum delivery request was satisfied, a message was sent back to Alcatel as a reminder on the remaining part of the missed delivery. Otherwise, some comment on the readjusted delivery solution would be made by the expeditor and sent back to Alcatel.

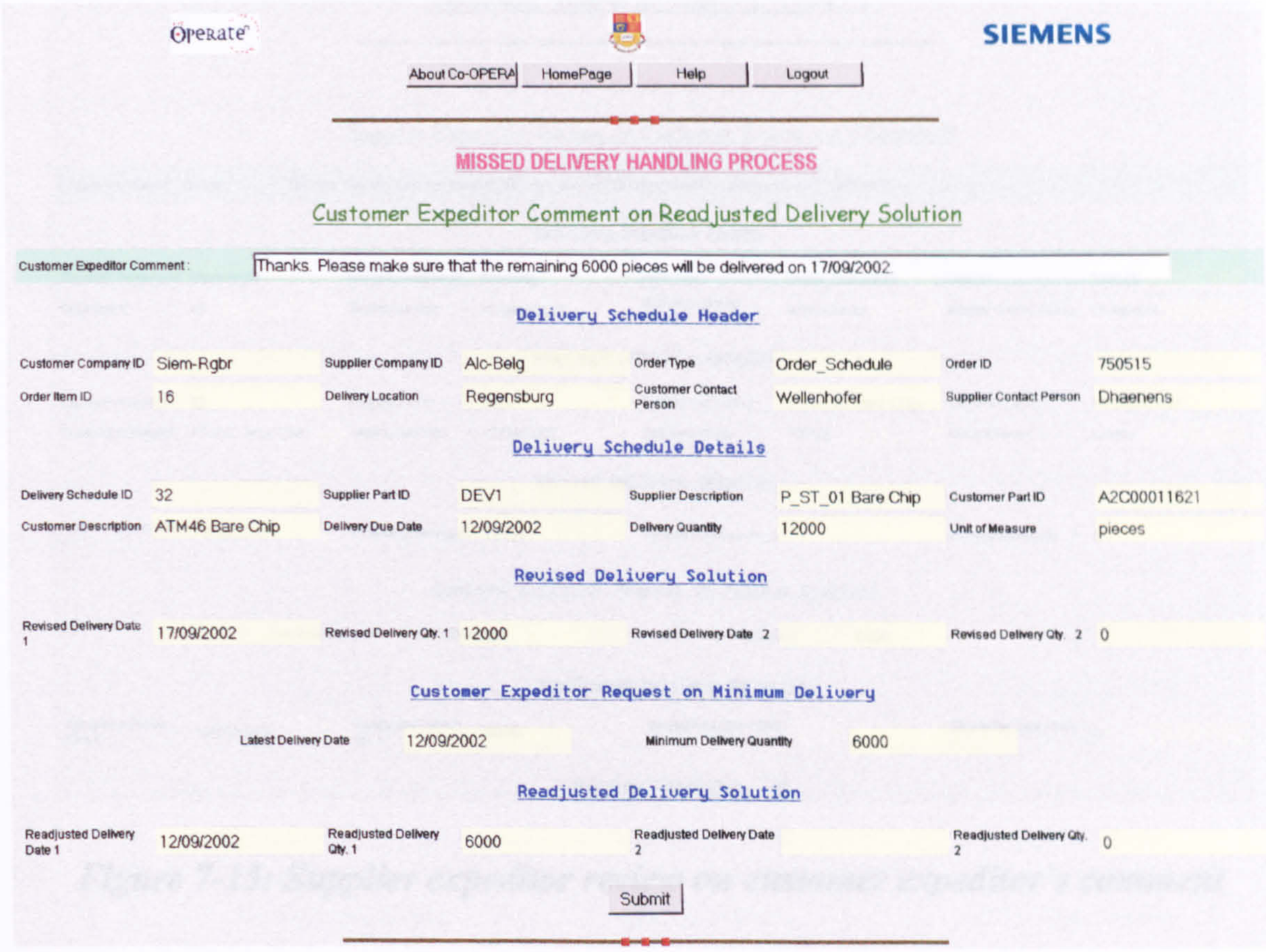


Figure 7-14: Customer expeditor comment on readjusted delivery solution

7. Alcatel expeditor reviewed Siemens VDO' comment

   Having received Siemens VDO's comment on the readjusted deliver solution, the expeditor in Alcatel reviewed it via screens as illustrated in Figure 7-15 and Figure 7-16. According to his or her own knowledge and experience, the expeditor evaluated the message and made a note to the shop floor regarding the delivery requirements in the near term.

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ALCATEL

MISSED DELIVERY HANDLING PROCESS

Supplier Expeditor Review on Customer Expeditor's Comment

Customer Expeditor Comment: Thanks. Please make sure that the remaining 6000 pieces will be delivered on 17/09/2002.

Delivery Schedule Header

Customer Company ID	Siem-Rgbr	Supplier Company ID	Alc-Belg	Order Type	Order_Schedule	Order ID	750515
Order Item ID	16	Delivery Location	Regensburg	Customer Contact Person	Wellenhofer	Supplier Contact Person	Dhaenens

Delivery Schedule Details

Delivery Schedule ID	32	Supplier Part ID	DEV1	Supplier Description	P_ST_01 Bare Chip	Customer Part ID	A2C00011621
Customer Description	ATM46 Bare Chip	Delivery Due Date	12/09/2002	Delivery Quantity	12000	Unit of Measure	pieces

Revised Delivery Solution

Revised Delivery Date 1	17/09/2002	Revised Delivery Qty. 1	12000	Revised Delivery Date 2		Revised Delivery Qty. 2	0

Customer Expeditor Request on Minimum Delivery

Latest Delivery Date	12/09/2002	Minimum Delivery Quantity	6000

Readjusted Delivery Solution

Readjusted Delivery Date 1	12/09/2002	Readjusted Delivery Qty. 1	6000	Readjusted Delivery Date 2		Readjusted Delivery Qty. 2	0

Make Note to Shop Floor

Figure 7-15: Supplier expeditor review on customer expeditor's comment

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ALCATEL

MISSED DELIVERY HANDLING PROCESS

Supplier Expeditor Note on Shop Floor Feedback

Supplier Expeditor Note: Note that 6000 pieces must be ready for delivery on 16/09/2002 at the latest.

Delivery Schedule Header

Customer Company ID	Siem-Rgbr	Supplier Company ID	Alc-Belg	Order Type	Order_Schedule	Order ID	750515
Order Item ID	16	Delivery Location	Regensburg	Customer Contact Person	Wellenhofer	Supplier Contact Person	Dhaenens

Delivery Schedule Details

Delivery Schedule ID	32	Supplier Part ID	DEV1	Supplier Description	P_ST_01 Bare Chip	Customer Part ID	A2C00011621
Customer Description	ATM46 Bare Chip	Delivery Due Date	12/09/2002	Delivery Quantity	12000	Unit of Measure	pieces

Revised Delivery Solution

Revised Delivery Date 1	17/09/2002	Revised Delivery Qty. 1	12000	Revised Delivery Date 2		Revised Delivery Qty. 2	0

Customer Request, Allocated Stock and Shop Floor Request

Latest Delivery Date	12/09/2002	Min. Delivery Quantity	6000	Output Stock Allocated	3000	Shop Floor Due Date	11/09/2002
Shop Floor Quantity	3000	Shop Floor Priority	Very High	Priority Reason	Prime customer		

Shop Floor Feedback

Shop Floor Feedback Date	11/09/2002	Shop Floor Feedback Quantity	3000

Submit

Figure 7-16: Supplier expeditor note on shop floor feedback

7.3 EVALUATION METHOD FOR CO-OPERATE

As for any system development, it is essential to test and evaluate the system. Study of real business cases such as the one presented in the last section represents an important means for system evaluation, and constitutes a critical part of the evaluation method for the Co-OPERATE system. There are two important aspects in the evaluation method for the Co-OPERATE system: (1) a progressive, multi-phase evaluation strategy was envisaged, and (2) the evaluation results were achieved through study of typical real business cases. These two dimensions are apparent from Figure 7-17, which illustrates the overall evaluation process for the Co-OPEQATE system.

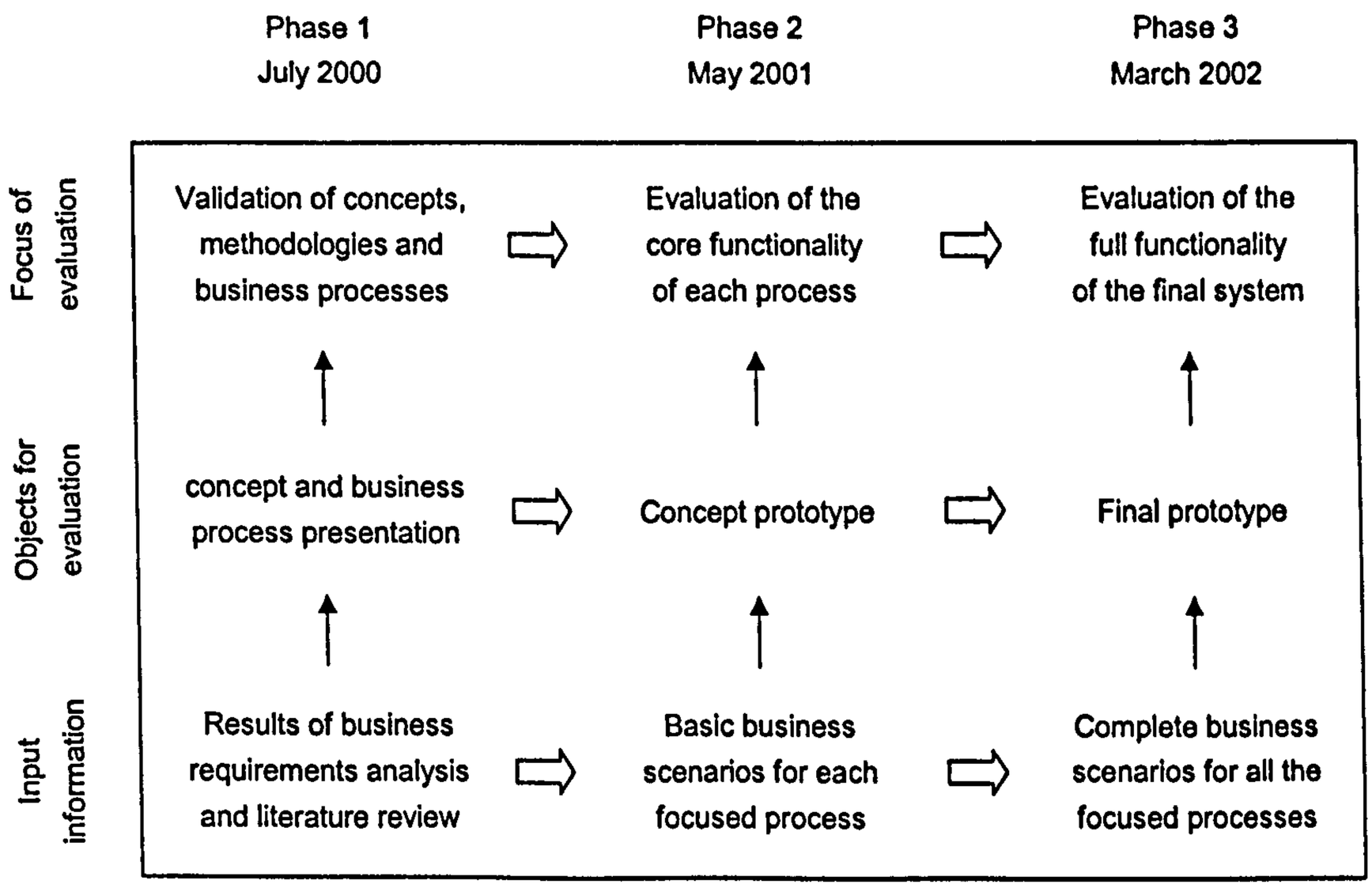


Figure 7-17: The overall evaluation process for the Co-OPERATE system

There were a number of fast design-implement-test-evaluate-feedback cycles during the project life span. The multi-phase evaluation strategy was aimed to get the industrial partners in the project involved throughout the system design and development process and to give valuable feedback for the further development and improvement of the software tool. Before the actual implementation, the new concepts and methodologies developed and the business processes designed had been validated from a conceptual perspective through multiple communications with the industrial partners and verified

by the evaluation of the concept prototype developed during the earlier stage of system development. Therefore, the focus of evaluation for the final Co-OPERATE system (i.e. the final prototype) was to assess whether the system functionality could satisfy the business and system requirements summarised in Chapter 3.

For the purpose of testing and evaluation, the Co-OPERATE system was available online over a period of three months in total. This was because it would take some time for company users to navigate the system and learn its functionality. In the beginning, they were trained by system developers through user manuals and scenario scripts, which explain the system functionality and provide guidance on a screen-by-screen basis. On the other hand, the users also wanted to know how their comments captured during the evaluation of the concept prototype had been taken into account in the system. Questions concerning the implementation were clarified through various communication channels between the users and system developers. Meanwhile, the industrial partners were preparing real business cases for the formal evaluation.

After the user trial and verification phase, project members from industry, consultancy and academia participated in a two-day evaluation workshop to make sample runs of real-world business scenarios and to judge the system's performance under these conditions. The scenarios were seeded with historical but real data distilled from the logistics operations of the industrial partners because it was not expected during the period of the project that user companies would turn over their critical business processes to the developed system. The workshop marked the beginning of the formal evaluation process based on case studies.

7.4 EVALUATION RESULTS FOR CASE STUDY

By virtue of the evaluation method described above, the pilot system was tested on the basis of real business scenarios. The evaluation results for the case studies were captured through a detailed questionnaire for evaluation, which compares both the current and the proposed business processes against a set of criteria, such as network communication, information visibility, early warnings to problems, ability in handling problems, etc. Based on the study of the missed delivery case described in Section 7.2, the evaluation results for the case study were given in the following table.

Criteria	Current process	Proposed process
Network communication	Not formalised way of communication through telephone, fax, email or EDI; lots of paperwork; inefficient and error-prone.	Formalised way of communication through the Internet; nearly no paperwork; efficient and error-proof.
Supply visibility	Almost no supply visibility.	Excellent supply visibility through Internet-accessible, fast information exchange on customer order status.
Early warnings to delivery problems	Almost no early warnings to customers on existing or potential delivery problems.	Significantly improved through continuous monitoring of order progress and timely exception alerts to delivery problems.
Ability to avoid delivery problems	Poor due to lack of visibility of order progress and inefficiency in communication, incurring lots of "fire fighting" work.	Significantly improved through fast communication of customer order status and exception alerts and enhanced exception handling capability.
Ability to solve delivery problems	Limited due to: predominantly reactive to delivery problems; usually telephone based negotiations; lack of decision support information; too much manual work.	Significantly improved due to: mainly proactive to delivery problems; Internet-based communication with standard business processes and user interfaces; readily available information for decision support; significantly reduced manual work.
Synchronized production	Limited; primarily dependent on the accuracy of demand	Improved due to early warning mechanism and enhanced excep-

Criteria	Current process	Proposed process
	information; material shortages due to lack of supplier coordination.	tion handling capability, leading to reduced material shortages.
Inventory levels	High if the supplier does not provide visibility of order progress and has a poor delivery performance.	Reduced due to near-real-time visibility of order progress and early warnings to potential delivery problems.
Cost reduction	Limited due to poor supply visibility and lack of supplier coordination incurring extra costs for expediting and expensive transportation.	Highly potential due to improved supply visibility and enhanced supplier coordination reducing costs for expediting and expensive transportation.
Network collaboration	Poor; often large companies dominant to their own benefits.	Improved through Web-enabled visibility of customer order status and collaborative exception handling to the benefits of all business partners.

Table 7-1: Comparison of current and proposed processes

7.5 Discussion and Conclusions

Based on the results gained from the case studies which were made during the final evaluation phase, the evaluation results for the Co-OPERATE system could be summarised as follows.

- Streamlined business processes for more efficient communication. Orders can be transferred anytime and not necessarily in batches as in the conventional EDI system. Meanwhile, accurate demand information based on actual consumption plan is communicated rapidly across the supply network, reducing inventory carrying costs and minimising the bullwhip effect to which SMEs are extensively exposed.

- Improved information visibility in the supply network. Customers can view online the updated information on the status of order progress and be alerted to exceptions in a controlled manner avoiding confusion and information overload. On the other hand, inventory information can be shared between the customer and the supplier, facilitating supplier managed inventory.
- Enhanced capability in avoiding and solving problems via timely communication of order changes and potential supply problems and efficient exception handling processes, reducing the chances for "fire fighting" and costs for expediting and expensive transportation.
- Peer-to-peer communication to the benefits of all the business partners promoting further collaboration. For example, if the planned delivery schedule cannot be met, opportunities exist to supply just the critical quantity required.
- Enhanced decision support reducing the response time and errors. For example, in case of a missed delivery, on the same web page, the expeditor in the customer company can view relevant information from local planning system (e.g. ERP), warehouse system (e.g. WMS) and shop floor system (e.g. MES), supporting more advisable decision making.
- Better coordination of medium- to long-term production planning across the relevant part of the supply network by taking suppliers' delivery capability into account, especially when large order changes or new orders are expected.

Through intensive testing of the Co-OPERATE system, the evaluation results confirm realisation of the intended benefits of the methodology developed in this work. It should be noted, however, that as with any system tests, the evaluation of the Co-OPERATE system has both strengths and weaknesses. The main strengths include analysing workflow in relation to existing working practices and IT tools and testing the system with real, historic data representative of typical business scenarios and by highly experienced people who have provided the business scenarios. On the other hand, the evaluation work was carried out by the industrial partners in the project, although they were not responsible for the detailed system design and implementation. Therefore, it may be argued that objectivity of their evaluation was compromised. However, the project team was fully aware of such potential criticisms. They were counteracted by basing the

evaluation on real, historical data, such that the proposed coordination processes can be analysed in comparison with the existing ones. Meanwhile, attention was paid to engage staff who are highly experienced with the existing methods and procedures, who can therefore be regarded as qualified experts.

Chapter 8

CONCLUSIONS AND FUTURE WORK

There are many issues to be addressed to enhance agility in supply networks in terms of organisations, people and technology. From the whole supply chain perspective, however, key to the success of an agile supply chain is the fast flow of material and information both upstream and downstream in the entire supply chain. Essentially, the problems in any supply chain process can be classified into: any time delay of material and information. If these two problems can be resolved, the entire supply chain and its constituent companies will stand to gain a significant competitive advantage. For this purpose, it is paramount to achieve an effective integration and coordination of participating firms at different levels of cooperation.

Based on the Co-OPERATE project, this PhD research proposed new concepts, methodology, business processes and implementation approaches for improved coordination of supply chain execution activities in a complex distributed supply network. This concluding chapter gives a summary of the main results of the presented research and provides suggestions for the future work.

8.1 CONCLUSIONS

The main novelty of the presented work relates to the overall Co-OPERATE system and the eXH process and can be described briefly as follows.

- A modular, fully decentralised coordination architecture which corresponds directly to the peer-to-peer structure of a real supply network, maintains the local decision autonomy and supports existing local planning systems (Xu et al., 2004).
- Standard exception handling processes via fast, effective negotiations which try to resolve conflicts between the customer's demand and the supplier's delivery capability in a timely, cost-effective way (Xu et al., 2003).

The main contributions of this work meet the objectives of the PhD research as described in Section 1.3 of Chapter 1 and can be summarised below.

- A conceptual model for an agile supply chain was developed including customer focus, core competence management, supply chain integration and knowledge workforce, which serves as the beacon for the presented work.
- A comprehensive overview of the current development and major issues in ERP and SCM, methodologies for supply chain integration and commercial solutions for network coordination.
- A thorough requirements analysis has been done to identify supply chain challenges in the automotive supply and the semiconductor industries and solutions. The business requirements include reduction of the bullwhip effect, supply chain reliability enhancement and supply chain responsiveness improvement. The system requirements cover adaptation to heterogeneous and distributed business environment, support of scalable and re-configurable system structure and respect for human users.
- Based on the business and system requirements and solutions, a research framework was conceptualised for improved coordination of production planning and control activities in a distributed supply network, which encompasses a comprehensive set of business processes, i.e. long-term planning, operational ordering and planning, visibility of order progress, exception handling, request and feasibility study, multi-sourcing coordination and network performance management.
- The overall Co-OPERATE system was presented, which covers the application of the completely decentralised system architecture to manufacturing coordination in a complex distributed supply network with highly customised products, overall guiding design principles and high-level design for the four focused business processes, i.e. OOP, VOP, eXH and ReFS.
- A holistic control, exception-focused methodology was advanced for supply chain execution management. A holistic control paradigm which integrates feedforward, concurrent and feedback control was first put forward for enhancing the reliability of the supply chain execution process. Based on this control paradigm, a systematic model for ESCEM was then proposed, which comprises three capabilities for

ESCEM, i.e. exception identification capability, exception handling capability and production adaptation capability.

- A design for the ESCEM system was presented. Guiding design principles specific to the eXH process were formulated to direct the detailed process design of the process, which was accomplished through process description, functional modelling and scenario analysis.
- An ESCEM pilot system was implemented in a prototype environment, which necessitated the choice of the implementation toolset, the design of the pilot system database and the description of the pilot system functionality.
- Evaluation work has been done on the concepts, the business processes and the pilot system. The concepts and the business processes were validated from a conceptual perspective through multiple communications with the industrial partners and further verified via the evaluation of the concept prototype. Based on some real business case studies, the evaluation of the pilot system aims to assess the pilot system functionality and to demonstrate the benefits of the system.

As outlined above, this thesis covers the entire development process of the Co-OPERATE system: from the initial business requirements analysis to the development of the concept prototype, and from the implementation of the final prototype (i.e. the Co-OPERATE system) to the evaluation of the final prototype. Based on carefully selected real business case studies, the results of the evaluation for the ESCEM pilot system show that the developed concepts, methodology and business processes bring great benefits such as improved network communication and supply visibility, early warnings on disturbances to the downstream companies, enhanced capability in avoiding and solving delivery problems and improved manufacturing synchronisation in the entire supply chain, leading to satisfied customers and enhanced supply chain performance.

8.2 FUTURE WORK

The pilot system evaluation has clearly demonstrated the strengths and benefits of the new concepts, methodology and business processes for improved coordination of supply chain execution activities in a supply network. It closes the gap between the supply

chain planning and the supply chain execution processes, providing near-real-time visibility and enhanced reliability of the supply chain execution process.

On the other hand, it is hoped that the research framework for manufacturing coordination, the decentralised system architecture, the developed concepts, the holistic control, exception-focused methodology for supply chain execution management and the designed business processes described in this thesis can be extended to support more supply chain applications. Therefore, the results presented in this thesis have formed a fertile ground for future research in the area of network coordination. To get the system up and running in a real industrial environment with the maximum possible cost-benefits in a reasonable period, future work must be directed towards integration with local legacy system and some other areas given below.

8.2.1 Integration with local legacy systems

As shown in Figure 7-3, it is clear that the Co-OPERATE system requires some input data from local legacy systems, e.g. ERP, WMS, MES. These data need to be extracted regularly, or on an event-driven basis from these legacy systems to update their corresponding fields in the Co-OPERATE system database. However, the effort for establishing the interfaces between the legacy systems and the application exceeds the scope of this PhD work. Even though XML has considerably reduced the time and labour involved in building such interfaces, it is still far from a trivial task as there are so many different ERP or local planning systems and XML specifications.

As today's conventional wisdom holds that XML is the key to helping disparate systems communicate each other, there are two important developments in the domain of application integration. One is that large ERP vendors have incorporated XML syntax into their products to help companies lower the cost and labour involved in B2B integration. For example, SAP R/3 features data extraction and integration via XML. The other is that Microsoft recently released Biztalk Server 2002, an XML-based product for enabling B2B communications, which is attractive to SMEs because of its low price and ease of use.

To provide connectivity between BizTalk Server 2002 and the most commonly used applications and technologies, BizTalk currently has about 400 adapters on the market for packaged applications such as SAP and Oracle, as well as technologies such as J2EE and CORBA. On the other hand, BizTalk also supports vertical standards such as RosettaNet by corresponding accelerators. With the launch of BizTalk Server 2002, an upgrade to the previous BizTalk Server 2000 release, Microsoft is adding more functionality to BizTalk to support not only SMEs but also large enterprise customers. On the other hand, Biztalk Server 2002 integrates extremely well with Microsoft's other Web tools such as IIS. It is therefore recommended that Biztalk Server 2002 be used for data exchange between the Co-OPERATE system and local legacy systems.

8.2.2 Areas for further research

Based on the experience with the pilot system, discussions with the industrial partners and the results of the pilot system evaluation, the following areas have been identified for and worthy of further research.

From the system functionality perspective, an extension for specific reporting will be a valuable addition to the ESCEM pilot system. For example, as the eXH process interacts with the shop floor on the supply side, a comprehensive report on current production status of the shop floor, such as backlogs, WIP and bottlenecks, will be helpful supporting the production planner for more advisable decision making.

From the whole Co-OPERATE system perspective, the exception-focused methodology adopted in the ESCEM pilot system can be extended to the collaborative supply chain planning process. Specifically, in the OOP process, both the customer and the supplier are guided through all demand exceptions, which can be identified through a filtering mechanism based on the mutually agreed contractual rules. Management attention is thus focused on handling the exceptional demand variations, which must be resolved before orders are actually placed and delivery schedules established.

From the training point of view, the pilot system can be extended as a demonstrator to show how best practices in SCM can be achieved through enhanced information sharing and integration with business partners and what are the expected benefits of improved

cooperation to all the parties involved. For example, the missed delivery handling process will get more and more responsive to delivery problems when information sharing migrates from the modest level, e.g. only the supplier has the visibility of inventories on the customer side, to the high level, e.g. the supplier has full control of inventories and clear visibility of the customer's short-term production schedule.

The conceptual framework and the coordination system were developed for a specific industrial setting covering the automotive supply and the semiconductor industries. However, the research framework for network coordination, the decentralised coordination architecture, the exception-focused methodology, the business processes developed and the implementation approach are generically applicable and can be transferred to different business environments. For example, the decentralised coordination architecture and the exception-focused methodology could be applied to manufacturing coordination in any distributed supply network.

Chapter 9

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Appendix A

PROCESS MODEL FOR EXH

The process model for eXH is illustrated from Figure A-1 to Figure A-7.

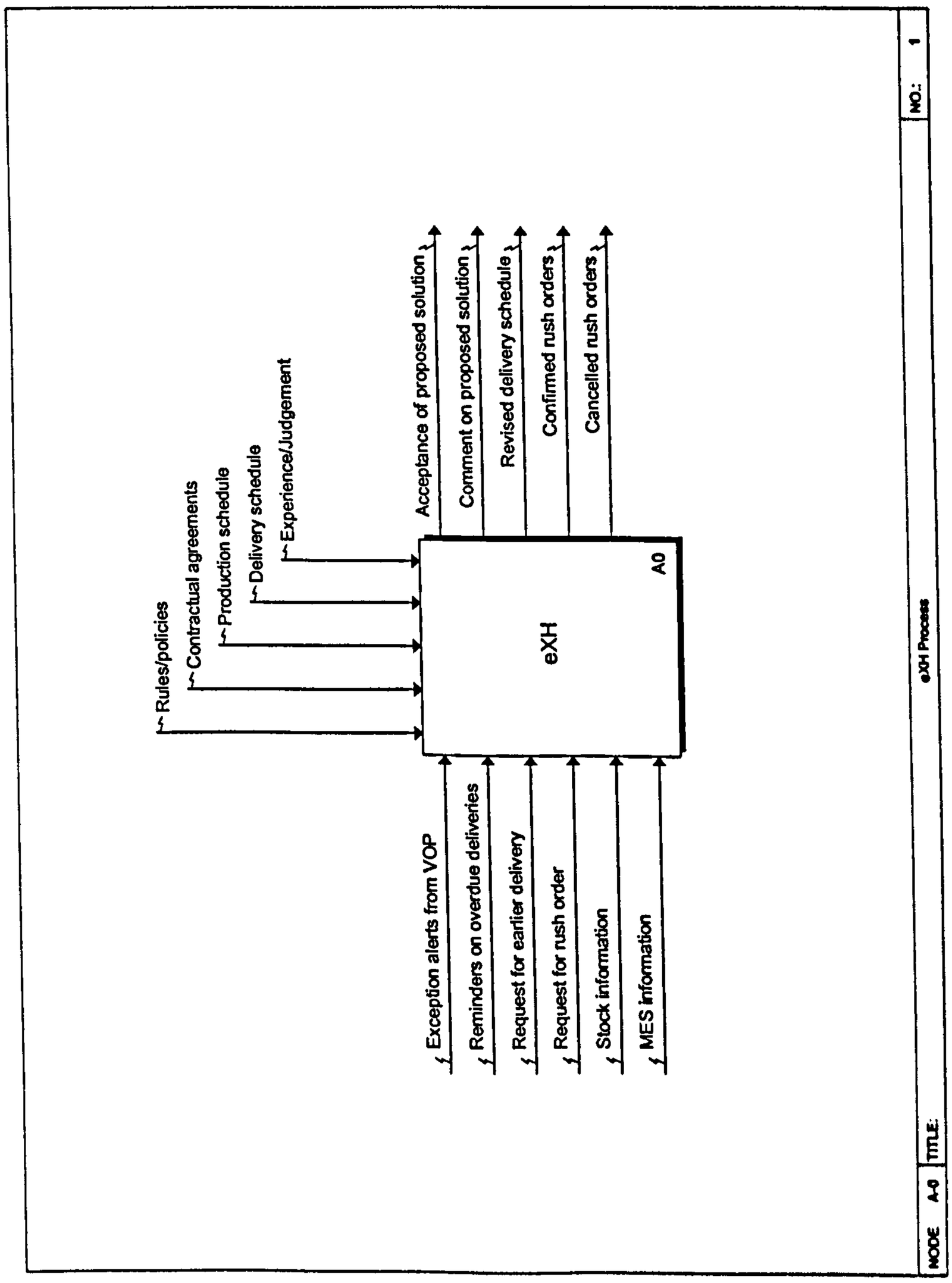


Figure A-1: eXH process

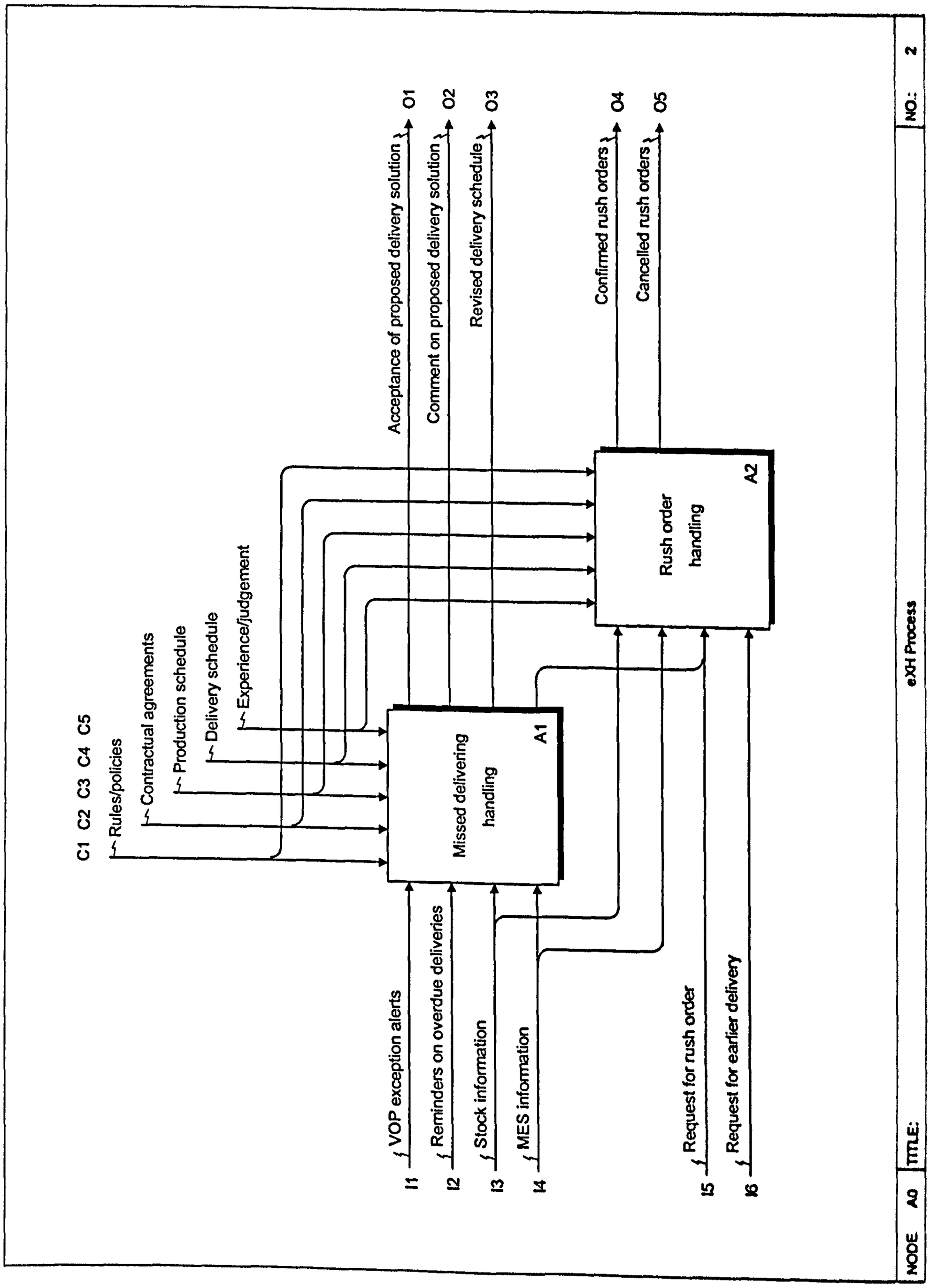


Figure A-2: eXH process – First level A0

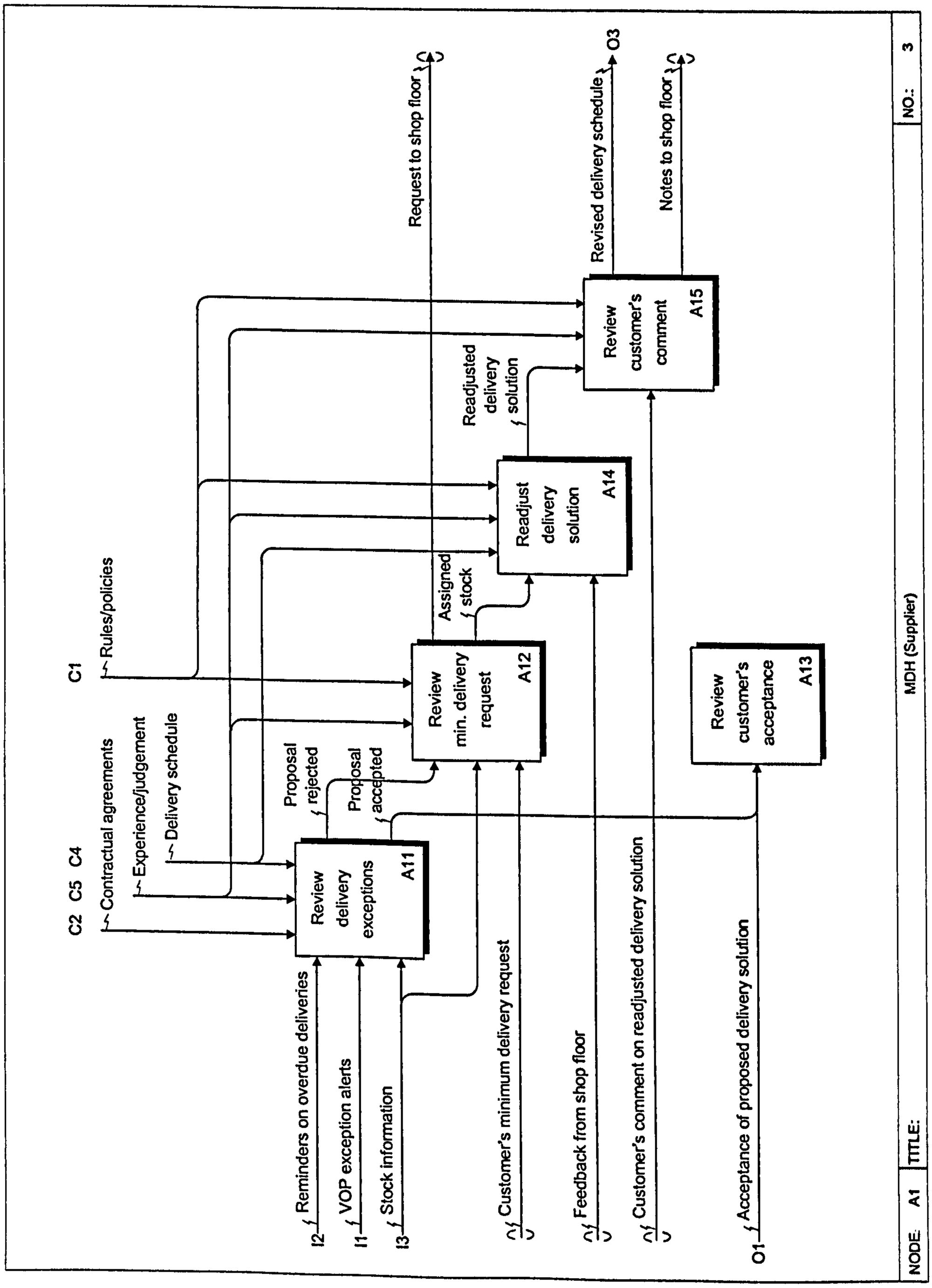


Figure A-3: Missed delivery handling process (supplier) – second level A1

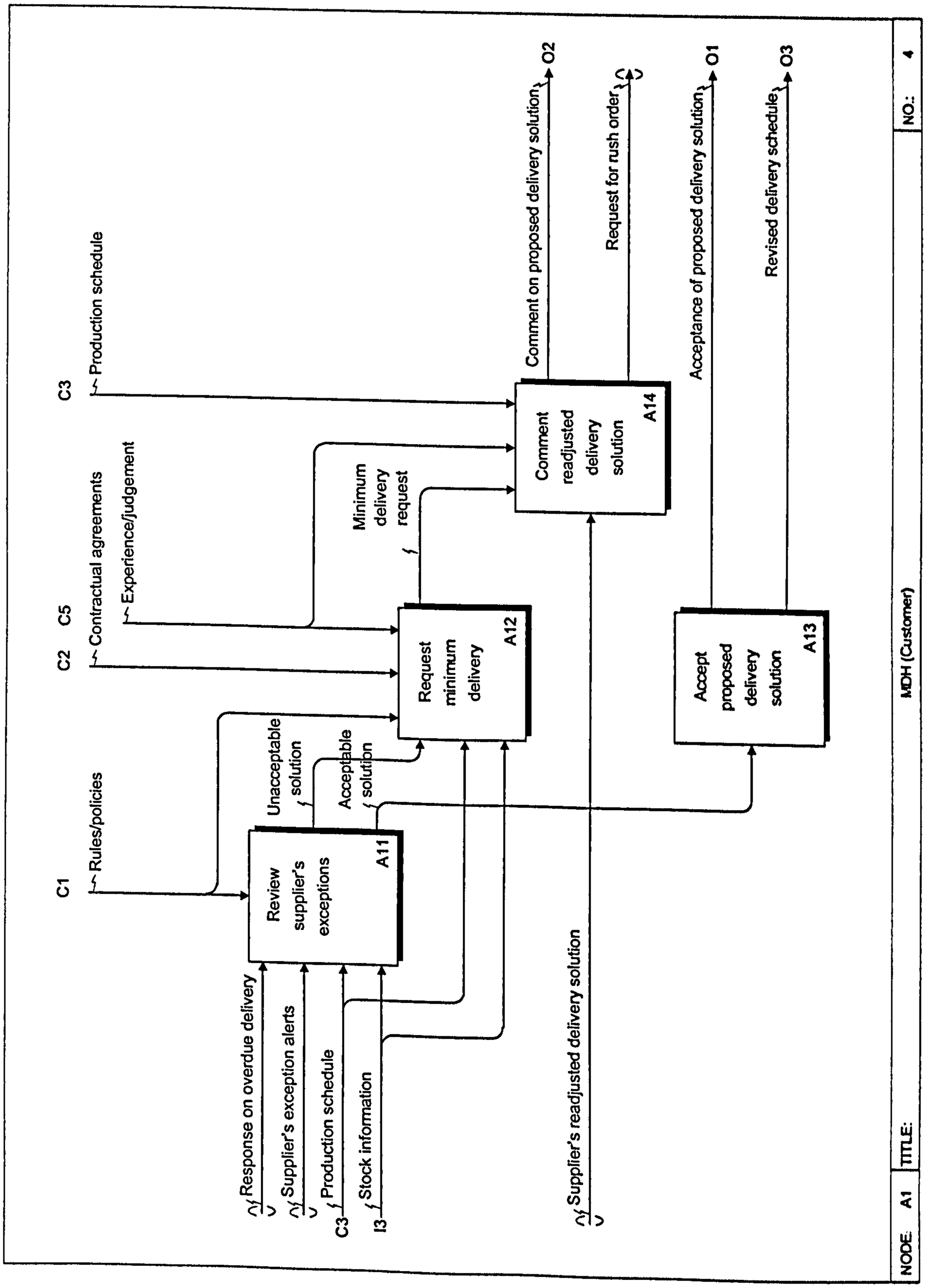


Figure A-4: Missed delivery handling process (customer) – second level A1

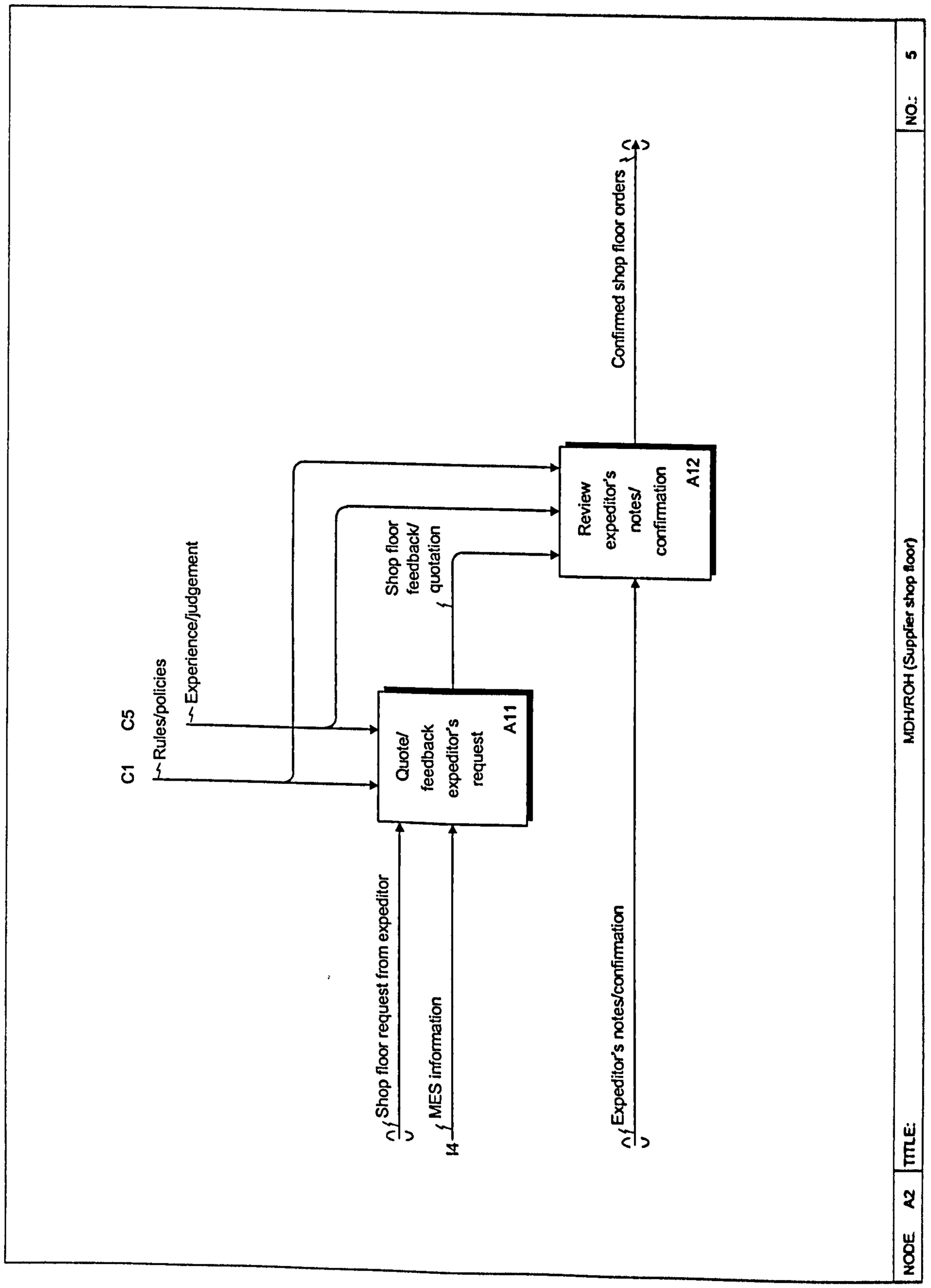


Figure A-5: MDH / ROH process (supplier shop floor) – second level A1

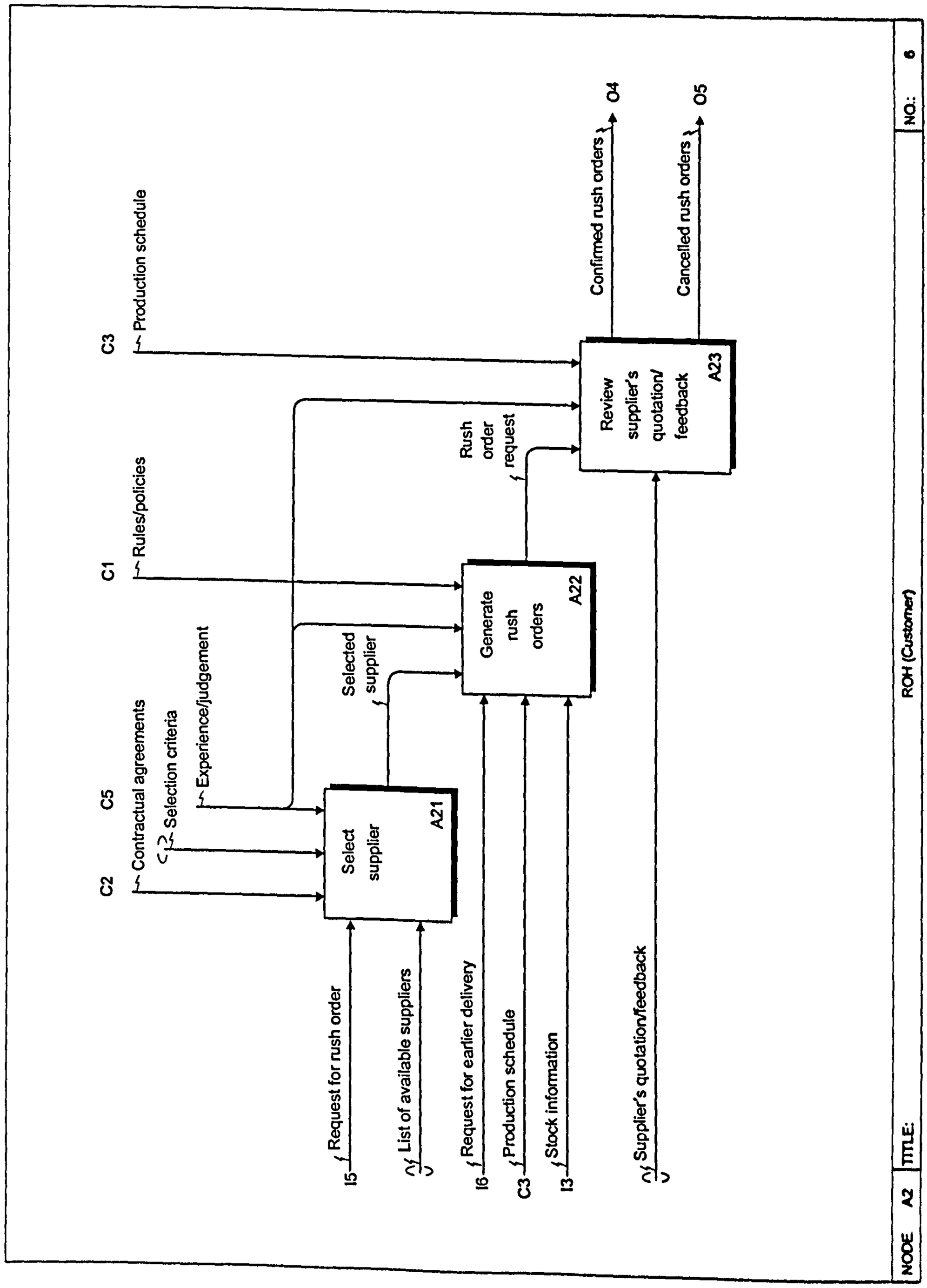


Figure A-6: Rush order handling process (customer) – second level A1

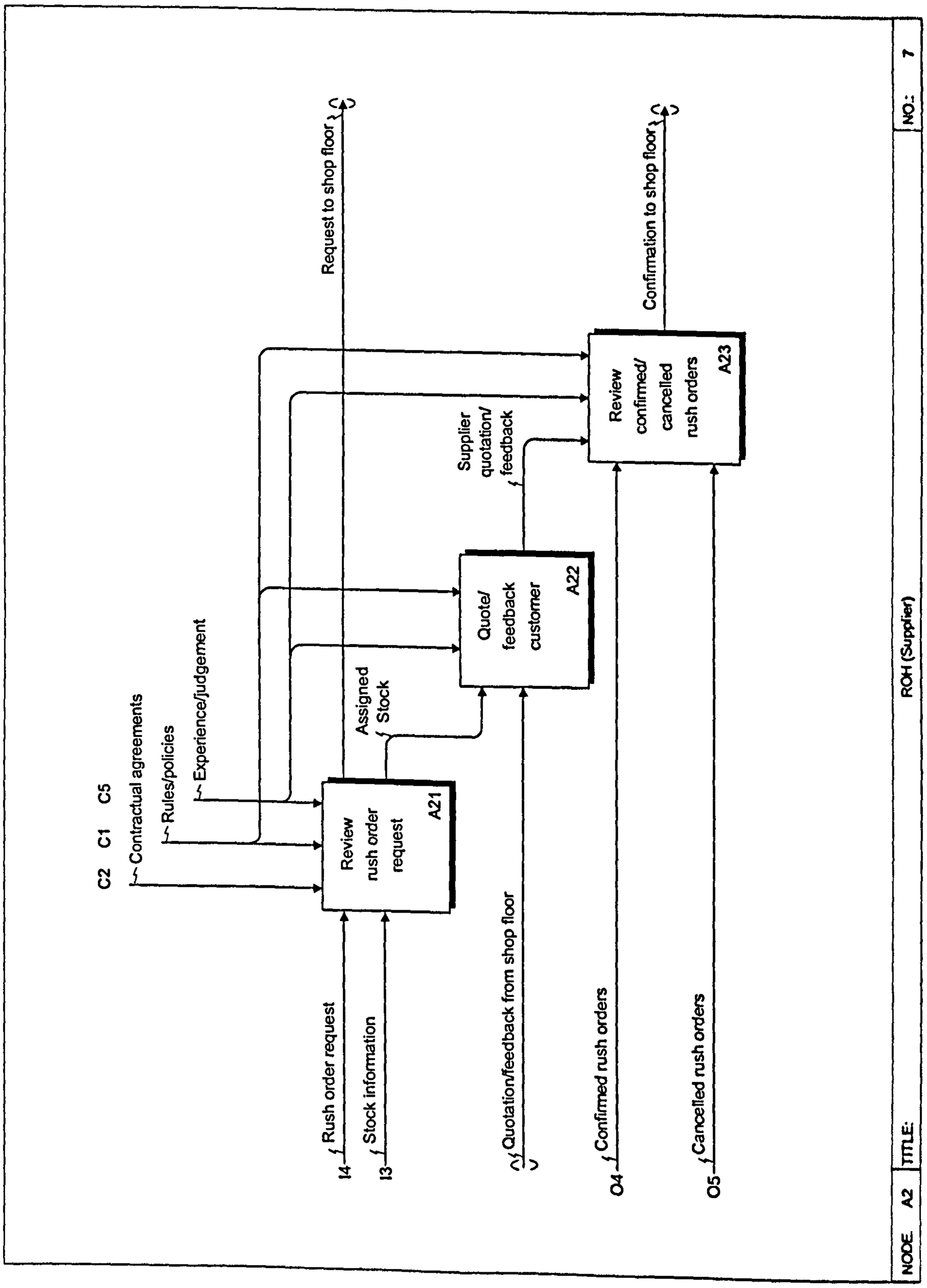


Figure A-7: Rush order handling process (supplier) – second level A1

Appendix B

DESCRIPTION OF PROCESS STEPS FOR EXH

Table B-1 summarizes each process step of the IDEF0 diagrams for the missed delivery handling process and Table B-2 for the rush order handling process.

Process Step	Description
Missed delivery handling process (Supplier)	
A11: Review delivery exceptions	The missed delivery handling process begins with this step. First, an internal VOP alert or a reminder on an overdue delivery is reviewed by an expeditor of the supplier. If the delay can be compensated by the finished goods inventory, the internal exception alert will not be escalated to an external one. Otherwise, an external exception alert will be sent to the customer. In case of an overdue delivery, a reminder will be generated by the system automatically and reviewed by the supplier expeditor. In both cases, a revised delivery solution will be posed and sent to the customer.
A12: Review minimum delivery request	The customer's minimum delivery request is reviewed by the supplier expeditor. The expeditor first checks if there is enough finished goods inventory to meet the request. If yes, he/she assigns the whole quantity to it from output stock and responds the customer directly. Otherwise, only partial quantity is assigned from the stock, and the remaining quantity is requested from the shop floor with the priority for the requested delivery and reason for it.

Process Step	Description
A13: Review customer's acceptance of revised delivery solution	This process step is triggered by the acknowledgement from the customer that the revised delivery solution proposed by the supplier has been accepted by the customer. This acknowledgement is reviewed by the supplier expeditor and the delivery schedule is updated accordingly.
A14: Generate readjusted delivery solution	In case of insufficient buffer stock, based on the assigned finished goods inventory and feedback from the shop floor, the supplier expeditor can readjust the previously revised delivery solution so that the customer' minimum delivery requirement can be met to the maximum.
A15: Review customer's comment	The customer's comment on the readjusted delivery solution is reviewed by the supplier expeditor. As a result, the delivery schedule is updated accordingly. Meanwhile, the expeditor notes the shop floor on its previous delivery quotation.
Missed delivery handling process (Customer)	
A11: Review supplier's exceptions	This process step is triggered either by a supplier's external exception alert or by a supplier's response on an overdue delivery. Each exception is assessed by the customer expeditor to see if the exception can cause material shortage. This is first calculated by the system using information on current production schedule, available finished goods inventory, stock on the shop floor and the revised delivery solution proposed by the supplier, and is then judged by the expeditor based on his/her knowledge and experience.
A12: Request minimum delivery	The impact of the supplier's exception on the customer's production is assessed by the customer expeditor. If the

Process Step	Description
	revised delivery schedule proposed by the supplier can not be accommodated by the customer, the system calculates the minimum delivery quantity and the latest delivery date of the required material or component, so that the customer's production will not be disrupted. This minimum delivery request is subject to the adjustment of the expeditor according to his/her own judgment.
A13: Accept proposed delivery solution	If the revised delivery schedule can be accommodated by the customer, the customer expeditor will inform the supplier's counterpart that it has been accepted. Meanwhile, the customer expeditor may make some comment regarding the revised delivery schedule so that material shortage will not take place in the near term.
A14: Comment readjusted delivery solution	After receiving the readjusted delivery solution from the supplier, the customer expeditor can make some comment as the readjusted delivery solution may fulfill only part of the minimum delivery requirement. For example, such comment can be "Please deliver the remaining 6,000 pieces before 17/8/2002".
Missed delivery handling process (Supplier shop floor)	
A11: Respond to expeditor's request	Upon receiving delivery request from the expeditor, the production planner checks the current status on the shop floor such as priority orders, WIPs and bottlenecks in the manufacturing process and other related information such as capacity and material availability. Then, a response in terms of the earliest delivery date and available quantity is fed back to the expeditor based on the related shop floor information and the priority of the requested delivery.

Process Step	Description
A12: Review expeditor's notes	This process step is the last one in the missed delivery handling process. The production planner reviews the expeditor's notes regarding how much needs to be delivered and when. These requirements will be taken into account during the next scheduling for the shop floor.

Table B-1: Missed delivery handling process steps

Process Step	Description
Rush order handling process (Customer)	
A21: Select appropriate supplier	This is the first step in rush order handling in a multi-sourcing case. The customer expeditor may want to choose some appropriate suppliers to send rush order requests so that the envisaged rush order can be fulfilled to the maximum. The selection of suppliers is based on certain criteria, such as relationship, delivery performance, stock level, location, etc.
A22: Generate a rush order request	A rush order request can be generated as a new order or as earlier delivery of an existing order than the planned delivery date. While the former case needs to indicate the urgency level (very urgent, urgent), the latter one is similar to the process step for generating minimum delivery request in the missed delivery handling process.
A23: Review supplier's response	This process step is triggered by a supplier's response on rush order request. In case of a new rush order for a multi-sourced material or component, the customer expeditor should decide how much to order from a supplier after consolidating the responses from the requested suppliers,

Process Step	Description
	and then confirm or cancel the request made previously to each of these suppliers.
Rush order handling process (Supplier)	
A21: Review rush order request	When receiving the rush order request from the customer, the supplier expeditor first checks whether finished goods inventory is sufficient to fulfill the requested order quantity. If yes, the expeditor can assign the whole quantity from output stock and respond the customer directly. Otherwise, only partial quantity is assigned from the stock and the remaining part of quantity is requested from the shop floor.
A22: Respond to rush order request	If the assigned finished goods inventory is not sufficient to fulfill the whole requested quantity, the supplier expeditor can respond to the rush order request with a proposed delivery solution after consolidating the assigned quantity of output stock and the quotation from the shop floor.
A23: Review customer's confirmation	This process step is necessary for a new rush order as a supplier's quotation has to be confirmed by the customer. After receiving the customer's confirmation on the rush order request, the supplier expeditor can eventually decides exactly how much finished goods inventory to be assigned from the output stock and how much to be requested from the shop floor.
Rush order handling process (Supplier shop floor)	
A21: Respond expeditor's request	This process step is primarily the same as the process step "A11: Respond expeditor's request" in the missed delivery handling process.

Process Step	Description
A22: Review expeditor's confirmation	This process step is primarily the same as the process step "A12: Review expeditor's notes" in the missed delivery handling process.

Table B-2: Rush order handling process steps

Appendix C

STRUCTURE OF THE PILOT SYSTEM DATABASE

Figure C-1: Structure of the pilot system database

Appendix D

DESCIPTION OF TABLES IN THE PILOT SYSTEM DATABASE

Table D-1 describes each table in the structure of the pilot system database.

Tables	Description
Company	Company ID, full name and address and logo provide a unique identification for each company in the supply network. Company Web site provides another source of electronic information about the company. New company records can only be created by the service provider, where the application is hosted. Meanwhile, the administrator user of each company is authorized to edit such fields as company address and Web site.
User	User ID, first name, last name, title and role identify each user in a company uniquely. User contact information (telephone number, fax number, email address, etc.) provides other means of communication. New user records can only be created by the administrator user of the company, while the list of user records can be viewed by all the users in the network.
SuppdProducts (Supplied products)	Each supplied product has its unique product ID and description. Minimum order quantity (MOQ) provides a constraint for order placement of a product. New product records can only be created by the company producing the

Tables	Description
	particular part, while the list of product records can be viewed by all the users in the network.
PurchProducts (Purchased products)	It describes supplied products from the customer's perspective. This is due to the fact that for the same product, the customer usually has a different part ID and description according to their own standards and coding system. Therefore, new records for purchased products can only be created by the administrator user of the company.
Order	As an order can be one of the three types: consumption order, order schedule and single order, and the same order ID can be used for an order over the entire period of the contract, it is essential to separate general order information from the type-dependent and time-dependent order information. The "Order" table provides a list of orders, some general order information (companies involved, order type and contact information) and links to type-dependent tables where order details can be found.
OrdSchedule (Order schedule)	The main characteristics of order schedules is that customer demand is divided into a series of deliveries in the form of {required quantity, due date} couplets, and these schedules are updated on a regular basis (usually weekly or monthly). This feature entails separation of detailed demand information on individual deliveries from other general order information. The "OrdSchedule" table provides some general order information on order schedules and provides a link to the "OrdSchedDetails" table. Fields: "SuppReply" and "SuppReplyDate" are used for recording the customer's feedback on order schedules (e.g. accepted, rejected).
OrdSchedDetails	It provides the detailed information for each delivery speci-

Tables	Description
(Order schedule details)	fied in a particular order schedule in the form of {required quantity, planned date} couplets.
ConsSchedule (Consumption schedule)	A consumption schedule concerns the current stock level and the planned consumption rate over a certain period in the near term, which is reflected in such fields as current stock level, average daily consumption, predefined upper and lower limits on stock levels. Similar to order schedules, consumption schedules are updated usually on a regular basis (e.g. monthly).
OrderItem	It contains data related to single orders that may have one or more items. Different from order schedules and consumption schedules, single orders, by their nature, do not require any updates. Changes to due dates and quantities can be made through negotiations between the customer and the supplier during the regular operational ordering and planning phase.
InputStock	Similar to the difference between supplied and purchased products, stocks can be divided into input (inbound) stock and output (outbound) stock. On-hand stock represents the quantity of an item shown in the inventory records as being physically in stock. Allocated stock refers to the amount of stock that has been reserved, but not yet withdrawn from the warehouse, and is thus not available for other purposes. On the other hand, maximum and minimum stock indicates the range to which the stock level of an item should normally be allowed to vary.
OutputStock	Despite the fact that there are differences in physical form, quantity and location between input and output stocks, the "OutputStock" table has all the corresponding fields with

Tables	Description
	very similar meanings as those in the "InputStock" table.
ProdMilestones (Production milestones)	The manufacturing process of a product can be grouped into major production stages (production milestones) along the mainstream of the process. Each milestone is uniquely identified by its milestone number and description and has a planned time to finish and a minimum time to finish to provide time standards whereby the progress status of a production order can be measured.
ProdOrders (Production orders)	Production orders can either be extracted from local ERP/ MES or created by a system user in a company. Production order ID uniquely identifies a production order. The {ordered quantity, planned release date} couplets reflect the immediate demand from the customer. The planned due date provides the deadline against which the progress status of a production order is measured.
ProdOrderStatus (Production order status)	The production order status is uniquely identified by its production order ID and current milestone. Current milestones and produced quantities can be extracted from local MES or manually input by a system user in case of a few milestones. The projected due date is calculated according to the status date, the current milestone of a production order and its planned time to finish for the remaining milestones. The amount of delay, reason for delay and action taken should be given in case of lateness.
CustSFStock (Customer shop floor stock)	The amount of stock of a particular part on the customer's shop floor can be obtained either from local ERP systems or from MES systems on the shop floor. This data is essential for the calculation of how much input stock of a purchased product is available for production in the near term.

Tables	Description
DelSchedule (Delivery schedule)	After an order has been placed, delivery schedules are created by the supplier as a commitment to fulfil the order. While orders have different structures for different order types, delivery schedules for all the order types have the same structure in the form of {delivery date, delivery quantity, delivery location} triplets. A delivery schedule is uniquely identified by its delivery schedule ID. Generally, there is a single delivery schedule for each item in a single order and for each {required quantity, due date} couplet in an order schedule, whereas there are multiple delivery schedules for a consumption schedule.
CustOrderStatus (Customer order status)	As there are usually multiple records showing the updated status information of a delivery on different dates over a period, the customer order status is uniquely identified by the combination of its related delivery schedule ID and status date. While the production order status is mainly used for internal monitoring and reporting, the customer order status provides the latest status information for a committed delivery associated with a specific customer order. However, similar to the production order status, the amount of delay, reason for delay and action taken should be indicated in case of "RED" customer order status.
MD_SuppEXH (Missed delivery handling by supplier)	It contains all the coordination data input by the supplier expeditor during the missed delivery handling process. Each record is uniquely identified by its delivery schedule ID and the date on which the exception is handled, which applies to all the following tables. Fields: "DeliveryDate1", "DeliveryQty1", "DeliveryDate2" and "DeliveryQty2" are used for the proposition of a revised delivery solution. Fields: "ReadjustedDate1", "ReadjustedQty1", "ReadjustedDate2" and

Tables	Description
	"ReadjustedQty2" are used for the proposition of a readjusted delivery solution. Fields: "AllocatedOS" and "Note" are used for recording the allocated quantity of output stock and notifications for the production planner respectively.
MD_SuppSFeXH (Missed delivery handling by supplier shop floor)	It contains all the coordination data for making a delivery request to the shop floor or responding to the request during the missed delivery handling process. Fields: "SFDueDate", "SFQty", "SFPriority" and "PriorityReason" are used by the supplier expeditor for making a request for an urgent delivery, whereas fields: "SFFeedbackDate" and "SFFeedbackQty" are used by the production planner for responding to the request.
MD_CustEXH (Missed delivery handling by customer)	It contains all the coordination data input by the customer expeditor during the missed delivery handling process. Fields: "LatestDate" and "MinQty" are used for making a minimum delivery request to the supplier, and "Comment" for recording the customer's view on the readjusted delivery solution proposed by the supplier.
RO_CustEXH (New rush order handling by customer)	It contains all the coordination data input by the customer expeditor during the new rush order handling process. Fields: "RO_DueDate", "RO_Quantity", "RO_UrgencyLevel" and "RO_UrgencyReason" are used for making a request for a new rush order. Fields: "RO_ConfmdDate1", "RO_ConfmdQty1", "RO_ConfmdDate2" and "RO_ConfmdQty2" are used for confirming the supplier's quotation.
RO_SuppEXH (New rush order handling by supplier)	It contains all the coordination data input by the supplier expeditor during the new rush order handling process. Fields: "RO_DelDate1", "RO_DelQty1", "RO_DelDate2",

Tables	Description
	"RO_DelQty2", "RO_ExtraCost" and "RO_ReasonForCost" are used for making a quotation to the rush order request.
RO_SuppSFeXH (New rush order handling by supplier shop floor)	It contains all the coordination data for making a delivery request to the shop floor, making a quotation to the expeditor and confirming the shop floor request during the new rush order handling process. Fields: "RO_SFDueDate", "RO_SFQty", "RO_SFPriority", "RO_PriorityReason", "RO_SFFeedbackDate" and "RO_SFFeedbackQty" have the same meaning as their corresponding fields in the "MD_SuppSFeXH" table. Fields: "RO_ConfmdSFDate" and "RO_ConfmdSFQty" are used for confirming the shop floor request.
ED_CustEXH (Earlier delivery handling by customer)	It contains all the coordination data input by the customer expeditor for making a request for an earlier delivery of an existing order and for confirming the supplier's delivery proposal. Each field in this table has a very similar meaning as that of the corresponding field, which can be found in either the "MD_CustEXH" or the "RO_CustEXH" table.
ED_SuppEXH (Earlier delivery handling by supplier)	It contains all the coordination data input by the supplier expeditor during the earlier delivery handling process. Each field in this table has a very similar meaning as that of the corresponding field, which can be found in either the "MD_SuppEXH" or the "RO_SuppEXH" table.
ED_SuppSFeXH (Earlier delivery handling by supplier shop floor)	It contains all the coordination data for making a delivery request to the shop floor or responding to the request during the earlier delivery handling process. Each field in this table has a very similar meaning as that of the corresponding field, which can be found in either the "MD_SuppSFeXH"

Tables	Description
	or the "RO_SuppSFeXH" table.

Table D-1: Description of tables in the pilot system database

Appendix E

PUBLICATIONS

Xu, H. Q., Besant, C. B. and Ristic, M., 2003, System for enhancing supply chain agility through exception handling, *International Journal of Production Research,* **41** (6), 1099-1114.

Xu, H. Q., Ristic, M., and Besant, C. B., 2004, A Web-based system for manufacturing coordination in complex supply networks. *International Journal of Production Research* (to be submitted).

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