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# An Information Systems Framework for Event Management in Supply Chain Operations

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# ABSTRACT

As competition has shifted from the company to the Supply Chain level, gaining a competitive edge becomes an issue of efficient collaboration amongst SC partners. Within the e-business era the level of competitiveness is determined by the ability of an SC to react and adjust rapidly to market and industrial changes and to overcome burdens originating both from inside and outside the SC borders. These features create the framework for defining *agility* within supply chains. Managing turbulence in SCs, while maintaining customer satisfaction at a low operational cost requires proactive dynamics towards risk factors. An agile Supply Chain addresses direct and indirect sources of risk, which expand outside the SC boundaries. Supply risk is related to the potential occurrence of an incident such as inbound supplies failure that results in customer dissatisfaction. Sources of risk in the SC have various origins which due to their dynamic nature cannot always be predicted, such as turbulence in oil or currency prices, physical or manmade disasters, production failures, product recalls and so on. Organizations need to respond to events as certain unexpected events can cause chaos in the SC and form patterns with negative impact, such as the bullwhip effect, backlogs etc. Chaos in the SC originates from managerial and computer control decisions and actions but apart from the internal sources, chaotic spikes in the SC demand can also originate from external changes.

This thesis proposes that Internet based Information Systems support is required for responsive Supply Chains, in order to address risk origins under a holistic perspective. An event driven architectural framework is proposed in the context of SC operations, which enables flexibility and agility in an e-business setting. The concept of events is explored within the Supply Chain domain and the information regarding patterns of occurring events is identified and disseminated. Initially the theoretical ground for event identification is set and unexpected events in a SC context are classified. Building on the events classification, a notation (EPN) to model event patterns is described. Finally an architecture (SCEDRA) which captures unexpected events and forms and disseminates event patterns is proposed.

# CHAPTER 1: INTRODUCTION

## 1.1 Background & Motivation

As there is no single definition of the concept of Supply Chain (SC), in this research we define the SC as the network of autonomous entities that are involved in the activities of procurement of raw materials, manufacturing, converting raw materials into finished products and distribution (Benisch, Greenwald & Grypary, 2004). The management of the upstream and downstream material and information flows, and of the interactions between suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole, constitutes the concept of Supply Chain Management (SCM) (Christopher, 1998). The importance of effective SCM is reflected in several cases when turbulences or disruptions during the SC have a negative impact on the overall business (Pellet-Gillay, Bhat & Sept, 2006). Some examples include:

- Cisco's $2.25 billion inventory write off (Barret, 2001) due to restricted inventory visibility which resulted in failure to control customer demand.
- Nike's planning system malfunction affecting factory orders, resulting in $100 million revenue miss due to the loss of 20% stock (Koch, 2004).
- The terrorist attack of the 9/11, that affected airfreight prices which increased by 15% as a result (Chandler, 2002).

The wide expansion and adoption of the Internet has impacted on business structures (Swaminathan & Tayur, 2003) and business models (Lee, 2002). The Supply Chain is transformed under the e-business umbrella towards the e-SC paradigms (O' Leary, 2000). E-Supply Chain practices are agile SC arrangements which dynamically respond to changing business conditions (Sadeh, Hildum & Kjenstad, 2003). The ultimate form of e-SC functionality is the Virtual Enterprise, where companies that participate in the network interoperate as a single unit taking advantage of the current market and environmental conditions. (Camarinha-Matos, *et al.*, 1998). E-Supply Chain Management refers to the impact that Internet has on the integration of key business processes from end user to the original suppliers (Giminez & Lourenco, 2004).

As competition has shifted from the company to the Supply Chain level (Christopher, 1998), gaining a competitive edge becomes an issue of efficient collaboration amongst SC partners. In previous research, this collaboration had been defined at the stage of internal integration (Stevens, 1989; Stock, Greis & Kasarda, 1998), based on the level of interaction between logistic units and business functional areas. However, as defined by Coopert and Lambert (1998), logistics units constitute one of the main wheels that drive the Supply Chain; hence competitiveness is located at the SC level.

To gain a competitive edge within a SC, researchers argue that effective Supply Chain Management activities are achieved through information sharing and information integration (Christopher, 1998; Christiansee & Kumar, 2000). Information integration requires however a large degree of information systems interaction and organizational structures to enable cross-organization data consistency and support knowledge dissemination through decision support systems (Sodhi, 2001). The above features create the framework for defining *agility* within Supply Chains (Christopher & Towill, 2001). Managing turbulences in SCs, while maintaining customer satisfaction at a low operational cost determine proactive dynamics towards risk factors (Christopher, 2000). An agile Supply Chain addresses direct and indirect sources of risk, which expand outside the SC boundaries (Svensson, 2000). According to Svensson, indirect sources of risk are not thoroughly examined by SC executives who fail to see and consider their interrelations.

Zsidisin (2002) connects supply risk with the potential occurrence of an incident such as inbound supplies failure that results in customer dissatisfaction. Extending the above definition, sources of risk in the SC originate from many dynamics, such as lack of ownership (Christopher *et al.*, 2002) and Just-In-Time relationships (McGillivray, 2000). This research considers risk in the form of events, as changes in the state of a process or triggers for processing and further execution (McGovern, Sims & Jail, 2006). Organizations respond to event types (Dickinson, 1998), as certain unexpected events can cause chaos in the SC and form patterns with negative impact, such as the bullwhip effect, backlogs etc. (Wilding, 1998b). Chaos in the SC originates from managerial and computer control decisions and actions (Wilding, 1998a). Apart from the internal sources of chaos, Levy (1994) argues that chaotic spikes in the SC demand can also originate from external changes.

Supply Chain Event Management practices and systems aim to monitor SC processes in order to identify disruptive events and transmit alerts to the appropriate participants or systems (Barrows & Using, 2003). Business Activity Monitoring (BAM) systems extend Business Intelligence (Moris & Vesset, 2004; Hasselt, 2004) in displaying real time information in the context of a runtime mechanism (Linthicum, 2004). However existing

SCEM systems fail to identify distributed SC structures as they lack adaptive behaviour and analytic capabilities (Bodendorf & Zimmerman, 2005).

Events constitute real business entities (Dickinson, 1998), thus they should be considered as the core concept when modelling enterprise Information Systems architectures (McGovern, 2006). The latest trend towards enterprise architecture is the concept of Service Oriented Architecture, that provides a service-based computing environment (Dheap & Ward, 2005). Building on this, an Event Driven Architecture, refers to "*applications and services that have the ability to react to changes in conditions regardless of whether the change is a failure in a downstream system or a sudden change in the marketplace, such as meltdown on Wall Street*" (McGovern *et al.*, 2006 p:317).

This research builds on the argument that the Internet and IT paradigms need to support responsive Supply Chains (Van Hoek, 2001), enhancing their speed and flexibility in order to achieve agility (Breu, Hemingway, Strathern & Bridger, 2001). Avoiding Supply Chain failures is critical for companies competitiveness in the e-Supply Chain era. This thesis proposes an event driven architectural framework in the context of SC operations that enables flexibility and agility in an e-business setting.

## 1.2 Research Aims and Objectives

Current research on event driven architectures provides the grounding for further investigation on expanding into the e-Supply Chain context, targeting SC agility using the event paradigm. The overall aim of this research is to:

*Propose a framework for handling unexpected events in the context of Supply Chain operations, which through an event-driven architecture supports SC activities in the effort to achieve agility within an extended e-business environment.*

The research aim is addressed through the following main objectives:

- O1: Bound the area of unexpected events and their relationships within the Supply Chain domain.

- O2: Use the theoretical ground defined in O1, to build an ontology which classifies unexpected events under SCOR[1] model processes.

- O3: Propose a notation for describing event patterns that is based on their ontological classification.

- O4: Design an Information Systems Supply Chain Event Driven Architecture (SCEDRA), which captures unexpected events, inside and outside the SC, identifies and propagates event detection information through the supply chain network.

## 1.3 Previous Research

Inter-Organizational Information (IOS) systems cross organizational boundaries in order to enable information flow (Hong, 2002). According to Hong (2002) IOS adapt to the need for agile SCs as they provide an electronic framework for processing, sharing and communication. IOS started initially with the development of EDI (Electronic Data Interchange) and the flourish of EDI s/w, VANS and standards, as adhering to EDI standards was considered an important aspect for organization business and process integration (Williamson *et al.*, 2004; Angeles & Nath, 2001). However Golden and Powell (1999) argue that EDI restricts the flexibility of suppliers with smaller economies of scale to achieve this readiness. In a more integrated approach ERP systems, developing from MRPII, promised transparency and visibility across the SC (Akkerman, Bogerd, Yucesan & van Wassenhove, 2003).

Expanding IOS on the events paradigm, researchers have developed Event–Condition-Action technologies to support event monitoring and reaction when rules and patterns are matched (Chakravarthy & Mishra, 1994). The ECA concept was generalised towards the Event-Trigger-Action methodology (Lam & Su, 1998) to trigger specifications that relate events with rule actions. These rules include granules of logic and can be extended to executable code that corresponds to an event or a set/pattern of events (Nagarajan, Lam & Sue, 2004).

Research on event patterns as they are formed during SC operations, has proposed modelling notations in the form of PetriNets (Liu, Kumar & Van der Aalst, 2004) or UML for describing event proxy structures (Gupta, Hartkopf & Ramaswamy, 1998). Cleland-Huang proposed an Event Based Traceability method to track changes in systems artefacts (Gupta

[1] SCOR is the official reference Supply Chain model proposed by the Supply Chain Council (see Chapter 2).

Hartkopf & Ramaswamy 1998; Cleland-Huang, 2003). The SIENA platform designs and implements a generic event notification service for subscription and publishing of events (Carzaniga, Roseblum & Wolf, 2001). Also the Event Driven Response Architecture, proposed by Dheap & Ward (2005), is a software framework designed to dynamically select service providers during run-time.

## 1.4 Thesis Scope

The thesis addresses the issue of how unexpected events during Supply Chain operations are identified, classified and inter-related in order to compose patterns of events that are disseminated to the SC network and how an Information Systems architecture can address this issue. There are three main aspects to examine before approaching the problem. The first involves the investigation of current trends and theories for efficient Supply Chain operation; the move towards the e-SC paradigms and the risks that threaten the balance and determine competitiveness in extended Supply Chain environments. The second aspect is the event paradigm, where events are defined in a SC context and modelled using different notations. Finally IS in the Supply Chain are examined with focus on event-driven mechanisms.

## 1.5 Research Methods

To achieve the first objective an extensive review of literature and research on events and event patterns research was performed. A framework that surrounds the events concept was designed and event relationship types were distilled from this generic framework to support event pattern identification.

The second objective was achieved through a two stages survey. Initially a survey was performed using economic and management journals and newspapers to identify and classify events. In the next step a questionnaire was formed and distributed to practitioners of the Supply Chain Council. The aim of the questionnaire was to elicit information about the frequency of unexpected events during SC operations. The questionnaire contained a rating scale and an open question. At that stage the results were statistically analysed using general Data analysis and Hierarchical Cluster Analysis. Data analysis contributed to determine whether listed events should be formally classified and Hierarchical Cluster Analysis assisted in identifying groups and dynamics between events in order to develop the unexpected events ontology.

To achieve objective 3, an Event Pattern Notation was designed using BNF for syntactical representation and the SCOR model as the roadmap to present event patterns. EPN was evaluated based on three comparative evaluation criteria sets against three event languages (STRAW-EPL, RAPIDE-EPL, DATALOG) and Web services specifications (WS-EVENTS). The criteria sets span over general evaluation and event and context specific requirements.

Finally, to address the fourth objective an event driven architecture was designed based on the interoperation of IT paradigms, such as Web services, software agents and Message Oriented Middleware. The proposed architecture was then evaluated by simulating its operation in two real world scenarios. These scenarios were developed based on the information elicited from interviews that were conducted in a frozen foods company. The results aimed to validate the agility and speed as improvements brought on by the SCEDRA approach.

## 1.6 Thesis Outline

This thesis consists of six chapters. Chapter 2 provides a deep insight into the relevant literature and research background. Initially, SCM is described in order to set the ground for the disciplines of Supply Chain and Supply Chain Management, with references to traditional SC practices that embrace the concept of unexpected events through Risk Management. E-Supply Chain drivers that transform current business structures are discussed and the paradigm of agility is presented. The role of Information Systems in the SC is described presenting a roadmap for IS and the business logic for IS integration. This is followed by an investigation and classification of unexpected events through literature and questionnaire survey. The chapter concludes with a description of events classification.

The following chapter, describes the framework that surrounds the concept of unexpected events and the theory that was developed to define events relationships and events patterns. Initially the connection between SCEM and SC networks is described and the definition of *event driven Supply Chain Network* is given. The following sections describe events relationships and how Cluster Event Patterns are formed. This is followed by the investigation for identifying and classifying unexpected events through a journal investigation and a questionnaire survey. The chapter is concluded describing the unexpected events classification.

Chapter 4 builds the Event Pattern Notation based on the unexpected events classification that is presented in chapter 3. EPN syntax and components are described while examples from the industry are modeled in EPN. This is followed by a requirements framework against which the notation is evaluated. The fifth chapter is divided in two main sections. Initially SCEDRA is described in terms of its technological components, construction principles and information schema. The second section described the evaluation stage of SCEDRA based on two real world scenarios. The thesis is concluded with the overall summary of the research, its contributions and implications and the presentation of limitations and the areas for further research. Figure 1.1 models the structure of the thesis based on the research objectives.

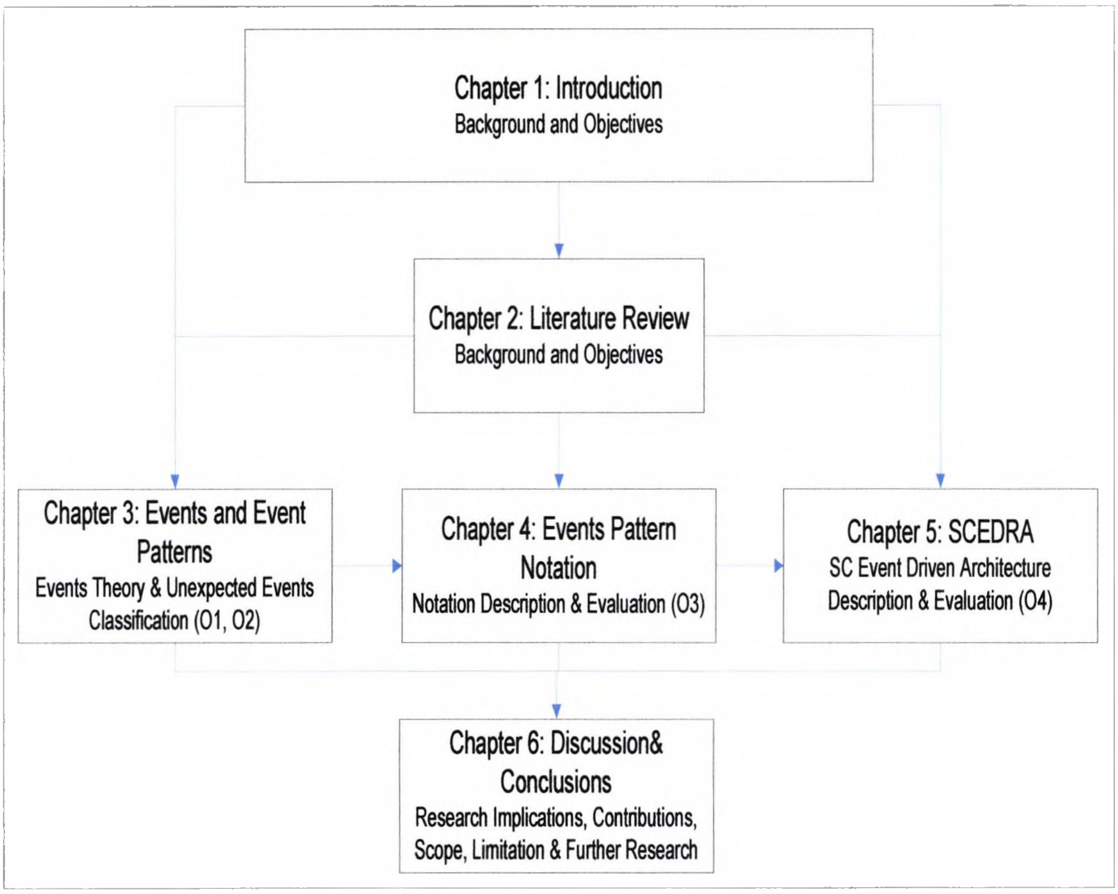



**Figure 1.1:** ***Thesis Structure***

## 1.7 Contributions

This thesis makes contributions to the event-driven information systems paradigm and the discipline of SC. Secondary contributions refer to areas that although were part of the research scope, were not intended beneficiaries.

- Events: the concept of events was examined in this thesis within the context of Supply Chain. A theoretical investigation of unexpected events within SC operations was initially conducted followed by an empirical evaluation of their frequency. A taxonomy classifying unexpected events was proposed and an Event Pattern

Notation modelling events patterns in the Supply Chain was designed.

- Supply Chain: the Supply Chain concept was expanded with the introduction of composite events that span across all SC components. Hence the Supply Chain is re-formed into an integrated network where operations are conceptually centralised.

- Information Systems: a Supply Chain Event Driven Architecture is proposed based on the operational interoperability achieved using Web services (Pavlou & Karakostas 2005b). Operations are exposed and consumed between participants. Additionally, SCEDRA is an event-driven architecture that is focused on a particular domain (SC).

Secondary Contributions

- SCOR Model: the design of the events classification pointed the need to extend current Supply Chain processes towards external factors that determine business operations. This thesis addresses the fourth level of SCOR which is beneficial for companies which apply SCOR practices.

- Industry: this thesis proposes an architecture that allows industries to operate flexible and agile SCs with minimized delays.

## 1.8 Chapter Summary

Operating in an open enterprise environment agility and flexibility are important aspects that determine the success of a SC to adapt to new environmental conditions. Risk is incorporated within any Supply Chain and is associated with multiple causes (Zsidisin, 2002). Unexpected events, such as physical disasters or production failures create waves of turbulences that span through the Supply Chain Network (Peleg-Gillai *et al.*, 2006). As current research has not focused on the concept of unexpected events within Supply Chain operations, this thesis describes a framework that investigates events and their relationships and proposes an event driven architecture to support the e-SC paradigms (O' Leary, 2002). The classification of unexpected events considers risk factors both from inside and outside the SC extending the current operational and business scope of SCOR model. EPN describes event patterns that involve events from diverse origins supporting the dissemination of combined event patterns. SCEDRA uses EPN to identify form and disseminate event patterns.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Introduction

This thesis investigates unexpected events in Supply Chain processes by proposing an architecture and a framework for analyzing and managing events impact. Addressing the main objectives requires extended study and comparative analysis of the existing literature surrounding the theoretical background of the particular research area and of the related research work.

Originating from the shift of manufacturing management towards SCM, two main disciplines underline the theoretical background of this research; SC Event Management (SCEM) and Information Systems (IS) support for SC activities. Traditional SC practices embrace the concept of unexpected events through Risk Management whereas the e-SC paradigm has developed theories and techniques to respond to such events using flexibility and agility (sections 2.2-2.4). Harvesting the benefits from the move towards e-SC requires the adoption of an IS strategy and platform that need to comply with certain SC requirements (section 2.5).

By combining the concept of Risk Management with agility within e-SC, the discipline of SCEM is formed that utilises event-driven concepts (2.6). To develop an event ontology and propose an event pattern notation, is important to examine the disciplines surrounding SCEM and the related IT paradigms (section 2.7). The main focus of this research is from the SC systems' perspective, thus the framework for incorporating IT in SCEM is examined. Finally, section 2.8 discusses some specific event-driven architectures.

## 2.2 Supply Chain & Supply Chain Management

The core discipline of this thesis, the SC, is presented in the following section describing the gradual move towards the era of e-SC.

### 2.2.1 The Need to Define Supply Management

The need to define and establish the concept of SM emerged from the National Association of Purchasing Management-NAPM, (whose name was subsequently changed to Institute for Supply Management), as the meaning and new implications of the related professions had to be reconsidered (Kauffman, 2002). No precise definition of SM was given, thus all related disciplines, purchasing, procurement, supply Materials Management (MM), logistics, SC were incorporated in the term SCM. This is obvious especially through the definitions given to procurement and purchasing. Leenders *et al.* (2002), define purchasing as the whole process of buying including the identification of a certain need the identification and negotiation with a supplier for delivery. Expanding the above definition procurement involves the elements participating in purchasing such as stores, traffic etc. (Leenders *et al.*, 2002). Approaches to MM are either holistic or internal. Arnold (2001) describes MM as the coordinating function which balances and controls materials flow, aiming to maximise available resources to achieve maximum customer satisfaction. A simpler single dimension approach is that MM activities involve the inbound movement of raw and first materials (Coyle, Bardi & Novack, 2000). The different approaches in the basic disciplines that compose the concept of SCM do have a common point; the establishment of linked relationships that add value to the various downstream levels (Kauffman, 2002).

What might seem a problem however in the overlap described above, is actually a challenge in defining common SC parameters for marketing and production management. Kauffman's approach (2002) is the effort to unify the elements and disciplines that compose SCM. The first step is to establish a SC strategy, which according to Cavinato (2001) revolves around the resources an organisation needs to accomplish its strategic objectives. The SC strategy will in turn have to support a corporate strategy which will be evaluated under certain constraints and challenges. Within this framework the most appropriate strategy combinations will be selected (Leenders *et al.*, 2002). The main elements that need to be considered as inter-dependent variables are product, cost, relationship and access. Relationships refer to suppliers dynamics, alliances and partnerships, whereas access refers to gaining use of the product provided, including the added value from the in-between stages (Kauffman, 2002).

### 2.2.2 Supply Chain & Supply Chain Management

Already eight years before Kauffman (2002) set the foundation to unify all disciplines and elements that compose SM, Poirier and Reiter (1996) defined the Supply Chain as a system that provides a channel for companies and organizations to deliver their products and services to their final customers. The structure of the SC is linear and typically consists of the following entities: suppliers, manufacturer, distributors, retail outlets and consumers. Reflecting the commercial and market needs of the electronic era, Handfield and Nichols (1999) define the SC as the association of all activities dealing with the transformation of raw materials to finished goods and the transition of finished products to consumers with information and material flow. Including the financial aspect Ayers (2001) defines the SC as the combination of physical, information, financial and knowledge flows, aiming to satisfy the final consumers via a link of suppliers.

The effort to achieve competitive advantage by analysing and evaluating the supplier-customer relationship and the activities that aim to improve this relationship is defined as Supply Chain Management (Handfield & Nichols, 1999). This view is enhanced by Lambert and Cooper (2000), who consider SCM both in upstream and downstream flows. Adopting a user-centric approach, Ayers (2001) identifies SCM in the design, planning, and operational management of SC processes to satisfy consumers' needs. Other researches define SCM through the needs that derive from SC activities like, product and company modelling, contracting, scheduling, planning and organising resources and analysing costs and resources usage (Laurikkala & Pajarre, 1999).

Ross (2003) examines SCM from three different perspectives tactical, strategic and Web enabled. Tactical SCM draws on value-enhancing activities such as product/service processing and support activities aiming to integrate and synchronise these operations at the most cost efficient way. Strategic SCM is reflected on the connectivity level of the value-enhancing activities aiming to develop a network between the SC partners that will operate smoothly illustrating innovation capabilities, increased reliability and reduced cycle time (Ross, 2003). Emphasizing on operational advantages, Zhang and Lado (2001) state that IT addresses operational inefficiencies in order to gain a competitive edge. Web enabled SCM expands the IT level to Web based applications. Web enabled SCM refers to the use of the Web to connect partners, increase efficiency and reduce cost. An example of cost reduction potentials is given by Costello (2001) pointing that Web enabled applications allow transactions to run at approximately 20% off the network cost.

The above definitions reflect the different approaches towards SCM, as a result of the different dynamics under which every research area and organization operates. As the procurement based NAPM evolved to the supply based ISM is important to demonstrate the evolution of procurement towards SCM. The figure below illustrates the four conceptual perspectives for the evolution from purchasing to SCM (Larson & Halldorson, 2002).

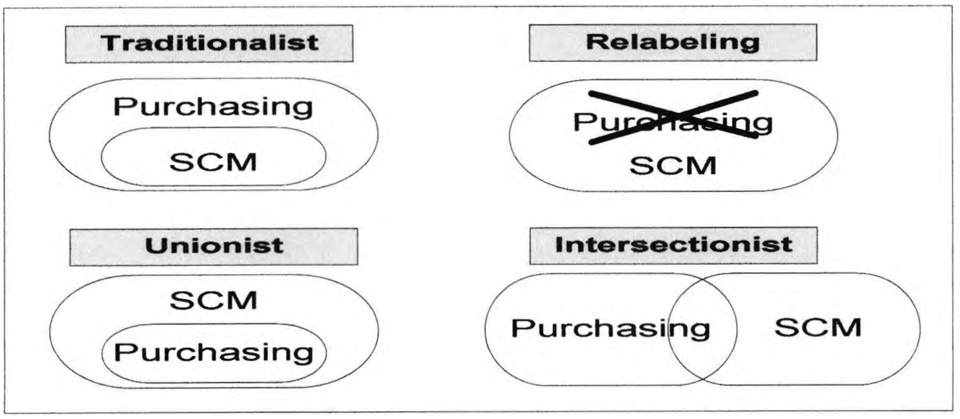



***Figure 2.1: Four Perspectives on Purchasing Vs SCM (Larson & Halldorson, 2002)***

Larson and Halldorson (2002) categorise these perspectives as:

- Traditionalism: SCM is a strategic part of purchasing and the emphasis is placed on supplier alliances and partnerships.
- Relabelism: the trend, which according to researches and practitioners such as Giunipero and Brand (1996) who consider that purchasing has involved to SM in some cases and to SCM.
- Unionism: the perspective under which purchasing is part of SCM, including more disciplines, logistics, marketing, operations management.
- Inter-sectionism: this perspective involves a number of disciplines associated with SCM, purchasing, logistics, marketing, organizational behaviour, strategic management, best practices etc. (Croom, Romano & Giannakis, 2000). SCM acts as a coordinator among them including elements from all the above disciplines.

### 2.2.3 A Formal Representation of SC Processes: the SCOR Model

The SCOR model is a product of the Supply-Chain Council (SCC), an independent, not-for-profit, global corporation with membership open to all companies and organizations interested in applying and advancing the state-of-the-art in supply-chain management systems and practices (SCC, 2003).

The SCOR-model provides a unique framework to connect business processes with metrics and best practices. SC operations are described through the linkages of five processes

Plan, Source, Make, Deliver, and Return. These processes are considered to be generic in any type of SC, regardless of the type, size or geographical location. The model spans through all customer and market interactions and product transactions. However, due to the diversity amongst companies and SCs the SCOR model has certain limitations. Certain business processes outside these boundaries are not described, such as sales and marketing, product development, elements of post delivery customer support. The assumptions the model is based on, without explicitly addressing are: training, quality, IT and the presence of administrative tasks and roles (SCC, 2003). Figure 2.2 illustrates the order and the links between the five processes:

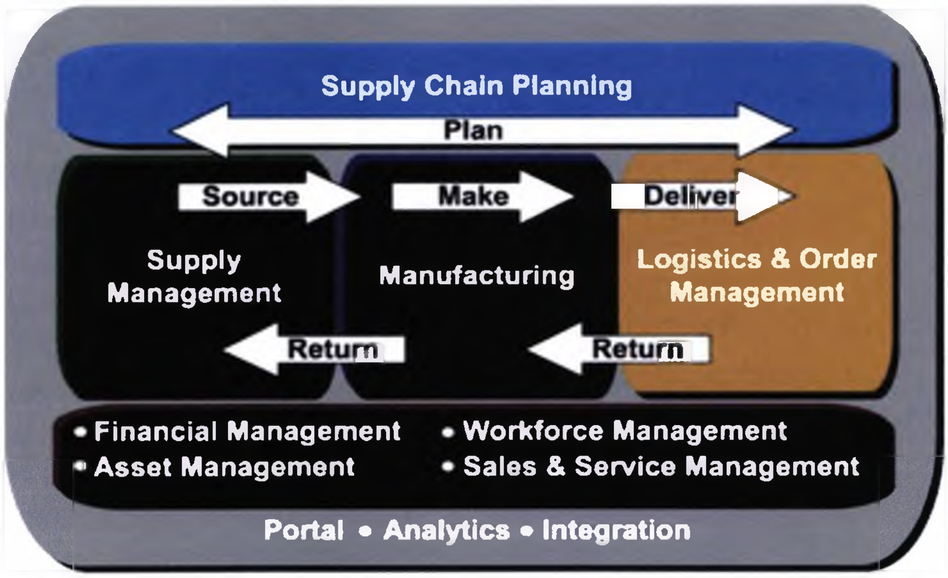



***Figure 2.2: SCOR Processes***

The model complies with all production type paradigms, Make To Order (MTO), Engineer To Order (ETO), Make-to-Stock. Detailed description for all processes is given for all different paradigms.

The PLAN process spans through all processes and connects their activities. Tasks in the PLAN process balance resources with requirements and establish/communicate plans for the whole supply chain, including Return, and the execution processes of Source, Make, and Deliver. Also, activities for managing business rules are set, measuring SC performance and methods for data collection, and inventory measurement, regulatory compliance are defined officially. Finally PLAN activities ensure the compliance of the SC unit plan with the financial plan (SCC, 2003).

The SOURCE process is responsible for scheduling deliveries, identifying sources, deal with supplier payments and transferring products. Managing inventory is a primary task that ensures the alignment with the original PLAN activities (SCC, 2003).

Following on the SOURCE activities, MAKE processes involve scheduling of production, issuing product, testing, packaging and release for delivery. Equipment facilities and production network are also part of the MAKE process and in the cases of Engineer To Order, finalization stage is dealt within this process (SCC, 2003).

DELIVER activities do not always follow on the MAKE process but are scheduled according to the production type followed. They involve all management steps from processing customer inquiries and quotes to routing shipments, invoicing customers and selecting carriers. Regarding warehouse activities, processes are described from receiving and picking to load and ship product (SCC, 2003).

There are different reasons to return a product, hence three different RETURN activities are described including the cases for, defective products, maintenance, repair and overhaul and excess products. All steps are described from source to transfer and receive products (SCC, 2003).

The model description is very detailed illustrating each process in terms of planning, executing and enabling. The SCOR model spans through three levels of detail, starting from process definition, moving to defining process types and finally to defining process elements. However implementation practices are not in the model's scope, as IT and change management practices differ between organisations and SCs (SCC, 2003).

Within this research the SCOR model is used to map events on processes and is considered an official reference model for SC processes. Also, through this thesis there is an attempt to expand the model towards the forth level of detail, as the proposed events' ontology consists a framework for SCOR practices implementation.

## 2.3 From Supply Chain Management to e-Supply Chain Management

Expanding on the SC concept this section describes electronic paradigms that assist and drive the transformation of traditional SC practices towards the e-business era.

### 2.3.1 e-Supply Chain Paradigms leading to e-Supply Chain Management

Moving into the e-business era requires new ways of doing business, as new driving forces determine the competitiveness between SCs. A survey conducted by the Yankee Group revealed that reduction of transaction processing costs, improving order accuracy, reducing inventory or increasing inventory turns and improving planning and scheduling capabilities are basic concerns among companies about integration within the supply chain (Derome, 2003). O' Leary (2000) addresses the above issues describing three SC driving forces towards the new era.

- Vendor Managed Inventories: Sale control shifts back from the retailer to the vendor, allowing the vendor to monitor the demand and view product stock levels. The paradigm has been successfully applied by Procter & Gamble (McKenney & Clark, 1995).

- Build to Order (BTO): In the effort to overcome incased inventory costs and the risk of products getting dated, the traditional Build to Forecast (BTF) production schedule shifts to BTO. Information flow substitutes product flows, avoiding warehouse overload and reducing cost and risk factors.

- Merge in Transit (MIT): A logistics challenge is reducing transportation cost and inventory expenses as well as increasing delivery efficiency. MIT is applied either by merging and forwarding the products or by synchronizing their time of delivery. The aim is to schedule cost effective shipments with reduced lead times.

### 2.3.2 Agility: a new Philosophy for e-SCM

Integrating the above paradigms under one SC, the paradigm of agility is formed. It refers to integrating information systems, organizational structures and logistics processes (Christopher & Towill, 2001). Christopher (2000) defines agility as the ability to manage turbulence in the effort to satisfy the final customer whilst keeping the cost at an acceptable level.

Agility is a prerequisite for SC proactive ness, towards any unexpected risk factors. Risk can be both internal and external to the SC and addressing risk "to" and "from" the SC a coordinated approach between SC participants needs to be established to achieve flexibility and consistency. Christopher *et al.* (2002) argue that current SC risk practices are divided mainly in two categories regarding the way of identifying and addressing risk. Detailed analysis for risk in the SC is in later section.

Traditional techniques follow certain steps which initially consist of risk identification and assessment (Souter, 2000). Risk profiles are established and alerts are programmed based on the particular needs of each industry allowing for the relevant continuity plans (Gilbert & Gips, 2000).

Agile SCs can effectively respond to all types of changes and risk sources, varying from natural disasters to severe delivery delays. Achieving agility is not simple as it requires the efficient management of a variety of disciplines such as, management coordination, supply chain design, information sharing and visibility (Bal, Wilding, & Gunry, 1999) (Crocitto & Youseff, 2003). The concept of agility derives initially from manufacturing where it initially opposed to all traditional rules for standardization (Womack, Jones & Roos, 1990).

However it is evident that speed and flexibility are IT related factors, hence agility depends on the IS supporting business and SC processes (Breu *et al.*, 2001). Extending the IT perspective of agility researchers argue that agility is also the ability to form communicational and operational hubs between trading partners and be able to dis-join and reform new links with different partners based on the market needs and conditions (White, Daniel & Mohdzain, 2005). This view is close to the concept of the VE, and Bal *et al.* (1999) describes agile SCs as virtual teams enhanced with features of VE, such as time compressed business processes (Mason-Jones & Towill, 1999).

### 2.3.3 Reverse Logistics in e-SCM

Complying with the e-SC paradigms new business drivers are created reflecting the need for efficient customer support and customer safety. The RETURN process was added in the 6.0 SCOR version indicating the need to identify policies and practices that maximize efficiency and reduce cost during RETURN. Reverse logistics answer to this need setting an official framework within the e-business processes.

Reverse logistics describe the management of product that is outside a normal distribution and delivery system and the activities of handling products and services after they have been delivered to the customer. According to Dowlatshahi (2000) reverse logistics is a process, during which the manufacturer accepts products from consumers. Reverse logistics activities can be divided into four main categories, manufacturing, recycling, reuse and disposal.

Reverse logistics manage the cost and usage of certain resources, as they extend the life cycle of a product and promote the alternative use of resources. Certain companies already practice reverse logistics, with obvious impact on their cost management. Some of these companies are BMU, DuPont, General Motors and HP (Dhanda & Hill, 2005). Dowlatshahi (2000) has listed the following factors as drivers assisting and pushing towards reverse logistics.

- Commitment to environmental issues
- Successfully developed and implemented ethical standards
- Customers
- Suppliers
- Competitors
- Governmental agencies

The diversity of the factors driving towards the need for reverse logistics is associated with the fact that in many cases where strategic systems do not deal formally with reverse logistics processes, these activities result into incoherent and paper intensive processes that increase decision and processing time and reduce operational flexibility. Thus treating the concept of reverse logistics within the borders of the traditional SCM practices is insufficient. For this reason in this thesis, managing reverse logistics is considered as a driving force towards the new era of e-SCM.

Utilising Web capabilities on SCM, to achieve the above paradigms a new philosophy is developed expanding SCM to e-SCM. A network links partners, resources, information and productive capacities of intersecting supply chain systems exploiting the Internet technologies and using innovative tools (Ross, 2003). e-SCM paradigms such as vendor managed inventories, allow real time update of customers' and suppliers' warehouse stock levels reducing cost and increasing productivity rates (Goodwin, Keskinocak, Murthy, Wu & Akkiraju, 1999). The main characteristic of the e-SCM is information visibility based on partners' collaborative relationships leading to the concept of Supply Chain Event Management (SCEM). SCEM allows companies to gain flexibility and apply/enforce business rules in the entire e-SC network (Nagarajan *et al.,* 2004).

To harvest e-SCM benefits, the security barrier needs to be overcome which prohibits collaboration among e-partners and in extend the creation of the e-SCM network. According to Fodor (2001) the security issue will be solved by addressing the need for confidentiality, integrity, authority and authentication.

### 2.3.4 Supply Chain Networks

Supply chain networks are more complex than supply chains as they spread over the traditional concept of networks allowing for internal links and operational hubs among SC partners that do not exist in the linear SC (Harland *et al.*, 2001). The need for a flexible and more manageable form of SC became evident in 1992, when efficient end-customer service was identified as a requisite for competitiveness (Christopher, 1992). Supply networks are nested within inter-organizational entities and inherit the attributes of traditional networks to form cross-functional links and hubs (Harland *et al.*, 2001). Supply networks like SCs have different dynamics and features. Harland *et al.* (2001) identified a two-dimension framework measuring two parameters, the degree of supply network dynamics and the degree of focal firm influence. Based on the combination of connections between these two features four different patterns are identified classifying networking activities.

Engaging the form and concept of SC, supply networks comprise chains through which goods and services flow from original supply sources to final customers (Lamming *et al.*, 2000). The concept of a logistics network that operates in a virtual environment overcoming interoperability issues is not new. In the past researchers like Pfol and Buse (2000) and Folinas (2001), define VLN (Virtual Logistics Network) as a temporary or permanent association of geographically distributed organizations that communicate with each other initiating logistics services.

### 2.3.5 From e-Supply Chain Networks to the Virtual Enterprise

Expanding on the concept of SCN and exploiting Web advantages, the linear SC is transformed to a dynamic entity the Virtual Enterprise (VE), composing of "collaboration process teams from across the supply chain. This provides business with the potential to maximize resources and achieve order-of-magnitude synergies of significant productive and innovative power" (Ross, 2003 p:320). Walton and Whicker (1996) add the element of short term collaboration defining the VE as co-operation nodes that form into a supply chain in order to address a particular opportunity in the market place.

Within the classification views, duration can be either single-business-opportunity or long term alliances. This classification given by Camarinha-Matos *et al.* (1998) includes broader concepts like, topology/geometry, coordination and purpose. Topology refers to the way of participating in the VE which can be as a single alliance, open market or monopoly. Geometry examines the structure of the VE in terms of being dynamic or fixed. Coordination depends on the type of industry and finally the purpose assists in understanding the motives for joining the VE (Camarinha-Matos *et al.*, 1998). In the single-business-opportunity view the basic requirement for a VE support infrastructure is high configuration and easy definition and modification of user desired behaviour (Camarinha-Matos & Afsarmanesh, 1999).

### 2.3.6 Re-engineering the Supply Chain

Creating a VE from the cooperation of current SC systems requires a change in the participating companies/organizations processes. Their current processes need to be redesigned and in some cases reengineered. However, the term “re-engineered” has often been misunderstood and misused.

Understanding the discipline of re-engineering requires the understanding of the exact concept of business processes. Davenport & Short (1990, p: 11) define *business process* as "a set of logically related tasks performed to achieve a defined business outcome." Processes can be approached from three dimensions: entities, objects and activities. Modeling the supply chain processes had to be done taking under consideration all dimensions that business processes inherit.The concept of Reengineering business processes was introduced by Hammer fifteen years ago when he published the article entitled: “Reengineering Work: Don’t Automate, Obliterate”. The concept of Business Process Reengineering (BPR) was defined as “the fundamental rethinking and radical redesign of business processes to achieve dramatic improvement in critical measures of performance” (Hammer, 1990 p: 104). To obliterate referred to disposing the unnecessary from business processes and replace these elements with entirely new and more effective processes (Poirier & Reiter, 1996).

There are two applied approaches when reengineering a project, the technology enabled approach and the clean slate reengineering method (O’ Leary, 2000). The technology enabled reengineering approach is driven by a particular technology that will perform the reengineering and the reengineering choices are based on this technology. On the other hand, in the clean slate approach the system starts from a clean slate and the IT solution to be chosen meets the company’s business requirements. The advantage when adopting a technology based approach is the starting point which sets certain bounds in the reengineering design analysis and design effort allowing designs to be cost effective. The main disadvantage is the use of a technology that other organizations can also access, thus competitiveness is compromised. Clean slate reengineering has no limitation in the use of an IT to support the reengineering effort which is treated separately from the technology implementation. The main drawback of a clean slate approach is the lack of bounds for the potential designs and the chance that there might not be a feasible IT solution to support the reengineering project (O' Leary, 2000).

To achieve the objectives of efficiency, SC processes driven by the event engine proposed by this thesis (SCEDRA) a certain degree of process re-engineering is required. The most suitable re-engineering approach is selected based on the characteristics of BPR approaches described on the previous sections. Based on the fact that a VE requires an integrated IT solution which specifies the boundaries of the reengineering project the technology enabled approach was considered more suitable for the proposed architecture. However, as examined in later sections, recent research has introduced more balanced and IT oriented approaches for redesigning processes (Manthou, Folinas & Vlachopoulou, 2005).

## 2.4 Risk Management and SCM

As agility has developed into an ideal paradigm for SC this section addresses the need to define agility within the particular research arena.

### 2.4.1 The Concept of Risk in the Supply Chain

Moving into a VE certain attributes of the re-engineered SC paradigm are implemented, increasing the vulnerability of the SC. Just in Time (JIT) practices increase the dependency between SCN members stretching the need to address risk features which are created (Christopher *et al.*, 2002). In the context of e-SC, risk is defined within the framework of understanding risk factors deriving from the e-business umbrella. As was mentioned in previous section, e-SC assists in implementing e-business activities, thus the definition of risk should be placed in the same framework. Indeed, (Christopher *et al.*, 2002) distinguish between two main risk categories: supply chain and external risk. The former refers to the risk deriving from the interactions and transactions amongst the members of a SC, whereas the latter refers to environmental and industrial risks targeted "to" the SC (Souter, 2000).

Traditionally external risks are part of the risk management and risk contingency plans and they can arise from various sources (Christopher *et al.*, 2002):

- Terrorist attacks (11th of September NYC, 7th of July London)
- Natural disasters (Hurricane Katrina, Tsunami)
- Industrial actions (fuel price protest in the UK September 2000)

SC risk appears in different forms resulting from different sources, such as:

- Lack of ownership: outsourcing and dispersing process centers affects the level of control, a feature which reflects on inventory and stock levels and passes on to the next member of the SC.
- Chaos risk: complexity and uncertainty result in mistrusts, interventions, distorted information hubs, causing a chain of continuous disruptions through the SC.
- Just-In-Time relationships: McGillivray (2000) argues that complying with the JIT paradigm, entails the danger of stock block-outs and reducing competition flexibility.

Figure 2.3 describes the connections between internal and SC risk, illustrating the interrelations between them as they move to lower abstraction levels. Expanding the hierarchy of Figure 2.3, Svensson (2000) developed a structure to distinguish between SC risk sources, the direct (atomistic) and indirect (holistic) events. Direct risk appears between the organization links and affects participants based on the linear structure of the SC. On the other hand, indirect risk appears anywhere in the SC and affects participants regardless of their linear and sequential order. Svensson investigated the effect of direct and indirect risk in the SC and argues that executives are mostly aware of direct sources of risk, failing to identify links between indirect sources of risk.

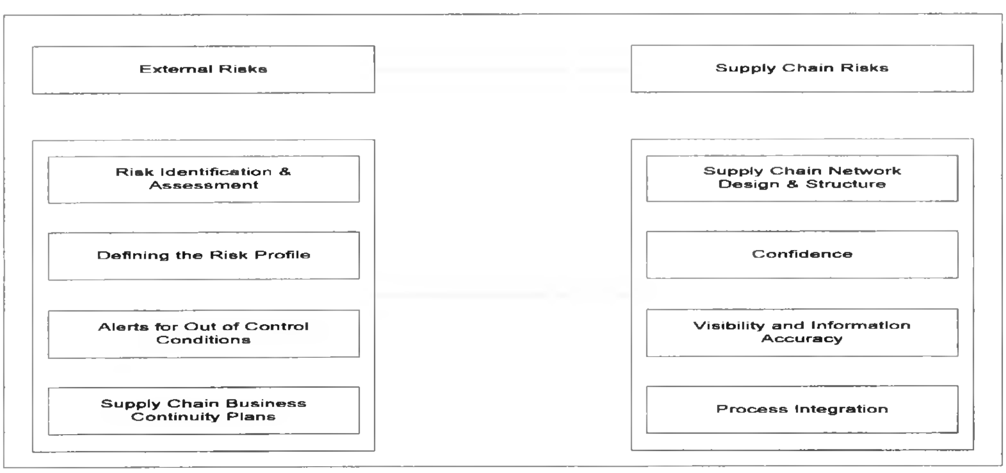



***Figure 2.3: Risk Management & SC (Christopher et al., 2002)***

This thesis proposes that the concepts of agility and risk are strongly related as agile SCs react proactively to external or internal risk factors. Addressing risk in the SC requires the early identification of risk factors. Traditional practices focus on specific risk sources, failing to react when a continuity plan has not been established. In the e-business era, creating agile SCs is a requisite for the SC to gain competitive advantage. However, these practices need to be designed under a different spectrum compared with the traditional theories and practices. All contemporary risk sources have to be examined and addressed, which is an impossible task as the new holistic framework for business entails dangers that have not yet been revealed. The challenge is to identify a manner of addressing risk, incorporating the knowledge gained from traditional practices, whilst supporting the agility paradigm. Expanding on the above question the concept of SC Event Management was formed.

## 2.5 Information Systems in SC

Achieving the e-SC paradigms that drive towards the new business era, IS needs to be adapted or customized according to the needs of each SC and organization. Adapting IS captures the needs for change and IS usage needs to be identified. Interorganizational Information Systems (IOS) achieve cross border operations supporting agility inside a SC, thus for the purposes of the particular research IOS is the main systems umbrella. The roadmap for integration of IOS in business processes is also presented in an effort to achieve consistency and integration.

### 2.5.1 Inter-organizational Information Systems for Agile SCs

To increase business efficiency, companies redesign and reevaluate their internal business operations (Williamson, Harrison & Jordan, 2004). Techniques such as MRPII and JIT assist in the efficient process operation (Tan, 2001) but narrow their focus to discrete functions within the organization, excluding external linkages. As a result, holistic risk identification is not feasible, thus agile SCs are difficult to implement. Focusing on the need for agile SCs presented in previous the section, it is essential to identify the appropriate IS.

The concept of Inter-Organizational Information (IOS) systems is defined as the ICT that crosses organizational boundaries in order to enable information flow (Hong, 2002). IOS adapt to the need for agile SCs as they provide an electronic framework for processing, sharing and communication. IOSs consist of several IT components and resources including communications networks, standards and human factor skills. Hong (2002) argues that with the involvement of IOS, IT acts as a cooperation enabler and not as a competition weapon.

IOS started initially with the development of EDI and the flourish of EDI applications, VANS adhering to EDI standards were considered an important aspect for organization business and process integration (Williamson *et al.*, 2004) (Angeles & Nath, 2001). However Golden and Powell (1999) argue that EDI restricts the flexibility of suppliers with smaller economies of scale to achieve this readiness. In a more integrated approach ERP systems, developing from MRPII, promised transparency and visibility across the SC (Akkerman, Bogerd, Yucesan & van Wassenhove, 2003). Expanding on the concept of integration IOS, SC strategic partnerships allow for information integration and standardization through the use of XML.

### 2.5.2 A roadmap for IS integration

To adopt an IT solution for VE operations requires mapping this effort on a framework to achieve efficiency and consistency between the members of the SCN. To support a Virtual Logistics Network, Manthou, Folinas, Vlachopoulou (2005) propose a framework to integrate logistics processes using a methodology that can be used as a roadmap supporting efficient virtual partnerships. This framework supports the main IT paradigm's adoption in logistical operations.

The proposed architecture by Manthou and colleagues (2005) defines a platform to support VLN addressing at the same time the issue of logistic processes modeling and integration and creating common standards for the development of the proposed framework. The integration of logistics processes is achieved via a roadmap supporting efficient virtual partnerships. The roadmap consists of five main steps covering a wide spectrum from defining and establishing ICT standards, to deploying business vocabularies by virtual network partners.

The first step refers to determining and establishing technical and communication standards that support data and information transmission between partners. This task refers to a selection of protocols and techniques for message management. Both asynchronous and synchronous communication tools are suggested. The second task involves the modeling of logistics information regarding both data and processes. UML diagrams are used to communicate technical and management knowledge and XML schemas enable the coding of information being exchanged. During the third step the adoption of common business vocabularies is addressed. The requirement for a particular message initiates the search for a specific XML schema in the data repository but when required the vocabulary can be created from scratch. The next step deals with the dissemination of business vocabularies as they are published on a Logistics Service Provider (LSP) and can be downloaded by supply chain partners. The last step involves the deployment of the vocabularies by the VLN partners. The following figure describes the above approach through an example from the agribusiness sector in Greece. In the example of Figure 2.4 the involved members have created a network operating over the internet using the VLN-Mod concept.

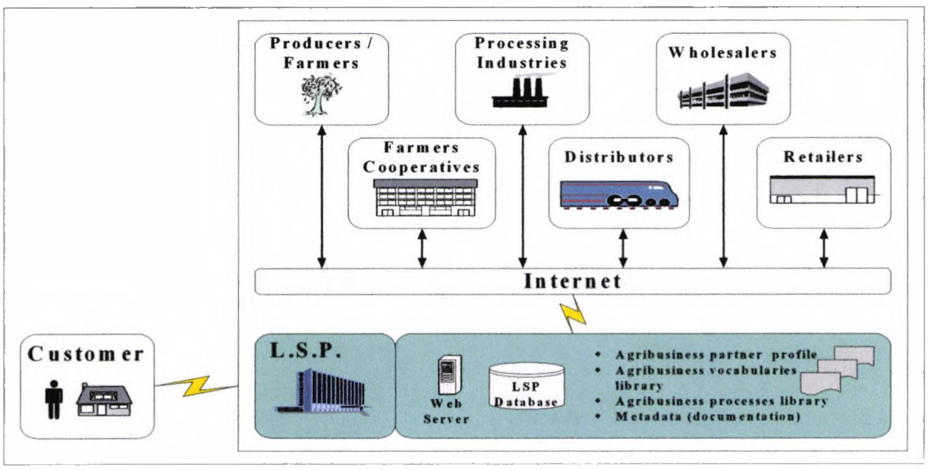



***Figure 2.4: Integration in the Greek Agribusiness Sector (Manthou et al., 2005)***

The proposed framework addresses issues that complicate the creation of a VN and sets the basis for communication overcoming geographical boundaries. However certain difficulties need to be overcome, such as agreeing on the common standards and disseminating the agreed standards to potential partners that do not currently participate in the VN. One of the main challenges is how to overcome interoperability in a inexpensive manner and in a large company scale. Additionally, as the main difficulty in defining a framework for IS adoption is the agreement of common standards the issue of setting this basis rises. The challenge is to incorporate business logic in IS within the context of SC, while at the same time interoperability between systems does not restrict the operation of IOSs.

### 2.5.3 Business in IS to support SC operations

Based on an agents approach, MASCOT supports SC operations (Sadeh-Koniecpol *et al.* 2003). Agents are customisable decision support tools acting as coordination and collaboration wrappers. These wrappers relate to management modules connected to a particular SC entity. Agents provide an open communication and coordination interface between modules from different SC entities, or between entities within the same organization. Additionally they can be customised to users at different levels to manage and evaluate different SC solutions. A MASCOT agent can have different roles, such as serve as a coordination wrapper for SC planning and scheduling activities. Events involve incoming orders, requests for bids etc. and are received from the MASCOT agents. They are then posted on the agent's event queue and handled by the event mechanism. The mechanism ignores events that cannot affect the solution and allows handling conditional events.

### 2.5.4 Web services logic in SC

Towards the effort for systems interoperability in the SC the Web services concept has emerged. Web services are based on open architecture and on widely accepted protocols and standards (Crauldwell, 2003). This factor makes the creation of a lock-in-vendor solution difficult and hence minimises the risk of excluding small partners from the supply chain. The main characteristic of Web services is that they manage to overcome interoperability issues. This is a factor that when exploited appropriately, can set the basis for communication and data exchange between different operating systems. Additionally Web services can leverage existing systems by utilising legacy applications, as they are reusable software components (Pavlou & Karakostas, 2005a). Web services can be either a complete application or a functional component of a larger solution, which affects the flexibility of their use in supply chain software systems (Freeman & Jones, 2003). Web services can assist the creation of "virtuality" in the supply chain, where companies create a partnership that will enable them to cooperate effectively and dominate the market (Evans, 1995). The first step to achieve virtuality is the internal reengineer of the supply chain processes in order to guarantee consistency between all supply chain partners. To redesign the supply chain processes in order to comply with the e-supply chain paradigms is important to take under consideration the advantages of network connectivity and how the use of a network can result in adding value to the supply chain (El Sawy, 2001).

IOS in the SC should be designed addressing the issues of interoperability and systems' integration. Web services allow rapid creation of VEs, or virtual teams, as partners can form linkages regardless of their operational systems and software (Wu, 2004). These dynamic features in combination with the fact that Web services assist to overcome interoperability issues amongst partners, supports agile SCs.

An early effort to encode application business logic for Supply Chains using Web services is specified in WS-I Basic Profile 1.0, where the basic features are located on the *Web services Stack*. The stack consists of three layers each representing one of the fundamental functional areas of a Web Service instance: the data layer, the SOAP message layer and the transport layer (Werden, Evans & Goodner, 2002).

Further investigation on the Web services role during SC operations was performed by Pavlou and Karakostas (2005c), identifying role patterns of services that participate in SC operations. A formal representation of a framework describing the steps to integrate Web services with business logic is described by Folinas, Pavlou and Karakostas (2006), where partner logic is integrated with workflow processes within the operations of a Virtual Organisation.

## 2.6 Supply Chain and Events

The concept of Supply Chain event management (SCEM) was first introduced as a term by AMR Research in 2000. SCEM refers to systems that monitor and flag events that disrupt SC operations and react based on set conditions, such as sending e-mail alerts (Barrows & Using, 2003). Five main operations of SCEM systems have been identified by AMR Research:

- Monitoring: tracking and identifying events as they occur during fulfilment processes, source, produce, store etc.
- Notification: when disruptive events are identified alerts are produced that are distributed to the appropriate actors, that can be humans or systems.
- Simulation: being able to measure the impact of an event and to identify the predefined reaction act, is important to simulate the effects of disruptive events.
- Control: design and implement the managerial decisions that will handle unexpected events when they occur.
- Measurement: long-term measurement is required to evaluate the performance of managerial decisions and of the existent SC plans.

The concept of SCEM is not recent as it was originally implemented in the form of tracking systems in Logistics Service Providers (LSPs). Their role has been to monitor orders and production and track disruptions without however providing with alerts or triggers for further action (Teufel, Rohricht & Willems, 2000). Recent systems have included more advanced features in their solutions such as the commercial systems by SAP, i2, Manugistics.

These systems act as an additional business enabler, since they do not aim to substitute existing planning systems. For example SAP Event Manager adds to planning applications by providing feedback from the executed processes (Bodendorf & Zimmerman, 2005). Even though existing systems address the first two main SCEM operations, they do not fulfil their goal as they lack simulation, control and measurement capabilities. Bodendorf & Zimmerman (2005) have identified a list of deficits in current SCEM systems:

- Missing observance of distributed SC structures, such as lacking cross enterprise information processing and external communication.
- No focus on monitoring efficiency, as monitoring activities are mostly concentrated on every order instead of specialising in critical orders.
- No proactive data gathering, as no up-to-date information is collected and the time information about a particular event is not recorded.
- Missing adaptive behaviour, new types of problems are not possible to be identified and this limits the tracking capabilities of SCEM systems.
- Restricted analytic capabilities, as current systems are not able to monitor and analyse data
- Inflexible and complex alert generation, as a result of the inability to track new disruptions.

From the above issues the need for systems that are able to respond to all five main operations in example proactive systems is emerged. Being able to operate within the context of a proactive system the cost of solving specific problems is reduced, as there is a bigger variety of reaction possibilities and certain situations can be improved (Pfeiffer & Weiss, 1992).

Bodendorf & Zimmerman (2005) have identified the four main functionalities a SCEM system must serve. These refer to the main operations that need to be performed in order to achieve full efficiencies in a proactive event based system.

- Gathering order status data: a SCEM system has to distinguish between suborders due to procurement activities and suborders due to LSPs. The system should access the available knowledge databases in order to provide with the appropriate information about planning activities and to be able to communicate with the appropriate actors.

- Proactive monitoring: where the system uses data to monitor orders based on profile information. The concept of critical orders is introduced as CCP, Classified Critical Profile. In order to evaluate the criticality level of an order/suborder certain data is required. This data is categorised based on three main types:
    - Basic data, which is mainly stable.
    - Status data, providing information about orders' current situation level.
    - Decision data, which provides information about disruptive events.

- The third activity refers to flexible monitoring where three main methodologies are used:
    - Evaluation of criticality, where orders are evaluated on a permanent basis according to their CCP.
    - Monitoring priorities, where an evaluation mechanism is used to rate the profile of each order.
    - Random screening of orders, where the order selection is done either randomly or directly.

- Finally, the fourth activity involves data analysis and alert generation signals. Monitoring data is analysed using customised rules, which trigger the status of alert limits when violated.

Addressing agility and implementing SCEM practices can only be achieved when an appropriate IS infrastructure is deployed. To comply with business requirements while overcoming technical limitations and challenges, requires effective mapping of business requirements on the system.

## 2.7 Technologies Supporting SCEM

Events are a general concept that can be approached from different perspectives depending on the operational environment. In this section a proposed event approach is described along with related IT approaches. Following the events definition within the particular scope, events notations are presented. This sets the background for event ontology analysis and Event Pattern Notation (EPN) comparative evaluation. Sections 2.7.2 and 2.7.3 describe two main paradigms for event monitoring and rule activation, disciplines which are fundamental for an event driven architecture.

### 2.7.1 Event-Driven Architecture within the Global Event Cloud

Within the operational skeleton of dynamic software systems events are occurrences that maybe serialised or happen independently during execution architecture (Vera, Perrochon, & Luckham, 1999) Lam and Su (1998) categorise events in three types, operation triggered, explicitly posted and timer events. Luckham (2003) expands the above definition towards the VE in both internal and external company level. Events flow is bidirectional and moves to all channels between supply chain partners, e-market hubs, network gateways and firewalls. In the new e-business environment, events occur at a global level and they form a universal framework within which any open organization operates. Luckham defines this framework as the "global event cloud" where "cloud" indicates the lack of a certain order during event traffic. Identifying patterns which are formed from these events is the first step for developing any managing process. IT tools are used to capture events patterns as they occur within the global event cloud. Software and applications which assist to monitor, propagate and issue events create the concept of event-driven architecture (Luckham, 2002). Exploiting the events paradigm in e-SC requires architecture designs to support and comply with the event-driven concept.

### 2.7.2 Event-Trigger-Rule (ETR) Technology

Event patterns prompt a rule to be applied which then triggers an action. Luckham describes pattern rules as reactive rules that initiate the action to be taken when an event pattern is matched (Luckham, 2002). A popular way to express these control flows is using the Event-Condition-Action (ECA) rules (Chakravarthy & Mishra, 1994). ECA rules specify the action to be taken and the guarding conditions of events. The ECA paradigm can be implemented using both Statecharts and Object-Process-Methodology (Reinhatz-Berger, Sturn, & Dori, 2002).

The ETR methodology is a generalisation of the ECA paradigm where event and rule specifications are separated and trigger specifications relate events with rule structures (Lam & Su, 1998). There are three main components of an ETR approach, events, rules and triggers. In ETR approach events are usually operation triggered and occur before, after or during a particular operation takes place.

Rules are a small granule of logic; they are high level specification of executable code that correspond to an event or a set/pattern of events (Nagarajan *et al.*, 2004). They consist initially of a condition which is authenticated in order to execute a particular set of action.

The second element of rules is the set of actions that occur after the condition has been validated and the third component is a set of alternative actions.

Finally, triggers indicate the events which initiate a set of rule at particular occasions. Additionally the structure of the set of rules is determined which can be the composition of four main logic constructs: sequential, parallel, AND-synchronised, OR-synchronised (Nagarajan *et al.*, 2004). Figure 2.5 illustrates the interoperation of events/rules/triggers in the ETR paradigm.

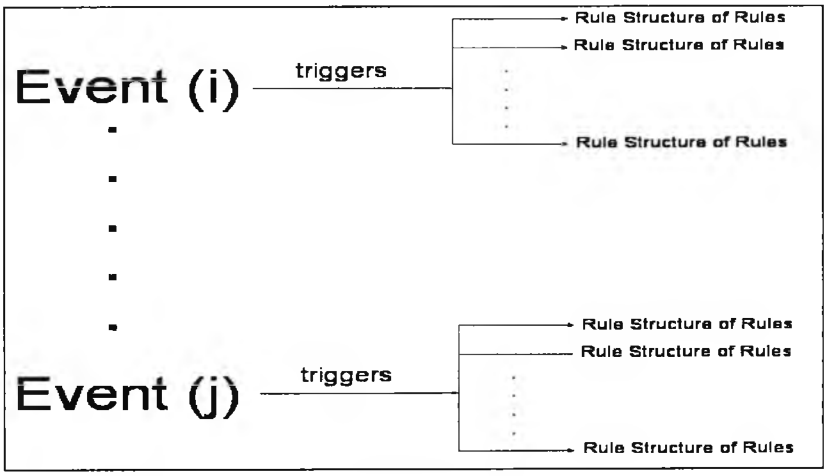



***Figure 2.5 ETR Paradigm ( Nagarajan et al., 2004)***

### 2.7.3 BAM

The concept of BAM (Business Activity Monitoring) is not recent. Real time information displays have been used in the past but mostly on top of individual systems without connecting different applications within or outside a company (Linthicum, 2004). The main characteristic of current BAM systems is the ability to utilise application integration technologies in the effort to link to different information systems. Linthicum (2004) identifies three main categories for BAM technologies:

- Process metrics technologies display real time information in the context of a runtime mechanism. These process metrics provide monitoring capabilities but fail to assist in decision support facilities.

- Passive BAM utilises integration technologies displaying information that can be meaningful to users without allowing them to interact with any changes.

- Active BAM supports interaction between the alert system and the user providing for example the capability to set alerts when required.

BAM has been described as the extension of the traditional theory of Business Intelligence (BI) utilising the concept of event monitoring (Moris & Vesset, 2004). The main difference between BAM and BI is that contrary to BI, the former analyses data from a variety of applications without relying solely on data warehouses (Hasselt, 2004). Researchers suggest that event based technology adoption rates undergo a certain scepticism as current systems are not equipped to handle event driven operations (Moris & Vesset, 2004). They conclude that in businesses and organizations where decision support systems and review mechanisms are not required the investment on an event based, in this case BAM, solution is not justified. On the other hand the investment is justified in companies that rely on real time information requisition and dissemination such as banks and oil companies.

### 2.7.4 Event Patterns

Illustrating event patterns as they are formed during SC operations requires a solid notation that manages to portray both temporal and causal relationships between events. Two methodologies are presented below, one categorising events under general pattern types, using Petri nets, and a more general approach based on the concept of the Event Notifier Design Pattern.

#### 2.7.4.1 Modeling with PetriNets

A modeling approach towards events patterns organization is through the use of Petri nets (Liu, Kumar & van der Aalst, 2004). Petri nets is a technique used to model problems where more than one domains are involved, allowing at the same time to model time intervals as well. They assist in describing time constraints between events, thus allowing efficient analysis of event and events.

Using Petri nets Liu and colleagues (2004) developed seven patterns to express SC rules of events. Event related rules are formulated as Petri net structures and events reflect places of a Petri net. Causal rules and formulas apply to the proposed structures and Petri net patterns achieve to portray temporal relationships between events. The most basic pattern is the *cause-result pattern*, illustrating the causal link between a *cause* and an *effect*. The case where multiple occurrences of one event occur within a specific time frame causing another single event is represented by the *repeat cause-one_effect pattern*. Other patterns represent:

- Inclusive choice: temporal conditions result into multiple alternative events.
- *1-of-N causes – single effect*: the same single event is a result of an alternative causes.
- *1 cause – N results*: the reverse condition of the above pattern is applied.
- *N causes – 1 result*: the conjunction of multiple causes produce one result.
- *Non – occurrence of an event*: causal events result in the non-occurrence of any result event.

Simulating event patterns with Petri nets allow capturing delay times and combine event patterns creating aggregated events and the patterns they form. However, illustrating time with Petri nets is argued due to complexity, scalability and composition factors. The main disadvantage though is state explosion, as simplicity is Petri nets structure inherits the lack of states and transitions in describing systems (Jenneck & Esser, 2002). Petri nets use a static approach towards events where events are predefined based on a status or a certain attribute: START, COMPLETE. (Wen *et al.*, 2004).

#### 2.7.4.2 Event Pattern Design

The Event Notifier design pattern was an initial approach for an event-based environment proposed by Gupta, Hartkopf, and Ramaswamy (1998). They proposed an object oriented pattern to address behavioural design for general-purpose event notification. Their Event Notifier model is described in UML and is based on the Proxy pattern (Gamma, Johnson, & Vlissides, 1995). Other researches, such as Landis have expanded the Event Notifier model to support asynchronous and many-to-many communication in an event-based distribution environment using the Remote Method Invocation (Landis, 1999).

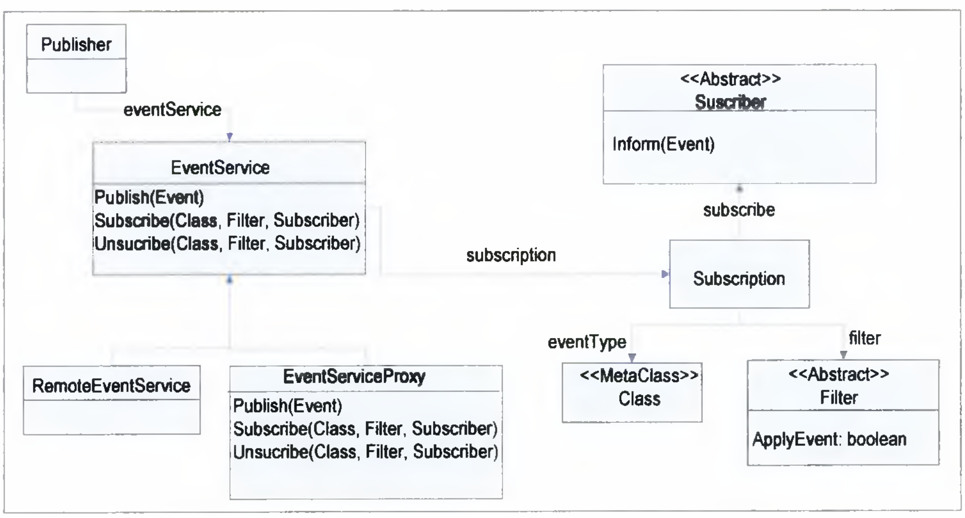



***Figure 2.6** : **Event Proxy Structure (Gupta et al., 2001)***

Expanding Gupta's concept, an initial approach for an event based environment was proposed by Cleland-Huang (2003) for an Event-Based Traceability (EBT) method, to track changes in systems' artifacts. According to Ramesh and Jarke (2001) artifacts are defined as parts of software engineering process. Huang designed an event engine to support artifact traceability based on the Event Notifier Design Pattern.

The proposed EBT scheme implements an event engine that can be expanded to support project management activities by enabling the efficient maintenance of artifacts in a software system. More specifically, the proposed EBT design addresses problems that affect traceability that result from the lack of coordination between team members and luck of visibility (Cleland-Huang, 2003).

The proposed event engine consists of three main components, the Event Server, the Requirements Manager and the Subscriber Manger. Interaction links are established between the components and all include separate data repositories. The proposed scheme addresses the issue of updating artifacts based on changes that occur on the requirements level, thus the requirements manager is responsible for the requirements handling and triggering the change events when they occur. The subscriber manager handles events notifications according to the type of artifact and the change message that has been received. These messages are change notifications published from the requirements manager to the event server. The event server, is responsible for subscription handling, receiving change messages and forwarding the customised messages to the subscriber manager (Cleland-Huang, 2003).

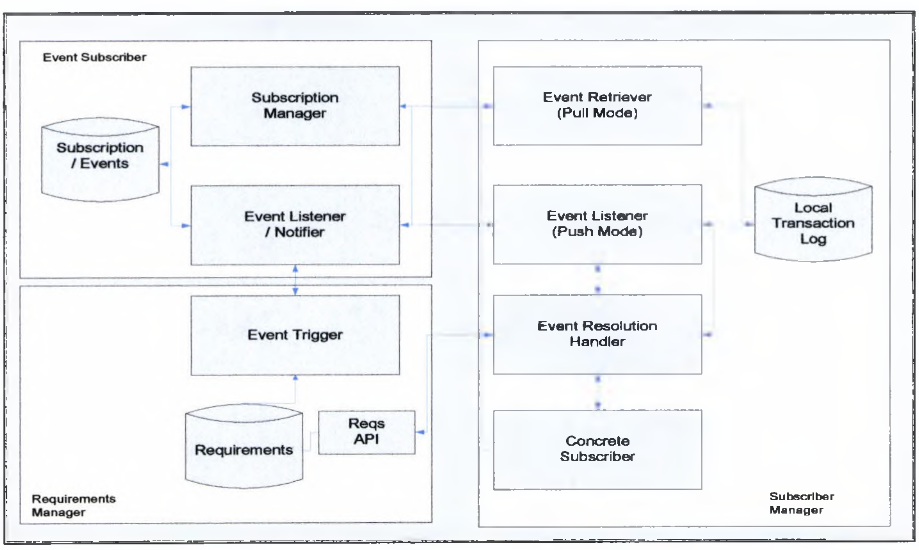



***Figure 2.7 System level model of Event-Based Traceability (Cleland-Huang, 2003)***

The proposed EBT scheme deals with issues similar to those SCN has to address. The problem of poor communication and coordination between artifact owners is an issue that affects members of a supply chain network, in particular when artifacts, in the VN environment SCE, span between more than one participants. However it does not manage the aggregation and composition of change events, as the focus is mainly on traceability (Cleland-Huang, 2003).

### 2.7.5 Event Languages & Notations

Events and event patterns expressions use certain notational and syntactic techniques depending on the context in which events occur. One of the primary objectives of this research is to analyse and propose a notation to express events and event patterns. This section describes two representative languages that are used in a later section to perform comparative evaluation of the proposed notation.

#### 2.5.7.1 STRAW-EPL: Event Pattern Language

This thesis investigates the main components of an event-driven architecture, aiming initially to develop a notation to support event description. A main element on events languages is the concept of event patterns, based on the chaos theory. The concept of event patterns was defined as a template that matches certain sets of events. An event pattern explains the causal or time dependencies, between events and any data/context parameter that might interfere (Luckham, 2003).

STRAW-EPL is a pattern language adopted by Luckham (2003) in his event theory specification. STRAW-EPL uses three main logic components to indicate the relationships between events: AND, OR, → (causal dependency). In any STRAW-EPL specification four elements need to be declared: a list of variables, even types, a pattern and the condition on the context of any match. Table 2.1 illustrates a declaration for a data transfer pattern specified in STRAW-EPL:

Table 2.1 Pattern: Data Transfer (Luckham 2003 p:117)

| *Element* | *Declarations* |
|---|---|
| Variables | Data D, Bit B, Time T, Time1 T1, Time2, T2 |
| Event Types | Send(Data D, Bit B, Time T) Receive (Data D, Bit B, Time T), Ack(Bit B, Time T), ReAck(Bit B, Time T) |
| Relational operators | → (causal) |
| Pattern | Send(D,B,T1)→ Receive(D,B)→Ack(B)→ReAck(B,T2) |
| Context test | T2-T1< 10 secs |

STRAW- EPL is not a high level language, hence not suitable for commercial applications. It provides however a simple and user friendly approach in understanding the way event patterns need to be expressed. Similar to the concept of events, but expanding on a different perspective, are the Web services events specifications, which were developed to support the communication through events between services.

#### 2.5.7.2 Web Services Events Specifications

Different WS specifications have been developed that define services and approaches to support event-driven systems. The following section describes two specification frameworks: WS-Events by HP and WS-Eventing, a proprietary specification written by BEA Systems, Microsoft and Tibco Software.

*WS-Events*

WS-Events provides both an asynchronous push and a synchronous pull capability allowing services to push events to each other. Four basic WSDL operations support the subscription to an event (Catania, 2003):

- DiscoveryInterface: allows the discovery of the event types of a particular event producer.
- GetAllEventTypes: the consumer can access a list of all the events he can subscribe to.
- EventTypeDefinition: provides an XML list with details about the event types definitions.
- GetEventInstnceInfo: provides details about event types that are still held by the producer.

During subscription the consumer passes to the producer a selector for these event types that need to be subscribed, a timeout subscription to indicate when it should time out, an optional filter and a call-back URL where events will be pushed to (Catania, 2003).

This specification entails three main drawbacks in terms of filter missing, allowing synchronous pull and identifying consumer endpoints by URLs. The lack of filtering results in increasing network and operational consumption as unnecessary events are also processed. Allowing synchronous pull requires increased buffer capacity by the producer which can affect the producer scalability. Finally using URLs as a specification element is not efficient because URLs specify a single protocol instead of multiple protocols, they do not sufficiently describe transport mechanisms and they do not express interface information (Vinoski, 2004).

*WS-Eventing*

Considered to be simpler than the WS-Event specification, the WS-Eventing allows a WS, the event sink, to subscribe to the event source (Vinoski, 2004). Utilising the WS-Addressing specification capabilities it builds on the endpoint reference and message information header defined by WS-Addressing (Bosworth, 2003).

Upon subscribing to an event source an application sends a subscription message with a header set to a specific value indicting the subscription action. The message body contains the reference properties and an event filter specification. The event source returns a message containing a subscription identifier and a subscription expiry time. When an event is sent to the event sink it is checked against the filters that have been specified by the event sink. The event sink can also renew the subscription before it expires by sending a renewal message (Box *et al.*, 2004).

The drawbacks of WS-Eventing could have been avoided if the specification was not based on the WS-Addressing. In this case other bindings rather than SOAP over HTTP could be applicable. Additionally concerns are raised regarding the proprietary nature of the specifications as these standards tend to develop relatively slow. A final drawback refers the lack of metadata discovery capabilities (Vinoski, 2004).

In this section the concept of events and agile theories and practices were examined. The EBT scheme revealed the need for the expression of composite events and patterns as they occur in the SC. Similarly, the Petri nets patterns mapping pointed out the importance of dynamic representation of event patterns that overcome scalability representational issues.

## 2.8 Event Driven Architectures

Utilizing the event driven paradigm, several SC architectures and designs have been proposed that adapt in main technologies like Web services and agents, which consist main components of the proposed Supply Chain Event Driven Architecture.

### 2.8.1 Event Based e-Business Solution Utilizing Web Services

An ETR-enabled Web Services Model was developed by Nagarajan, Lam and Su (2004) and is applied to distributed e-business applications. The user is allowed to choose the methods that will be exposed as a Web service and the events to be installed on the ETR server. This information is deployed to create a Web service wrapper that posts the installed events and additionally a WSDL document is created. When an operation is invoked the related method is triggered the wrapper will post the event to initiate the selected business rules from the ETR directory. Figure 2.8 shows the way events and rules integrate with Web services.

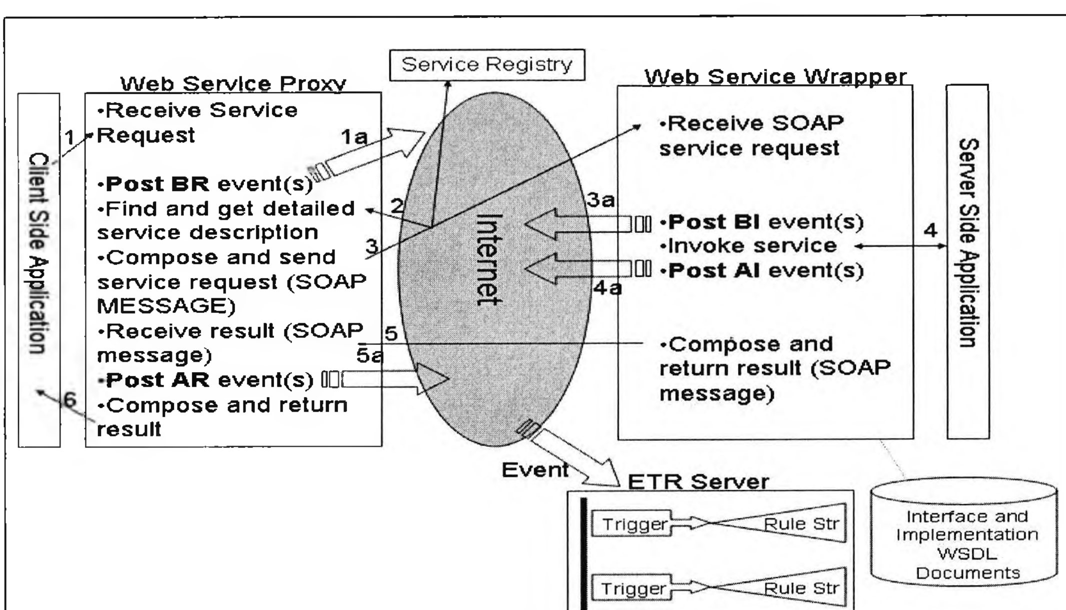



***Figure 2.8 Integration of Business Events/Rules with Web Service Invocation (Nagarajan et al., 2004)***

The model consists of four main components. The GUI for Web service creation is the tool through which the user can choose the methods to be exposed as Web services' operations and define the operation events. The GUI involves three main phases, the service definition phase, the operations selection and event definition phase and the generation phase. The Wrapper generator is responsible for generating the wrapper code at the server side application taking as input the Web service interface information. The WSDL document generator uses the Web service interface information and additional information regarding the WSDL documents that need to be generated. Using the Java2WSDL tool provided by Apache Axis toolkit, the document generator implements the WSDL documents. The last component is the events installation service of the ETR server. It interacts with the ETR server to install events.

The model provides an interesting view of how Web services interact with events and proves that the creation of an event platform that incorporates Web services is feasible. However, it doesn't address explicitly the e-supply chain area, thus provides no specific solution for supply chain operations and unexpected events that occur during a supply chain process.

### 2.8.2 Active Events over the SIENA Platform

Interoperating on a large network, applications are asynchronous, homogeneous with loose coupling, thus event notification is becoming the natural design abstraction among these applications. To address the above characteristics the SIENA (Scalable Internet Event Notification Architectures) project aims to design and implement a generic event notification service for subscription and publishing of events (Carzaniga, Rosenblum & Wolf, 2001).

Expanding on SIENA, ActEvents is an intelligent event model that was created in the effort to support the communication between data-source probes and action-based gauges (Gross & Gupta, 2001). ActEvents are built on conventional event concepts and are also proposed as a solution to distributed collaborative environments. In this research probes are defined as individual sensors which are attached on a running program and can be either static or dynamic (Gross & Gupta, 2001). Gauges have a more dynamic behaviour as they are software entities which gather, aggregate, compute and manage measurement information about software systems.

Both probes and gauges can be activated and deactivated and migrate to different applications and machines. In a distributed collaborative environment, to support the communication between probes and gauges three issues need to be addressed:

- The dynamic probe behaviour
- The dynamic topology of the components and participants

- The heterogeneous systems involved by the distributed participants

The ActEvents model addresses the above issues by proposing two sub-models that deal with the different nature of probes and gauges, SmartEvents and Gaugents. Due to the nature and the operations of the two models this section focuses on the SmartEvents model.

SmartEvents are XML structured events that contain references to their syntactic and semantic models and operate on the SIENA platform, so the problem of topology is pushed to the distributed middleware application. Each event carries a tagged document in order to identify both the structure of the text and also the semantic model under which the event should be interpreted and the semantic sub-components are identified by a parsing and looking-up engine of the system, thus they address the issue of dynamic probe nature and the complications in identifying the correct semantics. Any unfamiliar tags are handled by the data repository which map unknown information (tags) to syntactic and semantic information and delivers this information back to the parsing and looking-up engine. When the semantic information has been identified further processing is applied by the looking-up engine that include augmenting, deleting etc. The use of XML grammar supports interoperability and communication among different systems (Gross & Gupta, 2001).

The realization of SmartEvents is implemented extending SIENA's flat structure. The main structure of a SmartEvent consists of an envelope of metadata and a payload of specific probe results (Gross & Gupta, 2001). The envelope metadata contains:

- A locally unique identifier
- The IP address and port of the generating probe
- A timestamp

The payload information contains:

- Object
- Class
- Method
- Type value pairs for the parameters

The Event Packager is the component that constructs SmartEvents from primitive probe events and these events are then placed in a log for later use. The Event Packager consists of several tools that implement the identification functionality. The Metaparser is the parsing engine which performs the initial examination to identify the appropriate sub-components. These sub-components are compared against database information, retrieved from ORACLE. ORACLE, deals with unfamiliar tags, XPATHs, and returns an appropriate schema back to the paring engine. The tag-processor performs domain-specific processing to the event-message in order to assist the consistent data format (Gross & Gupta, 2001).

The SmartEvents model is an implementation of event-based communication system that could be applied to SC distributed environments operating over a virtual framework. The Event Packager is the view of an event engine that aims to identify and augment events in a distributed operating network. It addresses issues such as dynamic topology and heterogeneous systems involved. However, it deals with events which are created by a system software component, thus reducing the flexibility in an organization to address events that occur in other areas such as production, external environment etc.

### 2.8.3 SCEM Utilizing Agent Technology

Based on the characteristics of a proactive system, an agent based SCEM system was developed by the departments of Information Systems and Artificial Intelligence of the University of Erlanger-Nuremberg. The system was developed as part of the "Agent Based Tracking and Tracing of Business Processes project" (Bodendorf & Zimmerman, 2005).

A SCEM platform utilizing the agent technology has been designed consisting of three layers, each corresponding to a particular agent. Consisting of three layers, layer 1 relates to a discourse agent that communicates monitoring information between agents in other supply chains. The role of this layer is to create the basis for the operation of the agents operating in Layer 2, as they would also need to deal with conduction inter-organizational dialogs between different supply chains (Bodendorf & Zimmerman, 2005).

Layer 2 is an application layer based on the event-driven architecture paradigm. It relates to two agents, the coordination and the surveillance agent. The coordination agent serves with two roles: requesting for event signals and triggering event monitoring actions. The surveillance agent is triggered for each monitored order and identifies information inside the knowledge base of the company about order status. In order to reduce the complexity of order monitoring, a single agent is needed for each order under surveillance. After the required information is gathered is transmitted to the coordination agent, which specifies the further action. The actions and policies that will be the skeleton of further action create a filter the coordination agent uses in order to disseminate the information to the appropriate actors (Bodendorf & Zimmerman, 2005).

In the third layer, the agent is a wrapper providing an interface to proprietary information, such as queering internal databases about a certain order status. Without the use of wrapper agents Layer 2 surveillance agents would access simultaneously the same data (Bodendorf & Zimmerman, 2005).

An example of the suggested system has been implemented through the PAMS prototype, which has mapped the proposed agent technology on LSPs. In PAMS prototypes the main components have a Web interface instead of a SCEM agent. The evaluation of the prototype verified the initial aim that information can be monitored, identified and proactively disseminated to the users. However two main limitations raise, as it is still important to record all Critical Control Profiles, which limits the functionality of the system when critical profile have not been identified. Additionally, milestones and plans also need to be inserted as an input, reducing the system's flexibility (Bodendorf & Zimmerman, 2005).

The above architectures address IOS issues, which are important for the analysis of an event driven architecture. Main points that compromise benefits from the efficient SC operation are mentioned. Initially the interaction between events and IS is described, however the proposed mechanism is not SC oriented and doesn't address the concept of unexpected events. Another aspect is expanding the conventional concept of events to distributed collaborative systems which are the core element of a VE. However the particular architecture doesn't incorporate events outside the IS context, thus market and industrial flexibility is reduced.

## 2.9 Conclusions

As the concept of procurement developed according to the technological and business needs, the SC concept assisted in integrating a wide range of inter and cross organizational processes under one goal: final customer satisfaction. Moving towards the e-business era, competition drivers and e-SC paradigms create new SC forms and structures leading to the concept of VE. Agility and flexibility are two metrics that determine SC competitiveness and requires rapid response to internal and external factors that compromise SC operations. To assist agility event-driven paradigms have been used in SCM practices and new event-driven theories and methodologies have emerged.

The traditional concept of SC is challenged within the e-framework for agility and flexibility and the need towards event-driven management practices is highlighted. Current event theories practices supporting events relationships and event patterns, compose the theoretical background for event pattern notation (O1: Bound the area of unexpected events and their relationships within the Supply Chain domain) and event classification based on the formal SC processes (O2: Use the theoretical ground defined in O1, to build an ontology which classifies unexpected events under SCOR model processes). Additionally, main event and event pattern languages are described assisting the comparative evaluation of an unexpected events pattern notation (O3: Propose a notation for describing event patterns that is based on their ontological classification). Finally, existing event based architectures assist the design of an unexpected event engine that will address the needs for re-engineered SC practices (O4: Design an Information Systems Supply Chain Event Driven Architecture (SCEDRA), which captures unexpected events, inside and outside the SC, identifies and propagates event detection information through the supply chain network).

# CHAPTER 3: EVENTS IN THE SUPPLY CHAIN

## 3.1 Introduction

The previous chapter described how in the new e-business era agility and flexibility drive competitiveness, thus SCs need to respond to any internal and external stimuli. These stimuli originate from events occurring in different organizational areas, such as customer and vendor environment, production lines, governmental and regulatory policies, affiliated partners etc (Dickinson, 1998). Event sources increase as the SC operates in an extended Virtual Network and companies are exposed to dynamic features that determine organizational operations. Turbulence in external markets and in external factors that affect SC and business operations have a direct impact on the PLAN process creating patterns of events.

Events are identified through their direct impact or their causal or temporal impact on operations and resources. In many occasions events occur, as information about changes in resources needs to be communicated within the related processes. Event notification systems transfer this information at the application level, allowing component communication on events, filters and patterns (Carzaniga, Rosenblum & Wolf, 2000). This thesis aims to utilise the concept of event notification systems to achieve unexpected event monitoring and event pattern identification.

This chapter presents the framework that surrounds the concept of events and the theory that was developed to define events and describe their relationships within the e-SC network. The following sections contribute to the objectives below:

- O1: Bound the area of unexpected events and their relationships within the Supply Chain domain.

- O2: Use the theoretical ground defined in O1, to build an ontology which classifies unexpected events on SCOR model processes.

After the examination of existing literature, event relationship types were distilled into a generic framework to support event pattern identification (O1).

Events were initially categorised after thorough investigation of economic journals and newspapers and this categorization was used to evaluate the frequency of events within members of the Supply Chain Council. The final outcome was to develop an ontology which unexpected events are mapped based on the five main processes of the SCOR model (O2).

The chapter is organised in four main sections. Initially the link between SCEM and SC networks is described and a formal definition of an *event driven Supply Chain Network* is given (section 3.2). The theoretical framework about events is described from three perspectives: events definition, events relationships and the concept of event patterns (sections 3.3). The methodology used to classify events is presented (sections 3.4 - 3.5 - 3.6) and finally the ontology mapping unexpected events is described (section 3.7).

## 3.2 Events in Event Driven SC Network

Defining events depends on the context within which they occur. Extracting events from Luckham's global event cloud (2002) requires bounding the area that is going to be examined. This section links the concept of Supply Chain Event Management (SCEM) to the Virtual SC network and the extended environment in which SCs operate. Since the aim of this project is to design an architecture that will cover different Supply Chains, the SCOR model is used as the reference point to communicate processes and tasks. Events occur during SCOR processes SOURCE, MAKE, DELIVER and RETURN, but not during PLAN. PLAN, the initial SCOR process, spans through all processes aiming to balance resources with requirements (SCC, 2003). All activities are connected through the PLAN process which schedules tasks and sub-tasks. For this reason, PLAN events are future activities scheduled to occur in the short or long term. However, a wide number of unexpected occurrences can interrupt the planned activities and alter the scheduled balance.

These unexpected occurrences during SC operations are incorporated within the context of SCEM. Chapter 2 (Literature Review) revealed that SCEM is a concept that has evolved as an extension to process control in Logistic Service Providers (LSPs). SCEM is not a standalone application but a feature of SC solutions, which are responsible for monitoring events in order to collect and organise day to day transaction data (Marabotti, 2002). Currently, a SCEM application is seen at mySAP Supply Chain Management which monitors, captures and propagates events during supply chain operations and flags problems, unusual events that may occur (SAP, 2001). SCEM software assist companies to rapidly address sudden changes during SC processes. This is achieved by capturing and transmitting relevant information such as delivery delays (Marabotti, 2002).

SCEM monitors events from customer demand to company shipments (Ross, 2003 p: 20). Unpredicted disruptions are not within the SCEM scope, however an e-SC network requires a management strategy where events are the basic underlying structure. The concept of event driven Supply Chain utilises events in this dynamic context.

The concept of Supply Chain Network, as expanded in this particular thesis, is presented scoping the area under examination. David Luckham (2002) defines *event driven* for the electronic enterprise as “the set of tools and applications that are used in the effort to automate business and management processes by receiving events which monitor the progress of a process and issue events that initiate business processes” (Luckham, 2002 p:29). In this research the above definition given by Luckham is extended to become the driving force towards e-supply network’s new structure. The concept of events is scoped within this framework to allow events definition inside the following context.

*Event driven supply network is the dynamic association of events that are created by the driving factors and determine the order, the frequency and the associations among the supply chain processes and the related participants.*

## 3.3 Event & Event Patterns Theoretical Framework

In this thesis the theory that surrounds events occurring in an event driven supply network, is examined from three perspectives: event definition, events relationships and patterns of events. The following framework describes these three dimensions and presents the way they are interconnected.

### 3.3.1 Events in the Context of Supply Chain

In literature, events in dynamic software systems are defined as occurrences that maybe serialised or happen independently during execution architecture (Vera, Perrochon, & Luckham, 1999). During e-SC Network operation, events are identified when they are captured. The implication is that external events are often captured through their impact on SC operations, and information about the origin of any unexpected occurrence is not propagated. Contingency policies and plans require information about the exact event path, so is important to distinguish between an impact and its origin. This project examines the extended SC; hence both internal and external events are defined. By extracting events out of the global event cloud (Luckham, 2002) and within the context of the dynamic supply network an event is defined as:

- *A change in the status of a resource/process/task*, such as
  - "Stock availability status changing from *available* to *unavailable*"

- *A trigger for initiating a resource/process/task*, for example
  - "Receive an order or a delivery return"

- *Composite event;* the combination of two or more events often results to the aggregation of events. In this thesis the concept of composite events derives from composite event descriptions in event algebra, (Carlson & Lisper, 2004). An example of a company with two production plants, Plant A (ID: A001) and Plant B (ID: B002) is described below.
  - Event 1: production machine failure in A001;
  - Event 2: critical deadline for production fulfilment.
  - Event 3: the composite event from E1 & E2 aggregation: production shift from A001 to B002.

- *A non-event* state is defined either as non event occurrence (a PLAN event that did not occur), or as an event that occurs outside SC activities and scope.

### 3.3.2 Events Relationships

To examine events interoperation the first step requires to identify the relationships which determine the way events can be combined or generated by the aggregation of former events. The way they are interrelated is governed by the logical connections between events. There are three basic forms defining the nature of event relationships, causal, temporal and the independent event. According to Lukcham, *causal event execution* is a partially ordered set that consists of events and their relationships generated by a system (Luckham 2002 p: 102). Temporal relationships refer to time connections, time expressions and timestamps that connect independent events. In RAPIDE-EPL temporal operators act as event connectors, such as DURING, AT, AFTER (Luckham, 2002). This project builds on the current context of causality and temporality towards the paradigm of e-Supply Chain Network.

1) <u>Causal Relationships</u>: Within the context of an event driven supply network causal relationships refer to the logic link between an initial event and a resulting one. This link refers to business rules which can be set up to avoid or deal with exceptional occasions and also to define the task sequence of a process. For instance, an increase in oil prices is causally

connected to the increase of production cost, Figure 3.1. The former event triggers the latter and the association between them is based on a causal link.


***Figure 3.1: Causal Relations between Events***

2) Temporal relations: Temporal relations are another form of logic connection between events. They can be considered as a subset where the link between events depends on the time period within which they occur and on the type of events. For instance the event of an unexpected temperature rise within production premises is temporarily related with the event of return of damaged products. It is impossible to reprocess the damaged products when the environmental conditions do not meet the expected requirements (Figure 3.2). If the temperature is not adjusted to normal before the delivery is returned the two events are not temporarily related.

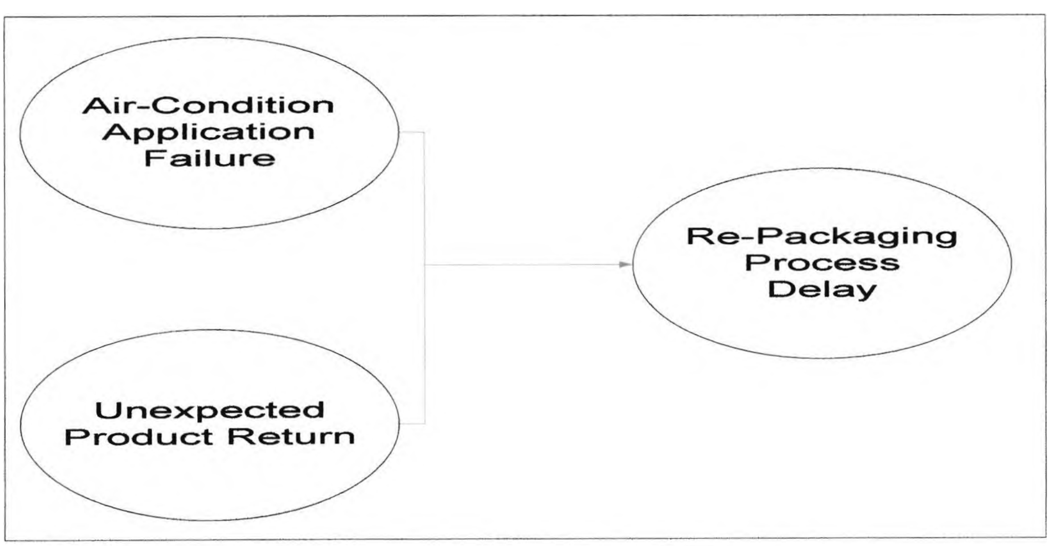



***Figure 3.2: Temporal Relations between Events***

3) Independent Events: These events occur and are handled independently. If over a certain time period there is no causal or temporal relation between the occurring events, these instances constitute independent events. For instance, a change in the billing address of an order is a single event if this information is captured and does not create any further complications, such as invoice errors.

Temporal and causal relationships are often combined depending on the events that occur within the examined time frame. In some occasions temporarily related events are aggregated and form a composite event which has further causal impacts. For instance, the rise in oil prices and the unexpected return delivery of damaged products are two events temporarily related. The aggregation of the two events results into the composite event of total cost increase. The relationship between the resulting event and the two temporarily combined events is based on causal association.

### 3.3.3 Cluster Event Patterns

An event occurrence may vary depending on the time period it occurs and the process within which it appears. Events that are scheduled to be part of the PLAN process occur according to a certain order. Unexpected occurrences, for example billing errors and delivery delays, alter the PLAN flow and create new causal and temporal relationships between events. Event interoperation creates clusters of events which form *Cluster Event Patterns* (CEPs). CEPs are structures of the way events are combined or aggregated and the effect they have when they form a cluster. The resulting CEPs differ according to the specific characteristics they inherit from their operational environment and attributes such as time, process type etc. The patterns created are more than relations between events as they embody both a consistency and completeness of relations (Bateson , 1988).

In his theory about chaos in SC Networks, Wilding (1998a), argues that chaos in the SC originates both from management decisions and computer control algorithms. This thesis expands the initial conditions of sensitivity, including factors originating from external markets and operational and physical environments. The implication however, is that along with sources of uncertainty, temporal relationships increase as well; hence resulting CEPs are almost impossible to predict (Senge, 1990). Hence repeatability in patterns is not considered in this research.

The identification of CEPs requires the automatic and on real time capture and propagation of this information to all SC Network participants. Events occurrence is not predictable thus resulting CEPs are not feasible to be forecasted and examined in advance. In order to utilize the resulting CEPs their basic characteristics need to be identified and measured. Each CEP in an event driven supply network is based on three parameters; time, order and logical relationships between events.

The time period of events determines temporal relations that are created within CEPs. In a certain time period events occur before, after or simultaneously with each other. The order of events is strongly related to the time aspect, as in causal associations resulting events happen in an order which cannot be predicted. Order and time affect the logical relationships between events and the resulting CEPs.

## 3.4 Supply Chain Event Classification

### 3.4.1 Initial Events Categorization

Events are initially divided into Actual Events (AE) and Estimated Events (EE). EE are defined as scheduled occurrences of the PLAN process with pre-defined time and operational process attributes. The time period and the task within which they occur have been scheduled and events that actually take place with these attributes are Actual Events. Estimated Events that do not occur are considered as *non-events*, and events that either happen outside the PLAN scope or alter the time and operational attributes of PLAN events are unexpected events.

To categorize events, requires to define the environment within which events occur. In this project the main framework is the e-SC Network, however if this network is isolated from the general operational, business and physical environment only the impact of certain events will be captured. Placing the e-SC Network within a broader scope it becomes a non-linear complex system, thus it is subject to unpredictability and is more sensitive to initial conditions and small changes (Lorenz, 1963). Unexpected events can cause chaos in the SC and the impact of unexpected event patterns (Wilding, 1998b) could be serious in phenomena like the bullwhip effect, backlogs etc.

To address the implications of supply chain's chaotic behavior, the proposed Event Driven Supply Chain Architecture (SCEDRA) aims to identify event patterns and disseminate their path to the related participants. To achieve this, an ontology that maps main SC unexpected occurrences was designed, where events are classified according to the SCOR process within which they appeared and the representation of major disruptions is enabled.

### 3.4.2 Event Classification

The research method used to classify unexpected events into an ontology consisted of a three steps: event identification, event evaluation and event classification. The initial part was a periodical survey for the identification of events as they occur in different supply chain processes in a variety of industrial sectors. For this reason a range of logistic and management journals, magazines and newspapers were examined during the period January 2004 – March 2005, including one case dating at 2003. A thorough examination of related financial and retail newspapers and magazines revealed a wide number of different examples of unexpected events within different industries and market sectors. The next step was the ranking in terms of frequency of unexpected events, by members of the Supply Chain Council. The analysis of the evaluation results determined the type of events that would be classified and the way they would be grouped.

#### 3.4.2.1 Surveyed Periodicals

One of the main questions this research had to initially address was to scope the business/industrial domain. It was considered that a specific industry-focused survey would compromise the validity of the research. As SCEDRA would had been targeted towards a specific SC, omitting disruptions and events that are common to other SCs. For this reason a holistic approach was adopted and the analysis scope involved several industrial sectors. To elicit the most common unexpected events that disrupt the scheduled SC processes a variety of economic and retail journals was examined. The periodicals that were examined were:

- Financial Times (FT)
- The Economist
- The Guardian
- Business Week
- Business Weekly
- Computing
- Electronic Business
- Supply Chain Demand Executive
- The Grocer
- Retail Week

Over a time period these periodicals were scanned for news about any disruptions or unexpected events that had an impact on companies or industries SC operations. Newspapers like *FT* and the *Economist* cover a variety of industries whereas *The Grocer*, or *Retail Week* are industry-specific. To avoid recording overlapping news, especially when examining different periodicals, the survey span over a two-years period. To establish the objectiveness of the survey and avoid biased news, a variety of periodicals was examined.

#### 3.4.2.2 Questionnaire Participants

The next step involved the evaluation of the previously identified events by members of different SCs. As it was important to elicit information from a broad cross section of industries, questionnaires were sent to members of the Supply Chain Council (SCC). SCC members represent all participants of the SC such as, manufacturers, 3PLs, consultants, retailers etc. Since 1969, when it was first established, the SCC has 1000 members including both practitioners and academics. For the particular research academic members were not included in the survey. Also during data collection on it was decided that consultant responses should be also omitted.

## 3.5 Event Identification from Periodical Survey Findings

### 3.5.1 A List of Event Types

Fifty different occurrences of unexpected disruptions in the SC were recorded and listed. Most events were identified through their impact on SC processes and were documented based on the following attributes: industry sector, cause (origin of event), description (event or event impact), and source (periodical reference). All information in the periodicals was utilized for the purposes of the research and industry sectors are described as specific types of general industries. It was not always clear to distinguish between events and events impact, in particular in cases where an article addressed a general issue, such as an oil price increase, rather than referring to a specific company. In many occasions the impact of events results into the formulation of causal and temporal or composite events. Table 3.1 illustrates some of the recorded events based on the four-attribute model that was used to document them. The table points out that events are of diverse nature and they constitute a variety of different occurrences.

**Table 3.1: Recorded Events**

| Sector | Cause | Example | Source |
|---|---|---|---|
| Automotives | Hurricanes | GE reduced insurance profits and increased raw material costs in its plastic business where benzene is 3 times normal price. | D. Roberts (9/10/04), The Financial Times, FT Money and Business, "GE Struggles with effect of hurricanes", pM8, N: 35580. |
| Beer Industry | Hurricanes | Heineken sales decreased due to hurricanes spoil major US holidays. | S. Thompson (9/10/04), The Financial Times, FT Money and Business, "Hurricanes hit Hieneken", pM8, N: 35580. |
| Automotive | Defective Components | Chrysler Group unit. Problem was, when a drive train was one-eighth of an inch too long or a widget a half-centimeter too wide. | T. Mayor (2004), CIO, "The supple Supply Chain", available at: http://www.cio.com/archive /081504/supply.html |
| Banking | Security Discrepancy | Bank of America computer types including information of 1.2 million US government employees are missing and was found during transferring back up storage tapes to an undisclosed storage facility. | D. Wells (28/2/05), FT Money and Business, "Bank of America loses tapes of data on 1.2 m customers", p M1, N: 35698. |
| Airline | Strikes | Alitalia cancelled 62 international and 28 domestic flights as the result of a strike. On the 10/2 cancelled 141 flights. | T. Barber (22/02/05), FT Companies and Market, "Attendents strike ground Alitalia flights", p:30, N: 35694. |

Industry sectors are categorised based on company types, to assist event description of the events. Even though placing companies under the main classification of industry types was not part of the research scope, certain industry types are classified under their general sector for the purposes of simplicity. For instance furniture companies, like MFI, are categorized under RETAIL. On the contrary, due to their cross industrial impact, oil companies are classified separately. Table 3.2 portrays the main industry types that were identified, based on their product and service type and not on their role in the SC.

**Table 3.2: Industry Types**

| Industry Type | Description |
|---|---|
| Retail | Includes both large and small retail companies (John Lewis) |
| e-Retail | Refers to on-line retailers (Amazon) |
| Aviation | Includes companies dealing with the aviation sector (ALITALIA) |
| OIL | Refers to both oil producers and oil traders (STATOIL) |
| Clothing | Comprises of fashion, shoe and clothing companies (BENETTON) |
| Pharmaceutical | Includes companies in the drug sector (Pfizer) |
| Electronics | Includes both h/w and s/w companies (MICROSOFT) |
| Food | Refers to companies in the beverage sector (PREMIER FOOD) |

Fifty different event occurrences were identified and listed based both on their origin and their impact, depending on the available information. The different sectors that were examined assisted in achieving a holistic approach in event impacts and origins as the diversity in company types revealed that certain occurrences influence the SC not only as a source event but also as a causal effect. An example is the product recall due to the chemical substance SUDAN I found in Premier Foods products. The origin event was the detection of the substance and the causal event was the product recall (Burgers, 2005). However, the action of product recall has many causal impacts, as the mechanisms of reverse logistics need to be set in action in many warehouse and retail spots which are geographically dispersed. It was also noticed that certain events had diverse causal and temporal effects in different industry sectors. Hurricanes caused companies in the automotive sector to increase raw material costs as a result of benzene price increase (Roberts, 2004), where as at the same time they affected beer sales due to holiday disruption (Thompson, 2004).

The listed events were divided based on their sources and 15 different cause events were identified. Certain events were combined under a general type, for example the event category *market changes* included oil price and currency turbulences. It is common that certain event types are the cause for other main event types, such as *physical disasters* could often be the origin for *production plant failure.* Table 3.3 illustrates these main categories that classify events occurrences (for all listed events see Appendix C). Events elicited from the periodical survey have been defined according to the events explanation bounded in the previous section. Event types are primary sources of causally related events as they indicate the change in the status of a resource, process or task.

**Table 3.3: Event Types**

| Event Type | Description |
|---|---|
| Defective Component | Product components that do not adhere with quality standards, such as certain dimension. |
| Quality Control (QC) | Ingredients, raw/first materials, semi-ready and ready product that fail QC tests. |
| Application Failure | Failures of application and machine units (including on-line units) disrupting the SC, such as stock updates, on-line payments etc. |
| Production Plant Failure | Production unit breakdown, disabling production. |
| Component Reaching EOL (End of Life) | Components that cannot be further used and ingredients/first material that have expired. |
| Product discontinued | Most common in electronics, series of certain product that will not be further produced. |
| Excess Inventory | Stock above the acceptable limit, increasing operational cost. |
| High Priority Orders | Orders that due to quantity or customer type (i.e. government), gain first priority in production and completion. |
| Product Recall | Customer protection agencies or companies recalling series of product(s) when the public health needs to be protected. |
| Market Oversupply | Excessive availability of certain component, first material or finished product reducing prices for manufacturers. |
| Delayed Deliveries | Delays both from suppliers (first material) and to customers (finished product). |
| Strikes | Workforce strikes affecting production and service activities |
| Security Discrepancies | Security issues disrupting any business or SC activities. |
| Physical Disasters | Storms, earthquakes, hurricanes and any other natural and physical phenomenon interrupting SC and business processes. |
| Fire | Fires that cause damages in the entire or part of production units or any resources used in the SC. |

### 3.5.1 Combining Event Types

The next step involved filtering the resulted list to identify the main event types that will be further evaluated. The examination of the above categories, pointed out certain similarities within particular event types; thus for example, the *product discontinued* type is combined with the *components reaching EOL*. As in any extended SC a finished or a semi-ready product is part of the first materials or components for another product, when a product is discontinued all its ingredients and components are affected. *Fires* are classified under the *physical disaster* type which is broadened to *physical and manmade disasters*.

The event type *excess inventory* is omitted as it is the result of managerial activities and decisions and does not occur unexpectedly, but builds gradually. Certain types appear in different forms between SC processes. *Delayed deliveries* in the SOURCE and the DELIVER process are a typical example; hence it is further divided into *delayed deliveries from supplier* to *delayed deliveries to customer*. Event types that are not listed but appear in the literature are errors in orders, invoices, billing and delivery information (O' Leary, 2000). Due to the lack of information visibility and integration in the IS used to submit and process orders, the former event types have a 20% possibility of occurring. Other important SC issues, such as bottlenecks and increased stock "traffic", are classified under *stock unavailable*. The produced event type list provided the core for the next stage of evaluation which involved a questionnaire answered by members of the Supply Chain Council.

## 3.6 Event Evaluation

### 3.6.1 Questionnaire Description

The aim of the questionnaire was to validate the event types previously identified according to qualitative measures by professionals participating in the SC. The periodical survey suggested that most event types are unexpected occurrences that happen on a regular scale without previous notification, however is important to examine whether their occurrence is considered by SC participants. The evaluation of event types varies with industry sector for instance *strikes* are most common on the public sector and *unexpected product returns* have a bigger impact on 3PL companies.

The questionnaire consisted of two sections. The first part requested general information regarding the company and the industry sector and the second one consisted of two questions. Question 1 was based on non-comparative scaling and contained a list of unexpected events as they were categorised from the periodical survey. Users were asked to rate in a scale of 1 (never) to 4 (common) these occurrences according to their experience in the particular industry sector. It was considered that an odd numbered scale would promote non-response bias, thus an even unit scale was adapted. The second question examined whether the company followed any particular policies or structures to address unexpected events when they occur (Pavlou, 2005). Table 3.4 illustrates an excerpt of question 1 (for the full questionnaire see Appendix B).

**Table 3.4: Questionnaire**

**Section B.**

**Events in Supply Chain Processes**

*1) From a range of 1(never), 2(rare), 3(occasional) and 4 (common) how would you rate the occurrence of the following events that affect supply chain processes? (Please write your answer next to the described event)*

Financial market turbulence (e.g. oil price increases):
Physical or manmade Disasters:
Machinery Failure:
Plant/Production Unit Failure:
Strikes:
Security Issues:
Defective Components:
Product Recall:
Unexpected Product Return:
Components Reaching EOL:
Components Fail Quality Control:
Market Oversupply:
Delayed Deliveries from Supplier:
Delayed Deliveries to Customer:
Unavailable Stock:
Errors in Orders:
Errors in Billing/Delivery Information:
Invoice Errors:
Other (Please specify):

### 3.6.2 Questionnaire Findings

Professionals, excluding academics, associated with the Supply Chain Council were the target sample for this part of the research. At the time of the particular survey (Spring 2005) the contacts of approximately 400 SCC members were available. A random sample selection was initially performed followed by a further assortment to span over cross-industry spectrum. Questionnaires were distributed via e-mail to the SCC delegate appointed by each company. It was decided that the consultants responses should not be considered, as many of the variables (event types) were not applicable to their service activities and would compromise the validity of the final results. Additionally, consultants responses are customer-oriented and they depict their clients experience, hence issues regarding data-sensitivity had to be avoided.

The first mailing was sent to a sample of 200 SCC professionals. A reminder followed the initial mailing 15 days later to non-respondents. A total of 33 usable questionnaires were returned. Figure 3.3 illustrates the respondents percentage according to their industry type.

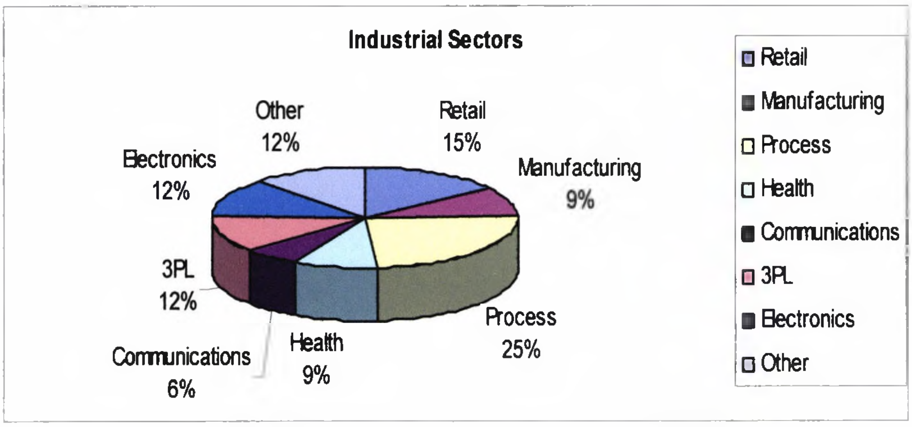



***Figure 3.3: Industrial Sector Participating Percentage***

Participants were divided according to their industry sector, apart from 3PL parties that even though could be classified under retail, were considered separately. The differences in variable means are illustrated by Figure 3.4, which explain the need to treat RETAIL and 3PL as different industry sectors.

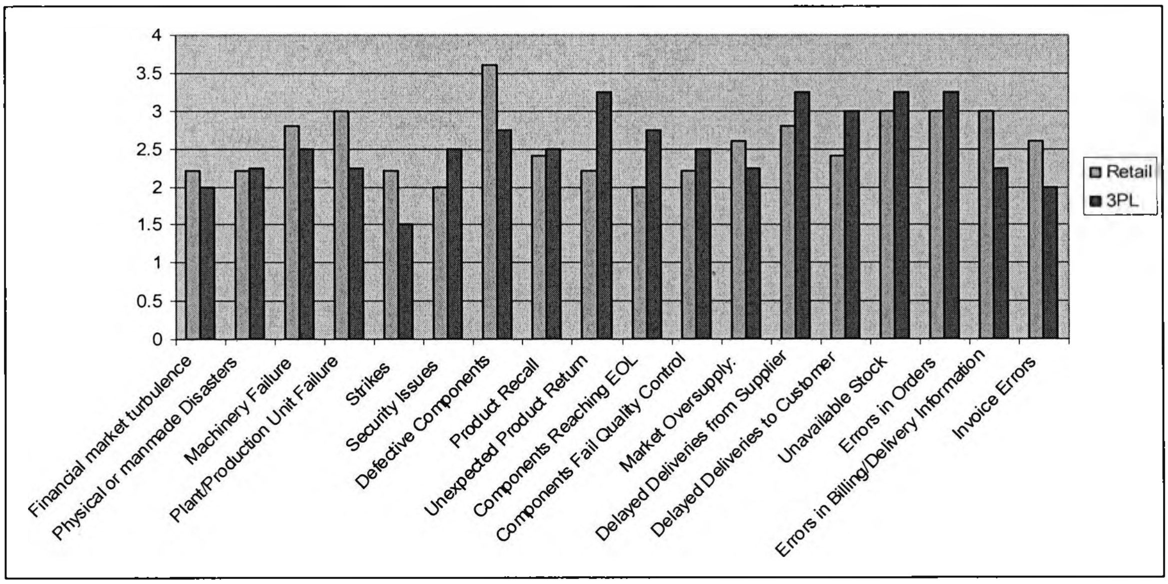



***Figure 3.4: Retail and 3PL***

The aim of the questionnaire was to identify whether the listed event types are recognized by SC professionals and to which extend. At this stage the questionnaire was used to examine if any of the variables had to be excluded from the event ontology, due to very low rating from the respondents. That would suggest that certain event types identified in the periodical survey are not acknowledged by SC participants; hence they should be omitted from the final classification. Table 3.4 presents the descriptive statistics which illustrate a tabular summary of the responses rates. The aim was to evaluate the frequency of events occurrence to determine which types should be classified.

**Table 3.5: Descriptive Statistics**

| | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Financial market turbulence | 33 | 1 | 4 | 2,58 | ,94 |
| Physical or manmade Disasters | 33 | 1 | 4 | 2,27 | ,91 |
| Machinery Failure | 33 | 1,00 | 4,00 | 2,6667 | ,8539 |
| Plant/Production Unit Failure | 33 | 1,00 | 4,00 | 2,6970 | ,9180 |
| STRIKES | 33 | 1,00 | 4,00 | 1,8788 | ,9273 |
| Security Issues | 33 | 1,00 | 3,00 | 2,0303 | ,7699 |
| Defective Components | 33 | 2,00 | 4,00 | 2,8485 | ,7550 |
| Product Recall | 33 | 1,00 | 4,00 | 2,3939 | ,8993 |
| Unexpected Product Return | 33 | 1,00 | 4,00 | 2,3636 | ,8594 |
| Components Reaching EOL | 33 | 1,00 | 4,00 | 2,4545 | 1,0923 |
| Components Fail Quality Control | 32 | 1,00 | 4,00 | 2,4688 | ,7613 |
| Market Oversupply: | 33 | 1,00 | 4,00 | 2,6667 | ,8898 |
| Delayed Deliveries from Supplier | 33 | 1,00 | 4,00 | 2,9394 | ,8638 |
| Delayed Deliveries to Customer | 33 | 1,00 | 4,00 | 2,9394 | ,7475 |
| Unavailable Stock | 33 | 1,00 | 4,00 | 2,9091 | ,7650 |
| Errors in Orders | 33 | 1,00 | 4,00 | 2,7879 | ,8572 |
| Errors in Billing/Delivery Infor | 33 | 1,00 | 4,00 | 2,5758 | ,9024 |
| Invoice Errors | 33 | 1,00 | 4,00 | 2,3333 | ,9895 |
| Valid N (listwise) | 32 | | | | |

The descriptive statistics demonstrate that although most of the variables extent between 1(never) and 4(common) half of them are below the average 2.5. In those event types the standard deviation points out that the respondents dispersion is not below 1.3. Two event types that don't follow the above behavior are v2 (physical and manmade disasters*)* and v5 (strikes). Despite the low mean value, the standard deviation of *physical and manmade disasters* indicates that average response rate is above 1.1, supporting the acknowledgement of the event. *Strikes* mean is 1.8788 and the cumulative percentage at values 1(never) and 2(rare) is 81.8% (for freqence% results see Appendix G). However one should consider that SCC members are companies operating in the private sector were strikes are not common. Figure 3.5 pictures how the event type *strikes* was rated by the different industrial sectors. Although most industries do not face strikes, retail, process and communications companies have responded that this is an event that occurs either rare or occasionally.

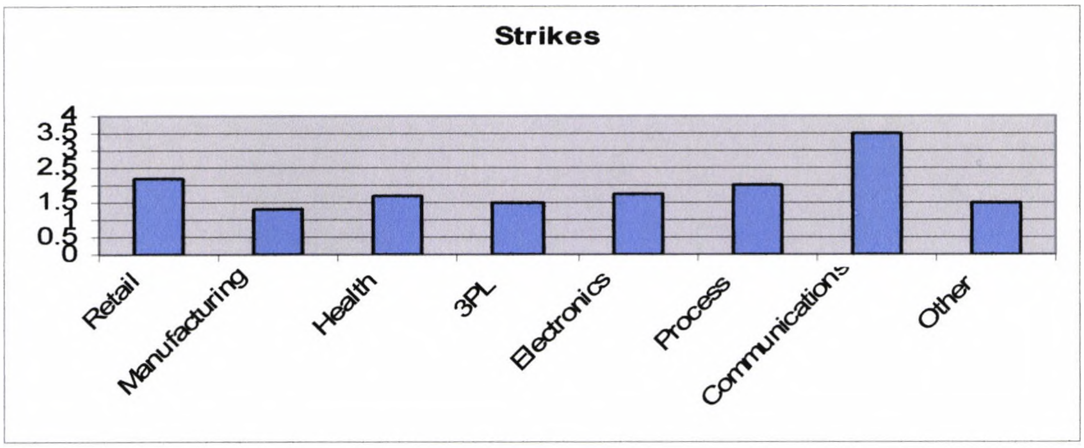



***Figure 3.5: Strikes rated from SCC participants***

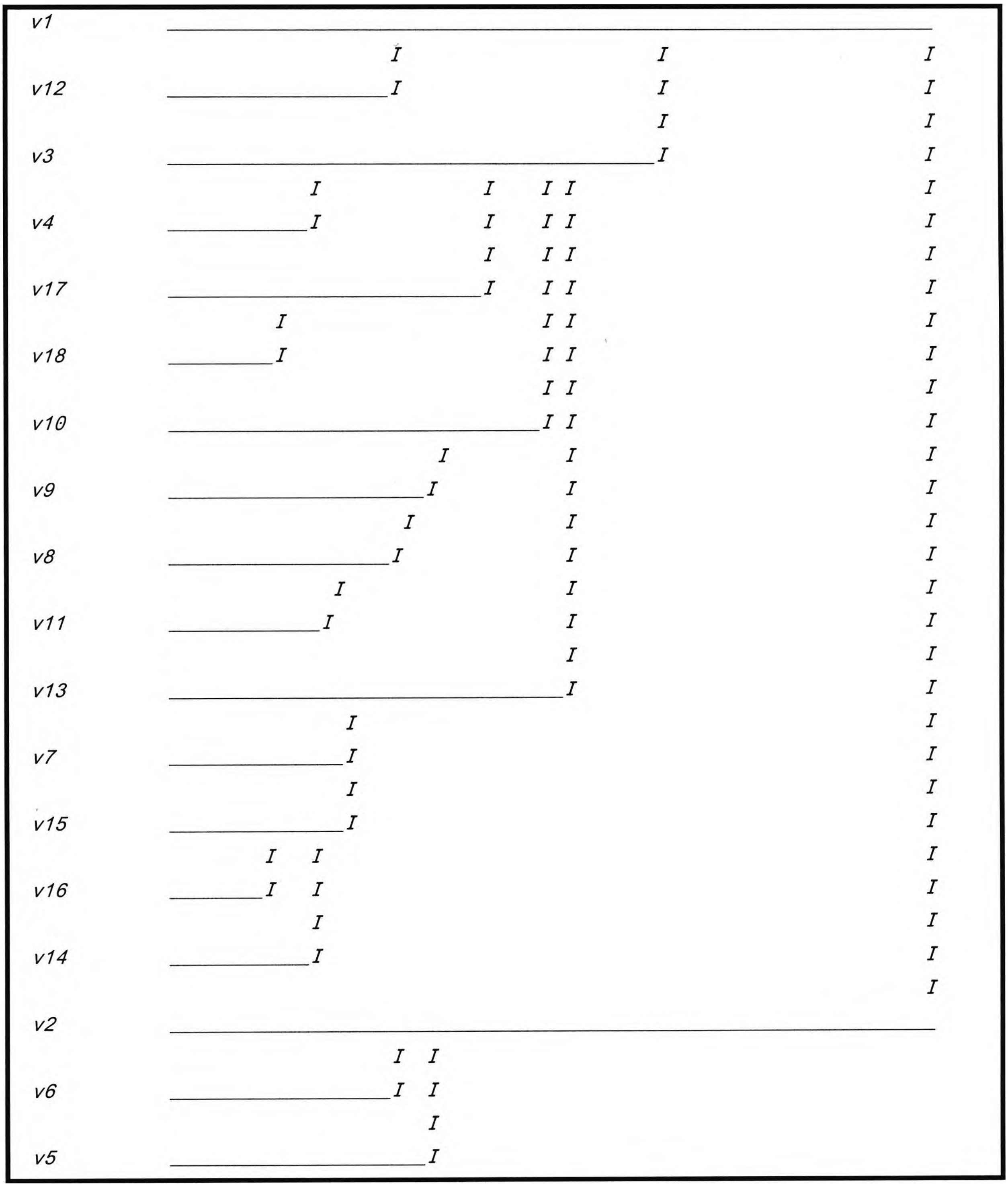
Event types with particular interest are variables with highest rate, v13 (delayed deliveries to customers) and v14 (delayed deliveries from suppliers). For both variables mean value is 2.9394 however, the standard deviation in the former (0.8638) suggests a bigger disparity in the responses, whereas the latter demonstrates tighter spread in the values. The difference in standard deviation and the high mean values, justify the division of the initial *delayed deliveries* event type. V10 (components reaching EOL), is the only event were standard deviation is higher than one unit (1.0923), illustrating the increased dispersion between respondents rates. This is also obvious from frequency percentages (see Appendix G), reflecting the divergence between industry types. Combining the above analysis with the periodical survey results, the events to be classified under the ontology were determined.

## 3.7 Event Classification

### 3.7.1 Event Types Hierarchical Analysis

The evaluation stage revealed that all examined variables are considered by SC practitioners, thus should be classified in the event type ontology. Hierarchical Cluster Analysis was performed on those variables to identify the data structure that will be the skeleton for the event ontology. The results are shown in a tree diagram, picturing the hierarchical nature of the examined event types. Table 3.5 shows the Hierarchical Tree Diagram formed from the event types cluster analysis. This diagram suggests ways of classifying event types into groups of clusters. Conceptually is close to the concept of CEPs (Cluster Event Patterns) that was discussed in previous section. However, CEPs are patterns of unexpected events linked by causal or temporal relationships, whereas no causalities are reflected in the hierarchical tree diagram.

**Table 3.6: Hierarchical Cluster Analysis**




Grouping event types based on rate similarity, 5 hierarchies (H1-H5) are obvious.

- **H1:** (v1 Financial market turbulence, v12 Market oversupply)
- **H2:** (v3 Machinery failure, v4 Plant/Production unit failure, v17 Errors in billing/delivery information, v18 Invoice errors)
- **H3:** (v10 Components reaching EOL, v9 Unexpected product return, v8 Product

recall, v11 Components fail quality control)

- **H4:** (v13 Delayed deliveries from supplier, v7 Defective components, v15 Unavailable stock, v16 Errors in orders, v14 Delayed deliveries to customer)
- **H5:** (v2 Physical or manmade disasters, v6 Security issues, v5 Strikes)

The most obvious groups are H1 and H5 which both include event types external to a SC but with strong impact on SC operations. In particular, although environmental behaviour and strikes are predictable their causal impacts affect many aspects of the SC. *Financial market turbulence* and *market oversupply* are market dependent events that affect the links between SC participants, and also the relationships between SCs. H2 event types have strong similarities regarding both event context and frequency percentages, particularly between variables v3-v4 which relate to the MAKE process and v17-v18 relating both to SOURCE and DELIVER processes. H3 variables v10 and v8 are outside SC borders. The event type *product recall* is often controlled by external factors, such as FSA (Food Safety Agency) and HPA (Health Protection Agency) and *components reaching EOL* is managed by market trends. In H4, v13 and v7 are events that affect the SOURCE process, whereas v15 and v14 relate to the DELIVER process.

### 3.7.2 Classification of Unexpected Events

The Hierarchical Cluster Analysis pointed out that unexpected events either occur during certain SC processes or originate in the external SC environment. To develop an Event Driven Supply Chain Architecture (SCEDRA), events information needs to be communicated among SC participants. Mapping unexpected events against SCOR model processes standardises the way they are presented in the SC environment. The previous analysis presented how most of the unexpected events relate to specific processes SOURCE, MAKE, DELIVER. The PLAN process refers to EE (Estimated Events) that are scheduled to take place, thus they are not considered unexpected. The RETURN process is triggered by events that happen during the DELIVER process so certain occurrences are classified under DELIVER. For instance v16, *errors in orders*, are events detected during DELIVER verification tasks[2] and initiate the authorization process of returning an order. Thus, events such as v16 and v7, *defective components,* are classified under RETURN.

[2] In the DELIVER process these tasks are D1.11: Receive & Verify (Stocked) Product at Customer Site, D2.11: Receive & Verify (Make-To-Order) Product at Customer Site, D3.10: Receive & Verify (Engineer-To-Order) Product at Customer Site, D4.7: Deliver and/or Install (Retail Product).

Figure 3.6 shows the ontology that was designed to map unexpected events against the SCOR model and against the external environment, operational, physical and industrial, within which events affecting SC processes occur. Events with dashed border are shown in more than one process, as they are instances that occur in different SC tasks.

Ontology is a term originating in philosophy and has several definitions. Starting by defining what a formal ontology is and what requirements it needs to satisfy (Gruber 1993), ontology definitions span over a wide range of taxonomies, hierarchical representations, vocabularies and theories that describe a domain (Noy & Klein, 2003). The most representative definition in the IT domain is given in Finin, Labrou and Mayfield (1997) where ontology is defined as a specification scheme for describing concepts and their relationships in a certain domain. This definition has been applied by Craven and colleagues (1998) in identifying and developing a trainable system which extracts information by browsing the Web. Ontologies are accepted as inputs representing classes, and their relationships, of interest. Similarly the taxonomy that classifies unexpected events serves a dual purpose. The instantiation of certain occurrences against the taxonomy identifies and defines unexpected events within the Supply Chain context. Events classification under main SC processes models the relationships between them. For these reason the taxonomy used to classify events consists an ontology of unexpected events.

The ontology is designed based on a 4 level object class diagram were the super class is the *EVENT*. Sub-classes at level 2 are the main SCOR processes and two sub-classes referring to the external SC environment, INDUSTRIAL CHANGES and PHYSICAL DISASTERS. The 3rd level consists of event entities that either reflect the event types identified and evaluated, or constitute a parent class for similar event types. Entities in level 4 are sub-classes of event types that differentiate according to the tasks of the process within which they occur. For instance a DEFECTIVE COMPONENT in the SOURCE process, can either have wrong dimensions or ingredients that do not comply with the set standards. INDUSTRIAL CHANGES has three sub-classes emphasising the different operational environments that affect the SC. The ontology adheres to object oriented principles. The aim was to create a general classification to depict unexpected event entities, which will be instantiated when they occur (Booch, 1997) (Arlow & Neustadt, 2002). Boxes with dotted lines indicate similar event types.

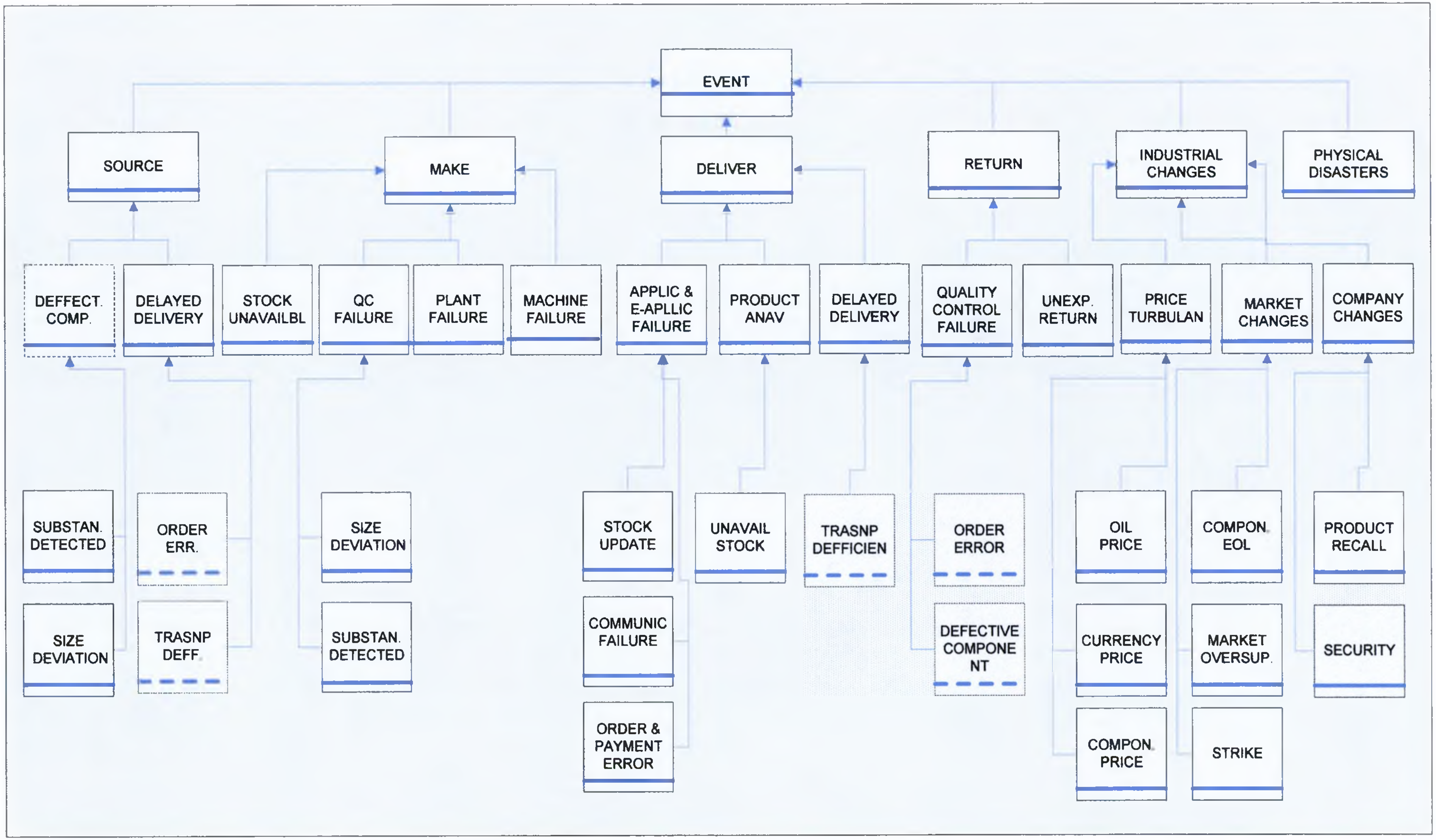



***Figure 3.6: Unexpected Events Classification***

The event class has one main attribute, as seen in Table 3.6, which is inherited by the sub-classes. Time attribute refers to the time that the event was captured. The actual time of occurrence however may differ and is not always known. It is important to distinguish between the time an event is captured and the time where its impact is known.

**Table 3.7: Event Class**

| EVENT |
|---|
| Time: time |

Moving down the ontology levels, these attributes are inherited by specific event types. Typical examples of event types that share the same methods and attributes are the two examples of QUALITY CONTROL FAILURE, SIZE DEVIATION and SUBSTANCE DETECTED. Figure 3.7 illustrates inheritance of attributes through levels 2-4 in the ontology.

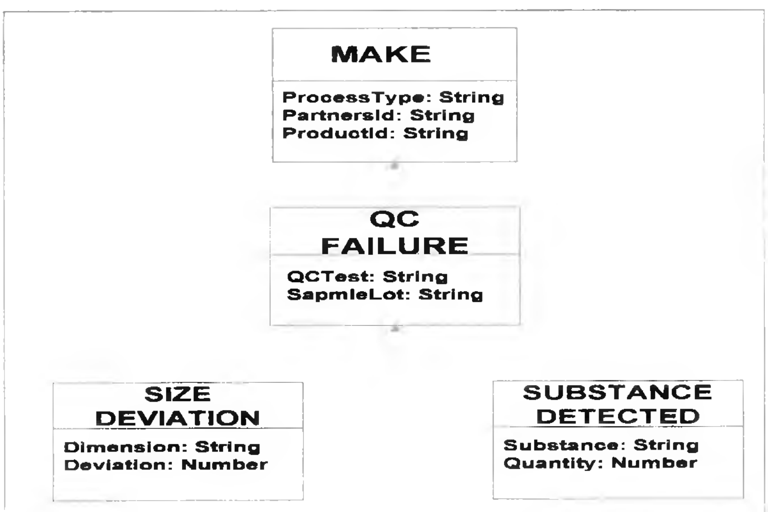



***Figure 3.7: Inheritance Attributes***

## 3.8 Chapter Summary

This chapter initially presented a detailed framework of events and event patterns. Current literature was extended towards the paradigm of Virtual SC Network and events were defined within this new context. The links between unexpected events framed the way event information is communicated. Based on this, an event classification methodology was presented consisting of three main stages, event identification, event evaluation and event classification. The resulting designed ontology maps unexpected events against the SCOR model and is the roadmap on an Event Pattern Notation (EPN) that describes events patterns which is presented in the following chapter.

# CHAPTER 4: EVENT PATTERN NOTATION

## 4.1 Introduction

In this section an Events Pattern Notation (EPN) is built on the theoretical framework presented in the previous chapter. EPN aims to add descriptiveness to the ontology presented in the previous chapter. The classification presented earlier constitutes the roadmap that portrays unexpected events during Supply Chain processes and EPN expresses these events and their relationships using common semantics between all SC participants.

EPN serves to complete the events ontology by the creation of a logic-based framework developed in a Supply Chain context. Traditionally, the declarative approach used for event planning was the *event calculus* where conditions change *fluent* values over time causing certain *actions* (Kowalski & Sergot, 1986). It was originally proposed as a general temporal logic framework; however ascribing semantics to the event calculus has been found to entail difficulties (Pinto & Reiter, 1995).

EPN aims to use SC domain specific semantics and syntax to compose an event pattern notation and support the representation of event patterns in a comprehensive manner. To achieve syntactic consistency the Backus Naur Form (BNF) was adopted. The challenge was to design a notation that adheres to the principle of simplicity in representing events and event patterns while at the same time is context specific. Events need to be expressed in a Supply Chain context illustrating the time of their occurrence and the process within which they occur.

This chapter describes EPN syntax and semantics by providing examples of events and event patterns as were acknowledged in the survey on documented Supply Chain unexpected events. The rational behind the Events Pattern Notation unifies the need for simplicity in events description with the requirement for a commonly accepted representation over a specific domain. Through the following sections the third objective of this thesis is realized which expands the events ontology towards a dynamic roadmap for expressing event patterns.

- O3: Propose a notation for describing event patterns that is based on their ontological classification.

The first section describes the rationale behind mapping EPN on to the SCOR model. The syntax and the main EPN components are presented in the second section, while these components are integrated through the illustration of real examples. Section 4.3 creates the requirements framework against which EPN is evaluated. A comparative evaluation is performed based on the features, attributes and logic of three other event languages (STRAW-EPL, RAPIDE-EPL, DATALOG) and Web services specifications (WS-EVENTS). The general evaluation criteria were initially adopted by Luckham (2002) and were expanded on the projects domain to span over the holistic Supply Chain environment.

## 4.2 The SCOR Model & EPN

The syntax for EPN is intended to model a practical Supply Chain oriented notation that illustrates events and event patterns. This is achieved by expressing the processes, sub-processes and Supply Chain Elements (SCE) that describe the context within which events occur. The Event Pattern Notation enhances the hierarchical taxonomy presented in the previous chapter and a dynamic ontology is formed which describes events according to their classification. EPN syntax supports pattern description through the illustration of causal and temporal relationships using reserved keywords for time expressions.

This thesis has defined events as instances in time which alter the status of a resource, process or task or as triggers that initiate a task or a process. During SC operations such events take place both inside and outside the Supply Chain boundaries. The taxonomy presented previously, spans over the extended SC environment classifying events under both the SCOR model and the market/physical environment that surrounds any SC. Event declarations are made up of processes and process tasks, and hence there was the need to define a common representation of processes using a widely accepted reference Supply Chain model.

The second chapter (Literature Survey) presented the main concepts of the SCOR model. Five main processes were examined; however, one of them, PLAN refers to estimated events and therefore is not included in the taxonomy. The other processes, SOURCE, MAKE, DELIVER and RETURN, span over a wide spectrum of business operations looking at different variants of production systems (MAKE-TO-ORDER, STOCK-TO-ORDER etc), which determine the entire SC. For instance DELIVER, covers four different production systems options:

- D1: Deliver Stocked Product
- D2: Deliver Make-To-Order Product

- D3: Deliver Engineer-To-Order Product
- D4: Deliver Retail Product

SCOR sub-tasks are organized according to different production types. EPN uses the SCOR processes and tasks formation to describe events. Combining this structure with the events taxonomy, unexpected occurrences are described strictly based on a SC context and on commonly accepted semantics. The structure of this representation is:

*PROCESS.PROCESSID.EventType.Event*

For instance, the unexpected event of stock unavailability during a RETAIL production type would be part of the process task numbered D1.9. D1 is the general coding for Deliver RETAIL Product and D1.9 is the number for the *Pick Product* sub-task.

*DELIVER.D1.9.ProductUnav.UnavStock*

With the use of the SCOR Model, EPN achieves the explicit declaration of events, providing at the same time information that is important to be communicated to the relevant participants. Distinguishing between different production types and codifying the exact task in an unexpected occurrence, assists to transmit the relevant event path.

## 4.3 Event Pattern Notation Specifications

### 4.3.1 EPN Basic Components

The components of the theoretical framework that comprises EPN refer both to notational features and domain specific attributes. Five main conceptual components have been identified that constitute the rational behind EPN. These are: Supply Chain Elements (SCE), Task Types, Events Relationships, Functions and Time.

Supply Chain Elements are domain specific features and are divided into three main categories: business entities, business objects and business resources. Documentation and coding of SCE depends on each SC Network where a common agreement is required to overcome semantic interoperability. Business entities refer to the information regarding SC partners, such as suppliers and 3PLs, and final products/services which are involved in the SC processes. Resources refer to raw/first materials, human and physical sources, components, and administrative/assisting material that support business processes and/or participate in value adding activities. Business objects are SCOR processes inputs or outputs that assist tasks and communicate task results among SC partners, such as warehouse reports, order collection lists and warehouse pallet labels. Each Supply Chain Element contains a set of information, for instance a warehouse pallet label, describes a pallet based on information about the product, the weight, the location in the warehouse and the time the pallet was on the scale before it entered the warehouse( for SCE examples see Appendix E). These values are not static but depend on certain conditions and can be changed because of unexpected events.

EPN task types describe the execution of processes and sub-processes in a particular context and under particular conditions. This is important, as conceptually each event occurs during a certain task. The previous section described the way the SCOR model is used to scope Supply Chain processes in EPN. Taking into consideration the expanded operational framework that bounds the concept of e-SC Network, SC processes are expanded in a broader context and external factors affect the SC.

Three event relationship types determine the event patterns: causal and temporal relationships and the concept of independence. These types are logically defined through the actions and time connections between events, EPN uses statements to depict these relationships.

Event dynamics create the need to model interactions between processes that have quantifiable results. EPN supports functions with discrete values for event attributes.

*SCE.Attribute.Value* +| - | * | / *SCE.Attribute.Value*

Functions in EPN are used to manipulate event attributes and/or Supply Chain Elements. EPN functions can be used inside the CHOICE construct to determine the constant value that will trigger certain actions.

Time in EPN is modelled as an event attribute. When the event is automatically generated by an ERP or other SC system, *time* represents the precise date and time of the event's occurrence. If an event has happened outside the SC system but inside the extended business environment, the time attribute shows the date and time the event has been captured by the system. Expressing time granularity is essential when modelling business processes and specific time units should be defined according to industry criteria. The interviews conducted during the final stage of this project, revealed that for most domains, production time is measured in minutes and that the finest time units are minutes.

### 4.3.2 EPN Syntax

To achieve consistency and eliminate ambiguity in representation, BNF is used to define the grammar and syntax rules of the proposed events notation. BNF is a formal mathematical way to describe a language. It was originally introduced by Backus, 1958, to describe ALGOL and Naur, 1960 modified the formal notation according to his own perception of ALGOL and after he examined the differences between the two different interpretations. BNF has been officially used for the description of other languages, including RAPIDE, due to its simplicity and ease to understand (Knuth, 1964).

EPN was developed in two iterative cycles using a two stages evaluation. After the initial EPN design was completed a set of real event pattern examples was used to test EPN representation capabilities and identify weaknesses. The results indicated that the notation had to be enhanced with more elements, such as time and reserved operators and manners to represent lists and tables. The second evaluation stage was through a comparative framework against a set of predefined criteria.

EPN grammar elements are divided into DIGITS and LETTERS (Table 4.1), symbols (Table 4.2) and OPERATORS (Table 4.3). DIGITS and LETTERS constitute the core of EPN as they represent the main alphabet for each event and event pattern description.

**Table 4.1: Digits & Letters**

| EPN Element | | Description |
|---|---|---|
| <digit> | :: = | 0 \| 1 \| 2 \| 3 \| 4 \| 5 \| 6 \| 7 \| 8 \| 9 |
| <lowercase letter> | :: = | a \| b \| c \| d \| e \| f \| g \| h \| i \| j............\| z |
| <uppercase letter> | :: = | A \| B \| C \| D \| E \| F \| G \| H \| I \| J.........\| Z |
| <alphanumeric string> | :: = | <digit> \| < lowercase letter> \| <uppercase letter> \| <alphanumeric string> |

Symbols are used to indicate causality ( → ) and to declare a variable ($).

**Table 4.2: Symbols**

| EPN Element | | Description |
|---|---|---|
| <control symbol> | :: = | → |
| <variable symbol> | :: = | $ |

Operators, Table 4.3, include all arithmetic, logical and syntactic elements which are used to combine and describe events in a certain order indicating and forming event patterns. Condition operators set rules and clauses allowing both alternative and exceptional scenarios. Most commonly they are used to complete the syntactic expression of an unexpected event.

Time operators were added after the first evaluation stage in order to express the temporal relationships between events. Three time operators are used: BEFORE, AFTER and SIM (simultaneously). Even though it is rare that two different events are captured exactly at the same time SIM is used to allow preciseness in time representation. Two more time operators were defined, PARALLEL and SEQUENTIAL. They are used to define the execution order of actions triggered by event patterns. Reserved operators indicate a pattern and/or an action that is triggered. DEFINE declares a pattern, where as NOTIFY, GET and HALT are action operators. They illustrate the kind of action that will be triggered by the proposed Supply Chain Event Driven Architecture (SCEDRA) after a certain pattern has been identified. MATCH is used both for patterns and actions depending on the particular event conditions. Causality between events, hence composite events and patterns, is described by the reserved operator CAUSE.

**Table 4.3: Operators**

<table>
<tr><th>EPN Element</th><th></th><th>Description</th></tr>
<tr><td><arithmetic operators></td><td>:: =</td><td>+| - | * | /</td></tr>
<tr><td><relational operators></td><td>:: =</td><td><| > | = | #</td></tr>
<tr><td><logical operators></td><td>:: =</td><td>V| Λ | X</td></tr>
<tr><td><condition operators></td><td>:: =</td><td>IF| THEN | ELSE | WHERE</td></tr>
<tr><td><separating operators></td><td>:: =</td><td>:| ; | ,</td></tr>
<tr><td><bracket operators></td><td>:: =</td><td>( | ) | [ | ] | ’ | “ | ” | BEGIN |END</td></tr>
<tr><td><time operators></td><td>:: =</td><td>BEFORE | AFTER | SIM| PARALLEL| SEQUENTIAL</td></tr>
<tr><td><reserved operators></td><td>:: =</td><td>DEFINE | NOTIFY | GET | HALT | MATCH|CAUSE</td></tr>
</table>

EPN elements allow the representation of event patterns and events in future states and express nondeterministic actions depending on the domain requirements. EPN predicates are enriched both with flexibility in presenting temporal relationships and describing actions.

### 4.3.2 EPN Constructs

EPN constructs are built using the grammar presented in the previous section and they translate main EPN semantics. Table 4.4 and Table 4.5 present EPN declaration constructs and event pattern statements semantics as translated in the Supply Chain context.

**Table 4.4: Declaration Constructs**

| Definition | | Translation |
|---|---|---|
| <statement> | :: = | <expressions> \| <statement> <expression> |
| <expression> | :: = | <letter> \| <expression> <letter> |
| <variable> | :: = | $ <alphanumeric string> |
| <list> | :: = | <uppercase letter>"[" <variable> "]" |

LIST was added after the first EPN evaluation was performed, to address the need for presenting grouped and classified Supply Chain Elements. The core EPN declarative is the STATEMENT, which translates events and event patterns. Building on the combinations between STATEMENTS and EXPRESSIONS, PATTERN STATEMENTS are formed.

**Table 4.5: Event Pattern Statements**

| Definition | | Translation |
|---|---|---|
| <pattern-statement> | :: = | DEFINE <composite event> <condition> |
| <composite event> | :: = | [{<time operator> <variable>}] <condition> <action> |
| <condition> | :: = | IF <atomic event> [{<time operator> [<logical operator>] <atomic event>}] |
| <atomic event> | :: = | DEFINE <variable> ":" <classification path> "=" <path> |
| <classification path> | :: = | <process path>"." <sub-class>"."<lower-class>"."<attribute> "=" <value> |
| <path> | :: = | <process path> \| <external path> |
| <activity> | :: = | <expression> |
| <SEC> | :: = | <expression> |
| <attribute> | :: = | <expression> |
| <value> | :: = | <expression>\|<digit> |
| <owner> | :: = | <expression> |
| <sub-class> | :: = | <expression> |
| <lower-class> | :: = | <expression> |
| <process path> | :: = | <owner>"."<process>"."<activity>"."<SCE>"."<attribute> "="<value> |
| <external path> | :: = | <time operator> [<condition_choice>] [<function>] <action > < separating operator> |
| <action>> | :: = | THEN <reserved keyword> <owner> "["<process path>"." <activity> [{<process path>"."<activity>}] "("<variable> ")" |
| <choice_statement> | :: = | CHOICE <function> {<condition_choice> <action_choice> } |
| <condition_choice> | :: = | <relational operator> <value> |
| <action_choice> | :: = | <action > |
| <function> | :: = | name "(" <atomic event> <digit> "." < attribute> <arithmetic operator> <atomic event> <digit> "." < attribute> [<relational operator> ":" <variable>] ")" |
| <input> | :: = | <variable> |
| <output> | :: = | <variable> |

<table>
<tr><td><query></td><td>:: =</td><td><reserved operator>{<variable>|<list>} “=” {<atomic event>|<composite event>|<function>} <condition operator> [<variable>|<list>] <reserved keyword>{<atomic event>|<composite event>|<function>}</td></tr>
</table>

At minimum, an ATOMIC EVENT and EVENT PATTERN declaration is made up of STATEMENTS and OPERATORS. Using TIME OPERATORS to denote the order of events through a particular time period, temporality is illustrated and composite events are described. Expanding on this, event patterns are formed containing all information which needs to be communicated. Both ATOMIC and COMPOSITE EVENTS are described using the capabilities of time representation. Conditions which determine the triggered ACTIONS are supported through atomic and composite events.

PATH consists of a set of information: the PROCESS or the EXTERNAL environment within which the event has been captured, the OWNER of the particular process, the task and the supply chain element that will determine the impact of the particular event. The combinations of RESERVED KEYWORDS, PROCESS OWNER, ACTIVITY and PROCESS constitute ACTIONS, which are transmitted to the interested Supply Chain parties. CHOICE is used to select the appropriate evaluation conditions that are stated in terms of event attribute values. CHOICE and QUERIES facilitate EPN non- determinism by allowing for flexibility in event patterns. INPUT refers to Supply Chain Element or event attribute value which is received to perform a process or function, whereas OUTPUT is a process or function’s outcome. FUNCTIONS perform mathematical operations on events attribute values and they determine the temporal relationships between events and the triggered ACTIONS.

### 4.3.3 EPN Examples

EPN aims to portray event patterns and actions that are triggered by events and/or event patterns. To describe these patterns, EPN components are combined to express of event – action statements. Each statement has two parts: the condition and the action part. The condition part describes the casual and temporal relationships between events which result in CEPs. An EPN advantage is the ability to model composite events as they are formed through temporal relationships which create and causal effects. The following examples illustrate the way EPN elements are combined to form event patterns.

#### 4.3.3.1 Invoice Error Scenario

A simple example is initially used to illustrate events and event pattern declarations. An invoice error is detected in the delivery of a stocked product during the product verification activity (D1.10: Load Vehicle Generate Ship Documents, Verify Credit and Ship Product). This event has a causal impact on the invoice processing task during DELIVER (D1.13: Invoice) and on the customer's SOURCE process (S1.2: Receive Verification). Table 4.6 illustrates the EPN description of the formed pattern.

**Table 4.6: EPN Invoice Error Description**

```
DEFINE $ P
IF
        {$E1:PARTNERA.DELIVER.D110.OrderError.InvoiceIncons}

THEN
        NOTIFY
            { PARALLEL
              E1.PARTNERA (( DELIVER.D110, $ P);
                              (DELIVER.D113, $P)
                            );
             E1.DELIVER.Order.CustomerID ( SOURCE.S13, $P)
            }
```

The pattern consists of two sections condition and action. The condition part includes one event which, in this case, is an atomic event. The impact on the DELIVER and SOURCE processes is communicated using the pattern path to transmit the delay notification to the interested parties.

#### 4.3.3.2 Car Supply Chain Scenario

The following example pictures a pattern which is created from the causality of two events. The Event Process Chain notation is used to graphically illustrate the process redesign using an event-driven approach (Davis, 2001). EPN is similar to the EPC approach as both notations focus on event-based process descriptions. A car manufacturer purchases defective car components and needs to reschedule the production and notify the customer about the deviation from the scheduled delivery date. Both the failure and the triggered actions are captured including the information inputs/outputs and the supply chain partners involved at each action are shown.

Table 4.6 contains the EPN description of the example presented above. One event pattern is formed ($P) as the result of the causality between two events E1 and E2. E1 occurs during the SOURCE process of the car manufacturer during task S2.3: verify product. The component doesn't conform to the general requirements and criteria due to a fault in component size.

***PA.SOURCE.S23.DeffectiveComponent.SizeDev***

The description originates from the event taxonomy presented in the previous chapter, where the event is classified initially under the SCOR process element (S2.3) and then is modeled as an object of the SizDev class.

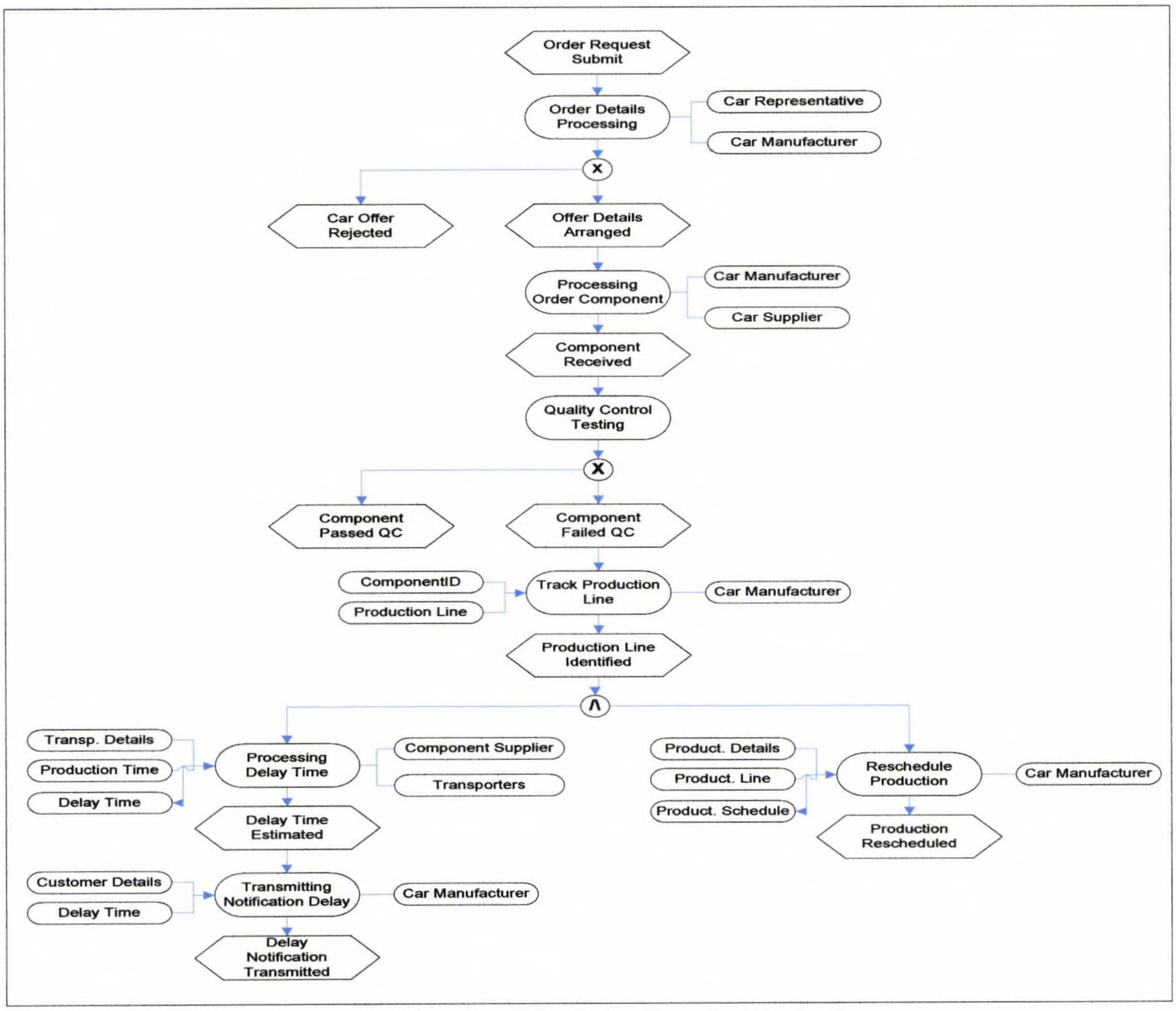



***Figure 4.1: EPC Model of Car Supply Chain Scenario***

Event E2 is the causal effect of E1 and is also illustrated as an object of the ProductAnav class. Condition operators are used to define the condition and action statements of $P. Two actions are triggered by this pattern and they are executed sequentially. Initially the component id is the Supply Chain Element which reveals the batch number that was planned to be completed and then the customer that this batch was intended to is notified. The customer is notified about the delay by receiving the path of the entire pattern:

***E2.Order.CustomerID (DELIVER.D23, $P)***

The pattern could alternatively use another SCE to get the information that needed to be transmitted depending on the elements which are available on each occasion.

**Table 4.7: EPN Car Scenario**

```
DEFINE $ P {$E1 CAUSE $E2}
IF
        {$E1: PA.SOURCE.S23.DeffectiveComponent.SizeDev = 10%
          CAUSE
        $E2: PA.DELIVER.D23.ProductAnav}
THEN
        SEQUENTIALLY
        {
   GET
              {$B = MAKE.M12.Batch.BatchID
                 WHERE    Batch.ComponentTID = E1.ComponentID };
  NOTIFY
                 PARALLEL
                 {E1.PA (MAKE.M11, $P);
                  E2.Order.CustomerID (DELIVER.D23, $P) }
        }
```

In this particular example events in the action and condition part of the pattern are described in different ways. At the condition part, events are declared as variables that are assigned with the event path and the attribute value (*$E2: PA.DELIVER.D23.ProductAnav*). In the action part events are illustrated as instantiated classes which are part of the path in order to communicate and transmit the pattern information.

#### 4.3.3.3 Temporarily Related Events Scenario

The following example illustrates two events which are temporarily related, a machine failure and a high priority order. The CHOICE construct is used to determine the action that will be triggered. CHOICE uses a time value as the constant that will trigger a particular action. The time function measures the time difference between an actual and an estimated event. All events and actions are mapped against the SCOR model. Due to the need to reschedule certain activities the PLAN process is also used to map future events. Also, the flexibility of EPN to describe unexpected events is illustrated, as the High Priority Order event is modelled under the DELIVER process. Table 4.8 pictures the pattern through the temporal relationship.

**Table 4.8: EPN Temporal Related Events**

```
DEFINE $ P1 ($E1 TEMP $E2)

IF
        {$E1: PARTNERA.MAKE.M13.Infrastracture.MachineFailure= "F123"
         BEFORE
         $E2: PARTNERA.DELIVER.D12.HighPriorirtOrder.Quantity> 1000
         }
THEN
   CHOICE TimeDifference (E1.Time - E2.Order.DeliveryTime)

  > 20 mins
       NOTIFY
         { E1.PARTNERA    ((MAKE.M11, P1);
                            (PLAN.P32,  P1);
                            (PLAN.P31, P1) ) ;
         }
  < 20 mins
       NOTIFY
          E2.Order.CustomerID(SOURCE.S1, P1)
```

The time function uses an arithmetic operator to estimate the time difference between two events. The value of the events time attribute is used and the result determines the action taken from the CHOICE construct.

EPN aims to express events in a business domain where participants have a strong managerial background, thus is difficult to communicate event pattern information using a traditional system design notation. The complexity of the compilation of a language/notation increases as the language/notation becomes richer in basic operations (Iverson, 1963). In the SC domain this feature reflects on the ability of Supply Chain participants to interpret the transmitted information. The above examples incorporate and communicate business logic in an object-oriented approach, thus reducing complexity and supporting information interaction.

## 4.4 Event Pattern Notation Comparative Evaluation

The second stage of EPN evaluation was accomplished through a comparative evaluation with four event languages and specifications. STRAW-EPL is a straw man language introduced by Luckham (2002). Although it is not a powerful language in terms of expressiveness, in this context serves in illustrating event patterns. RAPIDE as a declarative language has stronger notational capabilities (Luckham, 1995; Luckham, 1996). It uses mathematical expressions to describe events along with timestamps, causal dependencies and parameters. Additionally, RAPIDE has object oriented syntax, a feature similar to the class-diagram/taxonomy that EPN uses as a roadmap to express events.

The third language used in the comparative framework was Event Choice DATALOG. DATALOG combines the ability of choice construct with event activation rules, a feature that is similar to the CONDITION-ACTION structure in EPN. Event Choice DATALOG expands on these features to encapsulate dynamic knowledge, express non-deterministic state transitions and multiple time granularities (Greco & Zaniolo, 1998). Finally, the messaging notification specification WS-EVENTS between Web services was included due to its strong representation abilities for parameter passing and message exchange (Catania *et al.*, 2003).

The first part was the development of the evaluation framework within which EPN was compared and it consisted of three main sections: general event language, event pattern and domain specific requirements. The aim was to examine EPN from a holistic perspective by considering all aspects and criteria a notation needs to adhere to.

### 4.4.1 General Requirements

This section presents the general requirements an event pattern language has to address in order to express complex event patterns. General requirements are adapted from Luckham (2002) and customised in the context of the particular project. Their purpose is to create a general framework for event pattern languages. They are categorised on four main categories each representing criteria event pattern languages should meet:

Power of expression: Complexity in event patterns is addressed with powerful expression notational tools that illustrate causality, temporality and flexible execution.

**GR1:** Refers to notational symbols and keywords that express causal relationships between events.

Example: Rapide uses "→" to indicate causality between two events

**GR2:** Refers to notational symbols and keywords that express temporal relationships between events.

Example: Rapide uses keywords such as "at, after, during" to illustrate temporal relations between events.

**GR3:** Refers to notational keywords that allow action and rule execution to be performed either in parallel or sequentially.
Example: (STRAWMAN EPL) CREATE, CREATE PARALLEL.

*Notational Simplicity*: Simplicity is a two dimensional characteristic that refers to user oriented editing and presentation. In this project it is scoped both from the user perspective and error proneness.

User Oriented Editing

**GR4:** To create an easy-to-use and accessible notation strong mathematical logic knowledge should not be obligatory. The following example illustrates a non user friendly notation.
Example: (DATALOG) S_ U SM(D-KB U S U AI (chosen tr ) U RI (chosen tr )) U
U triggered (E), and E_ = E U EI (chosen tr ) − triggered (E).

**GR5:** Keywords, data parameters, components and events should support flexibility in their verbose expression in order to be expressed in any problem domain and allow editing by the user.
Example: (DATALOG) Proposition 5.6 A temporal model S,E_ for any program PEDB,H is stationary if and only if E = ∅.

Error Proneness

**GR6:** Allowing identifiers, like variable declaration, to be flexibly typed. The following example shows a case of strong typing.
Example: RAPIDE (Dollars ?D, Account_Type ?A ?B).

**GR7:** Commonly used symbols (parentheses, curly brackets, arrows) assist in stating the logical order of events which prevents from errors in composing patterns and supports user oriented editing.
Example: (DATALOG) S_ U SM(D-KB U S U AI (chosen tr ) U RI (chosen tr )) U triggered (E).

*Precise semantics*: A syntactically valid language is not always based on semantics for the purpose defined by the problem domain.

**GR8:** Pattern editing should be clearly identifying event combination/aggregation

Example: (STRAWMAN) Send(D, B, T1) → Receive(D, B) → Ack(b)→ ReAck (B, T2).

**GR9:** Components (parameters, keywords, data ) interrelationships and connections should be defined to avoid conflict in parameter passing and processing.

*Scalable pattern matching:* Patterns should comply with event descriptions, aggregations and combinations and should allow for scalability without increasing editing complexity.

**GR10:** Patterns should represent event descriptions, aggregations and combinations.

**GR11:** Patterns should allow description of complex events of unlimited size, for example:

```
[pathFinder()@S]
!pathFinder()@S++,
¬pos(X, Y),
+pos(XN, YN) ←□arrived(),
walk(D, XN, YN), pos(X, Y),
□movableWall(X, Y),
choiceAny().
!move()@sub(S),
!toBeCompleted(X, Y)@S, 30_ ← movableWall(X, Y).
```

### 4.4.2 Event Pattern Requirements

This section presents another set of requirements which refer to specific events characteristics. Emphasis is on benefits deriving from declarative formats to avoid complex algorithmic descriptions. The list of event pattern requirements was developed after studying the strong representation aspects of event languages.

**ER1:** Event data parameters should be explicitly defined, including event attributes, and values.

Example: (RAPIDE) typedef record {Node N1; Connection C; Node N2}

**ER2:** Event parameters should be used to communicate events and event patterns values and to exchange messages, hence notation should allow parameter passing.

Example: WS-Events, the notification producer uses the callback method on the event consumer to pass one or more notifications as parameters.

```
<xs:element name="Callback" type="evt:CallbackType"/>
<xs:complexType name="CallbackType">
```

```
<xs:sequence>
<xs:element name="port" type="wsdl:tPort" maxOccurs="unbounded"/>
<xs:any minOccurs="0" maxOccurs="unbounded" namespace="##other"
processContents="lax"/>
</xs:sequence>
<xs:anyAttribute namespace="##other" processContents="skip"/>
</xs:complexType>
```

**ER3:** Clear and explicit definition of different event types, to allow handling a variety of different events, event parameters and patterns.

Example: (WS-Event)

```
<xs:complexType name="SusbscribeType">
<xs:sequence>
<xs:element name="EventSelector" type="evt:EventSelectorType"/>
<xs:element name="ExpirationTime" type="xs:dateTime"/>
<xs:element name="Filter" type="evt:FilterType" minOccurs="0"/>
<xs:element name="CallbackUrl" type="evt:CallbackType" minOccurs="0"
maxOccurs="1"/>
</xs:sequence>
</xs:complexType>
```

**ER4:** Pattern creation depends on event aggregation, thus should be supported by the notation in an easy-to-read manner. Most languages achieve aggregation when describing patterns through the causal relationships developed between events that form the pattern.

Example: (RAPIDE) pattern Saving() is Deposit()→ Saving or Empty()

**ER5:** Single events should be uniquely defined. Most languages accomplish this either by defining event types or associating events with variables.

Example: (STRAWMAN) Send(Data D, Bit B, Time T)

**ER6:** Classification characteristics support mapping events to the problem domain, describing event attributes and identifying causalities between them.

**ER7:** Time in events is relative as IT systems capture events not only in real but near-real time. However the time attribute defines the order of events and determines temporal relations. Time is modelled either as an attribute or a parameter.

Example: (STRAWMAN) Send(Data D, Bit B, Time T)

### 4.4.3 Context Specific Semantics Requirements

Event pattern notations illustrate events which occur in a certain problem domain. Semantics should be flexible to adjust to particular context.

**CR1:** Specifying the event originator is essential to specify contextual meaning of the event, causalities and temporal relations that are created. This information is also required to identify related parties that patterns need to be disseminated to. Most languages indicate originators without stating them explicitly as part of an event.

Example:

```
(EPN)

DEFINE $E1
IF
   {$E1: PA.SOURCE.S23.DeffectiveComponent.SizeDev = 10%}
```

**CR2:** Consumers refer to partners that subscribe to events and require the dissemination of events and patterns. Similarly to CR1 most languages indicate consumers without stating them explicitly as part of an event's attribute.

Example:

```
(EPN NOTIFY)

{E1.PARTNERA    ((MAKE.M11, P1);
                 (PLAN.P32,  P1);
                 (PLAN.P31, P1)
                );
```

**CR3:** Notational symbols and expressions illustrating components, keywords and event types should be close to the problem domain or allow flexibility to describe precisely events contextual framework of events. Most languages achieve mapping to problem domain through their event type description.

Example:

```
(RAPIDE)

(Dollars ?X, ?Y; Account ?A)
(Deposit(?X, ?A) → Withdraw(?Y, ?A)) where ?Y < ?X
```

**CR4:** Event producers provide information about their origins and are needed for identifying causalities and temporal relations between events and for disseminating action rules to the interested parties.

Example: (RAPIDE) pattern Saving() is Deposit()→ Saving or Empty()

**CR5:** Pre-existent event libraries allow flexibility when defining event types and support efficient notational mapping to the problem domain.

**CR6:** Similarly to CR5, pre-existent component libraries allow efficient notational mapping to the problem domain.

### 4.4.4 Comparative Evaluation

Table 4.9 illustrates how the four events languages and specifications were evaluated against the requirements identified above. In this section the aim is to justify the reason for developing EPN rather than using one of the existing notations to model events. The proposed notation was designed to adhere to domain specific requirements.

**Table 4.9: Comparative Evaluation**

| | ID | STRAW-MAN EPL | RAPIDE EPL | EVENT-CHOICE DATALOG | WS-EVENTS | EPN |
|---|---|---|---|---|---|---|
| **GENERAL REQUIREMENTS** | | | | | | |
| **Power of Expression** | | | | | | |
| Illustrate causal relationships between events | GR1 | Y | Y | Y | ~ | Y |
| Illustrate temporal relationships between events (time bounds, time intervals) | GR2 | Y | Y | Y | ~ | Y |
| Support sequential/ parallel execution | GR3 | Y | ~ | Y | Y | Y |
| **Notational Simplicity** | | | | | | |
| No need for mathematical logic knowledge | GR4 | Y | Y | X | Y | Y |
| Flexible verbose | GR5 | Y | Y | X | Y | Y |
| *Error Proneness* | | | | | | |
| Typed identifiers | GR6 | Y | Y | ~ | ~ | ~ |
| Syntactic "sugar" (curly braces, begin/end, parenthesis) for user oriented editing and presentation | GR7 | Y | Y | X | Y | Y |
| **Precise Semantics** | | | | | | |
| Clear illustration of patterns & execution rules | GR8 | Y | Y | ~ | ~ | Y |
| Depended relationships between components are visible | GR9 | ~ | ~ | ~ | ~ | Y |
| **Scalable Pattern Matching** | | | | | | |
| Efficient pattern matching | GR10 | Y | Y | Y | Y | Y |
| Patterns of unlimited size and complexity | GR11 | X | Y | Y | Y | Y |
| **EVENT – PATTERN REQUIREMENTS** | | | | | | |
| Specify event data parameters | ER1 | Y | Y | Y | Y | Y |
| Support parameter & component passing to communicate events | ER2 | X | X | X | Y | ~ |
| Event type definition | ER3 | Y | Y | Y | Y | Y |
| Creation of higher level events – | ER4 | Y | ~ | Y | Y | Y |

| | | | | | | |
|---|---|---|---|---|---|---|
| aggregation of events | | | | | | |
| Support single event matching | ER5 | Y | Y | Y | Y | Y |
| Classification of events | ER6 | X | X | X | Y | X |
| Capture event creation time | ER7 | Y | Y | Y | Y | Y |
| **CONTEXT SPECIFIC SEMANTICS' REQUIREMENTS** | | | | | | |
| Explicit definition of event originator (producer) | CR1 | X | ~ | ~ | ~ | Y |
| Explicit definition of event consumers | CR2 | X | ~ | ~ | ~ | Y |
| Notation close to problem domain | CR3 | ~ | ~ | X | ~ | Y |
| Specific event libraries matching domain event types | CR4 | X | Y | X | ~ | Y |
| Specific component libraries matching domain components | CR5 | X | X | X | ~ | Y |

### 4.4.4.1 Comparative Evaluation: DATALOG

*GENERAL REQUIREMENTS*

**Power of Expression GR1- GR3:**

Strong capabilities in power of expression as the choice constructs illustrate non deterministic forms and dynamic time granularities support multidimensional planning for temporal relationships.

**Notational Simplicity GR4-GR7:**

Strict use of mathematical logic and notation reduces notational flexibility and error proneness.

**Precise Semantics GR8-GR9:**

Every DATALOG program is a set of rules which describe the course of rules' execution. The use of mathematical logic notation indicates components' interrelation.

**Scaleable Pattern Matching GR10-GR11:**

Mathematical logic notation supports scalability.

*EVENT PATTER REQUIREMENTS*

**ER1, ER3, ER4, ER5, ER7:** Support specified.

**ER2:** No parameters definitions specified.

**ER6:** No classification definition specified.

*CONTEXT SPECIFIC SEMANTICS REQUIREMENTS*

**CR1:** Causal effect indicating starting event.

**CR2:** Causal effect illustrating event consumer, but not explicitly stated.

**CR3-CR5:** No definition specified.

#### 4.4.4.2 Comparative Evaluation: WS-EVENTS

*GENERAL REQUIREMENTS*

**Power of Expression GR1- GR3:**

Poor support as execution is expressed via the exchange of messages (events) and although sequential execution is implied there is no explicit definition illustrating parallel execution. Relationships (both causal and temporal) between events are not explicitly defined but are supported by the notification element.

**Notational Simplicity GR4-GR7:**

XML syntax does not require mathematical logic knowledge and allows flexibility in verbose. No variables are used to support error proneness however mistyping identifiers is prevented by XML syntax.

**Precise Semantics GR8-GR9:**

No use of particular semantics to express patterns of events or rules' execution.

**Scaleable Pattern Matching GR10-GR11:**

Use of several elements (source/timestamps/duration) supports pattern matching and allows scalability. Additionally scalability is supported by the subscription mechanism.

*EVENT PATTER REQUIREMENTS*

**ER1:** Clear specification using XML.

**ER2:** Support through subscription mechanism.

**ER7:** Support by elements such as timestamp, GetEventByRange

*CONTEXT SPECIFIC SEMANTICS REQUIREMENTS*

**CR1, CR2**: Support through notification element, but not explicitly stated.

**CR3-CR5:** Depends on XML schema definition.

#### 4.4.4.3 Comparative Evaluation: A STRAWMAN EPL

*GENERAL REQUIREMENTS*

**Power of Expression GR1- GR3:**

Relational operator ( → ) is used to illustrate causality, which is also implied by the action statement. Temporal relations are shown using constraints (*never*).

Rule specifications (*create, create parallel*) support action execution.

**Notational Simplicity GR4-GR7:**

Sufficient support for notational simplicity as simple mathematical logic is required and verbosity supports flexibility.

Use of event and time variables prevents errors in typing identifications.

Parentheses and the tabular format to enhance user oriented editing.

**Precise Semantics GR8-GR9:**

Tabular format to illustrate patters that include four elements, variables, events, patterns, conditions.

Execution is shown with action statement.

Dependencies are implied by event declaration.

**Scaleable Pattern Matching GR10-GR11:**

Scalability is reduced with the tabular format because of lengthy descriptions to express complex patterns.

*EVENT PATTER REQUIREMENTS*

***ER1, ER3:*** Event types are defined and parameters are indicated as list of variables.

***ER2, ER6:*** No support for parameter checking is provided and no features fo classification.

***ER7:*** Time is represented using time variables.

*CONTEXT SPECIFIC SEMANTICS REQUIREMENTS*

***CR1, CR2, CR4, CR5:*** No support elements defined.

#### 4.4.4.4 Comparative Evaluation: RAPIDE

*GENERAL REQUIREMENTS*

**Power of Expression GR1- GR3:**

Relational operators ( →, || ) support causality.

Temporal operators (at, after, during) support temporal relationships.

No explicit definition regarding sequential/parallel execution.

**Notational Simplicity GR4-GR7:**

Basic mathematical knowledge is required and verbose is flexible.

Strong typing and extended use of variables support error proneness.

**Precise Semantics GR8-GR9:**

Patterns and execution actions are clearly defined (***pattern*** *macro,* ***action*** *declaration*).

Component relationships, event parameters, are illustrated when defining types but not explicated stated.

**Scaleable Pattern Matching GR10-GR11:**

Efficient illustration of complex patterns.

*EVENT PATTER REQUIREMENTS*

**ER1:** Notation elements (*?*) support naming parameters.

**ER3:** Generic event type is defined and also sub-types of events.

**ER5:** Support using basic event pattern element.

**ER7:** Time is illustrated using time stamp attribute.

**ER2, ER6:** No support defined.

*CONTEXT SPECIFIC SEMANTICS REQUIREMENTS*

**CR1, CR2:** Support through event attributes but not explicitly stated.

**CR3:** The context feature references to guards and information outside the events (*database queries, values returned from method calls*).

**CR5:** No support defined.

#### 4.4.4.5 Comparative Evaluation: EPN

*GENERAL REQUIREMENTS*

**Power of Expression GR1- GR3:**

Strong support from reserved (*CAUSE, TEMP*) and time operators (*BEFORE, AFTER*) which illustrate causal and temporal relationships.

**Notational Simplicity GR4-GR7:**

Sufficient support for simplicity and expressiveness in operators to avoid errors. However, GR6 is addressed mainly in terms of variable expressions.

**Precise Semantics GR8-GR9:**

Reserved operators support dependencies.

Condition operators allow separation between CONDITION and ACTION.

**Scaleable Pattern Matching GR10-GR11:**

Composite events provide unlimited pattern matching.

*EVENT PATTER REQUIREMENTS*

**ER1, ER3, ER4, ER5, ER6, ER7:** Support provided.

**ER2:** Parameter value passing between variables and NOTIFY messages.

*CONTEXT SPECIFIC SEMANTICS REQUIREMENTS*

**CR1:** Support through event owner feature.

**CR2:** Support through transmitting PATH to related parties.

**CR3:** Clear support.

**CR4:** Support through event taxonomy.

**CR5:** Support through Supply Chain Elements library.

In summary, STRAW-EPL is a straw man language used for the purposes of this thesis to demonstrate the difficulty of applying a general event language on a particular domain. Event Choice DATALOG is a declarative language and notation is mathematical based. WS-Events notation meets most of the above requirements, however fails to support specific domains and to depict dependencies between events, hence causal and temporal relationships are not clearly defined. RAPIDE-EPL is a simple notation with flexibility in verbose and error proneness support, but with no features to support a specific domain. EPN was built considering the above limitations based on a certain SC context requirements. Events are expressed in a Supply Chain context using libraries of objects (SCE) and of events (event-ontology).

## 4.5 Chapter Summary

This chapter had a dual purpose, to design an events and event patterns notation and to enhance the proposed taxonomy of events. EPN addresses the need for event and event pattern representation within the Supply Chain domain, as event occurrences are mapped against the SCOR model and the extended business environment. EPN incorporates business and domain knowledge in a representation form that is adopted by SC participants. SC processes and activities, Supply Chain Elements and partners are all combined to define composite and atomic events.

Events are the core ingredients of patterns, thus describing event patterns requires a powerful event notation. The challenge of this thesis was to design an event notation that was domain specific without compromising simplicity or scalability. The evaluation framework was built based on useful features of existing event notations and was adjusted to the particular needs of this project.

Strong modelling capabilities regarding temporal and causal characteristics and the use of the events taxonomy in EPN implies that the initial target of scoping the general events representation framework was achieved. EPN constitutes a core element of SCEDRA (Supply Chain Event Driven Architecture) that translates and transmits events, which is described in the next chapter.

# CHAPTER 5: AN EVENT DRIVEN INFORMATION SYSTEMS ARCHITECTURE FOR SUPPLY CHAINS

## 5.1 Introduction

The advent of e-technologies has supported the automation and increased effectiveness in time consuming business interactions and transactions. This is realized in the concept of the e-Supply Chain Network which allows for flexibility in partnerships with reduced cost and increased efficiency. As competition has shifted from the company level to the Supply Chain level, the need for a responsive business has shifted to the need for a responsive Supply Chain. Within the e-SC operational framework agility requires flexible mechanisms to address interruptions and changes in conditions that alter the planned schedule of Supply Chain activities. McGovern and colleagues (2006), identify these changes in conditions as "events" which constitute the core concept of an event-driven architecture. Similar to the events definition proposed by this thesis in chapter 3, McGovern describes these events as any disruption from a system failure to a market turbulence event.

McGovern *et al.* (2006) define as event-driven architectures, the applications and services that are capable of responding to unexpected changes in conditions regardless of their nature. They aim to expand traditional Service-Oriented-Architectures (SOAs) (Marks & Bell, 2006) towards Enterprise SOA through the design of services that model the business.

The Literature Survey (chapter 2), examined technologies that support event driven activities. Business Activity Monitoring solutions provide a shield from unexpected and unplanned events and allow the effective monitoring and user notifications when process metrics alert for unexpected occurrences. However they fail to identify the temporal relationships between events and to foresee the composite events and the patterns which are formed. This chapter proposes an architecture aiming to meet the operational requirements of a dynamic e-Supply Chain Network and address the IT challenges of an event-driven SC. The extended Supply Chain event driven system is realized in SCEDRA (Supply Chain Event Driven Architecture), which spans across the networks of SC partners. SCEDRA unifies the concept of event-based monitoring with the ability to disseminate events and event patterns to partners in the SCN. Through the following sections the fourth objective of this thesis is realized:

- O4: Design an Information Systems Supply Chain Event Driven Architecture (SCEDRA), which captures unexpected events, inside and outside the SC, identifies and propagates event detection information through the supply chain network.

The chapter is divided in two main sections. Initially the rationale for SCEDRA is described through its main components and construction principles (Section 2.5.1). Sections 2.5.2-2.5.6 describe the layers and technical levels that compose the architecture and the technological paradigms that support SCEDRA functionality. Finally, the information schema is modelled describing the relationships among SCEDRA data objects (Section 2.5.7). The second part describes an evaluation framework based on two industry scenarios elicited from the interviews (Appendix A). Each scenario describes process interactions between different members of the Supply Chain during unexpected events. Two different situations are compared for each scenario, one when no event driven mechanism is used and the other utilising SCEDRA to model the re-engineered processes and tasks.

## 5.2 Supply Chain Event Driven ARchitecture (SCEDRA)

SCEDRA realizes an architecture for distributed business environments. The goal is to integrate information and processes in order to capture events that occur inside and outside the Supply Chain and to identify the resulting patterns. In an event-driven architecture over a traditional Service Oriented one, control shifts to the event recipients, which in the particular case are the SC participants affected by events. Participant interoperation is also supported by the parallel and asynchronous flows through an event-driven network that overcome the tenacity of linear execution paths in SOA (Shulte & Natis, 1998).

SCEDRA spans across operational networks and monitors industrial, market and physical environments for any unexpected disruptions that affect the SC. The core of SCEDRA requires a specification that guarantees standardization at an enterprise level. The need to address interoperability is important as different architectural components would run over the same platform. Web services are used to achieve interoperability and XML semantics to communicate data. SCEDRA is a distributed multilayer architecture based on modular software components, including both Web services and agents.

### 5.2.1 SCEDRA Main Concepts & Principles

#### 5.2.1.1 *Main Components*

To identify and construct event patterns different architectural components need to be linked. These components include:

Agents: Agents in SCEDRA perform two types of operations, monitoring and transmission of information about events. Monitoring refers both to SC and ERP applications and to external systems that provide information about the extended business environment.

Web Services: Exposing partner functionality is realized in SCEDRA with the adoption of Web services. Operational functionality abstracted in application modules overcomes interoperability issues among the different SCEDRA partners ERP and logistics systems.

Rules: Rules define the way temporal and causal relationships are formed. Rules are stored in the Rule Repository which communicates with partners decision systems in order to incorporate partner and company knowledge and response policies.

Maps: Rules and relationships need to be mapped on the events that have been captured by a monitoring agent, thus the unexpected events classification is used to map events. The Filter Engine component translates events using the Event Pattern Notation.

Event Log: A temporal directory is required that stores events until they become void, in order to check for temporal and causal relationships.

Data Repository: A repository holds information about SCE, Partner Data and Operational Information that links to the ERP, SC and production applications used by partners.

#### 5.2.1.2 Main Principles

SCEDRA completes the framework which surrounds events and event patterns when they occur during SC operations. The initial step was to develop the theory of event patterns and the notation through which event pattern information is communicated. SCEDRA was designed to model the architecture which enables this communication.

The main characteristic of SCEDRA is that it is comprised of different modules and mechanisms that need to be linked. Due to this feature, a policy has to be set as a standard that unifies event patterns construction. The following principles propose the order and the main activities that should be performed when constructing event patterns:

Event capture: Events span across multiple heterogeneous applications that are either internal or external to the e-Supply Chain Network. Efficient monitoring should not only focus on internal applications, such as SC solutions but also to ERP systems and production operations. Monitoring activities should also extend to external systems that provide information about the general operational business environment.

Event monitoring: Unexpected events occur during any SC and business related operations. Continuous monitoring should be in place to capture disruptions of any kind, physical, technical, industrial etc.

Event translation: To communicate events with the pattern matching module EPN is used to translate the occurrence of the event describing the classification attributes and the causal or temporal relationships that result into patterns.

Rule identification: Rules are set by the SC participants which determine the general policy and strategy of SCEDRA network. Rules are described using EPN and they are encoded in the formed pattern either indirectly, through causal and temporal relationships, or directly as actions.

Form composite events: EPN manages to describe a composite event as the aggregation or combination of two or more atomic events.

Map composite events: Cluster Event Patterns are formed when rules are applied on atomic or composite events.

### 5.2.2 SCEDRA Architecture

Figure 5.1 presents an overview of the architecture, modeling the main layers and architectural components. The architecture consists of three layers, the physical layer (operational module), the application layer and the event pattern layer. Each layer is a conceptual representation of SCEDRA's contents and their communication is achieved using common semantics defined by the Event Pattern Notation. All three layers communicate with the Supply Chain Common Data Repository which is the main data warehouse that unifies SCEDRA's operations.

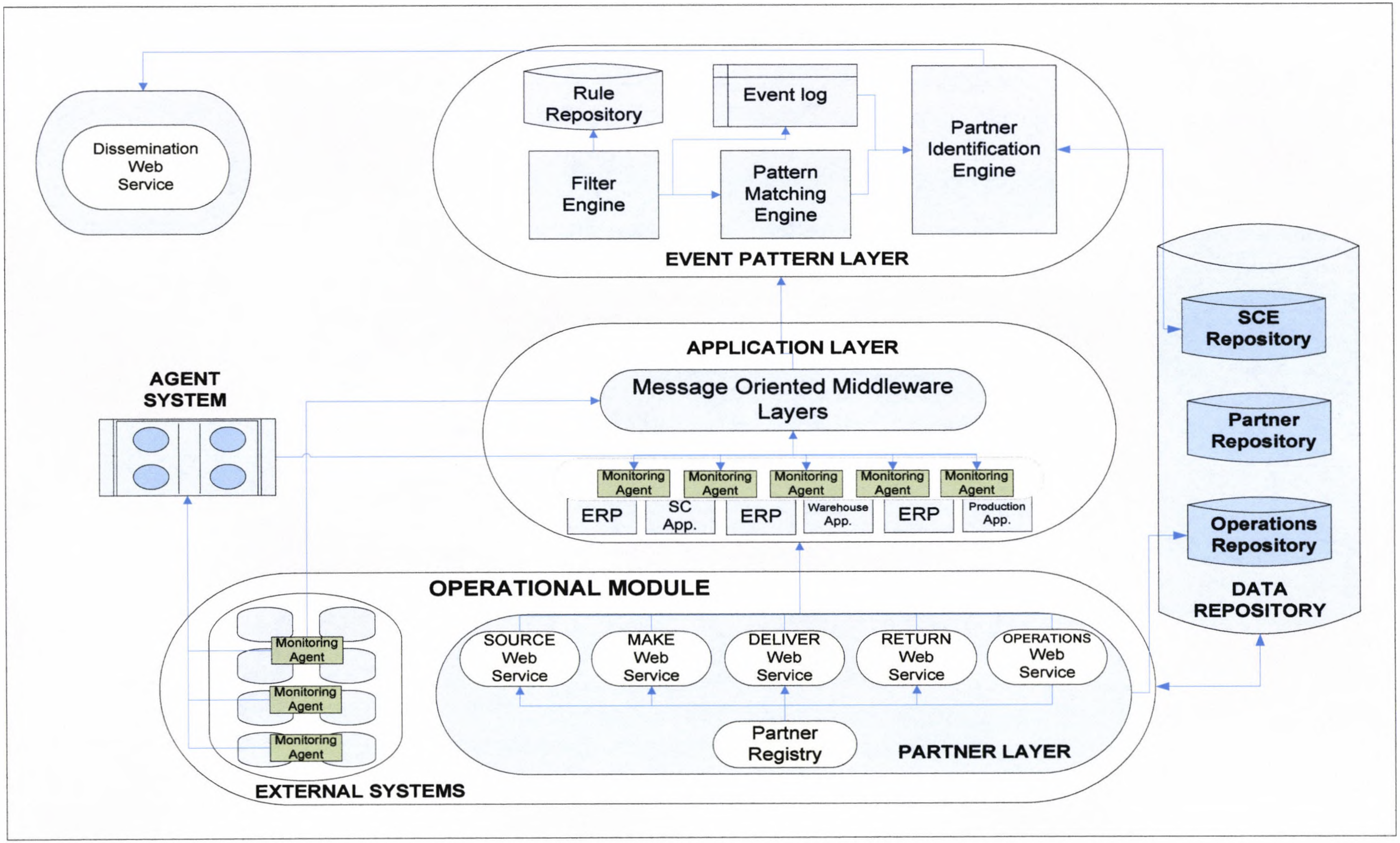



*Figure 5.1 Supply Chain Event Driven Architecture*

### 5.2.3 The Data Repository

To address the issue of distributed data across SCEDRA, a federated data warehouse architecture is proposed (Jarke *et al.*, 2003). The warehouse stores three data sets concerning operations and transactions between participants and information about partner's profile. Because Supply Chain Elements are included in the main database, it is important to unify heterogeneous data types and formats.

The proposed data warehouse consists of three main data repositories, SCE repository, Partner repository and Operational repository. The SCE repository contains all SCE elements that are exchanged across partners, such as invoices, delivery notes etc. These are business artifacts that are produced and updated by SCEDRA participants and are communicated through the SCEDRA Web-service partner module. The partner repository is tasked with the maintenance of Supply Chain participants master data including the information about particular services published by each participant and their registration type. The operations repository is mapped against the SCOR model, following the official SCOR structure and process elements numbering, to assist event translation to EPN.

### 5.2.4 The Operational Layer

#### 5.2.4.1 Partner Module

SCEDRA first layer consists of two main levels, the partner and the external environment level. The partner level connects all Supply Chain participants and represents them as nodes in an e-SC Network. One of the basic requirements in implementing SCEDRA was to address the issue of creating a dynamic network, where participation depends on dynamic environmental and business conditions. SCEDRA integrates partners using Web service modules. The partner module consists of two main layers, the registry and the Web services module. The registry holds information about each partner and enables services interoperation. Each SCEDRA participant publishes information that needs to be available for network integration. This information as shown in Figure 5.1 refers either to active or inactive participants of the Supply Chain Event Driven Architecture.

Partners are provided with three alternative methods of registration depending on their role through SCEDRA. They can update their registration automatically in order to be constantly registered and notified about event patterns and allow publication of their events through the network. The other option is instead of being registered on a regular basis, to be notified about patterns when their operations are affected. The third option is to update registration only when a partner requires information about particular events and patterns. In all three registration types event monitoring through partner processes is active.

The second level in the Partner Layer, the Web service module, communicates operational functionality performed by SCEDRA participants. SCEDRA needs to establish operational consistency, thus main operations and activities abstracted to application modules are mapped against the SCOR processes. SCEDRA Supply Chain Elements Repository contains information regarding the main SCOR inputs and outputs. In SCEDRA, 32 main application notifications are abstracted relating to SCOR processes (SOURCE, MAKE, DELIVER, RETURN) excluding PLAN activities. These operations relate to a particular activity either by an individual partner or from the interoperation between SCEDRA participants. The functionality of these operations is abstracted to application modules which are published as Web service components. The way these applications are consumed is driven by three factors; the type of Service Level Agreements (SLAs) participants are bound with, the manufacturing model which is used (MAKE-TO-ORDER, ENGINEER-TO-ORDER etc) and the particular specifications defined for each occasion from the business and physical environment.

Web service modules expose operational signals as events. Agents monitoring the ERP and SC systems performance capture unexpected events that have been exposed.

1. SOURCE
    a. ScheduleProductDelivery
    b. ReceiveProductVerification
    c. AuthoriseSupplierPayment

The above list of applications produces signals relating to the SOURCE processes. To address the wide range of manufacturing models employed by the industry these applications include more than one activity. *ScheduleProductDelivery* includes supplier identification and selection activities, *ReceiveProductVerification* spans over both receive and verify tasks and *AuthoriseSupplierPayment* includes tasks such as check inventory availability that are part of the Transfer process element.

2. MAKE
    a. CreateProductionSchedule
    b. ReceiveProducInformation
    c. GetProductionReport
    d. GetTestReport
    e. GetPackageReport
    f. CreateDeliverPlan

*GetProductionReport* and *GetTestReport* communicate among partners the results of adding value activities and tasks performed to convert sourced products from raw/first material to semi-ready or ready products (SCC, 2003). Since MAKE-to-ORDER and ENGINEER-to-ORDER manufacturing models are employed, iteration cycles between test and produce activities are frequent. Testing results are fed into production stages and quality control failures are communicated through the output of the particular application.

3. DELIVER
    a. ReceiveCustomerInquiry
    b. CustomerOrderValidation
    c. InventoryAvailabilityReport
    d. OrderVolumeNotification
    e. PlannedShipmentNotification
    f. ReceiveProductVerification
    g. GenerateShippingDocuments
    h. CustomerVerificationNotification
    i. ConfirmationInvoicePayment

DELIVER application signals span over the different manufacturing models and transmit information about more than one tasks and activities. The messages communicated from the above applications inform about DELIVER task results and unexpected events. DELIVER operational software modules transfer information which differs according to the manufacturing type; hence for DELIVER Make-to-Order and DELIVER Engineer-to-Order products, *CustomerVerificationNotification* communicates both installation confirmation and the test control result, as opposed to DELIVER Stocked product.

4. RETURN
    a. ReturnAuthorisationReceived
    b. ProductReceivedVerification
    c. CreditAuthorization

RETURN process elements depend on the original process that triggered the return activities. Due to the level of variation, only the most representative operations are abstracted as application modules. The action taken by the participants, repackaging, disposal, etc, is subject to SLAs and company requirements. Additionally, situations such as *product recall* are subject to governmental policies and health regulations.

The information which is received or generated from the above applications needs to be stored in the Data Repository. Additional applications support the communication between partner Web services and the data repository.

- UpdateStoredData
- InsertData
- DeleteData

The notification messages produced from the above applications are exposed by the Web services modules, allowing the communication between heterogeneous systems and achieving consistency when exposing notification signals.

#### 5.2.4.2 External Systems Component

The external environment component abstracts the conceptual links between SCEDRA and the environmental, physical and market information resources. Monitoring disruptions in the above areas is achieved using a Multi-Agent System mechanism described in the application layer. SCEDRA agents migrate to existing external systems that monitor turbulences in finance, oil and currency prices, industrial and physical environment disruptions.

Currently, there is a dramatic increase in monitoring systems developed and employed by financial institutions accompanied by the effort to integrate transactional information (Wang, Mylopoulos & Liao, 2002). SCEDRA agents migrate on pre-existing systems to make use of changes on their information domain. Similarly, agent monitoring is performed on stock exchange markets, oil and currency fluctuations and on physical environmental changes that affect the SC.

### 5.2.5 Application Layer

#### 5.2.5.1 Multi-Agent-System

On top of the physical layer is the application layer. Systems performing SC operations, production, management and administration operations are divided in an application level where each application exposes its functionality into the online network that acts a central hub amongst SC partners. Due to the heterogeneous systems adapted by the Supply Chain partners, SCEDRA treats them as one unified application. To achieve effective monitoring over a variety of different systems a Multi Agent System (MAS) is proposed with the following characteristics (Jennings, Sycara & Wooldridge, 1998):

- Multi agent systems are characterized as all types of systems composed of multiple autonomous components.
- All agents are semi-autonomous.
- Data is decentralized
- There is no global system control and asynchronous computation is supported.

These characteristics comply with the dynamic nature of the information in SCEDRA, as the multi agent system is not bounded by global rules or restricted knowledge (Heppenstall, Evans & Birkin, 2005).

The proposed MAS is a lightweight, distributed, intelligent agent-based system which performs two main tasks, monitor and capture unexpected events during SC processes using monitoring agents and transfer this information to the middleware layer. The proposed component includes a set of agent monitoring behaviour and communicates with the SC Data Repository. Agents monitor ERP, SC, production/warehouse and external applications. They perform continuous monitoring of the Supply Chain and related activities to detect and capture unexpected events and disruptions. Agents monitoring behavior is updated during initialization based on the Operations Repository updates. Thus, agents perform continuous monitoring while maintaining consistency with business processes.

#### 5.2.5.2 Message Oriented Middleware

For communication between the heterogeneous systems used by each partner a middleware level is employed. In the effort to reduce the level of complexity by building a system where several applications span across the heterogeneous systems a Message Oriented Middleware (MOM) mechanism is proposed (Banavar, Chandra, Strom & Sturman, 1999). Messages that are exchanged between the systems are captured by monitoring agents that belong to the same agent system as the one used to monitor ERP, production and warehouse systems.

The proposed MOM mechanism abstracts the application functionality of the integrated ERP, Supply Chain and warehouse systems and serves as a central operational hub. MOM components support application "gluing", implementing SC partnerships. Inter application communication software with MOM is based on asynchronous communication where messages can be broadcasted and multicasted allowing event pattern dissemination to more than one participants. Due to the dynamic number of participants and the diversity amongst their ERP and SC systems, more than one middleware system maybe required to communicate messages. Gateways and bridges maybe used to exchange information between MOMs.

Systems that exhibit many-to-many interactions require information dissemination from many publishers to many subscribers according to the dynamic transformation of the information that needs to be communicated (Bornovd, Cilia, Liebig & Buchmann, 2000). Similar to these environments, SCEDRA handles the coupling between notifications and transactions. To structure the dependencies between publisher and subscriber, reliability concerns over transactional types (enqueue/dequeue, publish/subscribe) need to be addressed (Tai & Rouvellou, 2000). Following the schema suggested by Liebig, Malva and Buchmann (1999) for structural dependencies between publisher and subscriber, SCEDRA considers visibility and context as two critical dimensions. These two factors are strongly interrelated as context knowledge is achieved through information visibility and data consistency. Transmitting EPN notifications amongst participants, the partner who will react to the message is notified immediately on a shared information context.

### 5.2.6 Event Pattern Layer

This layer describes the event pattern functionality of SCEDRA. It consists of two components, the Pattern Matching Engine and the Pattern Dissemination Module. The pattern matching engine, shown in Figure 5.2 below, examines the causal and temporal relationships between events and the resulting patterns which are formed.

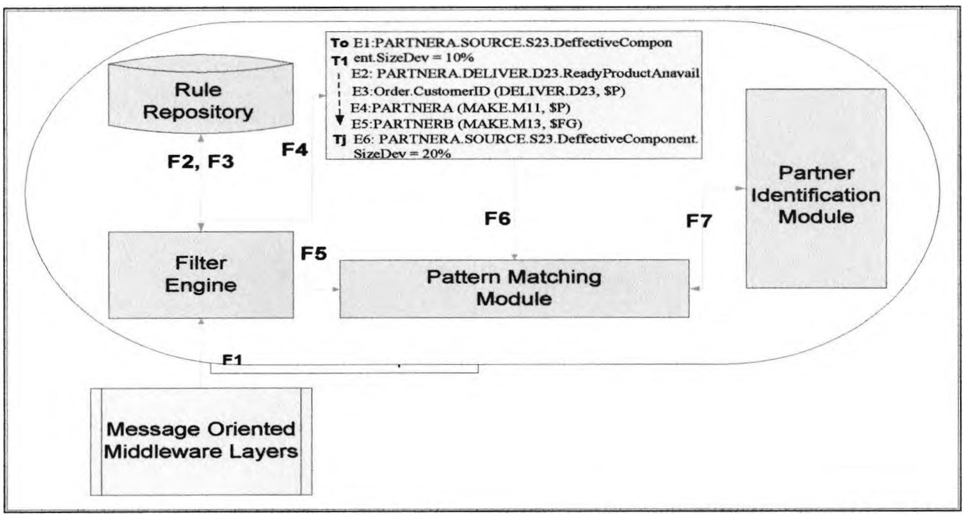



***Figure 5.2 Pattern Matching Engine***

Consistent interaction and communication between the engine's components is achieved using the Event Pattern Notation. The flows *F1*, *F2*, *F3*, *F4*, *F5*, *F6* and *F7* in Figure 5.2 represent the messages which are exchanged between the engine's components and the order of communication exchange messages. *F1* transmits the event captured from the monitoring agent to the Filter Engine from the Message Oriented Middleware level. The first task is to overcome vocabulary diversity. The Filter Engine maps the middleware message against the unexpected events ontology and creates a detailed Event Pattern Notation message to describe the event. This task prevents from processing events that might have been captured by the monitoring agents but do not comply with the unexpected events classification. The processed EPN messages are fed into a knowledge system which is customized according to the classification and determines the actions that need to be taken. The EPN message is fed into the Rule Repository which contains information about the possible patterns and provides the rules about events that need to be further investigated. The Filter Engine sends an EPN query to the Rule Repository requesting for event types that are causally or temporally created.

*GET \$T = E0.Time*

*WHERE (\$T = TimeDifference ( E0, Ek)*

*WHERE Ek.Process.Attribute = Rule.Value);*

The rule repository returns a value T(Ti – Ti+j) or T(Ti – Ti+j, Tk), representing the time period within which event patterns are formed. The Filter Engine sends another query to the Event Log, shown in Figure 5.3, requesting a list of events that have occurred during T(Ti – Ti+j). The returned list is transmitted to the pattern matching module. The Event Log acts as an EPN library. EPN messages which are received by the Event Log contain the information which is required about the storage of the new event.

*GET EventType = LIST \$ K*

*WHERE \$K MATCH (E0.Process.Attribute AND E0.Time);*

*F4* illustrates the message sent from the Filter Engine to the Event Log, which has two purposes; to request for the list of the events that will be compared with the initial event and to store the event that has occurred. This temporal storage of EPN events assists to identify event patterns and stores events based on the order they have occurred. The time granularity used in the Event Log depends on partners operational criteria and completion requirements.

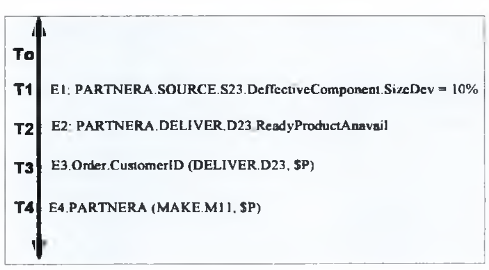



***Figure 5.3 Event Log***

*F6* represents the message sent from the Event Log to the Pattern Matching Engine containing the list that was originally requested from the Filter Engine, *F4*. *F5* models the message sent to the Pattern Matching Module from the Filter Engine to communicate the information about the event.

The Pattern Matching Module compares the *F5* event with the events in the *F6* list and identifies temporal or causal relationships between them. When temporal links with further causal effects are identified, they result in a composite event. This event is sent back to the Filter Engine, *F0*, to perform the same filtering if applicable. If the composite event is not classified under the events ontology it is examined to identify rules that might apply in the particular case. In Figure 5.3, *F7* shows the interaction between the Pattern Matching Module and the Partner Identification Module.

The Pattern Identification Module is a Web service-based mechanism with two core functionalities, to identify SCEDRA participants affected by the composed pattern and disseminate the information path. Partners consume services based on the subscription type they have defined in the Physical Layer. The EPN description of the composed pattern is passed as a message to the Partner Identification Module. Using the data stored in the SCE Repository the Partner Identification Module identifies the partners affected by the pattern. For instance in the event of a delayed delivery during transportation, the delivery notice is the Supply Chain Element which identifies the affected customers. The second functionality is pattern dissemination to a network of heterogeneous systems. XML based messages are used to communicate patterns to partners in order to overcome interoperability problems and transmit the pattern to the interested parties.

This is achieved using the Dissemination Web service. This module has Web service functionality and transfers the identified patterns to the registered service-consumers, partners. The composite events pattern is disseminated based on the type of participants subscription. Information that arrives to the Dissemination Web service could also be fed to an expert system, to assist knowledge management in the SCEDRA network.

### 5.2.7 SCEDRA Information Schema

Events in SCEDRA are realized as captured information that spans across main conceptual components. This information affects operations in different components across the Virtual Network and forms event patterns.

The proposed information schema model is focused on defining relationships between events and models the dependency between them, such as causal and temporal relationships, composite events and the resulting Cluster Event Patterns.

Figure 5.4 shows seven data objects that have been identified and modeled. The atomic event class represents the occurrence of a single event. It is linked with the rule class, which models the conditions events comply with, in order to identify relationships between atomic events. Event relationships is a super-class with two sub-classes representing causal and temporal links between events. The composite event class holds information about the path and structure of composite events, as they are formed according to rules and conditions. The event pattern class models characteristics of event patterns when created from composite events and SCE elements used for dissemination purposes. The Supply Chain Element class refers to characteristics of SCE, which link SCEDRA partners and assist to identify hidden interdependencies. The partner class includes information about SCEDRA participants, such as generic data and registration types.

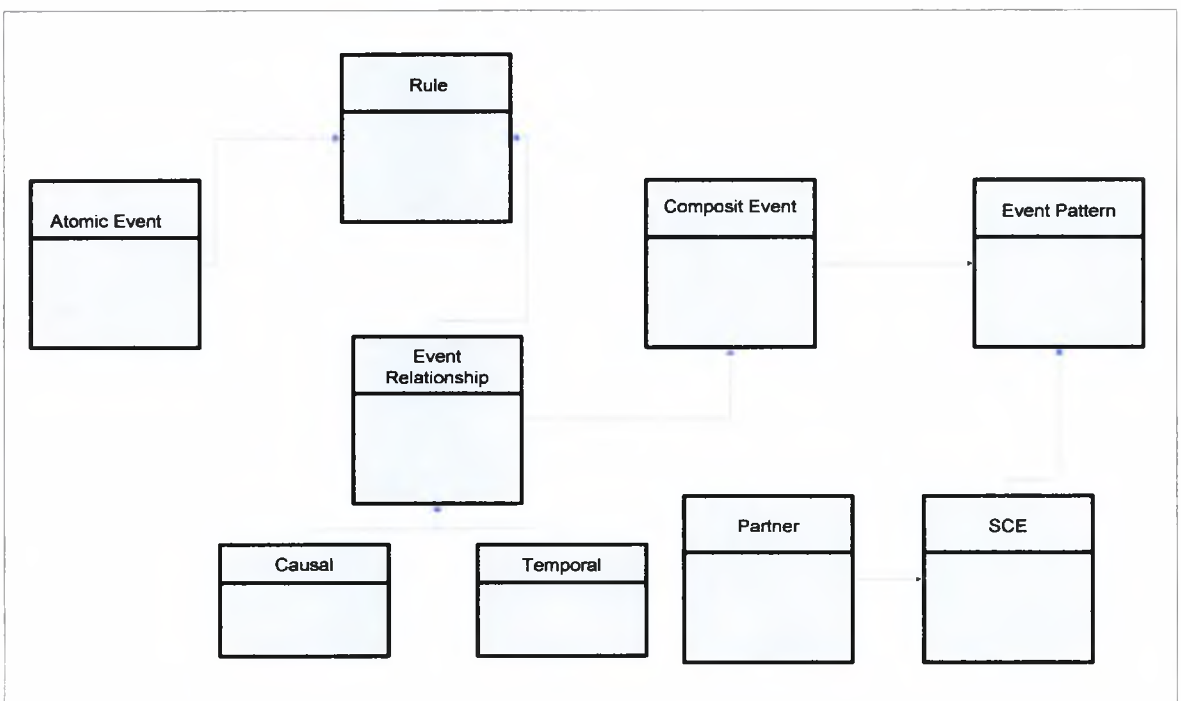



***Figure 5.4 SCEDRA Information Schema***

This thesis presents a framework to identify and disseminate event patterns within SC networks. SCEDRA completes the framework and builds on the disciplines presented in Chapter 3 and Chapter 4. SCEDRA information schema, models data objects that comprise the architecture's main conceptual components. These concepts are core disciplines of the events framework. SCEDRA sets the IT ground to unify these conceptual elements and handles the pattern information that is formed and produced through events.

## 5.3 SCEDRA Evaluation Framework

SCEDRA serves as the enabling IT which unifies the event, event pattern concepts and the Event Pattern Notation developed in the previous chapters. SCEDRA purpose is to identify, form and disseminate Clustered Event Patterns (CEPs) to the related Supply Chain participants. Transmitting the information of event patterns, partners are informed about disruptions through the entire SC network that affect their processes in any direct or indirect manner.

This thesis completes the event pattern framework by proposing an architecture to support information capture and dissemination. SCEDRA unifies several IT paradigms as it is tasked with the responsibility to achieve information integration and overcome interoperability issues. SCEDRA is a complex IT system whose implementation is outside of the scope of this research. To validate the design, SCEDRA had to be simulated based on real world case studies and using real timing and other business data. Each scenario runs in two different contexts, one without the use of SCEDRA and one where SCEDRA is assumed to be employed.

The two scenarios are drawn from a frozen foods company operating in the retail sector. The company was used as the case study to elicit the information for composing the two scenarios. A foods company was chosen due to the structure of the industry which allows the generalizing of results. According to the European Communities (2006) food and beverages has a heterogeneous structure operated by large multinational producers that compete on the global market. At the same time sub sectors are operated by small manufacturers serving at local and domestic regions. The company used as a case study operates both on a national and international level, while it cooperates with both small local and large multinational suppliers and customers. The two scenarios were simulated using Microsoft Project. The reasons for choosing the particular tool are:

- The capabilities to represent both actual and baseline times.
- The graphical and dynamically updated representation of tasks and task dependencies.
- Microsoft Project is used by many Supply Chain professionals. Thus, MS Project was employed as a tool that would allow to validate the accuracy of modelling the information and ensure consistency with the actual processes.

Two scenarios are presented in this section. Both are elicited from 4 interviews conducted with members of a company leading its supply chain in the food industry. The company is located in north Greece and operates in the frozen food sector. Operating since 1969 employs approximately 200 people and works with a large network of suppliers from Greece and from abroad.

To build the scenarios two steps were required. Initially the interviews were analysed and cross-examined to identify the unexpected events with the strongest impact and the related recovery policies. Additionally, two different processes were identified and modelled describing the interactions between participants. Each scenario is examined separately and is focused on the processes of the company under investigation, which is the leader of the supply chain it belongs to. Its leading position acts as an operational hub between suppliers and customers, thus it is suitable to examine a wide range of transactions between SC participants.

### 5.3.1 Exploring the Operational Domain

To identify the tasks and their sequence and model the two scenarios, the first step involved the analysis of the operational environment. Because of the company's policy there were time restrictions to examine the operational domain; hence the survey consisted of two stages. Observation was used as the initial technique for contextual survey to examine the processes of raw material procurement, production, sales, returned products and warehouse tasks. Based on the initial observation the roles and the order of the selected interviewees were decided as well as the information that had to be elicited.

Four company staff were interviewed in the following order:

- The warehouse manager who described activities regarding the warehouse.
- The coordination manager who explained the balance between sales and raw/first material procurement and gave an insight in problems occurring because of unexpected events.
- Similarly, the logistics manager who explained the impact of unexpected disruptions on the supply chain.
- Finally, the production manager who provided a holistic overview of processes and tasks and explained the main production activities.

The first interviewee initially listed the main operations that take place in the warehouse and explained the route and tasks regarding processing of raw and semi-ready materials. Processes are described in terms of details of the tasks involved and the information about the machinery and tools used to perform these operations. The logistics manager explained the storage techniques used by the company and the way these are affected by sales turbulence. He explained the impact and recovery policies employed to address the occurrence of the following unexpected events:

- High priority orders
- Returned products
- Physical disasters
- Machinery failure
- Delayed deliveries to customer
- First material unavailable
- Market oversupply

Additionally the logistics manager provided general information about packaging material suppliers and delivery times. More details regarding problems and delay times about packaging material were given by the coordination manager. Information regarding orders and procurements were elicited including details regarding planning and coordinating activities. Also, the coordination manager explained the impact of the following unexpected events on the logistics schedule:

- Physical disasters
- On time deliveries
- Machinery or production unit failure
- Errors in orders
- Unavailable product

In the final interview the production manager, provided a short description of the raw-first material procurement, explained the repackaging process and production.

### 5.3.2 Scenario A' – Atomic Event

While both scenarios are used to estimate the qualitative advantages of SCEDRA, each serves different objectives. The objective of the first scenario was to examine the causal effects of a single event and how causalities compose a pattern of events that is transmitted through all involved participants. The following textual description was modeled as a Ghant Chart. This scenario examines the impact of an error in order description as this has been explained by the coordination manager. (for the detailed process description models in MS Project see Appendix D).

*On the 30/05 Partner C, a food manufacturer, submits an order for 2 europallets of 250 gr. peas to Partner D. Partner D is an overseas supplier of semi-ready product. During order submission an error in the product description occurs and instead 500 gr. peas is delivered. Fulfill order processing time is 2 days and on the 31/5 the delivery ships and arrives 9 days later at the distribution centre (13/6). On the 14th of June Partner F, a small retailer, submits an order to Partner C requesting 20 Kg. of 500 gr. peas. As order lead time is two days the order is due to be fulfilled on the 16th of June. On the 15/6 the shipment originating from Partner D is delivered to Partner C, where the quality control procedures fail the delivery as the product was incorrect. The return to the distribution centre, were the delivery is re-packaged and redelivery to Partner C takes place on the 20th of June. Partner F order is processed and finally delivered on the 21st of June.*

The above description includes one unexpected event, which was temporarily related with an order submission by Partner F and caused an event pattern. Figure 5.5, models the process with the unexpected event. The model shows both the scheduled and the actual times of activities. The rounded triangles indicate events that occur during processes. In the particular process four events are modeled:

- Error in order information on the 30th of May.
- Products fail quality control on the 15th of May, which is the causal effect of the error in order information.
- Delayed delivery from supplier on the 20th of June, which is the causal effect of the delivery failing the quality control.
- Delayed delivery to customer on the 21st of June.

The difference between the baseline and the actual times (for the exact values see Appendix D) indicates the delay imposed on the processes of the partners. The impact of this delay is considered critical for Partner F especially, as this is a small retailer whose storage capacities and economies of scale do not allow maintaining a large safety stock. Activity and process times about production and warehouse activities were adopted from the interviews (warehouse and production manager). A snapshot of the scenario tasks is shown in the following figure (full model description see Appendix D).

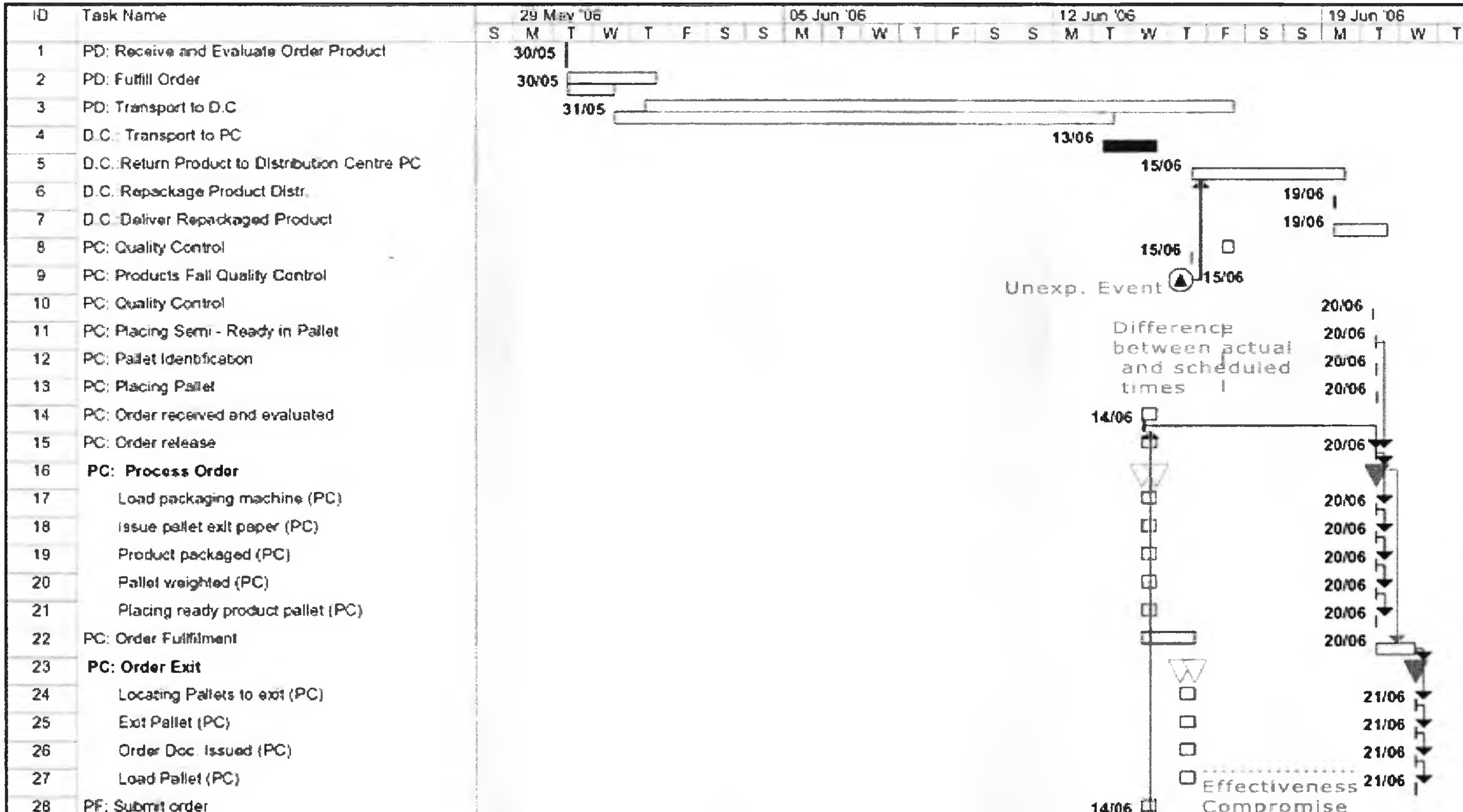



*Figure 5.5: Scenario A Process Model*

When simulating the effect of SCEDRA on the above scenario the information with the formed pattern is transmitted to the related parties. SCEDRA transmits the notification for delay to Partner F, who requests a quotation from another supplier, Partner E. At the same time Partner F requests Partner C to reschedule delivery. The interviews revealed that this is the strategy that ideally is used to avoid major delays, however requires information visibility across partners. The following table shows the EPN representation of the simulated scenario.

**Table 5.1: Scenario A – EPN Description**

```
IF $P

WHERE
  DEFINE $ P { ($P1 BEFORE $P2) }
    WHERE
      DEFINE $P1{ $E0 CAUSE  $E1}
        WHERE
          {$ E0: PartnerD.SOURCE.DelayedDelivery.INFOERROR.InvoiceNumber=123
           CAUSE
           $E1:PartnerC.SOURCE.DeffectiveComponent.DifferProduct.InvoiceNumber
           =123};

   BEFORE

    DEFINE $P2  { $E2 }
     WHERE
     {($E2: PartnerC.Delivery.D12.ProductType="IBN005")
      CAUSE
      NOTIFY
        PartnerPartnerF.DELIVER.D1.10.DelayedDelivery.ProductType="IBN005"}
 THEN
      {NOTIFY PartnerPartnerE.DELIVER.D1.1.ProductType="IBN005"
      AND
      NOTIFY PartnerPartnerC.PLAN.P4.4.ProductType="IBN005" }
```

As indicated from the EPN description, the event pattern information transmitted to the participants, results in changing the scheduled activities and processes based on recovery policy rules stored in the Rules Repository. A snapshot of the re-designed model is shown in Figure 5.6 (for the full model description see Appendix D).

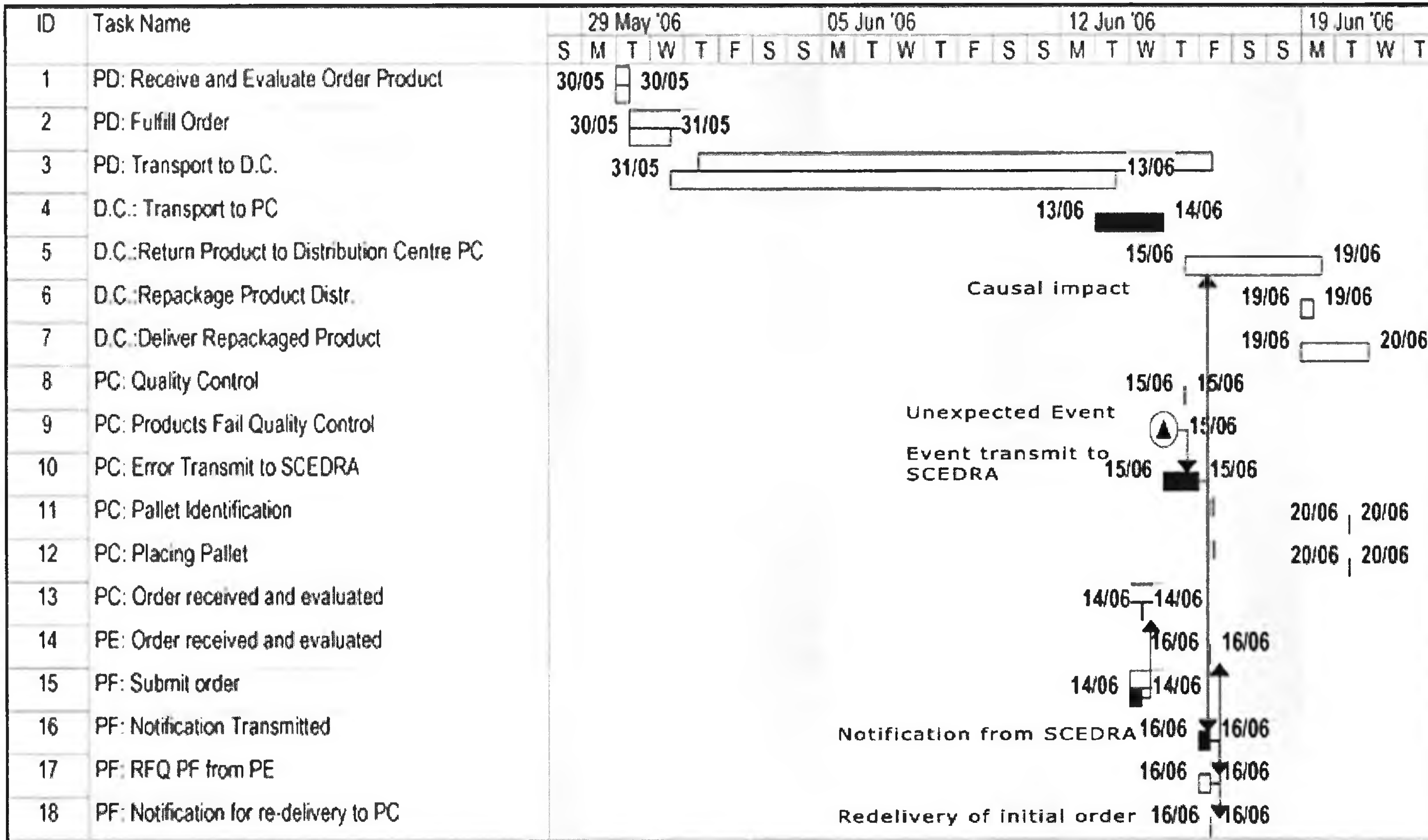



*Figure 5.6: Scenario A Redesigned Process Model*

The notification transmitted to Partner C results in rescheduling the delivery time; thus shipment of delivery to Partner F is not affected by the delays Partner D experiences. Figure 5.6 simulates SCEDRA operational impact on the time of order deliveries. The order of tasks and activity times remained the same as in the first run of the scenario. The process was re-designed according to the action rules elicited from the coordination manager based on the recovery policies to address delays in deliveries.

### 5.3.3 Scenario B' – Composite Event

The second scenario is more complicated than the first one, as more partners are involved and aims to describe a situation with more interactions among participants. Three main purposes are addressed through the second scenario. The scenario aims to:

- Explain how temporal relationships between events form composite events
- Describe how SCEDRA achieves business and operational agility and flexibility
- Model how SCEDRA handles production capacity demands for different products.

Composite events are identified by SCEDRA and are dealt as one single event. The following scenario examines the occurrence of two unexpected events that have no causal relation between them, the delayed delivery of packaging material and the prediction of dry weather forecast. To identify the events that were chosen it was important to ensure that no relation between the two unexpected events, delayed delivery and physical disasters, exists. For this purpose the correlation analysis was performed on the classified events based on the questionnaire responses. Kendall tau non parametric coefficient was used to examine the strength of dependence between the two variables (Conover, 1980). The results revealed that the agreement between the rankings of the two event types is 0.195, which proves that there is no correlation between the two events (for correlation values and results see Appendix F). Based on the above and on the information the interviewees provided, the second scenario is the following:

*This scenario involves seven SC participants. Partner A, who is Partner's C packaging material supplier, on the 2nd of June received an order from Partner C for 100 Kg. of peas in* *packages of 250 Gr., which is due on the $25^{th}$ of July. However the first material (paper carton) for Supplier A is in shortage and this causes delays in delivery. On the $24^{th}$ of June Partner D submits an order for 40 Kg. of 250 Gr. of packaged peas which has a lead time of two days. On the $25^{th}$ of June Partner E submits an order for 70 Kg. of peas packaged in 250 Gr. bags. Both Partners D and E are small and medium size retailers operating in summer resorts with self catering facilities. Again on the $25^{th}$ Partner F submits an order to Partner C for 65Kg. of packaged peas in 250Gr. bags. On the $6^{th}$ of August a weather forecast predicts a heat wave and this increases the sales of frozen spinach. On the $7^{th}$ of August Partner K submits an order for 50 Kg of packaged spinach and on the same date Partner H submits order for200 Kg spinach. All orders have a lead time of two days. On the $7^{th}$ of August the order for peas packaging material arrives form Partner A. The production unit however is already involved in other production activities. The initial orders are not released before the $9^{th}$ of August, when Partner H delivery has been dispatched.*

The lack of information visibility results in delayed deliveries to customers, which affect Partners during summer periods in holiday resorts since they do not have the storage capacities to maintain big amounts of safety stock. Similar to scenario A, task times and delivery periods were based on the information elicited from the interviews. A snapshot of initial process model is described in Figure 5.7 (for the full model description see Appendix D).

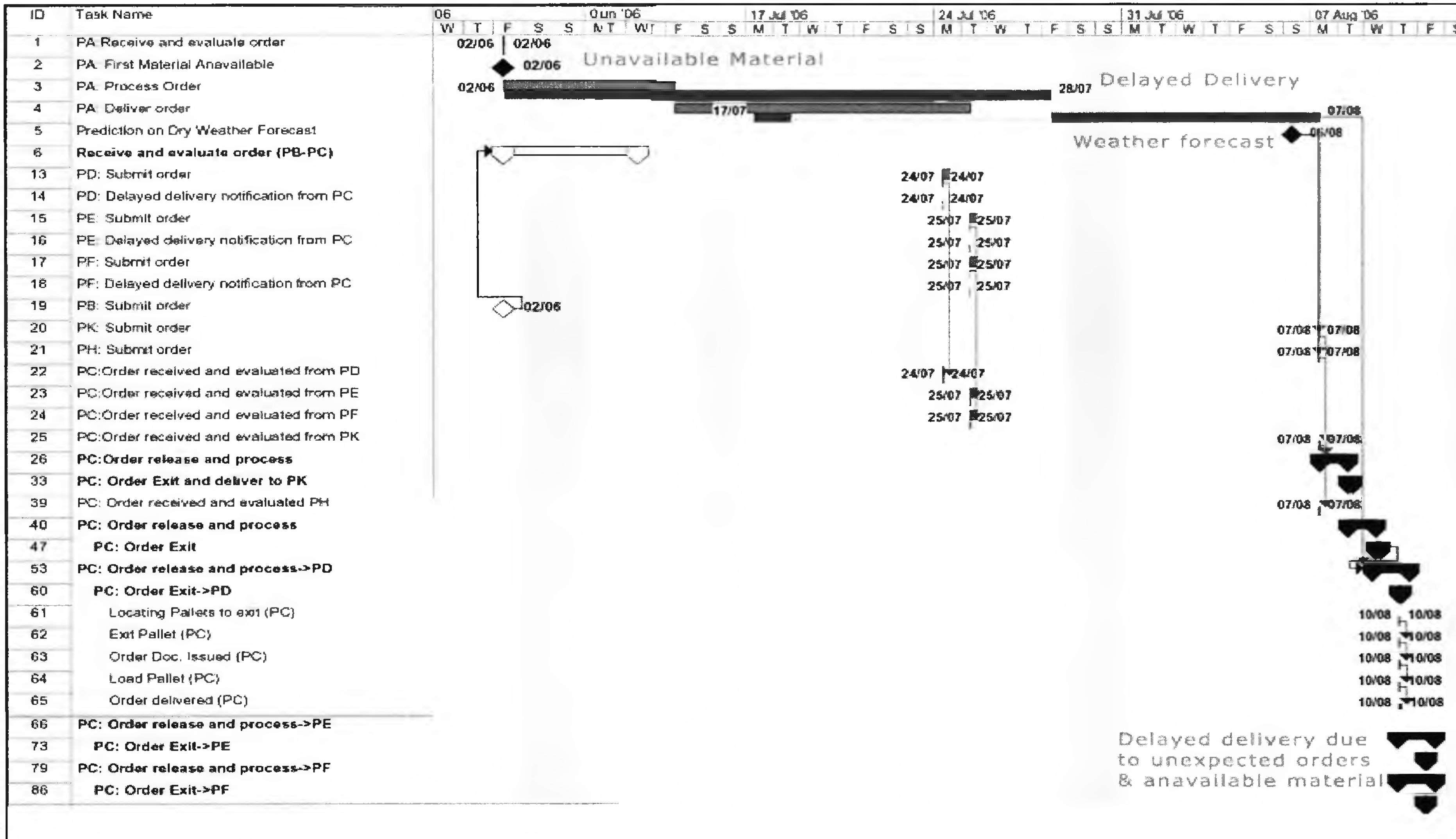



Figure 5.7: Scenario B Process Model

The comparison between the actual and the scheduled delivery times emphasizes the urge for information sharing and process re-design to cope with unexpected situations. The temporal relationship between the lack of first material and the weather forecast events forms a composite event which is transmitted to the related participants.

When the information about the weather forecast is captured by SCEDRA the events of the two orders, submitted by Partners H and K, are transmitted to the engine Partners D, E and F are informed about the composite event, which suggests that the fulfillment of their orders will not start until Partner's H order has been fulfilled. SCEDRA sends requests for quotation from Partners D, E and F to foods manufacturer Partner T, and transmits a re-delivery notification message to Partner C. These actions adhere to the policies and best practices elicited from the interviews. Table 5.2 describes the Event Pattern Notation of the composite event and transmits the RFQ and the re-schedule delivery notification from Partners D, E and F. Figure 5.8 below is a snapshot of the redesigned scenario (for the full model description see Appendix D).

**Table 5.2: Scenario B – EPN Description**

```
IF $P3 {$P1 BEFORE $P2}

 WHERE
   DEFINE $ P { ($P1 BEFORE $P2) }

  WHERE
    DEFINE $P1{( $E0 BEFORE  $E1, $E2, $E3)}

      WHERE
      {{$E0:PartnerA.DELIVER.ProductUnavailable.UnavStock.ProductType="PackMater"
          NOTIFY
          $E1: PartnerC.PLAN.P32.DelayedDeliver};
         BEFORE
          $E1: PartnerD.DELIVER.D1.1.ProductType="Peas250" ;
          $E2: PartnerE.DELIVER.D1.1.ProductType="Peas250" ;
          $E3: PartnerF.DELIVER.D1.1.ProductType="Peas250" }}

   AND
   DEFINE $P2{( $E4 CAUSE  $E5, $E6)}

     WHERE
      {$E4: PhysicalDisaster.DryWeather
       CAUSE
        $E5: PartnerC.DELIVER.D1.1.ProductType="Spinach500" ;
        $E6: PartnerC.DELIVER.D1.1.ProductType="Spinach500" }}
THEN
 {NOTIFY PartnerD.DELIVER.D1.0.DelayedDelivery(PartnerC).ProductType="Peas250";
     CAUSE
     {NOTIFY PartnerT.DELIVER.D1.1.ProductType= "Peas250" ;
      AND
      NOTIFY PartnerC.PLAN.P4.4.ProductType= "Peas250" ;}}

 AND
{NOTIFY PartnerE.DELIVER.D1.0.DelayedDelivery(PartnerC).ProductType= "Peas250" ;
  CAUSE
 {NOTIFY PartnerT.DELIVER.D1.1.ProductType="Peas250" ;
  AND
  NOTIFY PartnerD.PLAN.P4.4.ProductType= "Peas250" ;}}

 AND
{ NOTIFY PartnerF.DELIVER.D1.0.DelayedDelivery(PartnerC).ProductType= "Peas250" ;
   CAUSE
   {NOTIFY PartnerT.DELIVER.D1.1.ProductType= "Peas250" ;
    AND
   NOTIFY PartnerC.PLAN.P4.4.ProductType= "Peas250" ;};};}
```

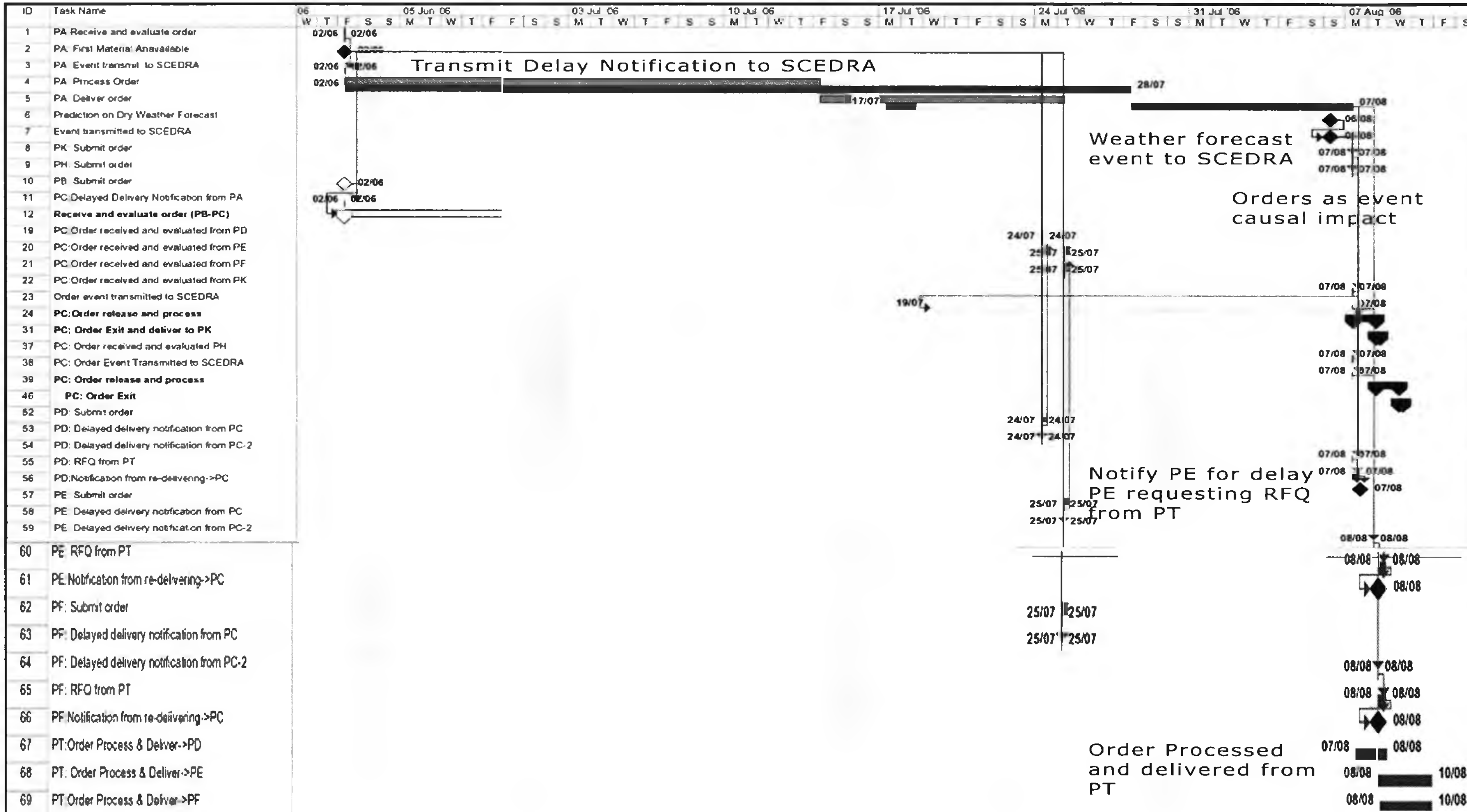



*Figure 5.8: Scenario A Redesigned Process Mode*

The composite event which is formed alerts Partners D, E and F to request Partner C to re-schedule their order delivery. As shown at Figure 5.8, the task of the request to re-schedule delivery (ID_18) is determined by the RFQ transmitted to Partner T (ID_16) and the notification for delayed delivery to Partner D (ID_15). Task ID_15 is affected by the submission of unexpected orders (ID_31 and ID_47) which are the causal effect of the prediction on heat wave (ID_29) and also form the delayed delivery from Partner A to Partner C. The information that is transmitted to Partner D contains the causal and temporal relationships between events:

(ID_29)$E4: PhysicalDisaster.DryWeather
**CAUSE**
(ID_31)$E5: PartnerC.DELIVER.D1.1.ProductType="Spinach500"
(ID_47)$E6: PartnerC.DELIVER.D1.1.ProductType="Spinach500"

(ID_25)**NOTIFY**PartnerF.DELIVER.D1.0.DelayedDelivery(PartnerC).ProductType= "Peas250"
**CAUSE**
(ID_26)**NOTIFY** PartnerT.DELIVER.D1.1.ProductType= "Peas250"
**AND**
(ID_28)**NOTIFY** PartnerC.PLAN.P4.4.ProductType= "Peas250"

### 5.3.4 Comparing the Process Models

The two different versions of scenarios A and B are compared in order to examine the differences when no event pattern engine is employed and when SCEDRA is operating. The main differences deriving from the above scenarios reflect on critical aspects for gaining a competitive edge within an e-SC context. As examined in the Literature Survey Chapter, agility determines the competitiveness both at company and at SC level. Speed and flexibility (Breu *et al.,* 2001; Zang, 2001), information sharing and information visibility (Bal *et al.*, 1999; Crocitto & Youseff, 2003) are key factors for gaining a competitive edge. SCEDRA operates according to the e-SC paradigms, thus enables Supply Chains in their effort to increase competitiveness by supporting and enhancing their agility. To evaluate the impact of SCEDRA on agility aspects a framework for comparison between the two versions of scenarios A and B was developed. The comparison framework includes both quantitative and qualitative aspects. Speed is measured in time units representing delays in deliveries and operations. Apart from speed, agility is measured in terms of flexibility. Information sharing and information visibility are not examined separately as they constitute integral parts of flexibility. The results of the comparison between the different scenarios are focused on the following aspects:

- Speed: as overall time reduction is considered a performance criterion (Sharlan, Eltantawy & Giunepiro, 2003), the first step to increase speed during SC operations is to reduce lead times. This requires minimizing delays in production and delivery. In both scenarios the delay time was reduced as a result of the notification for delivery delay transmitted to the participants. In the second run of scenario A', when SCEDRA was employed, there is no delay in the delivery of the order to Partner E, hence there was no compromise in operational speed. In scenario B' the difference in the delay time before and after SCEDRA has been applied, is one day for Partner D (order delivered on the $9^{th}$ of August instead of the $10^{th}$) two days for Partner E (order delivered on the $9^{th}$ of August instead of the $11^{th}$) and two days for Partner F (order delivered on the $9t^{h}$ of August instead of the $11^{th}$).

  The typical order lead time is two days, so the delay time is estimated based on this value. For partner D, SCEDRA reduces the total delay time by 6.6%, whereas for partners E and F SCEDRA reduces the delay time by 13.3%. These numbers indicate that time effectiveness is achieved as the network expands and delays are transmitted through partners.

- Flexibility: SCEDRA operates on an extended business environment where focus is on the Supply Chain and not on individual companies. Measuring flexibility at a Supply Chain level differs from examining flexibility aspects of a single company. Hence, flexibility is measured on the scale of the entire SC network. Duclos *et al.* (2003) identify the capability of dealing with a wide range of products as a measure of flexibility.

  Using SCEDRA, actions and rules are constantly updated at the Rule Repository increasing operational flexibility in unexpected circumstances. This is obvious in scenario B as the rigidity of Partner C to respond to orders due to the lack of packaging material, has a strong impact on two other supply chain members. In addition, the event of the heat wave reduces further the flexibility of Partner C and increases the delivery delay time for Partners E, D and F. On the other hand, at the second version of scenario B, all partners are able to change their scheduled activities and increase the SCs flexibility.

The results suggest that the SC as a whole has the ability to provide spinach (Partner C to Partners H and K) and peas (Partner T to Partners D and E) with the minimum possible delay. This feature supports productivity flexibility through the entire SC in terms of capacity and order completion for different products.

- Business Awareness: to counteract the impact of adverse events on Supply Chains it is important to understand their origins and inter-relationships. SCEDRA identifies event relationships and the participants affected by their unexpected occurrences. This information is translated using a common notation and constitutes the composite event. EPN translates messages overcome semantic interoperability issues and achieves data integration in communication. The composite event informs participants about causal relationships of events, about events origins and the conditions under which temporal relationships are formed.

Transmitting composite events to SC participants enhances partners business awareness. In the second version of scenario B, Partners D, E and F are informed about the reasons for delayed deliveries which is important for rating Partner C operational responsibility. Additionally, the environmental knowledge about international events affecting the SC becomes explicit. This is seen in scenario B, where information about the heatwave is transmitted, along with the causal impacts it has on DELIVERY processes.

## 5.4 Chapter Summary

This chapter had a dual purpose; propose a Supply Chain Event Driven Architecture and evaluate the architecture in real life scenarios. SCEDRA is the final component of the unexpected events framework initially introduced in previous chapters. Initially, the events theory and unexpected events ontology was applied to the development of the core concepts composing SCEDRA, as seen in SCEDRA Information Schema. The Event Pattern Notation is used by SCEDRA to transmit event patterns to SC participants.

SCEDRA conceptual basis is based on the fusion of a range of technologies and applications, such as Web services which are used to expose application functionality across a variety of systems. Intelligent agents monitor ERP and Supply Chain systems and capture unexpected events. Message Oriented Middleware mechanisms communicate messages exchanged between SCEDRA modules and transmit events to the Event Pattern Engine.

The evaluation of SCEDRA involved simulating its functionality on two business process scenarios. The interviews with company employees provided specific information regarding task and activities time and order for the scenarios and the conditions within which SC processes are performed. For this reason, no assumptions had to be made about timing activities, the impact events have on processes and the reaction conditions to certain unexpected events. The comparison of the two versions of scenarios A and B, pointed out qualitative and quantitative benefits. The delay time is reduced, while agility, flexibility and business awareness are enhanced.

# CHAPTER 6: DISCUSSION & CONCLUSIONS

## 6.1 Introduction

This chapter aims to summarize and discuss the overall research (Section 6.2). It presents the scope (Section 6.3) under which the research was performed and discusses the research outcome against the objectives set in the Introduction. The following sections outline the research and its findings (Section 6.4) as well as limitations (Section 6.5) and contributions (Section 6.6). The Chapter is concluded with the discussion of the areas for further research (Section 6.7).

## 6.2 Thesis Summary

This section describes the thesis summary in relation to the objectives described in the first chapter. Chapter 2 discussed previous research that was used as the theoretical underpinnings for the paradigm of event driven Supply Chain operations. By utilizing IT, the concept of Supply Chain Management has evolved into e-business management. Agility and flexibility became the drivers for achieving a competitive edge and were used to enhance risk management policies. Based on the premises of risk management, another approach to Supply Chain Management emerged; event management. Methods and notations to depict events, such as the Event Trigger Action, shaped further research in event driven architectures. However such approaches failed to examine events and their resulting patterns in the context of the extended Supply Chain operational network.

The literature review in the second Chapter, provided an insight into how SC concepts are combined with IT and highlighted three areas for investigation:

- A complete theoretical framework to examine unexpected events during Supply Chain operations.
- A formal representation of event patterns that is in compliance with official SC processes.
- The design of an architecture that fuses the above concepts and propagates events within the SC.

Chapter 2 explained the rational for the choice of research objectives, following a comparative evaluation in current event theories and event driven architectures. Chapters 3 to 5 presented the research approach that was structured based on the initial research objectives.

The work described in Chapter 3 related to the first two objectives "O1: Bound the area of unexpected events and their relationships within the Supply Chain domain" and "O2: Use the theory defined in O1 to build an ontology which classifies unexpected events on SCOR model processes". A comprehensive framework of event patterns was presented, which consolidated the key concepts of events definitions and relationships. This provided the basis for conducting further research to achieve objectives O3 and O4. To meet the first objective certain concepts had to be defined within the SC. The event driven network proposed in previous research was extended and events were defined from Luckham's concept of global event cloud (2002). Causal and temporal relationship characteristics were identified to define events that form Cluster Event Patterns.

To meet the second objective, a survey was conducted in two stages. Initially, instances of unexpected events were identified during business operations through a survey that examined economic, management and industrial journals and periodicals. These instances were evaluated by members of the Supply Chain Council to establish their frequency of occurrence. The aim was to determine which of those events would be incorporated into the proposed event taxonomy. The resulting taxonomy (ontology), mapped unexpected events to the main SC processes and to external factors that disrupt SC operations.

Following on the deliverable from Chapter 3, an Event Pattern Notation was developed and described in Chapter 4. Chapter 4 addressed the third objective: "O3: Propose a notation for event patterns according to their classification within the event ontology". EPN completes the event ontology, as common event pattern semantics are communicated between SC participants. The SCOR model is used to achieve operational representation consistency through the SC. EPN was described using BNF. The finalised notation syntax and semantics were evaluated using a comparison to other event languages and notations.

Finally, in Chapter 5 the last objective was met through the specification and evaluation of a Supply Chain Event Driven Architecture "O4: Design an Information Systems Supply Chain Event Driven Architecture (SCEDRA), which captures unexpected events, inside and outside the SC, identifies and propagates event detection information through the supply chain network". SCEDRA uses Web services to achieve interoperability and expose operational functionality among participants. Agents are used to monitor ERP, SC and warehouse systems and flag unexpected events. The core component is the Event Pattern Engine, which forms CEPs and identifies related partners to disseminate the event patterns. SCEDRA evaluation was performed by simulating its operation in two scenarios. The scenarios were extracted from a food company which is the leader in the SC that it operates.

## 6.3 Scope of the Research and Findings

The key factors which determined the scope of the research and its findings are the following:

- Industry Focus: operational and management requirements differ between industries. Adhering to the needs of a particular industry entails a strong degree of modeling customization in processes and entities. This thesis aimed to examine SC operations under a holistic perspective, thus no particular industry was targeted by the research. The literature and the questionnaires survey referenced several types of industries; however the research was performed at a generic industry level. During the evaluation of SCEDRA, a food company operating in the retail sector was chosen. However the results of the evaluation are not industry specific.

- Events Definition: events are a broad concept with varying interpretations. This thesis did not intend to narrow the field of events under examination, but to specify the conditions under which something that occurs in the Supply Chain constitutes an event. For this reason this survey initially recorded a wide range of such occurrences that seemed to comply with the definition about events in the SC given in Chapter 3. This survey also attempted to distinguish between events and events impact.

- Supply Chain: the Supply Chain is defined as a system whose structure is determined by the relationships between the entities composing it. These factors refer to the size of a SC, the production model followed, the geographical, social, market and economic aspects. This research did not limit its application to a particular SC type as the aim was to develop a generic SC framework. Also, in the e-business era partnerships have dynamic forms, hence narrowing the focus to certain SC models would have limited the applicability of the research to dynamic e-SC networks.

- Composite Events: In previous research, composite events have been expressed using event algebra to describe the primitive occurrences that constitute the composite event

(Carlson & Lisper, 2004). The motivation had been to define the events that would trigger certain conditions, as it is the combination of such events that determines when a rule or action will be executed (Bernauer, Kappler & Kramler, 2004). This approach had been adapted for the research and was customized for the Supply Chain domain. The main difference from previous approaches was that out of all the operational notifications published by the ERP systems, SCEDRA only considers unexpected SC events.

- Supply Chain Management: This research approached Supply Chain Management as the basis for risk management and following on that, Supply Chain Event Management. The proposed architecture and events pattern framework is not limited to certain managerial policies as this would restrict its operations.

- The SCOR Model: the examination of Supply Chain processes had to be performed on a generic and consistent ground in order to cover a wide range of SCs across different industry sectors. Thus, it was critical to include SC processes that are common, or commonly accepted, between companies as using arbitrary tasks and activities would compromise the research. The SCOR model was employed as the official reference model which is widely accepted and applied. This thesis did not aim to enhance the SCOR model or the Supply Chain Council's research. The objective was to use SCOR as a tool to achieve operational consistency and to avoid unjustified assumptions.

## 6.4 Research Discussion

Research findings compose a set of deliverables that relate to the main disciplines that are combined in this research. This section discusses the research and the findings and sets the basis for identifying research contribution areas.

- Events classification: the taxonomy in Chapter 3 classifies unexpected events under the extended SC environment, which includes SCOR processes, industrial turbulence and physical disasters which affect the SC. Certain events are mapped under more than one process, as their occurrence appears in more than one processes. The classification hierarchy was constructed using Hierarchical Cluster Analysis. Similarly to the tree object representations of events (Bernauer, Kappler & Kramler, 2004), the proposed classification exhibits the characteristics of a dynamic hierarchy. The unexpected events classification acts as an ontology that describes the unexpected events, their inter-relationships and their links to processes.

- Event Pattern Notation: an event representation language should represent the wide variety of events that people experience in their everyday life (Nevatia, Hobbs & Bolles, 2004). EPN describes unexpected events that are experienced in Supply Chain processes and occur within the extended SC, including external systems and markets. EPN exhibits strong representational characteristics which are not compromised by representation complexity or the need for deep mathematical knowledge. EPN uses the unexpected events classification to describe event patterns.

- SCEDRA: reactive systems or ECA condition mechanisms represent events as changes that occur in systems computations (Carlson & Lisper, 2004; Liu, Mok & Konana, 1998), where composite events consist of primitive occurrences triggering rules or actions. SCEDRA identifies events that are causally and temporarily connected and occur inside and outside SCs boundaries, thus awareness of market and industrial changes becomes possible inside the SC network. Overall SCEDRA narrows the focus of event reactive systems and extends their scope by covering all aspects that affect the SC.

## 6.5 Research Contributions

This research spans disciplines such as computer science and SC operations. Information Systems acts as the enabler for SC operations. Two sets of contributions are identified and listed below:

### 6.5.1 Key Contributions

This section describes the key contributions of this research in the following fields:

- Events: the concept of events has been thoroughly examined in this thesis within the domain of the SC. During the theoretical investigation of events which disrupt SC operations, it was noted that the discipline of risk management had already considered the use of events taxonomies. This however, referred to the identification of risk sources rather than the classification of events under SC processes. In contrast this research has classified unexpected events in the extended SC context, under both internal and external SC processes. This taxonomy sets the basis for developing an ontology for combining processes and events.

The main contribution in the events area is the development of the events theory which defines the concept of the composite event. Modelling events relationships and event patterns while preserving identity of atomic events is a novel contribution. SC participants have full visibility of the event pattern as well as of the source event. For example, in the second case study scenario described in chapter 5, final customers are aware of the initial delay which originated at the packaging material supplier. Finally, the Event Pattern Notation is the only notation that depicts events patterns in the SC while at the same time maintaining consistency of SC processes among the SC partners.

- Supply Chain: the SC is a dynamic discipline that combines IT advances with the evolution of business and industrial activities. From traditional (Poirier and Reiter, 1996) to most recent SC definitions (Kauffman, 2002) the SC has been described as an association of activities and entities participating in transformation and transition processes. This thesis enhances the concept of the Supply Chain adding new features to its current structure. Entities that compose existing SCs are extended and integrated. Composite events span across all SC components hence the Supply Chain is re-formed into an integrated network where operations are conceptually centralised.

- Information Technology: the proposed Supply Chain Event Driven Architecture is based on operational interoperability achieved using Web services. Operations are exposed and consumed by participants. To create a balanced operational SC network, it will need to adapt to balance conditions between service exposure and consumption. SCEDRA enables IT disciplines to reach a level of service equilibrium where operational balance among participants is achieved.

Additionally, SCEDRA is an event-driven architecture that is focused on a particular domain (SC). Unlike Business Activity Monitoring (BAM) technologies SCEDRA is not focused on reacting to alerts when measures and metrics are met. SCEDRA combines IT paradigms and disciplines to achieve an integrated framework for identifying the relationships between events, forms composite events and disseminate them.

### 6.5.2 Secondary Contributions

This section describes the second key contributions of the particular research. The following aspect was not in the initial scope of the research.

- SCOR Model: although the thesis objective was to use the SCOR model as a tool certain benefits derive from this research could expand the SCOR model's usage. The design of the events classification pointed the need to extend current Supply Chain processes towards external factors that determine business operations. SCEDRA addresses the fourth level of SCOR model which although is not within the Supply Chain Council's scope, is beneficial for companies that implement SCOR practices.

- Industry: even though this was an academic research that avoided focusing on specific industries it does consider Supply Chain practitioners as beneficiaries. SCEDRA distributes event pattern knowledge to the SC participants, hence their business awareness is enhanced. Additionally, delay times are reduced as practitioners operate in a flexible and agile SC with minimized delays. For instance, the evaluation scenarios calculated a reduction in the delay time of 6.6% and 13.3%. As competition is measured on a SC level, gaining a competitive advantage applies to all partners.

## 6.6 Limitations

To complete this research and obtain the desirable results and findings four limitations had to be addressed. Three limitations refer to methodological constraints that were met during the research whereas one relates to the research scope. These limitations are listed below:

- Questionnaire response rate: the questionnaire regarding the evaluation of unexpected events frequency was distributed to a large sample of the Supply Chain Council members. However, only 10% of the sample returned a valid questionnaire and this represents a limitation. This limitation was balanced by the quality of the respondents base, their expertise in the domain and their wide experience in SC. All respondents were active members of the Supply Chain Council, at the time of the survey, applying the SCOR excellence to their operations. They provided with real world evidence and knowledge from their operational domain.

- Adapting to qualitative research limitations: rating the frequency of unexpected events, entailed the danger of imposing the limitations of qualitative investigation to the particular research. To address this issue it was important to:
    - Distribute the questionnaire to a wide range of participants, in order to address a large sample.
    - Do not include subjective responses, which were achieved by omitting consultants' responses.
    - Ensure that at least 10% of the sample returned a valid questionnaire.
    - Categorize answers under predefined segments.

- Limited time for evaluation investigation: due to the policy and security regulations of the company used as a case study, the time allowed to investigate the operational environment was limited. To address this limitation the survey was divided in two parts; the contextual investigation of SC processes and the interviews.

- Reverse logistics: the final limitation relates to the scope of the research. Supply Chain processes of reverse logistics were simplified under the umbrella of RETURN processes. Reverse logistics are used by practitioners to address large scale returns such as product recalls or defective products returns. To avoid inconsistencies on an operational level it was important to view SC processes under one framework, hence reverse logistics were incorporated in RETURN processes.

## 6.7 Future Research

By avoiding focusing the research on a specific industry type, we obtained a broad context for eliciting information regarding unexpected events. Four possible directions to expand the work presented in this Thesis are presented below:

- Extending the Research Area: comparing unexpected events across industries could direct the research to examine and get a deep insight in specific industries needs. This would provide with details about the frequency rates of particular events and would allow companies to customize their activities. Additionally, it would be motivating to compare the frequencies of unexpected events between sectors and examine the differences between them. This would assist to measure the impact of unexpected events between different industries and enhance benchmark data and best practices. Particular focus would be on external unexpected events that span across all industries, such as physical disasters, industrial changes and oil/currency prices fluctuations.

- Extend EPN in business domains: EPN was developed and evaluated to describe event patterns in the Supply Chain domain. EPN could inspire other notations to describe and model unexpected event patterns in other business contexts, such as Customer Relationship Management.

- Applying SCEDRA to SC chaos theories: chaos in the SC originates from management decisions and systems computations (Wilding, 1998a; Wilding, 1998b), where the causal impact of chaos often results in undesirable patterns, such as the bullwhip effect or bottlenecks. Applying the knowledge from the unexpected events classification the sources of chaos are extended. SCEDRA logic could be employed to identify collective dynamics that create sources of chaos. Levy (1994) concludes that chaotic spikes and unexpected changes in demand result from small external changes that have a big impact on SC internal operations. SCEDRA rationale supports early identification of causal or temporal relationships between external and internal changes hence this logic can be investigated in regards to chaos relating theories.

- Implement SCEDRA: SCEDRA implementation is an advantageous move, which due to the technical and business complexity requires rigorous investigation in the aspects below:

  - Creating an architecture which evolves in line with business demands: this feature involves the requirements analysis on SC partners processes, Service Level Agreements (SLAs) and the development of a business framework that updates business intelligence in the implementation knowledge.

  - SCEDRA is a complex IT system and its implementation should provide real time performance, optimizing target response times and reducing processing overhead in the effort to avoid network overloads.

The implementation requires the alignment of IT paradigms and ensure application scalability in consistency with business knowledge.

- Integrate SCEDRA with Knowledge Management (KM) tools: event patterns include consistent descriptions of unexpected events and of their relationships and represent SC knowledge assets. SCEDRA can be expanded to supply this knowledge to KM tools and use it to improve operational efficiencies. Gateways and portals between companies will communicate SCEDRA patterns to the participants and integrate this knowledge with existent forms of KM asset.

## 6.8 Conclusions

This thesis provided a rich insight into event driven Supply Chains through the detailed description of unexpected events. The classification which maps unexpected events against the official SCOR processes assists the presentation of patterns with the Event Pattern Notation. The design of an architecture to monitor and compose patterns of events was based on combining IT paradigms, such as Web services and software agents. Detailed simulations of SC operations using real data indicate that e-SC paradigms, such as agility, flexibility are enhanced and supported by the approach proposed in this thesis.

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# APPENDICES

# A. Interviews

## A.1 Interview-Warehouse Manager

**Warehouse Manager**

**15 April 2006**
**Sindos, Thessaloniki**
**Greece**

**Mr. Bigenas, what are the main storage types?**
There are two main types of storage, storage of semi-ready product and packaged product.

**How different are these storage types?**
The former refers to product that is semi-ready and still needs to be processed and turn into packaged product. This accounts for almost 90% our products. There is a 10% which is ready product that is treated in the warehouse as packaged product.

**Which are the main processes in the warehouse?**
There are five main processes inside the warehouse.

- Weighting the semi-ready or packed products as pallets,
- Labeling the pallets
- Storing
- Picking pallets
- Picking cartoons.

**How is the warehouse organized?**
The process of storage is done based on the concept of the "anarchy warehouse", where we don't use one specific space to use a specific product or code, where the pallet is placed only in a specific shelf.

**Do you follow a particular coding system for organizing the positions in the warehouse?**
The warehouse is organized as followed:
19-01-007-0, warehouse number, corridor, shelf, position. On each shelf (3.40) four pallets (0.80) can be placed.

**What is the main unit you use in the warehouse?**
The main unit we use is the pallet. There is the euro-pallet with dimensions 0.80 * 1.20. Most of the trucks delivering finished products have a capacity of 12 or 13 pallets.

**Could you describe the main processes that you mentioned above?**
The process of semi- ready product is the following. When the track arrives with the raw material it is unloaded directly in the production plant where it is washed and processed. This is the semi-ready product which will be packaged at a later stage in order to be loaded for delivery. There are five production tunnels and the product is processed through one of those. This product is placed in the pallet which is placed on the scale where we measure the quantity and based on certain characteristics, and a certain label is produced that is placed on the pallet. The label contains the bar code of the product and the bar code of the pallets.

**How is the system updated about the position of the pallet?**
When the pallet is placed on the shelf the person who drives the Clark scans the bar-code of the shelf and the pallet code and the system stores the position of the certain pallet.

**How long does this process last?**
The time of the whole process is about 30 to 40 minutes.
At the first stage the semi-ready frozen product is placed in the warehouse. It usually depends on the operators but approximately each task is timed to 10-15 minutes.

**Are there are specific processes regarding the entrance to the warehouse?**
There are cases where the semi-ready product is delivered from suppliers abroad. In these cases the whole truck is weighted on the scale before and after the unloading. After that we compare the weight with the quantities on the invoice and the transportation document. The quality control process is different as we have to check the temperature of the product.

**Is the time different in this case?**
In this case the total time is about 45 minutes.

**What is the process of removing products from the warehouse?**
When the product is about to be removed from the warehouse, either because it needs to be packaged or because it is to be delivered in a certain order a certain process is followed. There is the FIFO (First In First Out) algorithm used in order to identify the oldest pallet that needs to be removed from the warehouse. The system gives the shortest path for the Clark to move inside the warehouse and picks up the certain pallets. Based on the pallet code we can have information about the history of each pallet.

**So the Clark is equipped with a scanner and a computer screen to monitor this path?**
Of course, this way we reduce the time the Clark would need to identify and collect the pallets. When we receive an order we receive the product codes and based on these codes we are able to get with the FIFO algorithm the way the Clark needs to move in the warehouse.

**And how is the warehouse system updated about the new quantities in the warehouse?**
After the ready product has exit the warehouse we verify it so that I can reduce the quantity from the ready stock.

**You mentioned orders. How many types of orders do you usually have?**
There are two kinds of orders. Orders which are for retail and usually are in cartoons and those for wholesalers in pallets.

**What is the difference in the warehouse activities for the two different order types?**
The difference is in the picking process and the time it takes. It is the same task like in the pallet, with the difference that the Clark collects cartoons and not pallets. This task lasts about 45 minutes for an average collection, where as the pallet collection lasts about 30 minutes. The cartoons are multiplicates of the rows for the particular product.

**How long does the loading process last?**
All orders are processed electronically and all are organized according to geographical areas. So the loading process tries to comply with this feature. The total loading time is about 30 minutes.

**What happens at the unexpected event of a rainstorm or snow? Does it affect the warehouse activities?**
No, it doesn't because all warehouse tasks are made under protected space. This affects however transportation and deliveries that are delayed.

**And what happens in case there is a machinery failure that affects the warehouse processes?**
Well that would be something like, a failure or breakdown in the scale for example. In that case we could use a supportive scale or in some cases when no scale can be used, everything is processed manually. This doubles the required time, so for instance if there are four pallets that need to be stored, all information is processed manually and instead of 20 minutes the required time is around 35-40 minutes. Of course this depends on the weight and the quantities of the products inside a pallet.

**What about the process of Returned products?**
After all the documents are issued (credited invoice etc.) these items enter the warehouse and are placed n a designated area. A label indicating that they are returned items is laced on the pallet so that they cannot be resold immediately.

**How different are the warehouse processes regarding first material? I am not referring to semi-ready product.**
First materials like packaging material have a similar entrance and placing to the warehouse however due to their size and the fact that they don't require special conditions they are placed in a different corridor of the warehouse. Processing times are less for first material as the quality control tests are simpler.

**So, on a concluding note, there are two different product types in the warehouse and five main processes. Each for these consists of tasks that are timed to 10-15 minutes under normal conditions. Similar to these are the processes regarding first material. Is there anything more you would like to add?**
Actually, I want to make clear that due to the nature of the products we can't speak with absolute times about all products. For example processing and storage time of peas is much smaller than beans because of size differences.

**Thank you for your time**
Thank you Miss Pavlou.

## A.2 Interview- Coordination Manager

**Coordination Manager**

**15 April 2006**
**Sindos Thessaloniki**
**Greece**

**Miss Siskaki, in terms of Supply Chain operations what is your role exactly involved in?**
I am responsible for the coordination of production processes. This needs to be based on the requirements given by the sales and procurement department. It is what is called the scheduling process, with the difference that is scheduled on a weekly basis instead of a long term that someone might assume.

**Is there a particular reason for scheduling production a weekly basis?**
This is important as we need to know what we are going to produce at what time and for which order. Based on the reports given about the sales prediction and the needs and resources it is my responsibility to create the weekly schedule based on which the production is programmed.

**Miss Siskaki, under what terms do you measure stock availability?**
We measure stock availability in days.

**How do you schedule the production activities?**
I create a form with two columns; one illustrating days 1 to 5 (corresponding Monday to Friday) and the other days 6 to 10. We always refer to working days. I list usually 30 to 40 products and for those I examine the available raw material, packaging material, personnel and machinery capacity. Based on this information I see what are the trends for these products and accordingly I move the product to the appropriate column.

**What is the main factor based on which you classify products' priorities?**
The main factor is how I can maximize production capacity.

**Based on what factors do you maximize capacity?**
Based on the available personnel and machinery resources. Everything is based on the sales budget that has been developed from the marketing and sales department.

**What is your safety stock level?**
As you know we produce food based on frozen vegetables. First we create the semi-ready product which consists mainly of processed vegetables and then we package this product and it is ready to go. We don't package unless there is an order to satisfy. We keep safety stock in the semi-ready product which is for one month.

**How do you work this stock out in terms of schedule?**
As a company we have a certain characteristic which is a big branch in the South of Greece which consumes 60% of our weekly produce. We have to make up for this amount and also produce the remaining 40%. Just to clarify that this 60% is not considered an internal distribution but a sale. So, based on this scenario the factors that affect the schedule are:

- Product types
- Machinery

- Raw material and packaging material
- Order of priorities according to the sales

**What is the delay in the execution of a production schedule?**
The delay time exists when we change from one product to another and there are changes that need to be made in the production unit area. We try to minimize the "dead-time" in these cases by utilizing the personnel. For example the workers go on lunch break at that time and in general we try to cover this time by other activities that need to take place. The only period that there is purely dead time is during cleaning where no machine is operating.

**How do you measure dead time?**
Dead time in production is measured when during production hours no production process takes place. Increased dead time can affect delivery of finished and packaged products.

**Earlier you mentioned that the security stock is for one month. Could you be more precise about the general stock policy of the company?**
The main policy of the company determines that semi-ready product is kept for one month and packaging material is kept for four months. The reason for giving such a broad period to the packaging material is due to the fact that we need four time periods to move in order to:

- Verify and receive the order from the supplier
- Smoothen any sales fluctuations
- Run the current production schedule

We allocate the period of one month to each one of these activities. Then we add an extra month as a security bound. The problem with packaging material is that, as it is a custom made product there is only one supplier for a specific packaging type, so any delays are critical. Also occasionally there are suppliers providing packaging material that set a plafond on the order, so out flexibility is reduced.

**Is this the general practice for all first material?**
More or less yes but with certain differences. We set up annual contracts with our suppliers and the agreed delivery period is set for one month earlier to cover the needs of the current month. This way we give a space of two months for the first material. In general we try to have a space of four months for packaging material and two months for first material. In the past it used to be six months and four months, but this would affect the storage space and increase the cost of maintenance.

**What are the practices you use in order to prevent the shortage of a particular material?**
When we realize that a certain material is on high demand we try to get it centrally in the production plant and not in a peripheral storage, thus we reduce the response and lead time. Also it is my job to put pressure on the supplier to get it delivered and finally, our quality control manager gets in touch with the supplier to resolve any quality issue that might have been the cause of any delay.

**How does the delay or luck of material affect delivery time?**
There has been one case where the supplier took three weeks to deliver packaging material and this resulted in the delay of the delivery of the certain product, or what we call code. The rest of the order was completed but the particular code was dispatched one month later.
**What is the minimum amount of a code order?**

This depends on the code of the particular product. The minimum is 10-15 kg when it comes to unpackaged products. To be more precise with kilos, keep in mind that 50 kilos are part of one cartoon that is the 1/10 or 1/15 of one pallet.

**What is the impact on the schedule process of an unexpected event of a natural disaster? Like snow or hale for instance?**
These events affect the transportation and distribution processes and is impossible to predict how because this is a factor that depends on the traffic and the other vehicles on the street. However, the continuation of a certain climate period affects production and sales, as fresh produce vegetables get very expensive and people tend to buy frozen. The same thing happens if there is a strike from the water supplier. In this case there is a rise in the sales of frozen spinach for example.

**Did you ever face the problem of not being able to deliver on time because of this reason?**
There are delays but these are really low. As you know there is a 48 time to execute an order. A typical delay would be maximum 8 hours.

**Would that however cause implications the customer?**
In certain occasions it would .In particular if the customer is a small retailer who doesn't have large storage capacities.

**What is the impact on the schedule process of an unexpected event of a machinery failure or a more extreme situation of a production unit failure?**
In these cases it is the delivery process that is mostly affected. Because we have a reasonable amount of security stock, one day, a breakdown would have to be major in order to affect the time of the deliveries.

**What is the most common delay time in delivery processes?**
As we mentioned earlier, each order is executed within 48 hours. Usually it is 1-2 hours.

**What is the impact of an unexpected event of errors in orders?**
In case that an order is executed and is incorrect, incorrect type of product, this is a serious and important issue, because there is a cost that we have to deal with and products that are packaged. Also there is the cost of taking the products back and producing the correct ones. In a normal scenario that would create a delay of 96 hours, provided that both orders are executed correctly.

**What is the impact on the schedule process of an unexpected event of unavailable product?**
In this case we prioritize the orders, or we get to an agreement for financial distribution of the product value to all customers until the required quantity is ready to be dispatched.

**So, to summarize the main points of this interview: your responsibility is to create the weekly schedule based on sales requirements aiming to maximize production capacity. Stock is measured in days and there is a security stock of one day to cover unexpected breakdowns. The stock security policy differs between products and first materials and you have experienced major delays from the packaging material supplier which affected the delivery to customers. Extreme physical phenomena such as heat waves or events of**

**strike increase the sale of frozen vegetables and events of errors in orders are costly and time effective. Is there anything else you would like to add?**
No, I think we have covered more or else my field.

**Thank you very much for your time.**
Thank you as well.

## A.3 Interview-Logistics Manager

**Logistics Manager** **15 April 2006**

**Sindos Thessaloniki**

**Greece**

**What is the main type of product you work on?**
There are two types of product. 90% of the products consist of industrialized products, where we collect the raw material from the field, it is processed and packaged. We don't resell or merchandise to someone else these products. Only 10% is ready made product.

**Who makes the decision of the quantities of ready made product?**
In these cases the logistics department is responsible to order the quantities for ready made product which is usually delivered from abroad.

**What is the main process of collection and manufacturing the collected product from the filed?**
Because these are seasonable products they are collected when they are supposed to and then they are processed. We can't determine exactly the collected quantity but it needs to be enough to satisfy the requirements as set from the marketing department.

**What is the storage process that you follow regarding ready product?**
There are three ways of storage:

- 3PL
- Central warehouses
- Distribution

When a 3PL is involved buys the product from us and then the retailer gets the product from him. In these cases our company sends an inspector to the retailer to examine the quality of the products on the shelf.
Central warehouses are part of the company. The difference with the other two storage types is that when a delivery is made to these warehouses, it is not considered as a sale.
Finally there is the distribution in the area of Thessaloniki and the distribution in the area of Athens. In this case all orders from small suppliers are gathered electronically, the invoices are created, the orders are dispatched and the delivery is ready to go. The transportation is done using our means.

**How do you control the orders which are dispatched?**
We use the warehouse software, ABERON, which controls the warehouse stock. When an order is submitted it checks for stock availability and if there is no stock available the warehouse manager is notified and the invoice is issued the next day.

**What is the maximum time to execute an order?**
The maximum time is days. We aim to execute an order within 2 days.

**Does this apply to all types of orders? I mean regarding the quantity of orders.**

There are cases where a big retailer wants to fill his warehouse. In this case the time is 5 days. Based on the sales budget that has been given to us from the Sales department we know that there is 400 Kg that need to be produced for the current month. The next month before the production schedule is produced; we take into account any left over quantity from the previous month.

**What happens when you receive a high priority order and you can't satisfy all of your customers?**
In this case we change the priority of the order execution. Distributing to warehouses which belong to the company in a variety of geographical areas is not considered a sale, so we try to execute orders that are considered a sale. This is common towards the end of the month but we are aware of it so we try to be prepared.

**How do returned products come back to the factory?**
It is very difficult to return products everyday, as it is expensive to operate tracks just for five cartoons. So we allocate a track once a month in retailers and every six months in a 3PL. when a retailer buys from a 3PL the products are returned to the 3PL.

**What are the main reasons to return products? I am not referring to product recalls or any governmental policies.**
There many reasons. In most occasions they have to do with the packaging of the product or the pallet. When a package back or a pallet is torn for example.

**What is the impact of the event of physical disasters, such as hale or snow?**
It doesn't really affect the production or packaging process. However it affects storage. Because of weakness in transportation products that would be ready to be delivered are stored in the warehouse and the cost of maintenance is bigger.

**Would it affect distribution?**
The impact on the distribution process depends on the day. In the beginning of each week the impact is bigger and the delay could be up to three days, which is the biggest period that we faced. At the end of the week this is minimized. So if there is snow and the roads are blocked on a Wednesday the delay could be maximum of 2 days.

**What is the impact of the event of machinery failure?**
Due to the security stock level that we keep (15-30) days it would have a major breakdown to affect production. If it happened during packaging then the delay wouldn't be more than an hour or two.

**What happens regarding delayed deliveries to your customer?**
Because our customers do not have the storage capacity that we do, keeping their fridges empty affects their sales level, as they don't have security stock. Thus, we try not to delay a delivery more than 2 hours.

**What happens when a first material is unavailable?**
The problem is with packaging material. If the machine used to produce packaging material exists inside our premises then we can get a technician directly and minimize the repair time. However, when we have a supplier for it, then it could affect the delivery of a code inside an order.

**What are the main errors in orders?**
This is a common error and there different types of it:

- Ordering the wrong product
- Packaging the wrong product
- Delivery to the wrong branch

**What is the impact of the event of errors in orders?**
Usually the delay time until the correct order is executed is 24 hours.

**What is the impact of the event of quality control failure in the raw material?**
This is very unlikely, as the cultivation is monitored by agro-food specialist from our company and also due to the nature of the product is not very common.

**What is the average SC cycle time of the products?**
Packaged products last for 24 months but they are always consumed within the first 8 months.

**What is the impact of the event of market oversupply?**
It affects in two ways. The first one is the lack of codes (products) increasing the cost and the cost of packaging. The luck of availability results in altering the priorities about product execution.

**Can you describe the life cycle of a product, such as peas?**
The product is collected in May and is processed to semi-ready product directly. In September it starts getting into packages to satisfy the orders. The total file cycle is 30 months but it can stay on the shelf 2 months.

**And what happens with packaging material?**
We have either 2 or 3 suppliers for packaging material. We aim at a four months security stock. When we set an order to our suppliers it is usually executed within 40 days.

**So, to sum up, there are two types of products, 90% of industrialized and 10% of ready made. There are also three main types of storage which changes when a high priority order arrives. Usual order lead time is 2 days apart from occasions that a supplier wants to fill in the entire warehouse. Unexpected events that might occur such as errors in orders, we mentioned three most typical, result in delivery delays. Is there anything more you would like to add on these?**
Well these are from my perspective and department. For example I know that when there is an event of cut in water supply there is an increase in sales for frozen vegetables. Also, the life cycle of products changes depending on the product. That would be all.

**Thank you very much sir.**
Thank you.

## A.4 Interview-Production Manager

**Production Manager** **16 April 2006**

**Sindos Thessaloniki**

**Greece**

**What are the differences between the productions in different nature industries?**

According to the product you have different kinds of production. For example in this case that we deal with food we use the lot number that enables us to know not only the date of the production but the people who were working that day and in their particular places. But you have to bear in mind that the production in a company is useless when a factory is not able to "move" within the boundaries of it's supply chain.

**How flexible is a company in terms of unexpected changes in scheduled deliveries?**

This would depend on the actual suppliers and the type of product. We strictly operate with a two day order lead time through this SC.

**How do you face cases were you are aware of delay in a certain material you need to complete a customer order?**

The agreement we have with our customers allows them to request a re-delivery of the scheduled order in cases that we delay to deliver a certain order. In these cases the customer requests to change the date of delivery for next month for instance and he contacts a different supplier to remain within schedule.

**How do you estimate the needs for first-raw material?**

We need to take under consideration the following:

The current stock in the particular materials, the budget of the current month, the time during which they will be used, the time between the order until the delivery and finally the minimum quantity that the supplier can provide.

**Can you describe the process of raw material procurement?**

When we order a raw material this has to be based on the monthly budget that defines the daily production schedule. When it is noticed that a material is required the person who is responsible for the procurement of raw materials creates an order that includes: the quantity and the delivery date. The order is approved from the production manager and is transmitted to the supplier either with fax or by hand. If the supplier does not operate a fax machine then the order takes place over the phone and this has to be noted on the delivery note. When the material arrives at the factory the guard first checks whether this delivery is targeted for our factory. Then the guard informs the warehouse manager that the delivery has arrived. The warehouse manager is responsible for two kinds of controls: for the quantity control and to check whether the products are in a "acceptable" state. In case that there is a difference with the order note and the delivered quantity he informs the production manager in order to change the production schedule and he also contacts the supplier. The warehouse manager places a label on each product pallet which can be torn into two pieces and one piece writes "accepted" and the other "not to move". The quality control is done from the quality control manager and if the products are accepted then the appropriate part of the label is placed on the pallet.

**What is the next task after you have received an order?**
After we have received the order the warehouse manager submits all the accompanying papers to the supplies manager and then he delivers them to the accountant.

The suppliers that are contacted are certain people that in the beginning of each year make their offers and when it is possible we also gather a sample of the materials that we will be using. Then the evaluation of the bids takes place and in order to accept a bid it has to agree with the standards that we set. After the evaluation the general manager, the quality control manager and the person who is responsible for the supplies create the catalogue of the "approved" suppliers.

**How can you track the consumption of the raw materials?**
We use a certain program that controls the production. In this program we enter the daily schedule and this automatically creates the list with the raw materials and their quantity that we need. In a daily basis we count the raw materials that are used in every spot of production. The supplies manager gathers all these information and he compares them with a rough count from the warehouse. At the end of each month we are able to know the exact consumptions of each material as we conduct a manual count that is compared with the one from the accountancy.

**Could you describe what happens when a customer returns a product?**
There are certain conditions in order to return a product such as the expiration date has to be over. In these cases the products are return with the order of the sales department. But the actual people who decide for the return are the general manager and the people who are responsible for the quality control. The products that are returned when they can be reused they enter the production and when they cannot be used they are destroyed. The way these products enter back the factory is decided from the sales department. When they come back and they be promoted again they enter the warehouse and we issue a credited invoice.

**What exactly happens when you repackage a product?**
This means that we might use a product again put it in a new package and it enters again the warehouse.

**That would be great. Thank you very much for your time. Because of the amount of information I will send a copy of the interview to you ASAP to go through the content.**

That would be ok. Thank you.

# B. Questionnaire

## B.1 Questionnaire Structure

This questionnaire is part of a PhD research project that aims to identify patterns of events that happen during supply chain processes. The project aims to define a language for describing event patterns in supply chain management, and use it in a system that captures significant events as they occur in near real time and transmits them to interest parties in the supply chain.
All information submitted here will be treated with strict confidentiality.
All respondents will be emailed the findings of this study when they become finalised.
You can complete the questionnaire just by replying to this e-mail.

**Section A.**
General Information:

Company Name:
Industry Sector:
Your Role:

**Section B.**
Events in Supply Chain Processes

**1) From a range of 1(never), 2(rare), 3(occasional) and 4 (common) how would you rate the occurrence of the following events that affect supply chain processes? (Please write your answer next to the described event)**

Financial market turbulence (e.g. oil price increases):

Physical or manmade Disasters:

Machinery Failure:

Plant/Production Unit Failure:

Strikes:

Security Issues:

Defective Components:

Product Recall:

Unexpected Product Return:

Components Reaching EOL:

Components Fail Quality Control:

Market Oversupply:

Delayed Deliveries from Supplier:

Delayed Deliveries to Customer:

Unavailable Stock:

Errors in Orders:

Errors in Billing/Delivery Information:

Invoice Errors:

Other (Please specify):

Other (Please specify):

Other (Please specify):

Other (Please specify):

**2) Does your organization use any particular policies for addressing unexpected events during SC processes?**

### B.2 Response I

Company Name: The Boeing Company, Integrated Defense Systems

Industry Sector: Aerospace and Defense

Your Role: Senior Manager

## Section B.

Events in Supply Chain Processes

**1) From a range of 1(never), 2(rare), 3(occasional) and 4 (common) how would you rate the occurrence of the following events that affect supply chain processes? (Please write your answer next to the described event)**

Financial market turbulence (e.g. oil price increases):3

Physical or manmade Disasters: 3

Machinery Failure: 2

Plant/Production Unit Failure: 2

Strikes: 2

Security Issues: 2

Defective Components: 2

Product Recall: 2

Unexpected Product Return: 2

Components Reaching EOL: 3

Components Fail Quality Control: 3

Market Oversupply: 3

Delayed Deliveries from Supplier: 2

Delayed Deliveries to Customer: 2

Unavailable Stock: 3

Errors in Orders: 3

Errors in Billing/Delivery Information: 3

Invoice Errors: 3

Other (Please specify):

Other (Please specify):

Other (Please specify):

Other (Please specify):

**2) Does your organization use any particular policies for addressing unexpected events during SC processes?**

None at this time.

### B.3 Response II

Company Name: Queensland rail

Industry Sector: Transportation

Your Role: Supply Chain

## Section B.

Events in Supply Chain Processes

**1) From a range of 1(never), 2(rare), 3(occasional) and 4 (common) how would you rate the occurrence of the following events that affect supply chain processes? (Please write your answer next to the described event)**

Financial market turbulence (e.g. oil price increases):3

Physical or manmade Disasters: 2

Machinery Failure: 3

Plant/Production Unit Failure: 3

Strikes: 2

Security Issues: 1

Defective Components: 3

Product Recall: 3

Unexpected Product Return: 2

Components Reaching EOL: 2

Components Fail Quality Control: 3

Market Oversupply: 2

Delayed Deliveries from Supplier:4

Delayed Deliveries to Customer: 3

Unavailable Stock: 3

Errors in Orders: 2

Errors in Billing/Delivery Information: 4

Invoice Errors: 3

Other (Please specify): Data referencing Issues:4

Other (Please specify):

Other (Please specify):

Other (Please specify):

**2) Does your organization use any particular policies for addressing unexpected events during SC processes?**

Scenario planning

Contingency planning

### B.4 Response III

Company Name: Sappi Fine Paper North America

Industry Sector: Manufacturing

Your Role: Director Supply Chain

## Section B.
Events in Supply Chain Processes

**1) From a range of 1(never), 2(rare), 3(occasional) and 4 (common) how would you rate the occurrence of the following events that affect supply chain processes? (Please write your answer next to the described event)**

Financial market turbulence (e.g. oil price increases):4

Physical or manmade Disasters: 2

Machinery Failure: 3

Plant/Production Unit Failure: 2

Strikes: 2

Security Issues: 1

Defective Components: 2

Product Recall: 1

Unexpected Product Return: 2

Components Reaching EOL: 1

Components Fail Quality Control: 1

Market Oversupply: 4

Delayed Deliveries from Supplier:2

Delayed Deliveries to Customer: 4

Unavailable Stock: 2

Errors in Orders: 2

Errors in Billing/Delivery Information:1

Invoice Errors: 1

Other (Please specify):

Other (Please specify):

Other (Please specify):

Other (Please specify):

**2) Does your organization use any particular policies for addressing unexpected events during SC processes?**

No

## C. Recorded Events

| Sector | Cause | Example | Source |
|---|---|---|---|
| Automotives | Hurricanes | GE reduced insurance profits and increased raw material costs in its plastic business where benzene is 3 times normal price. | D. Roberts (9/10/04), The Financial Times, FT Money and Business, "GE Struggles with effect of hurricanes", pM8, N: 35580. |
| Beer Industry | Hurricanes | Heineken sales decreased due to hurricanes spoil major US holidays. | S. Thompson (9/10/04), The Financial Times, FT Money and Business, "Hurricanes hit Hieneken", pM8, N: 35580. |
| Automotive | Defective Components | Chrysler Group unit. Problem was, when a drive train was one-eighth of an inch too long or a widget a half-centimeter too wide. | T. Mayor (2004), CIO, "The supple Supply Chain", available at: http://www.cio.com/archive /081504/supply.html |
| Banking | Security Discrepancy | Bank of America computer types including information of 1.2 m US government employees are missing and was found during transferring back up storage tapes to an undisclosed storage facility. | D. Wells (28/02/05), FT Money and Business, "Bank of America loses tapes of data on 1.2 m customers", p M1, N: 35698. |

| Sector | Cause | Example | Source |
|---|---|---|---|
| Food Industry | Hazardous substance SUDAN I | Premier Foods had to recall a wide range of products due to substance relating to cancern. | K. Burgers (19/02/05), FT Money and Business, "Cancer links sparks recall at Premier Foods" p:M2, N:35692. |
| Electronics | Defective Components | Microsoft's Xbox game consoles. 20m consoles have been sold. A small number of fires in machines caused by component failure. Minor cases of users burning their hands. Found out after examining warranty claims. | R. Waters (18/02/05), Business and Markets, Financial Times, " Microsoft acts over defective Xboxes", p:24, N:35691 |
| Pharmaceutical Industry | Drug causing possible death reported | AstraZeneca cholesterol medicine: Crestor a patient died of a condition possibly connected to the medicine. | K. Capell (3/11/05), BusinessWeekly, "No relief for this drugmaker", p:18. |
| Furniture Retailer | S/w delays orders and reduces stock availability | MFI actual deliveries drop due to software malfunctions. | J. Watson (9/01/04), Computing, "Supply Chain failures dog furniture retailer" p: 64. |
| Electronics | Components reaching EOL | Key components reaching end of life. | B. Jorgensen (2005), Electronic Business, "The end is near", pp:33-34, 31(2). |
| Airline | Strikes | Alitalia cancelled 62 international and 28 domestic flights as the result of a strike. On the 10/2 cancelled 141 flights. | T. Barber (22/02/05), FT Companies and Market, "Attendents strike ground Alitalia flights", p:30, N: 35694. |

| Sector | Cause | Example | Source |
|---|---|---|---|
| Electronics | Excess inventory | 1999-2000 excess inventory had to be written off by many electronic companies. | B. Jorgensen (2004), Electronic Business, "LCD Supply Chain: reservations we know", p:39-40, 30(1). |
| Electronics | Counterfeit goods | In cases there is a shortage for companies getting components without testing can result to counterfeit defective components. | B. Jorgensen (2004), Electronic Business, " Don't get burnt by bogus parts", p:41-42, 30(1) |
| Electronic | Product discontinued | Product Discontinued | P. Scheider Taglv (2003), Electronic Business, "Tools to stay on top component obsolesce", 37-38, 29(1). |
| s/w equipment technologies | Placing high priority orders | Net.com once receiving orders from government has to precedes it over other orders in the queue | S.S. Mecker (2005), Supply Demand Chain Executive, "Managing your supply chain on the rebound" www.sdecec.com/article.arch.asp?article_id=6730 |
| Food industry | Tsunami | Large number of vessels were shipwrecked or destroyed in ports, while ports, processing facilities, acquisitive sites were wrecked. | Anonymous (March 2005), The Grocer, Market Edge, "Brussels works to repair tsunami damage", p:73, vol.228, no:7694. |

| Sector | Cause | Example | Source |
|---|---|---|---|
| Food industry | Price Increase | A price increase in raw materials cost (animal feed, packaging) increases final price of milk in Tesco and Asda | Anonymous (March 2005), The Grocer, "Asda and Tesco put up milk prices", p:74, v:228, N:7694 |
| Food Industry | Cold/Frost | Spansih tomatoes, fruits volumes are limited which affects buyers like Mack Salads | Anonymous (19/02/05), Grocer, Market Edge, "Grocers hit by cold snap", 228(7692), p:62. |
| Food industry | Fire | Kettle crisps fire incident in Norwich in one cook room | S. Mowbray, (12/02/05), Grocer, News, "Kettle recovers from crisp fire", 228(7691), p:12. |
| Food industry | Fish over-production | UK and Irish government had to respond to severe price cuts due tp fish overproduction by third countries. | K. Davies (12/02/05), Grocer, "EU safeguard for Scottish salmon", 228(7691), p:49. |
| Retail | Returned products | Survey from TNS shows that 40% of customers after Christmas returned products. Transport costs are high because of absence in tight controls in the reverse supply chain. Costs can be 4 times the cost of delivery | Anonymous (04/02/05), Retail Week, News: Technology, "UK retailers fall behind on returns", p15. |
| Retail | Delayed deliveries | Amazon delays in delivering iPods | Clemens (04/02/05), Retail Week, Online Retail: Supply, p25. |

| Sector | Cause | Example | Source |
|---|---|---|---|
| Clothing | Matching stock unavailable | Atlantic clothing buys EOL and cancellation stock and cannot get exact replacement | N. Booth (13/8/04), Retail Week, "Atlantic clothing tweaks stock management to cut lead times", p:18. |
| Retail | Fire | In Manchester no communications and not feasible for John Luis to check credit cards. | Anonymous (09/0305), Retail Week, " Manchester fire costs retailers 4.5 m per day", p:5. |
| Electronics | Shipping delays leads to shortages of the slim line PS2 console | Playstation 2 by Sony has delays causing problems to Woolworths and Game so they had to stop taking preorders. | J. Riera (26/11/04), Retail Week, "PS2 supply woes hit game retailers", p:1. |
| Retail Online | Unprecedented traffic | M&S web customers face difficulties ordering online. | Anonymous (10/1204), Retail Week, News: Technology "Retailers face Christmas website woes", p:13. |
| Aviation Industry | Surcharges because of oil price increase BA | British Airways is likely to raise fuel surcharges on its passenger tickets within the next couple of weeks in the wake of oil prices hitting new peaks | N. Fletcher (21/3/2005) The Guardian British Airways expected to raise fuel surcharges. |
| US Airlines | Oil price increase | Quarterly loss widened to more than $1 bn plus with pension costs and record fuel prices | J. Birchall (22/04/05) Companies, Financial Times, "Earnings at US airlines hit by high fuel prices", N: 35744, p:27. |

| Sector | Cause | Example | Source |
|---|---|---|---|
| US Airlines | Oil price increase | Northwest , the fourth biggest US Carrier loss to 458 m from 230 m last year. | J. Birchall (22/4/05) Companies, Financial Times, "Earnings at US airlines hit by high fuel prices", N: 35744, p:27. |
| US Airlines | Oil price increase | Jetblue, net income fell $7m or 6 cents per share compare with 15.2 m or 14 cents per share a year earlier. | J. Birchall (22/4/05) Financial Times, "Earnings at US airlines hit by high fuel prices", Companies, N: 35744, p:27. |
| Pharmaceutical | Medicine related to heart attacks | Pfiser: Celebrer medicine is linked to heart attacks. | Barret (10-17 /01/2005), BusinessWeek, "Pfiser has plenty of pain to kill", p:27. |
| Pharmaceutical | Medicine withdrawn | Merck & Co pulled blockbuster painkiller Vioxx as a study showed it was linked to heart attacks. | J. Carey (10-17 /01/2005), Business Week, "Side effects of the drug scares", p:30. |
| Oil Industry | Plant Disaster | BP caused two spills in the Alaska operations spewing oil and volatile gas. | S. McNalty (14/4/2005) Financial Times, Companies, "BP suffers double spill sat Alaska operations", no:35735. |
| Retail | Currency Turbulence | Universal imported bicycles in the UK from China. But now with dollar falling down the shopping carts have moved. | S. Johnson (12/4/2005 ) Companies, Financial Times, "Retailers produce some fancy moves to cover their exposure", 35735 p:23 |

| Sector | Cause | Example | Source |
|---|---|---|---|
| Retail | Currency Turbulence | Vesunus selling mostly in continental Europe benefited from euro tendency against the pound. | S. Johnson (12/4/2005), Companies Financial Times, "Retailers produce some fancy moves to cover their exposure", 35735 p:23 |
| Shoe Industry | SARS | Camper sales in Asia were reduced because of SARS. SARS hit all branded goods | J. Lawless (18/4/2005), Business Week, "One step ahead and running hard", p:17. |
| Airline Industry | Increase Oil Prices | Aviation Industry has suffered net losses of $58 bn in last 4 years.<br>United Airlines, US Airways & ATA Holdings are trying to recover from Chapter 11 protection from their creditors | K. Dome (15/12/04), The Financial Times, International Economy, "Oil price rise adds to airlines woes losses continues", no 35637. |
| Oil Traders | Cold Weather | Oil traders increase inventory due to cold weather forecast. | Fak (15/12/04), The Financial Times, Capital Markets & Commodities, "Cold weather forecasts boost crude for oil prices", no: 35637. |
| Oil Manufacturers | Gas Leak | Statoil Sea fields had to interrupt their production and restart after January. | Fak (15/12/04), The Financial Times, Capital Markets & Commodities, "Cold weather forecasts boost crude for oil prices", no:35637. |

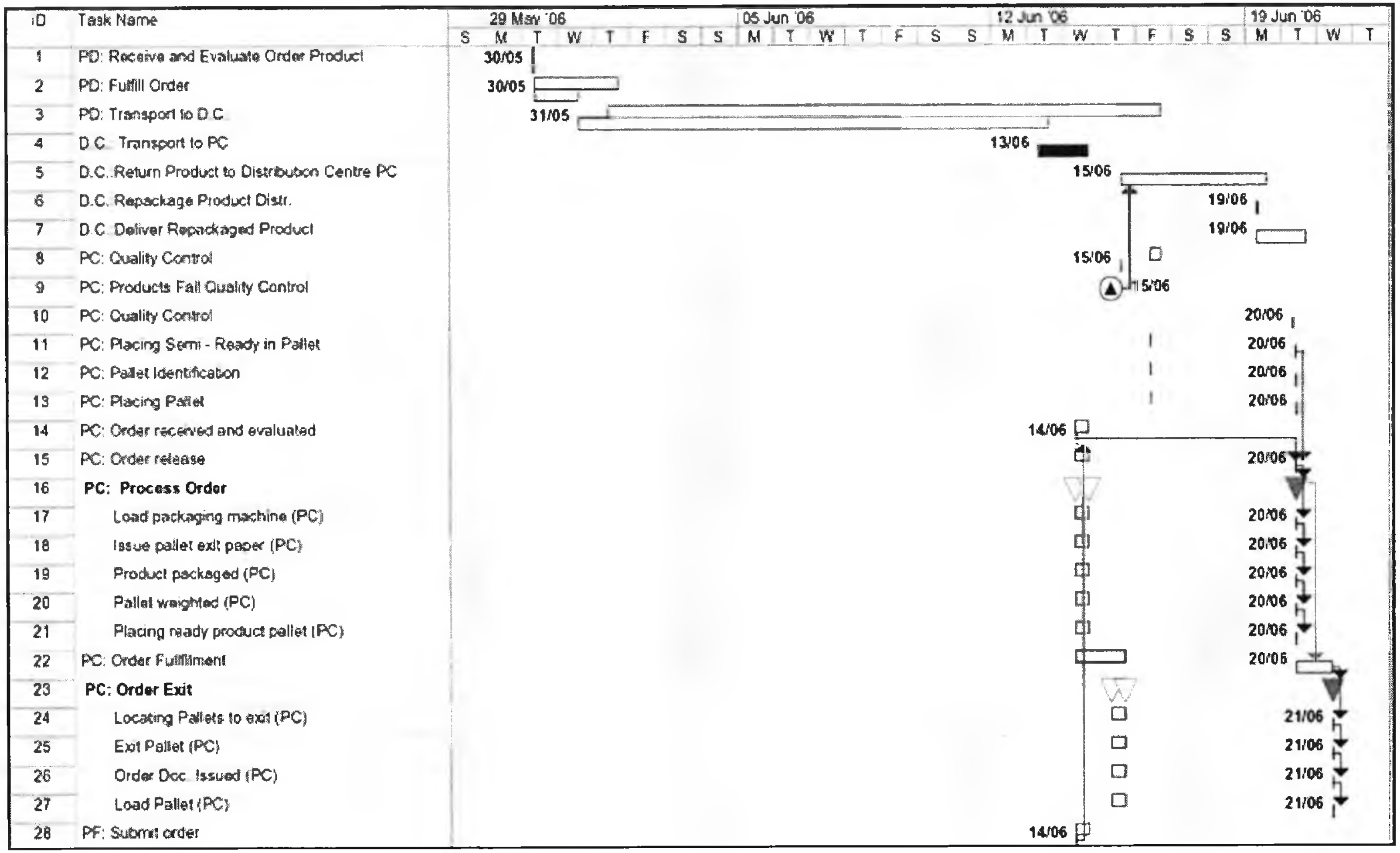
| Sector | Cause | Example | Source |
|---|---|---|---|
| Fashion Industry | Not updated Web site about available quantities | Assos company. Delays in items appearing on the Web site causing large backlogs. | L. Urquhart (4/3/05), The Financial Times, Smaller Companies, "Distribution problems leads to Assos warning", no:35703. |
| Chip Manufacturers | Inventory Buildups & Weak Demand | Downturn caused by increased inventory buildups and slowdown in demand. | E. Nuttal (4/3/05), The Financial Times, Companies International, "Strong chip sales lift sector", no 35703. |
| Telecommunications | Security (Bribery) | Share value reduces as former president is jailed for bribery, regarding assigning contracts to the company. | C. Matlack (12/2004), Business Week, "Cracky doom on corporate bribery", p: 20-22. |
| Finance | Currency Turbulence | Dollar to a record decline reducing investors' interest. | R. Miller (12/2004), Business Week, "Why is dollar giving away", pp:33-34. |
| Cruise Lines | Storms | CARNIVAL storm related expenses around $40 million. | C. Palmeri (11/2004), Business Week, "Plenty of ports in a storm", p:56. |
| Retail | Increased Car sales | September sales have jumped up to 1.5% thanks to string car buying. | J. Cooper, K. Madigan, (11/2004), Business Week, "will the latest oil shock bring a barrel of woe?", pp:33-34. |

| Sector | Cause | Example | Source |
|---|---|---|---|
| Oil industry | Hurricane | Hurricane Ivan walloped nature important oil production and import region of the gulf of Mexico. | C. Palmeri (11/2004), Business Week, "Why Bush is ripping into oil reserves", p:39. |
| Car industry | Banks deny loans | Automotive dealer are trimming invests as banks deny loans. | F. Balfor (09/2004), Business Week, "Letting up the edges", pp: 28-29. |
| Retail | SARS | Hong Kong shoppers drop $4.3 million on heavily taxed goods. | S. Cartledy, C. Wu (9/2004) Business Week, "Shopping makes a comeback", p: 40. |
| Electronic | Security regulations | Complex regulations cause costly delays in electronic manufacturing. | B. Jorgensen (2005) Electronic Business, "Commerce gets more complex", 31(5), pp: 41-42. |
| Electronics | Packaging problems | Complex EDF tools require time effective installation and customization and cause delays in production. | J. Jaces (2004) Electronic Business, "Package deal, why are EDF tools so clunky?", 30(9), pp: 36. |
| Electronics | Production Increase | Increase production in new generation electronics bolsters the business of distribution. | B. Jorgensen (2004) Electronic Business, "Distributors in China double whams", 3(8), pp: 34. |

## D. Evaluation Process Models

This section presents the detailed description of the models designed to perform SCEDRA evaluation. Each model is described through detailed screenshots and the baseline and actual times of tasks are also described. Baseline times refer to the scheduled activities, whereas actual times indicate the real time of tasks start and end. Unexpected events that affect the scheduled times result in tasks that have no baseline time, as they had not been scheduled.

### D.1.1 Scenario 1 – Initial Process Model

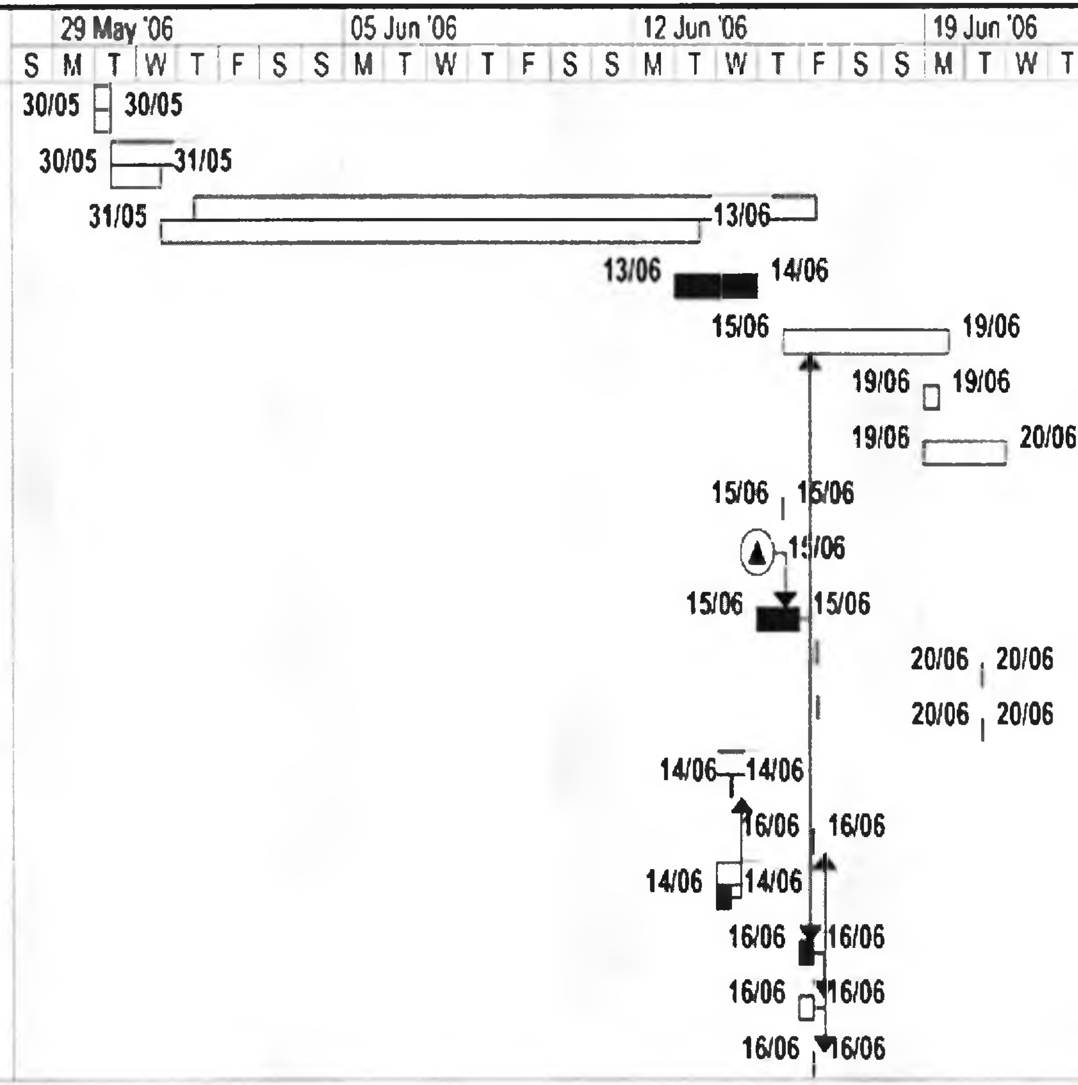


### D.1.1.1 Scenario – Initial Process Baseline & Actual Times

| ID | Task Name | Duration | Start | Finish | Baseline1 Start | Baseline Finish | Predecessors |
|---|---|---|---|---|---|---|---|
| 1 | PD: Receive and Evaluate Order Product | 2 hrs | Tue 30/05/06 | Tue 30/05/06 | NA | Tue 30/05/06 | |
| 2 | PD: Fulfill Order | 2 days | Tue 30/05/06 | Wed 31/05/06 | Thu 01/06/06 | Thu 01/06/06 | |
| 3 | PD: Transport to D.C. | 9 days | Wed 31/05/06 | Tue 13/06/06 | Fri 16/06/06 | Fri 16/06/06 | |
| 4 | D.C. Transport to PC | 2 days | Tue 13/06/06 | Wed 14/06/06 | NA | NA | |
| 5 | D.C. Return Product to Distribution Centre PC | 2 days | Thu 15/06/06 | Mon 19/06/06 | NA | NA | 9 |
| 6 | D.C. Repackage Product Distr. | 1 hr | Mon 19/06/06 | Mon 19/06/06 | NA | NA | |
| 7 | D.C. Deliver Repackaged Product | 2 days | Mon 19/06/06 | Tue 20/06/06 | NA | NA | |
| 8 | PC: Quality Control | 20 mins | Thu 15/06/06 | Thu 15/06/06 | Fri 16/06/06 | Fri 16/06/06 | |
| 9 | PC: Products Fail Quality Control | 0 days | Thu 15/06/06 | Thu 15/06/06 | NA | NA | |
| 10 | PC: Quality Control | 10 mins | Tue 20/06/06 | Tue 20/06/06 | NA | NA | |
| 11 | PC: Placing Semi - Ready in Pallet | 15 mins | Tue 20/06/06 | Tue 20/06/06 | Fri 16/06/06 | Fri 16/06/06 | |
| 12 | PC: Pallet Identification | 20 mins | Tue 20/06/06 | Tue 20/06/06 | Fri 16/06/06 | Fri 16/06/06 | |
| 13 | PC: Placing Pallet | 10 mins | Tue 20/06/06 | Tue 20/06/06 | Fri 16/06/06 | Fri 16/06/06 | |
| 14 | PC: Order received and evaluated | 1 hr | Wed 14/06/06 | Wed 14/06/06 | Wed 14/06/06 | Wed 14/06/06 | 28 |
| 15 | PC: Order release | 20 mins | Tue 20/06/06 | Tue 20/06/06 | Wed 14/06/06 | Wed 14/06/06 | 11,14 |
| 16 | **PC: Process Order** | **0.03 days** | **Tue 20/06/06** | **Tue 20/06/06** | **Wed 14/06/06** | **Wed 14/06/06** | **15** |
| 17 | Load packaging machine (PC) | 10 mins | Tue 20/06/06 | Tue 20/06/06 | Wed 14/06/06 | Wed 14/06/06 | 15 |
| 18 | Issue pallet exit paper (PC) | 10 mins | Tue 20/06/06 | Tue 20/06/06 | Wed 14/06/06 | Wed 14/06/06 | 17 |
| 19 | Product packaged (PC) | 10 mins | Tue 20/06/06 | Tue 20/06/06 | Wed 14/06/06 | Wed 14/06/06 | 18 |
| 20 | Pallet weighted (PC) | 15 mins | Tue 20/06/06 | Tue 20/06/06 | Wed 14/06/06 | Wed 14/06/06 | 19 |
| 21 | Placing ready product pallet (PC) | 15 mins | Tue 20/06/06 | Tue 20/06/06 | Wed 14/06/06 | Wed 14/06/06 | 20 |
| 22 | PC: Order Fulfilment | 1 day | Tue 20/06/06 | Wed 21/06/06 | Thu 15/06/06 | Thu 15/06/06 | 16 |
| 23 | **PC: Order Exit** | **0.06 days** | **Wed 21/06/06** | **Wed 21/06/06** | **Thu 15/06/06** | **Thu 15/06/06** | **22** |
| 24 | Locating Pallets to exit (PC) | 20 mins | Wed 21/06/06 | Wed 21/06/06 | Thu 15/06/06 | Thu 15/06/06 | 22 |
| 25 | Exit Pallet (PC) | 20 mins | Wed 21/06/06 | Wed 21/06/06 | Thu 15/06/06 | Thu 15/06/06 | 24 |
| 26 | Order Doc. Issued (PC) | 15 mins | Wed 21/06/06 | Wed 21/06/06 | Thu 15/06/06 | Thu 15/06/06 | 25 |
| 27 | Load Pallet (PC) | 30 mins | Wed 21/06/06 | Wed 21/06/06 | Thu 15/06/06 | Thu 15/06/06 | 26 |
| 28 | PF: Submit order | 20 mins | Wed 14/06/06 | Wed 14/06/06 | Wed 14/06/06 | Wed 14/06/06 | |

### D.1.2 Scenario 1 – Redesigned Process Model

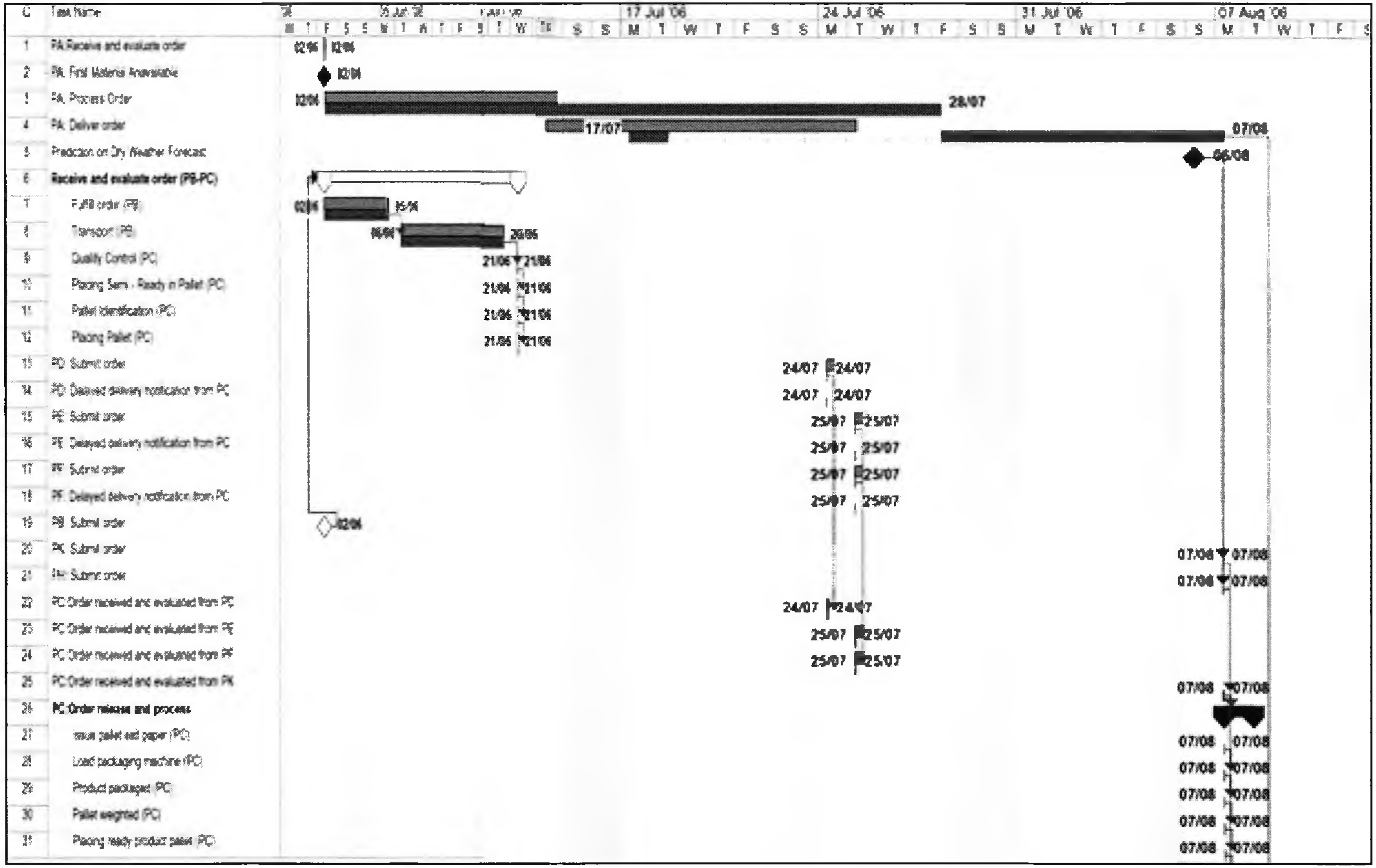
| ID | Task Name |
|---|---|
| 1 | PD: Receive and Evaluate Order Product |
| 2 | PD: Fulfill Order |
| 3 | PD: Transport to D.C. |
| 4 | D.C.: Transport to PC |
| 5 | D.C.:Return Product to Distribution Centre PC |
| 6 | D.C.:Repackage Product Distr |
| 7 | D.C.:Deliver Repackaged Product |
| 8 | PC: Quality Control |
| 9 | PC: Products Fail Quality Control |
| 10 | PC: Error Transmit to SCEDRA |
| 11 | PC: Pallet Identification |
| 12 | PC: Placing Pallet |
| 13 | PC: Order received and evaluated |
| 14 | PE: Order received and evaluated |
| 15 | PF: Submit order |
| 16 | PF: Notification Transmitted |
| 17 | PF: RFQ PF from PE |
| 18 | PF: Notification for re-delivery to PC |



### D.1.2.1 Scenario – Redesigned Process Baseline & Actual Times

| ID | Task Name | Duration | Actual Start | Actual Finish | Baseline Start | Baseline Finish | Predecesso |
|---|---|---|---|---|---|---|---|
| 1 | PD: Receive and Evaluate Order Product | 2 hrs | Tue 30/05/06 | Tue 30/05/06 | Tue 30/05/06 | Tue 30/05/06 | |
| 2 | PD: Fulfill Order | 2 days | Tue 30/05/06 | Wed 31/05/06 | Tue 30/05/06 | Thu 01/06/06 | |
| 3 | PD: Transport to D.C. | 9 days | Wed 31/05/06 | Tue 13/06/06 | Thu 01/06/06 | Fri 16/06/06 | |
| 4 | D.C.: Transport to PC | 2 days | NA | NA | NA | NA | |
| 5 | D.C.:Return Product to Distribution Centre PC | 2 days | Thu 15/06/06 | Mon 19/06/06 | NA | NA | 10 |
| 6 | D.C.:Repackage Product Distr. | 1 hr | Mon 19/06/06 | Mon 19/06/06 | NA | NA | |
| 7 | D.C.:Deliver Repackaged Product | 2 days | Mon 19/06/06 | Tue 20/06/06 | NA | NA | |
| 8 | PC: Quality Control | 20 mins | Thu 15/06/06 | Thu 15/06/06 | Fri 16/06/06 | Fri 16/06/06 | |
| 9 | PC: Products Fail Quality Control | 0 days | NA | NA | NA | NA | |
| 10 | PC: Error Transmit to SCEDRA | 1 day? | NA | NA | NA | NA | 9 |
| 11 | PC: Pallet Identification | 20 mins | Tue 20/06/06 | Tue 20/06/06 | Fri 16/06/06 | Fri 16/06/06 | |
| 12 | PC: Placing Pallet | 10 mins | Tue 20/06/06 | Tue 20/06/06 | Fri 16/06/06 | Fri 16/06/06 | |
| 13 | PC: Order received and evaluated | 1 hr | NA | NA | Wed 14/06/06 | Wed 14/06/06 | 15 |
| 14 | PE: Order received and evaluated | 20 mins | NA | NA | NA | NA | 17 |
| 15 | PF: Submit order | 20 mins | NA | NA | Wed 14/06/06 | Wed 14/06/06 | |
| 16 | PF: Notification Transmitted | 1 min | NA | NA | NA | NA | 10 |
| 17 | PF: RFQ PF from PE | 20 mins | Fri 16/06/06 | Fri 16/06/06 | NA | NA | 16 |
| 18 | PF: Notification for re-delivery to PC | 15 mins | NA | NA | NA | NA | 17 |

## D.2.1 Scenario 2– Initial Process Model



| | | | |
|---|---|---|---|
| 32 | Order Fullfiment (PC) | 07/08 | 08/08 |
| 33 | **PC: Order Exit and deliver to PK** | | |
| 34 | Locating Pallets to exit (PC) | 08/08 | 08/08 |
| 35 | Exit Pallet (PC) | 08/08 | 08/08 |
| 36 | Order Doc. Issued (PC) | 08/08 | 08/08 |
| 37 | Load Pallet (PC) | 08/08 | 08/08 |
| 38 | Order delivered (PC) | 08/08 | 08/08 |
| 39 | PC: Order received and evaluated PH | 07/08 | 07/08 |
| 40 | **PC: Order release and process** | | |
| 41 | Load packaging machine (PC) | 08/08 | 08/08 |
| 42 | Issue pallet exit paper (PC) | 08/08 | 08/08 |
| 43 | Product packaged (PC) | 08/08 | 08/08 |
| 44 | Pallet weighted (PC) | 08/08 | 08/08 |
| 45 | Placing ready product pallet (PC) | 08/08 | 08/08 |
| 46 | Order Fullfiment (PC) | 08/08 | 09/08 |
| 47 | **PC: Order Exit** | | |
| 48 | Locating Pallets to exit (PC) | 09/08 | 09/08 |
| 49 | Exit Pallet (PC) | 09/08 | 09/08 |
| 50 | Order Doc. Issued (PC) | 09/08 | 09/08 |
| 51 | Load Pallet (PC) | 09/08 | 09/08 |
| 52 | Order delivered (PC) | 09/08 | 09/08 |
| 53 | **PC: Order release and process->PD** | | |
| 54 | Load packaging machine (PC) | 09/08 | 09/08 |
| 55 | Issue pallet exit paper (PC) | 09/08 | 09/08 |
| 56 | Product packaged (PC) | 09/08 | 09/08 |
| 57 | Pallet weighted (PC) | 09/08 | 09/08 |
| 58 | Placing ready product pallet (PC) | 09/08 | 09/08 |
| 59 | Order Fullfiment (PC) | 09/08 | 10/08 |
| 60 | **PC: Order Exit->PD** | | |
| 61 | Locating Pallets to exit (PC) | 10/08 | 10/08 |
| 62 | Exit Pallet (PC) | 10/08 | 10/08 |

| | | | |
|---|---|---|---|
| 63 | Order Doc. Issued (PC) | 10/08 | 10/08 |
| 64 | Load Pallet (PC) | 10/08 | 10/08 |
| 65 | Order delivered (PC) | 10/08 | 10/08 |
| 66 | **PC: Order release and process->PE** | | |
| 67 | Load packaging machine (PC) | 10/08 | 10/08 |
| 68 | Issue pallet exit paper (PC) | 10/08 | 10/08 |
| 69 | Product packaged (PC) | 10/08 | 10/08 |
| 70 | Pallet weighted (PC) | 10/08 | 10/08 |
| 71 | Placing ready product pallet (PC) | 10/08 | 10/08 |
| 72 | Order Fullfiment (PC) | 10/08 | 11/08 |
| 73 | **PC: Order Exit->PE** | | |
| 74 | Locating Pallets to exit (PC) | 11/08 | 11/08 |
| 75 | Exit Pallet (PC) | 11/08 | 11/08 |
| 76 | Order Doc. Issued (PC) | 11/08 | 11/08 |
| 77 | Load Pallet (PC) | 11/08 | 11/08 |
| 78 | Order delivered (PC) | 11/08 | 11/08 |
| 79 | **PC: Order release and process->PF** | | |
| 80 | Load packaging machine (PC) | 10/08 | 10/08 |
| 81 | Issue pallet exit paper (PC) | 10/08 | 10/08 |
| 82 | Product packaged (PC) | 10/08 | 10/08 |
| 83 | Pallet weighted (PC) | 10/08 | 10/08 |
| 84 | Placing ready product pallet (PC) | 10/08 | 10/08 |
| 85 | Order Fullfiment (PC) | 10/08 | 11/08 |
| 86 | **PC: Order Exit->PF** | | |
| 87 | Locating Pallets to exit (PC) | 11/08 | 11/08 |
| 88 | Exit Pallet (PC) | 11/08 | 11/08 |
| 89 | Order Doc. Issued (PC) | 11/08 | 11/08 |
| 90 | Load Pallet (PC) | 11/08 | 11/08 |
| 91 | Order delivered (PC) | 11/08 | 11/08 |

## D.2.1.2 Scenario 2– Initial Process Baseline & Actual Times

| ID | Task Name | Duration | Actual Start | Actual Finish | Baseline Start | Baseline Finish | Predecessors |
|---|---|---|---|---|---|---|---|
| 1 | PA:Receive and evaluate order | 1 hr | Fri 02/06/06 | Fri 02/06/06 | Fri 02/06/06 | Fri 02/06/06 | |
| 2 | PA: First Material Anavailable | 0 days | NA | NA | NA | NA | |
| 3 | PA: Process Order | 40 days | Fri 02/06/06 | Fri 28/07/06 | Fri 02/06/06 | Fri 14/07/06 | |
| 4 | PA: Deliver order | 9 days | Mon 17/07/06 | Mon 07/08/06 | Fri 14/07/06 | Tue 25/07/06 | |
| 5 | Prediction on Dry Weather Forecast | 0 days | Sun 06/08/06 | NA | NA | NA | |
| 6 | **Receive and evaluate order (PB-PC)** | **13.14 days** | **Fri 02/06/06** | **Wed 21/06/06** | **Fri 02/06/06** | **Wed 21/06/06** | **19** |
| 7 | Fulfill order (PB) | 2 days | Fri 02/06/06 | Mon 05/06/06 | Fri 02/06/06 | Mon 05/06/06 | |
| 8 | Transport (PB) | 11 days | Tue 06/06/06 | Tue 20/06/06 | Tue 06/06/06 | Tue 20/06/06 | 7 |
| 9 | Quality Control (PC) | 20 mins | Wed 21/06/06 | Wed 21/06/06 | Wed 21/06/06 | Wed 21/06/06 | 8 |
| 10 | Placing Semi - Ready in Pallet (PC) | 20 mins | Wed 21/06/06 | Wed 21/06/06 | Wed 21/06/06 | Wed 21/06/06 | 9 |
| 11 | Pallet Identification (PC) | 10 mins | Wed 21/06/06 | Wed 21/06/06 | Wed 21/06/06 | Wed 21/06/06 | 10 |
| 12 | Placing Pallet (PC) | 15 mins | Wed 21/06/06 | Wed 21/06/06 | Wed 21/06/06 | Wed 21/06/06 | 11 |
| 13 | PD: Submit order | 15 mins | Mon 24/07/06 | Mon 24/07/06 | Mon 24/07/06 | Mon 24/07/06 | |
| 14 | PD: Delayed delivery notification from PC | 1 min | Mon 24/07/06 | Mon 24/07/06 | NA | NA | |
| 15 | PE: Submit order | 15 mins | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | |
| 16 | PE: Delayed delivery notification from PC | 1 min | Tue 25/07/06 | Tue 25/07/06 | NA | NA | |
| 17 | PF: Submit order | 15 mins | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | |
| 18 | PF: Delayed delivery notification from PC | 1 min | Tue 25/07/06 | Tue 25/07/06 | NA | NA | |
| 19 | PB: Submit order | 15 mins | Fri 02/06/06 | Fri 02/06/06 | Fri 02/06/06 | Fri 02/06/06 | |
| 20 | PK: Submit order | 15 mins | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 5 |
| 21 | PH: Submit order | 15 mins | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 5 |
| 22 | PC:Order received and evaluated from PD | 1 hr | Mon 24/07/06 | Mon 24/07/06 | Mon 24/07/06 | Mon 24/07/06 | 13 |
| 23 | PC:Order received and evaluated from PE | 1 hr | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | 15 |
| 24 | PC:Order received and evaluated from PF | 1 hr | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | 17 |
| 25 | PC:Order received and evaluated from PK | 1 hr | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 20 |
| 26 | **PC:Order release and process** | **1.14 days** | **Mon 07/08/06** | **Tue 08/08/06** | **NA** | **NA** | **25** |
| 27 | Issue pallet exit paper (PC) | 10 mins | Mon 07/08/06 | Mon 07/08/06 | NA | NA | |
| 28 | Load packaging machine (PC) | 10 mins | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 27 |
| 29 | Product packaged (PC) | 15 mins | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 28 |
| 30 | Pallet weighted (PC) | 15 mins | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 29 |
| 31 | Placing ready product pallet (PC) | 15 mins | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 30 |

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| ID | Task Name | Duration | Actual Start | Actual Finish | Baseline Start | Baseline Finish | Predecessors |
|---|---|---|---|---|---|---|---|
| 32 | Order Fullfilment (PC) | 1 day | Mon 07/08/06 | Tue 08/08/06 | NA | NA | 31 |
| 33 | **PC: Order Exit and deliver to PK** | **0.43 days** | **Tue 08/08/06** | **Tue 08/08/06** | **NA** | **NA** | |
| 34 | Locating Pallets to exit (PC) | 20 mins | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 32 |
| 35 | Exit Pallet (PC) | 15 mins | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 34 |
| 36 | Order Doc. Issued (PC) | 30 mins | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 35 |
| 37 | Load Pallet (PC) | 20 mins | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 36 |
| 38 | Order delivered (PC) | 2 hrs | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 37 |
| 39 | PC: Order received and evaluated PH | 1 hr | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 21 |
| 40 | **PC: Order release and process** | **1.14 days** | **Tue 08/08/06** | **Wed 09/08/06** | **NA** | **NA** | |
| 41 | Load packaging machine (PC) | 10 mins | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 39 |
| 42 | Issue pallet exit paper (PC) | 10 mins | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 41 |
| 43 | Product packaged (PC) | 15 mins | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 42 |
| 44 | Pallet weighted (PC) | 15 mins | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 43 |
| 45 | Placing ready product pallet (PC) | 15 mins | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 44 |
| 46 | Order Fullfilment (PC) | 1 day | Tue 08/08/06 | Wed 09/08/06 | NA | NA | 45 |
| 47 | **PC: Order Exit** | **0.43 days** | **Wed 09/08/06** | **Wed 09/08/06** | **NA** | **NA** | |
| 48 | Locating Pallets to exit (PC) | 20 mins | Wed 09/08/06 | Wed 09/08/06 | NA | NA | 46 |
| 49 | Exit Pallet (PC) | 15 mins | Wed 09/08/06 | Wed 09/08/06 | NA | NA | 48 |
| 50 | Order Doc. Issued (PC) | 30 mins | Wed 09/08/06 | Wed 09/08/06 | NA | NA | 49 |
| 51 | Load Pallet (PC) | 20 mins | Wed 09/08/06 | Wed 09/08/06 | NA | NA | 50 |
| 52 | Order delivered (PC) | 2 hrs | Wed 09/08/06 | Wed 09/08/06 | NA | NA | 51 |
| 53 | **PC: Order release and process->PD** | **2 days** | **Wed 09/08/06** | **Thu 10/08/06** | **NA** | **NA** | **47,4** |
| 54 | Load packaging machine (PC) | 10 mins | Wed 09/08/06 | Wed 09/08/06 | NA | NA | |
| 55 | Issue pallet exit paper (PC) | 10 mins | Wed 09/08/06 | Wed 09/08/06 | NA | NA | 54 |
| 56 | Product packaged (PC) | 15 mins | Wed 09/08/06 | Wed 09/08/06 | NA | NA | 55 |
| 57 | Pallet weighted (PC) | 15 mins | Wed 09/08/06 | Wed 09/08/06 | NA | NA | 56 |
| 58 | Placing ready product pallet (PC) | 15 mins | Wed 09/08/06 | Wed 09/08/06 | NA | NA | 57 |
| 59 | Order Fullfilment (PC) | 2 days | Wed 09/08/06 | Thu 10/08/06 | NA | NA | 58 |
| 60 | **PC: Order Exit->PD** | **0.25 days** | **Thu 10/08/06** | **Thu 10/08/06** | **NA** | **NA** | |
| 61 | Locating Pallets to exit (PC) | 20 mins | Thu 10/08/06 | Thu 10/08/06 | NA | NA | 59 |
| 62 | Exit Pallet (PC) | 15 mins | Thu 10/08/06 | Thu 10/08/06 | NA | NA | 61 |

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| ID | Task Name | Duration | Actual Start | Actual Finish | Baseline Start | Baseline Finish | Predecessors |
|---|---|---|---|---|---|---|---|
| 63 | Order Doc. Issued (PC) | 30 mins | Thu 10/08/06 | Thu 10/08/06 | NA | NA | 62 |
| 64 | Load Pallet (PC) | 20 mins | Thu 10/08/06 | Thu 10/08/06 | NA | NA | 63 |
| 65 | Order delivered (PC) | 2 hrs | Thu 10/08/06 | Thu 10/08/06 | NA | NA | 64 |
| 66 | **PC: Order release and process->PE** | **2 days** | **Thu 10/08/06** | **Fri 11/08/06** | **NA** | **NA** | |
| 67 | Load packaging machine (PC) | 10 mins | Thu 10/08/06 | Thu 10/08/06 | NA | NA | |
| 68 | Issue pallet exit paper (PC) | 10 mins | Thu 10/08/06 | Thu 10/08/06 | NA | NA | 67 |
| 69 | Product packaged (PC) | 15 mins | Thu 10/08/06 | Thu 10/08/06 | NA | NA | 68 |
| 70 | Pallet weighted (PC) | 15 mins | Thu 10/08/06 | Thu 10/08/06 | NA | NA | 69 |
| 71 | Placing ready product pallet (PC) | 15 mins | Thu 10/08/06 | Thu 10/08/06 | NA | NA | 70 |
| 72 | Order Fulfilment (PC) | 2 days | Thu 10/08/06 | Fri 11/08/06 | NA | NA | 71 |
| 73 | **PC: Order Exit->PE** | **0.25 days** | **Fri 11/08/06** | **Fri 11/08/06** | **NA** | **NA** | |
| 74 | Locating Pallets to exit (PC) | 20 mins | Fri 11/08/06 | Fri 11/08/06 | NA | NA | 72 |
| 75 | Exit Pallet (PC) | 15 mins | Fri 11/08/06 | Fri 11/08/06 | NA | NA | 74 |
| 76 | Order Doc. Issued (PC) | 30 mins | Fri 11/08/06 | Fri 11/08/06 | NA | NA | 75 |
| 77 | Load Pallet (PC) | 20 mins | Fri 11/08/06 | Fri 11/08/06 | NA | NA | 76 |
| 78 | Order delivered (PC) | 2 hrs | Fri 11/08/06 | Fri 11/08/06 | NA | NA | 77 |
| 79 | **PC: Order release and process->PF** | **2 days** | **Thu 10/08/06** | **Fri 11/08/06** | **NA** | **NA** | |
| 80 | Load packaging machine (PC) | 10 mins | Thu 10/08/06 | Thu 10/08/06 | NA | NA | |
| 81 | Issue pallet exit paper (PC) | 10 mins | Thu 10/08/06 | Thu 10/08/06 | NA | NA | 80 |
| 82 | Product packaged (PC) | 15 mins | Thu 10/08/06 | Thu 10/08/06 | NA | NA | 81 |
| 83 | Pallet weighted (PC) | 15 mins | Thu 10/08/06 | Thu 10/08/06 | NA | NA | 82 |
| 84 | Placing ready product pallet (PC) | 15 mins | Thu 10/08/06 | Thu 10/08/06 | NA | NA | 83 |
| 85 | Order Fulfilment (PC) | 2 days | Thu 10/08/06 | Fri 11/08/06 | NA | NA | 84 |
| 86 | **PC: Order Exit->PF** | **0.25 days** | **Fri 11/08/06** | **Fri 11/08/06** | **NA** | **NA** | |
| 87 | Locating Pallets to exit (PC) | 20 mins | Fri 11/08/06 | Fri 11/08/06 | NA | NA | 85 |
| 88 | Exit Pallet (PC) | 15 mins | Fri 11/08/06 | Fri 11/08/06 | NA | NA | 87 |
| 89 | Order Doc. Issued (PC) | 30 mins | Fri 11/08/06 | Fri 11/08/06 | NA | NA | 88 |
| 90 | Load Pallet (PC) | 20 mins | Fri 11/08/06 | Fri 11/08/06 | NA | NA | 89 |
| 91 | Order delivered (PC) | 2 hrs | Fri 11/08/06 | Fri 11/08/06 | NA | NA | 90 |

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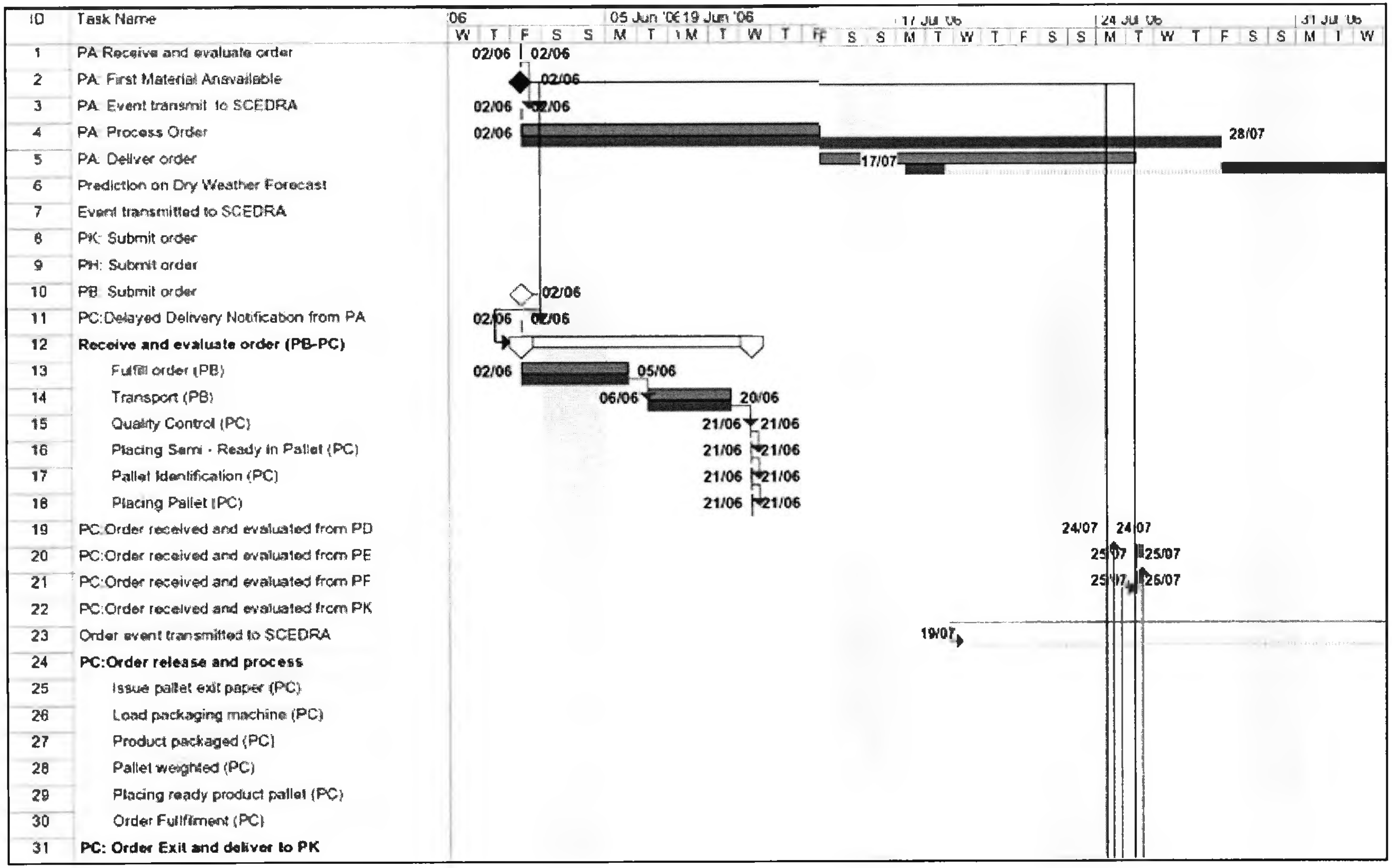
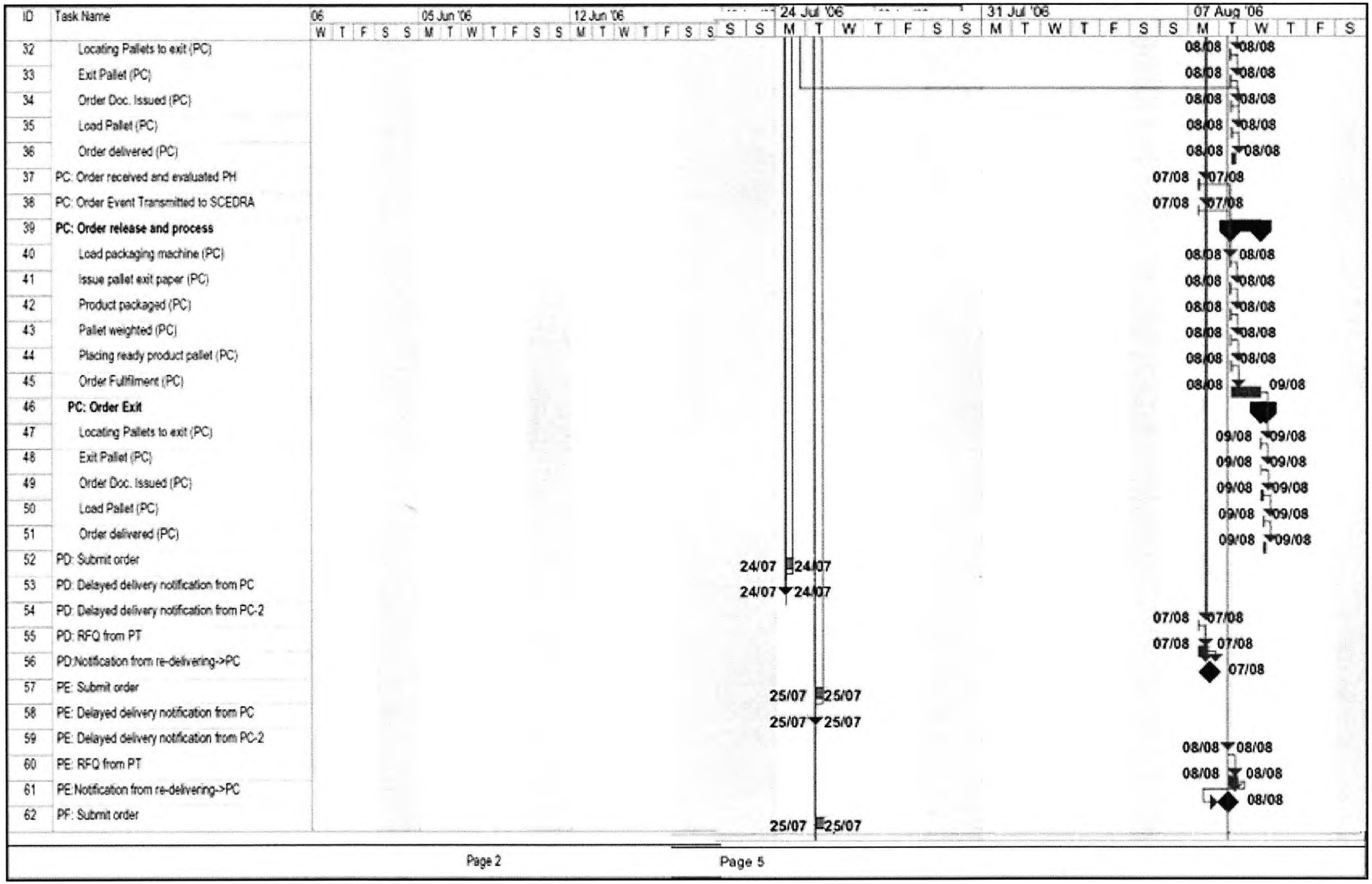
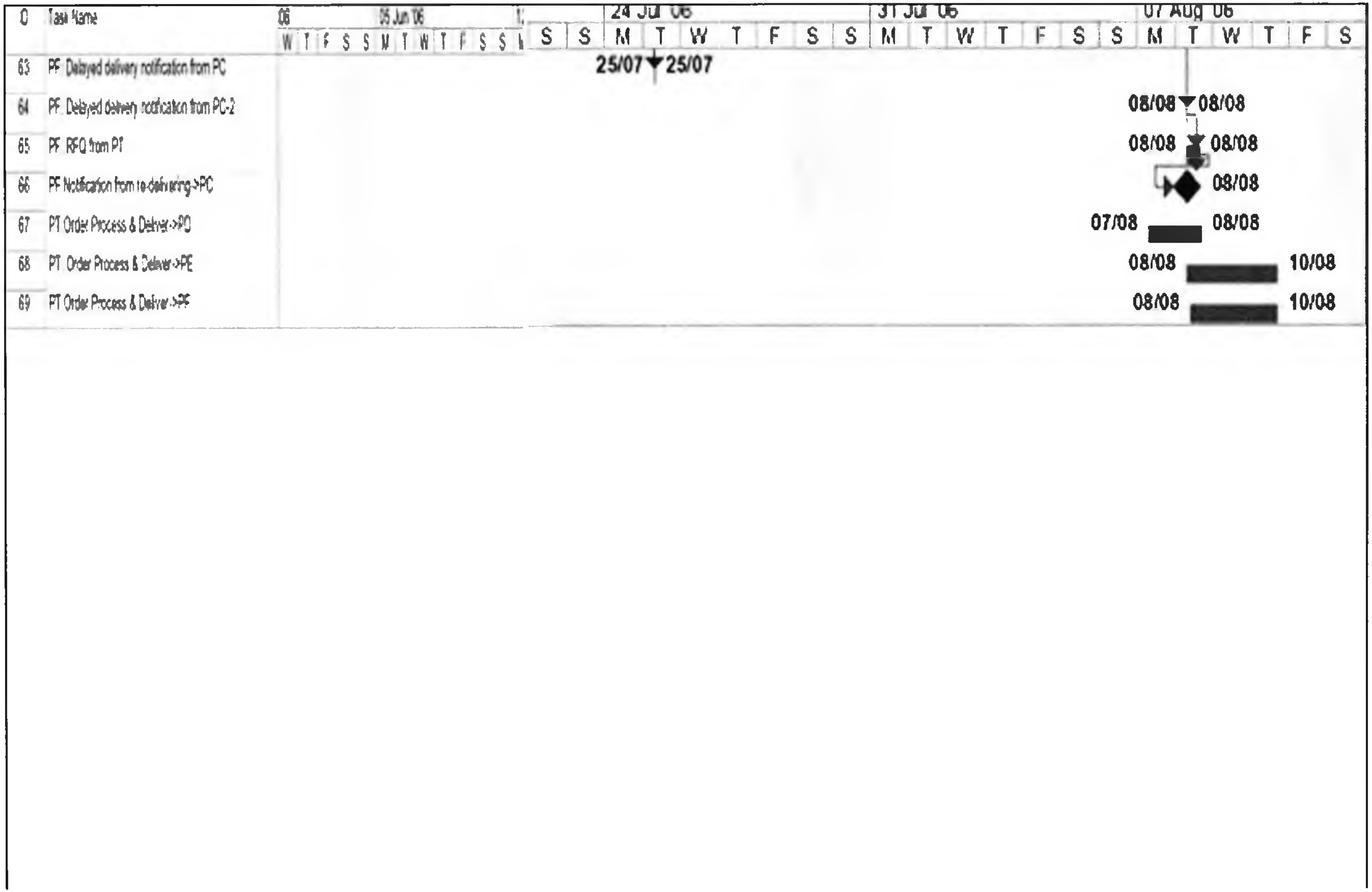
### D.2.2 Scenario 2– Redesigned Process Model




ID
Task Name
05 Jun '06
12 Jun '06
24 Jul '06
31 Jul '06
07 Aug '06
32 Locating Pallets to exit (PC) 08/08 08/08
33 Exit Pallet (PC) 08/08 08/08
34 Order Doc. Issued (PC) 08/08 08/08
35 Load Pallet (PC) 08/08 08/08
36 Order delivered (PC) 08/08 08/08
37 PC: Order received and evaluated PH 07/08 07/08
38 PC: Order Event Transmitted to SCEDRA 07/08 07/08
39 PC: Order release and process
40 Load packaging machine (PC) 08/08 08/08
41 Issue pallet exit paper (PC) 08/08 08/08
42 Product packaged (PC) 08/08 08/08
43 Pallet weighted (PC) 08/08 08/08
44 Placing ready product pallet (PC) 08/08 08/08
45 Order Fulfilment (PC) 08/08 09/08
46 PC: Order Exit
47 Locating Pallets to exit (PC) 09/08 09/08
48 Exit Pallet (PC) 09/08 09/08
49 Order Doc. Issued (PC) 09/08 09/08
50 Load Pallet (PC) 09/08 09/08
51 Order delivered (PC) 09/08 09/08
52 PD: Submit order 24/07 24/07
53 PD: Delayed delivery notification from PC 24/07 24/07
54 PD: Delayed delivery notification from PC-2
55 PD: RFQ from PT 07/08 07/08
56 PD:Notification from re-delivering->PC 07/08 07/08
57 PE: Submit order 07/08
58 PE: Delayed delivery notification from PC 25/07 25/07
59 PE: Delayed delivery notification from PC-2 25/07 25/07
60 PE: RFQ from PT 08/08 08/08
61 PE:Notification from re-delivering->PC 08/08 08/08
62 PF: Submit order 08/08
25/07 25/07
Page 2
Page 5



Task Name
24 Jul 06
31 Jul 06
07 Aug 06
S S M T W T F S S M T W T F S S M T W T F S
63 PF Delayed delivery notification from PC
64 PF Delayed delivery notification from PC-2
65 PF RFQ from PT
66 PF Notification from re-delivering->PC
67 PT Order Process & Deliver->PC
68 PT Order Process & Deliver->PE
69 PT Order Process & Deliver->PF
25/07 25/07
08/08 08/08
08/08 08/08
08/08
07/08 08/08
08/08 10/08
08/08 10/08

## D.2.2.1 Scenario 2– Redesigned Process Baseline & Actual Times

| ID | Task Name | Duration | Actual Start | Actual Finish | Baseline Start | Baseline Finish | Predecessors |
|---|---|---|---|---|---|---|---|
| 1 | PA Receive and evaluate order | 1 hr | Fri 02/06/06 | Fri 02/06/06 | Fri 02/06/06 | Fri 02/06/06 | |
| 2 | PA First Material Anavailable | 0 days | NA | NA | NA | NA | |
| 3 | PA Event transmit to SCEDRA | 1 min | NA | NA | NA | NA | 1,2 |
| 4 | PA Process Order | 40 days | Fri 02/06/06 | Fri 28/07/06 | Fri 02/06/06 | Fri 14/07/06 | |
| 5 | PA Deliver order | 9 days | Mon 17/07/06 | Mon 07/08/06 | Fri 14/07/06 | Tue 25/07/06 | |
| 6 | Prediction on Dry Weather Forecast | 0 days | Sun 06/08/06 | NA | NA | NA | |
| 7 | Event transmitted to SCEDRA | 0 days | Sun 06/08/06 | NA | NA | NA | 6 |
| 8 | PK Submit order | 15 mins | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 7 |
| 9 | PH: Submit order | 15 mins | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 7 |
| 10 | PB Submit order | 15 mins | Fri 02/06/06 | Fri 02/06/06 | Fri 02/06/06 | Fri 02/06/06 | |
| 11 | PC:Delayed Delivery Notification from PA | 1 min | Fri 02/06/06 | Fri 02/06/06 | NA | NA | 2 |
| **12** | **Receive and evaluate order (PB-PC)** | **13.14 days** | **Fri 02/06/06** | **Wed 21/06/06** | **Fri 02/06/06** | **Wed 21/06/06** | **10** |
| 19 | PC:Order received and evaluated from PD | 1 hr | Mon 24/07/06 | Mon 24/07/06 | Mon 24/07/06 | Mon 24/07/06 | 52 |
| 20 | PC:Order received and evaluated from PE | 1 hr | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | 57 |
| 21 | PC:Order received and evaluated from PF | 1 hr | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | 34 |
| 22 | PC:Order received and evaluated from PK | 1 hr | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 8 |
| 23 | Order event transmitted to SCEDRA | 1 min | Wed 19/07/06 | Mon 07/08/06 | NA | NA | 22 |
| **24** | **PC:Order release and process** | **1.14 days** | **Mon 07/08/06** | **Tue 08/08/06** | **NA** | **NA** | **22** |
| **31** | **PC: Order Exit and deliver to PK** | **0.43 days** | **Tue 08/08/06** | **Tue 08/08/06** | **NA** | **NA** | |
| 37 | PC: Order received and evaluated PH | 1 hr | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 9 |
| 38 | PC: Order Event Transmitted to SCEDRA | 1 min | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 37 |
| **39** | **PC: Order release and process** | **1.14 days** | **Tue 08/08/06** | **Wed 09/08/06** | **NA** | **NA** | |
| **46** | **PC: Order Exit** | **0.43 days** | **Wed 09/08/06** | **Wed 09/08/06** | **NA** | **NA** | |
| 52 | PD: Submit order | 15 mins | Mon 24/07/06 | Mon 24/07/06 | Mon 24/07/06 | Mon 24/07/06 | |
| 53 | PD: Delayed delivery notification from PC | 1 min | Mon 24/07/06 | Mon 24/07/06 | NA | NA | 2 |
| 54 | PD: Delayed delivery notification from PC-2 | 1 min | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 23,38,5 |
| 55 | PD: RFQ from PT | 0.88 days? | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 54 |
| 56 | PD:Notification from re-delivering->PC | 0 mins | Mon 07/08/06 | Mon 07/08/06 | NA | NA | 54,55 |
| 57 | PE Submit order | 15 mins | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | |
| 58 | PE Delayed delivery notification from PC | 1 min | Tue 25/07/06 | Tue 25/07/06 | NA | NA | 2 |
| 59 | PE Delayed delivery notification from PC-2 | 1 min | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 23,38,5 |
| 60 | PE RFQ from PT | 0.88 days? | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 59 |
| 61 | PE.Notification from re-delivering->PC | 0 mins | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 59,60 |
| 62 | PF: Submit order | 15 mins | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | Tue 25/07/06 | |
| 63 | PF: Delayed delivery notification from PC | 1 min | Tue 25/07/06 | Tue 25/07/06 | NA | NA | 2 |
| 64 | PF: Delayed delivery notification from PC-2 | 1 min | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 23,38,5 |
| 65 | PF: RFQ from PT | 0.88 days? | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 64 |
| 66 | PF:Notification from re-delivering->PC | 0 mins | Tue 08/08/06 | Tue 08/08/06 | NA | NA | 64,65 |
| 67 | PT:Order Process & Deliver->PD | 2 days? | Mon 07/08/06 | Tue 08/08/06 | NA | NA | |
| 68 | PT: Order Process & Deliver->PE | 3 days? | Tue 08/08/06 | Thu 10/08/06 | NA | NA | |
| 69 | PT:Order Process & Deliver->PF | 2.69 days? | Tue 08/08/06 | Thu 10/08/06 | NA | NA | |

## E. Supply Chain Elements examples

Supply Chain Elements contain information that is exchanged between partners. The examples below describe the original sources of this information through transactional documents and ERP inputs/outputs. The documents illustrated below were taken during the interviews in order to provide a better understanding of the information communicated inside a company and between partners.


Figure E.1: Palet Identification Label - A'

Figures E.1 above and E.2 below, illustrate the identifier that is placed on pallets when they enter the warehouse. The bar codes indicate the position and location inside the warehouse and the type of product that is stored. In SCEDRA, this information is partially exposed to assist the vendor managed inventories paradigm that increases partner flexibility.


Figure E.2: Palet Identification Label - B'

Figures E.3 and E.4 illustrate screenshots of the warehouse system used and they are the output of the initial pallet processing.

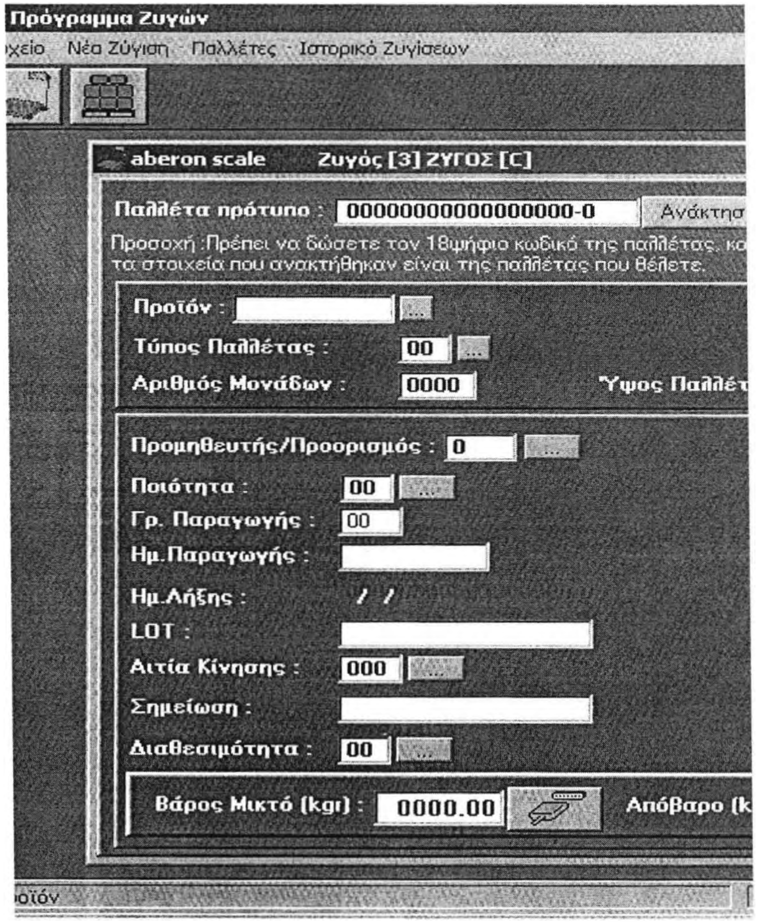



*Figure E.3: Warehouse System Screenshot – A'*

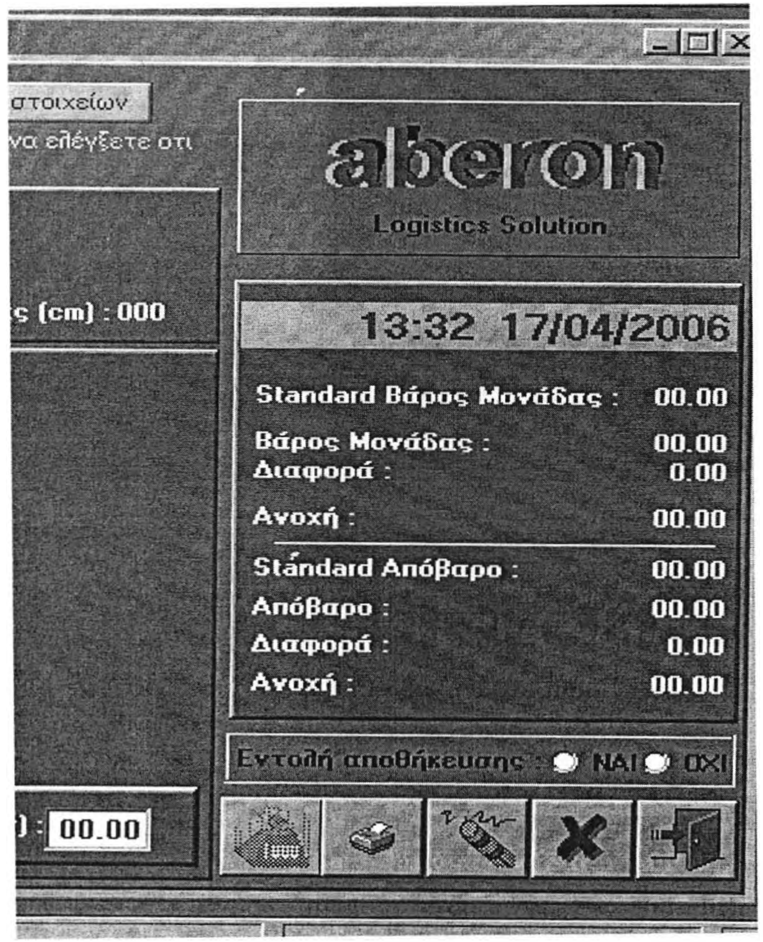



*Figure E.4: Warehouse System Screenshot – B'*

Figure E.5 is a collection list that contains information about the orders received from a customer and need to be retrieved from the warehouse.

**Λίστα Συλλονής Μονάδων Εξανωνής**

17/04/2006 14:27

Εξαγωγή/Παραγγελία : ΚΑΡΦΟΥΡ    Ημ.Καταχώρησης : 17/04/2006

Δρομολόγιο :

Σχόλια : ΔΡΥΜΟΣ, ΠΑΡΑΔ. 18/4, ΟΚ

Προς Αποθηκη : 00

Ζώνη Προετοιμασίας :90 ΠΡΟΕΤ.ΕΞΑΓ.

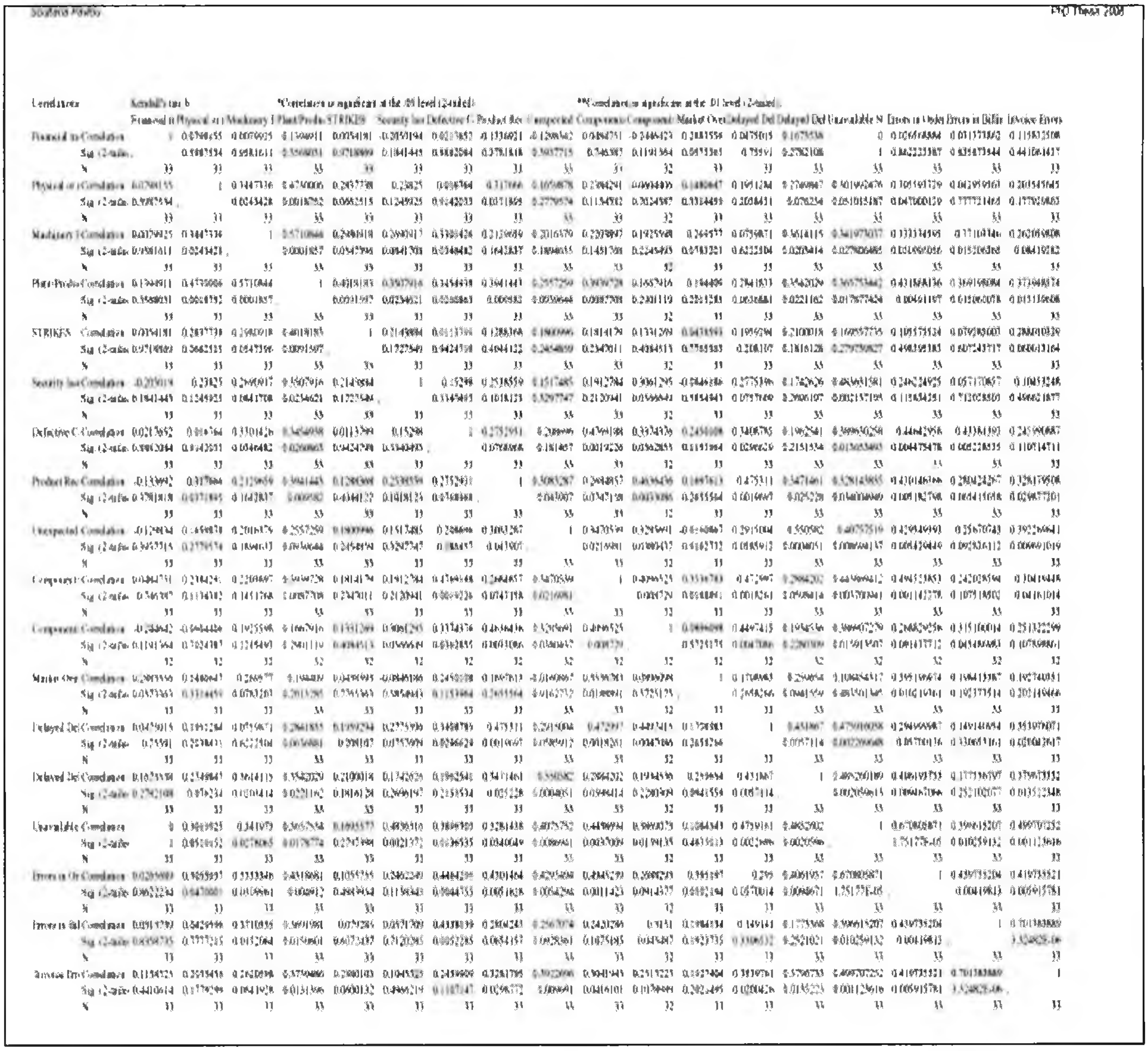
0000123556

| | | Κιβώτια | Συλλεγ. | Τεμάχια | Θ.Βάρος(kgr) | Παλλέτες | |
|---|---|---|---|---|---|---|---|
| 19-01-001-0 | 1001226 ΑΡΑΚ.24x450g | 0 | 0 | 0 | 0.00 | 1 | ΜΠ-ΣΤ |
| 19-01-003-0 | 1001228 ΑΡΑΚ.10x1000g | 0 | 0 | 0 | 0.00 | 2 | ΜΠ-ΣΤ |
| 19-01-005-0 | 1003224 ΜΠΑΜ.ΕΧΤ.20x450g | 0 | 0 | 0 | 0.00 | 1 | ΜΠ-ΣΤ |
| 19-01-007-0 | 1003229 ΜΠΑΜ.Ν1 10x1000g | 0 | 0 | 0 | 0.00 | 1 | ΜΠ-ΣΤ |
| 19-01-009-0 | 1007208 ΦΑΣ.ΠΛ1000g | 0 | 0 | 0 | 0.00 | 1 | ΜΠ-ΣΤ |
| 19-01-011-0 | 1009228 ΦΑΣ.ΣΤΡ.10x1000 | 0 | 0 | 0 | 0.00 | 1 | ΜΠ-ΣΤ |
| 19-01-013-0 | 1020202 ΣΠΑΝ.Φ.ΜΕΡ1000g | 0 | 0 | 0 | 0.00 | 1 | ΜΠ-ΣΤ |
| 19-01-002-0 | 1003220 ΜΠΑΜ.ΑΝΘ.ΕΧΤ.FIN 16x400g | 0 | 0 | 0 | 0.00 | 1 | ΜΠ-ΣΤ |
| Σύνολα : | | 0 | 0 | 0 | 0.00 | 9 | |

Figure E.5: Collection List

# F. Kendal Tau Correlation Results

Table F.1: Correlation Results


Soultana Pavlou PhD Thesis 2006

Correlations Kendall's tau_b *Correlation is significant at the .05 level (2-tailed). **Correlation is significant at the .01 level (2-tailed).

| | | Financial n | Physical ar | Machinery I | Plant/Produ | STRIKES | Security Iss | Defective C | Product Rec | Unexpected | Component | Component | Market Ove | Delayed Del | Delayed Del | Unavailable N | Errors in Order | Errors in Billin | Invoice Errors |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Financial n | Correlation | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Sig. (2-tailed) | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Physical ar | Correlation | [illegible] | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Sig. (2-tailed) | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Machinery I | Correlation | [illegible] | [illegible] | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Sig. (2-tailed) | [illegible] | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Plant/Produ | Correlation | [illegible] | [illegible] | [illegible] | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Sig. (2-tailed) | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| STRIKES | Correlation | [illegible] | [illegible] | [illegible] | [illegible] | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Sig. (2-tailed) | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Security Iss | Correlation | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Sig. (2-tailed) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Defective C | Correlation | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Sig. (2-tailed) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Product Rec | Correlation | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Sig. (2-tailed) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Unexpected | Correlation | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Sig. (2-tailed) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Component | Correlation | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Sig. (2-tailed) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Component | Correlation | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Sig. (2-tailed) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Market Ove | Correlation | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Sig. (2-tailed) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Delayed Del | Correlation | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | Sig. (2-tailed) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Delayed Del | Correlation | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1 | [illegible] | [illegible] | [illegible] | [illegible] |
| | Sig. (2-tailed) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Unavailable | Correlation | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1 | [illegible] | [illegible] | [illegible] |
| | Sig. (2-tailed) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Errors in Or | Correlation | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1 | [illegible] | [illegible] |
| | Sig. (2-tailed) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Errors in Bil | Correlation | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1 | [illegible] |
| | Sig. (2-tailed) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Invoice Err | Correlation | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1 |
| | Sig. (2-tailed) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | |
| | N | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

## G. Questionnaire Events Percentage

Table G.1: Unexpected Events Percentage

| | 1 | 2 | 3 | 4 | sum |
|---|---|---|---|---|---|
| Financial market turbulence | 0.67% | 2.02% | 1.85% | 1.01% | 5.56% |
| Physical or manmade Disasters | 1.01% | 2.69% | 1.18% | 0.67% | 5.56% |
| Machinery Failure | 0.51% | 1.68% | 2.53% | 0.84% | 5.56% |
| Plant/Production Unit Failure | 0.67% | 1.35% | 2.53% | 1.01% | 5.56% |
| Strikes | 2.19% | 2.36% | 0.51% | 0.51% | 5.56% |
| Security Issues | 1.52% | 2.36% | 1.68% | 0.00% | 5.56% |
| Defective Components | 0.00% | 2.02% | 2.36% | 1.18% | 5.56% |
| Product Recall | 1.01% | 1.85% | 2.19% | 0.51% | 5.56% |
| Unexpected Product Return | 0.84% | 2.36% | 1.85% | 0.51% | 5.56% |
| Components Reaching EOL | 1.18% | 2.02% | 1.01% | 1.35% | 5.56% |
| Components Fail Quality Control | 0.67% | 2.19% | 2.36% | 0.34% | 5.56% |
| Market Oversupply: | 0.51% | 1.85% | 2.19% | 1.01% | 5.56% |
| Delayed Deliveries from Supplier | 0.17% | 1.68% | 2.02% | 1.68% | 5.56% |
| Delayed Deliveries to Customer | 0.17% | 1.18% | 3.03% | 1.18% | 5.56% |
| Unavailable Stock | 0.17% | 1.35% | 2.86% | 1.18% | 5.56% |
| Errors in Orders | 0.17% | 2.19% | 1.85% | 1.35% | 5.56% |
| Errors in Billing/Delivery Information | 0.67% | 1.85% | 2.19% | 0.84% | 5.56% |
| Invoice Errors | 1.18% | 2.19% | 1.35% | 0.84% | 5.56% |
| sum | 13.30% | 35.19% | 35.52% | 15.99% | 100.00% |