Whitestein Series in Software Agent Technologies

This series reports new developments in agent-based software technologies and agent-oriented software engineering methodologies, with particular emphasis on applications in various scientific and industrial areas. It includes research level monographs, polished notes arising from research and industrial projects, outstanding PhD theses, and proceedings of focused meetings and conferences. The series aims at promoting advanced research as well as at facilitating know-how transfer to industrial use.

About Whitestein Technologies

Whitestein Technologies AG was founded in 1999 with the mission to become a leading provider of advanced software agent technologies, products, solutions, and services for various applications and industries. Whitestein Technologies strongly believes that software agent technologies, in combination with other leading-edge technologies like web services and mobile wireless computing, will enable attractive opportunities for the design and the implementation of a new generation of distributed information systems and network infrastructures.

www.whitestein.com

Agent-based Supply Network Event Management

Roland Zimmermann

Birkhäuser Verlag
Basel · Boston · Berlin

Author

Roland Zimmermann
Witschaftsinformatik II
Universität Erlangen-Nürnberg
Lange Gasse 20
D-90403 Nürnberg

2000 Mathematical Subject Classification 68T20, 68T35, 68T37, 94A99, 94C99

A CIP catalogue record for this book is available from the Library of Congress, Washington D.C., USA

Bibliographic information published by Die Deutsche Bibliothek
Die Deutsche Bibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data is available in the Internet at <http://dnb.ddb.de>.

ISBN 3-7643-7486-1 Birkhäuser Verlag, Basel – Boston – Berlin

Part of Springer Science+Business Media
Cover design: Micha Lotrovsky, CH-4106 Therwil, Switzerland
Printed on acid-free paper produced from chlorine-free pulp. TCF ∞
Printed in Germany

ISBN-10: 3-7643-7486-1
ISBN-13: 978-3-7643-7486-0
e-ISBN: 3-7643-7487-X

9 8 7 6 5 4 3 2 1
www.birkhauser.ch

Contents

Preface

After all that I was able to observe in the last years, IT-based supply chain management on the one hand still focuses on planning and scheduling issues while on the other hand an increasing awareness for negative effects of disruptive events is observable. Such events often render schedules in production, transportation and even in warehousing processes obsolete and ripple effects in following processes are encountered. This second focus in application-oriented supply chain management is often referred to as *Supply Chain Event Management (SCEM)* and an increasing number of IT-systems promise to cure the underlying fulfillment problems. However, in my opinion many such solutions lack conceptual precision and currently available client-server SCEM systems are ill-suited for complex supply networks in today's business environment: True integration of event management solutions among different enterprises is currently only achievable with centralized server architectures which contradict the autonomy of partners in a supply network. This is the main motivation why in this book I present a concept for distributed, decentralized event management. The concept permits network partners to implement individual strategies for event management and to hide information from network partners, if they wish to (e.g. for strategic reasons). Besides, this concept builds upon existing data sources and provides mechanisms to integrate information from different levels of a supply network while it prevents information overflow due to unconstrained monitoring activities.

Agent technology is selected since it provides the flexibility and individualized control required in a distributed event management environment. Agent interaction based on communicative acts is a means to facilitate the inter-organizational integration of event management activities. In essence, a complex system of agent societies at different enterprises in a supply network evolves. These societies interact and an inter-organizational event management based on order monitoring activities emerges. This concept promises benefits not realized by today's SCEM solutions due to its loosely coupled integration of event management agent societies.

It was my objective in this book to provide a thorough analysis of the event management problem domain from which to develop a generic agent-based approach to *Supply Network Event Management*. The main focus lies on practical issues of event management (e.g. semantic interoperability) and economic benefits to be achieved with agent technology in this state-of-the-art problem domain.

This book is the result of my PhD studies undertaken in recent years at the Department of Information Systems in Nuremberg. I would especially like to thank Prof. Dr. Freimut

Bodendorf who provided me with the opportunity to work and research as part of his staff on this interesting research project. The project was largely funded by the Deutsche Forschungsgemeinschaft (DFG) as part of the priority research program 1083 which focuses on applications of agent technology in realistic scenarios. The research project is conducted in cooperation with the chair of Artificial Intelligence in Erlangen, hence many thanks to Prof. Dr. Günter Görz and his crew, especially Bernhard Schiemann who contributed so much to the overall DFG research project.

I owe specific gratitude to Prof. Peter Klaus who accepted to be the second reviewer for my PhD thesis and to Whitestein Technologies, specifically Dr. Monique Calisti, Dr. Dominic Greenwood and Marius Walliser, for publication of this book.

On the long journey to finalization of such a project many people have contributed in long discussions with helpful advice. Among them are many students, namely Adrian Paschke, Simone Käs, Thomas Schnocklake, Martin Baumann, Clemens Meyreiss, Ulf Schreiber, Kristina Makedonska, Moritz Goeb, Dirk Stepan and certainly others I have missed but who have contributed in varying aspects to the overall DFG research project and thus also brightened the path to this book. A large handful of thanks go to all team members at Wi II (= the Department of Information Systems). I would especially like to thank Dr. Oliver Hofmann who had the initial idea for this research project, Dr. Stefan Reinheimer for many valuable subprojects conducted with industrial partners and Julian Keck as well as Dr. Bernd Weiser for reading part of the early manuscript. All others, namely Christian Bauer, Robert Butscher, Michael Durst, Kai Götzelt, Florian Lang, Marc Langendorf, Dr. Susanne Robra-Bissantz, Dr. Manfred Schertler, Günter Schicker, Mustafa Soy, Dr. Sascha Uelpenich, Stefan Winkler and Angela Zabel, also know the struggles one undergoes in preparing such a book and they are the major source of motivation and support in this process.

Besides, the research work would not have been possible without industry partners who provided knowledge and resources for an industry showcase. Among them are Jörg Buff and Cornelia Bakir who always had remarkable interest in new IT-trends and Prof. Dr. Jörg Müller, Prof. Dr. Bernhard Bauer and Dr. Michael Berger from Siemens Corporate Technology who opened up the opportunity to fruitful research cooperation.

Last - but not the very bit least - my family has always encouraged me on this path and I owe the deepest thanks to my parents Amrei and Horst and my beloved wife Ina for without them this book would never have been written.

Nuremberg, November 2005 *Roland Zimmermann*

Chapter 1

Introduction

Operational problems in fulfillment processes occur in every industry. These problems have severe negative effects within a given enterprise and multiply in multi-enterprise supply networks. However, *Supply Chain Management* has for a long time focused on the optimization of procurement, production and distribution planning (e.g. *Stadtler et al. 2002*), while neglecting fulfillment problems: The execution of fulfillment plans regularly deviates from original plans due to unexpected events. Interdependent processes are affected negatively by these events, and ripple effects in inter-organizational networks are common. The awareness for these operational problems increased in the last years, although in management science concepts such as *Management-by-Exception* already existed. Terms such as *Supply Chain Monitoring* or *Supply Chain Event Management* (e.g. *Bittner 2000*) illustrate the interest in operational problems of fulfillment processes in supply networks. However, current solutions primarily focus on intra-organizational processes within single enterprises, while implementations with a true inter-organizational supply network perspective are rare (*Masing 2003*, pp. 88). One reason is that current offerings of SCEM systems build upon centralized architectures which prevent the integration of multiple systems among different enterprises. This is illustrated by an initiative of the automotive industry to interconnect existing supply chain monitoring systems. In its official recommendation it points out that decentralized infrastructures are needed which aim at the cooperation between enterprises. But such solutions are not available (*Odette 2003, pp. 26*).

As a consequence, the work presented here has the objective to analyze those problems which result from disruptive events in supply networks with emphasis on relationships between independently acting enterprises. To achieve this, the constraints and requirements for inter-organizational event management are identified, and a concept based on a decentralized IT-solution is proposed which employs innovative agent technology. This concept provides proactive event management in the distributed environment of supply networks. Proofs-of-concept and an evaluation of economic benefits to be achieved with this concept complete the work. A short overview is given in fig. 1-1. Chapter 2 provides a detailed analysis of the information deficits which disruptive events cause in supply networks. These deficits have to be reduced by an event management solution. The analysis is concluded with a formal definition of the problem. From this definition the requirements of an event management solution are derived. With respect to these requirements the potential benefits of event management solutions are analyzed and the existing approaches to event management are assessed.

Chapters 3 and 4 define the information base and the functions needed for event management. The information base consists of a data model and an ontology which facilitates interoperability among different enterprises in supply networks. In addition, the main data sources relevant for event management are identified (chapter 3). In chapter 4 mechanisms are proposed which are needed to fulfill the functional requirements, as defined in chapter 2. Since the inter-organizational supply network perspective guides the development of the concept, mechanisms for proactive information gathering in inter-organizational settings are proposed. Further functions concern the interpretation and distribution of the gathered event-related data. An integrated event management process is defined, based on all functions. This process is applicable to every enterprise in a supply network, and it provides a focus on interdependencies between enterprises.

In chapter 5 the data model and the event management functions are integrated in an agent-based concept. The use of software agents in the domain of event management in supply networks is discussed, and a structured method for designing an agent-based application is introduced. This method is then used to develop an agent-based event management system. Two prototypes are presented in chapter 6: One is situated in a laboratory environment needed to conduct experiments, and the second provides an industry showcase to apply the agent-based event management concept to a realistic environment.

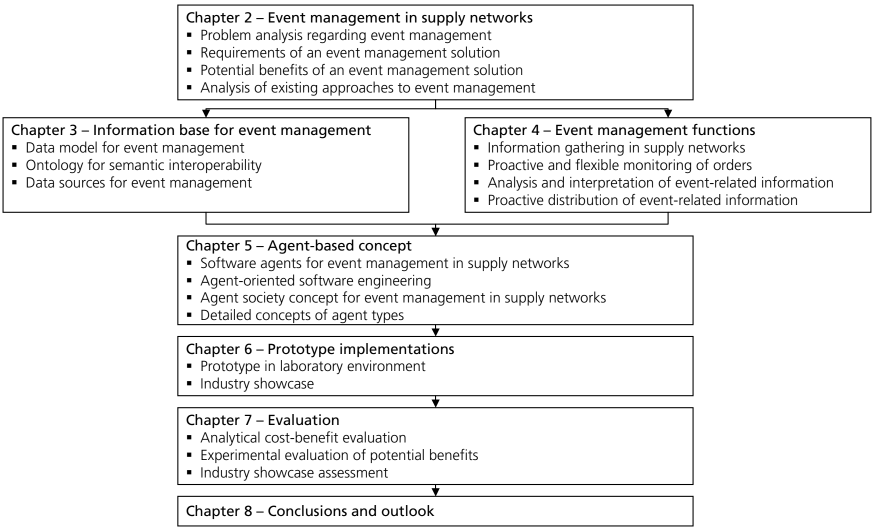

Fig. 1-1. Overview of chapters

An evaluation is conducted in chapter 7 to find out whether an agent-based event management concept can truly realize monetary benefits. Three perspectives for the evaluation are selected: First, a theoretical cost-benefit-model is developed to compare the agent-based concept with existing approaches to event management. Second, experimental results from the laboratory prototype are used to substantiate hypotheses of the cost-benefit-model. Third, the industrial showcase is assessed, and cost measurements for the showcase are analyzed. In all three perspectives, constraints of the agent-based concept are identified and discussed with respect to their effect on a possible implementation of an agent-based event management. Concluding, chapter 8 summarizes the results and provides an outlook on future developments and further research opportunities.

Chapter 2

Event Management in Supply Networks

A detailed analysis of the supply network domain is conducted with special attention to issues of nondeterministic problems in operational processes of enterprise networks (see section 2.1). Results of this analysis are used to determine basic requirements for a solution to these *event management* issues (see section 2.2). Potential benefits of event management are identified for the supply network domain and existing IT-systems are evaluated (see sections 2.3 and 2.4) to illustrate the potential for improvement.

2.1 Problem

The problem of event management is analyzed regarding two major aspects: First, characteristics of nondeterministic events and their effects on information logistics are assessed (see section 2.1.1). Second, specific characteristics of operational fulfillment processes in multi-enterprise networks are reviewed (see section 2.1.2). Both results are integrated in a model which formally describes the problem and tasks of event management in complex supply networks (see section 2.1.3).

2.1.1 Event-related Information Logistics

2.1.1.1 Information Deficits in Supply Networks

In every industry problems occur during the execution of processes. These problems have an impact on the performance of enterprises and their supply networks[1]. Performance is

[1] An enterprise takes, for instance, the role of a supplier which provides basic parts to manufacturers which in turn sell their goods to other network partners.

affected negatively with respect to timeliness, quality, cost and revenues of supply network partners. Some examples illustrate these impacts which are at the heart of the problem to be solved by event management in supply networks.

In the automotive industry just-in-time partnerships between first-tier suppliers and car producers are very common. They rely on very tight schedules for delivery of parts often directly to the production line. Thus, inventory costs are reduced to a minimum (*Shingo 1993, pp.171*). One of the side effects is the requirement for high reliability of the delivery processes. Otherwise complete production lines have to be stopped in a matter of hours, if only one supplier fails to meet the pre-planned schedule of delivery. A very extreme example occurred at General Motors in 1996 when an 18-day labor strike at a supplier of brakes halted production in 26 production plants (*Radjou et al. 2002, p.3*). However, even small problems in suppliers' processes result in deviations from globally planned and optimized schedules with serious impacts on supply network performance. Only warnings of such events, if provided in a timely fashion, enable affected network partners to react to arising problems. For instance, a supplier can only deliver a fraction of the ordered quantity: If this information is conveyed directly to his customer (e.g. a production facility) and other parts planned for later delivery can already be shipped, the customer might be able to change his own schedule for production provided that enough time for rescheduling is given.

Customers in the consumer goods industry are very sensitive to temporarily unavailable goods during shopping hours. One of the largest problems for producers of consumer goods is the lost-sale problem due to unavailability of their products in the shelves of supermarkets. Studies reveal that about three percent of the potential sales volume in the retail sector are lost due to out-of-stock situations (*Seifert 2001, p.87*). In consequence, any kind of delay or shortage of deliveries from production to warehouses and from warehouses to market facilities pose the threat of lost sales and consumers turning their attention to competitors' products (*Wagner et al. 2002a, pp.353*). Early warnings on delays permit, for instance, to use express deliveries from other warehouses of the producers or wholesalers which still have inventories on stock.

Additional examples of problems associated with supply networks underline the relevance of unanticipated events for supply network performance as illustrated in table 2-1. Although such extreme situations may occur rarely, they emphasize the need to react as soon as possible. In some cases these actions may even be vital for the survival of supply network partners, and the impact of failures in supply networks can have major negative effects on shareholder value[2].

Company	**Supply network exception**	**Cost of lost transactions**
Boeing	Two key suppliers fail to deliver critical parts on time (1997)	Deals lost worth $2.6 billion
Sony	Shortage of PlayStation 2 graphics chip (2000)	Console shipment in US was 50% less than planned

Table 2-1. Consequences of supply network events (*Radjou et al. 2002*)

Company	Supply network exception	Cost of lost transactions
Ericsson	Fire in a plant (Philips Electronics) disrupts chip supplies for new handset	Loss of 3% market share against Nokia in 2000 and exit from handset market

Table 2-1. Consequences of supply network events (*Radjou et al. 2002*)

All examples share the following features:
- Initial triggers for the problems are unexpected events that cannot be prevented by one of the actors involved. These events can be characterized as disturbances, disruptions or malfunctions of processes.
- Most of the events occur during processes of actual order fulfillment - i.e. production, warehousing and transportation or closely related administrative processes.
- Consequences of the events affect not only the single enterprise where the event occurs, but also related companies. Many of those are direct customers, but also customers of customers on different levels of the supply network.
- Consequences may be avoided or at least reduced to an acceptable level, if decision-supporting information on serious events is available as soon as possible.
- In reality time-lags between the occurrence of events, their identification and the communication of related information to affected actors in a supply network reduce the ability of reacting to a problem. In many cases such information is neither identified nor communicated at all, and the consequences affect the network with their full impact (*Bretzke et al. 2002, pp.1*).

In summary, negative consequences for supply network processes are due to unavoidable events. But consequences can be reduced, if high-quality information is provided to supply network partners at an early stage shortly after such events have occurred. However, a lack of reliable and accurate information on events and insufficient communication of event-related data between network partners is observed. The resulting information deficit regarding event-related information will be referred to as the *Supply Network Event Management (SNEM) problem*.

2.1.1.2 Role of Information Logistics

Information management in supply networks needs to be improved to solve the SNEM problem outlined in section 2.1.1.1. It is a task in the field of *information logistics*, which is a major area of research in logistics sciences.

Management of information that accompanies physical processes in supply networks is an important task for information logistics. The associated information processes can either be directly value-adding (e.g. product design) or supporting in the sense of controlling and managing the associated physical processes (*Augustin 1998*).

---

2. On average an 11% decrease of stock prices is attributed to each severe supply network problem made public by a company (adjusted to market and industry movements) (for details see (*Singhal 2003*)).

A more general definition of information logistics is based on the assumption that information consists of data which is relevant for somebody. Information represents input for decisions that are the basis of economic behavior resulting in transactions and their fulfillment. Consequently, the aim of information logistics is to provide relevant information to actors (*Kloth 1999, pp. 57*). Three basic dimensions have been proposed, that characterize this aim in greater detail (*Föcker et al. 2000, p.20*):

- *Content*
  Only selected information is relevant for a decision-maker (actor) in a given context. Therefore, content has to be matched with the current situation of the actor.
- *Time*
  Information is only useful, if it is available at the point in time when the actor needs it. A second aspect is the timeliness of information. It restricts its use for decisions, if it is outdated.
- *Location*
  Information needed by an actor has to be communicated to the location where the actor is situated when he is meant to act upon the information.

In the context of the SNEM problem, information logistics has to provide a solution for overcoming the information deficit and thereby improving the management of the supply network processes. It has to consider the three basic dimensions of *content* (e.g. characterization of an event), *time* (e.g. real-time quality of information) and *location* (e.g. where is an affected supply network partner located and who is the relevant contact). Regarding the SNEM problem, deficits in information logistics exist because the required content is often not available or at least not at the right time and not for the relevant actors (the supply network partners) that could react upon the information.

2.1.1.3 Disruptive Events

Non-deterministic events as the triggers of the SNEM problem are characterized on an abstract level as triggers for state transitions of some kind of object. In fig. 2-1 an example is depicted as an UML state chart. The object that changes its state might either be some kind of actor, physical resource, process or, in general, some kind of system endowed with a behavior. The event that triggers the transition of the object into a new state (e.g. from "idle" to "occupied") is characterized as "a significant occurrence" (*Larman 1997, p.379*).

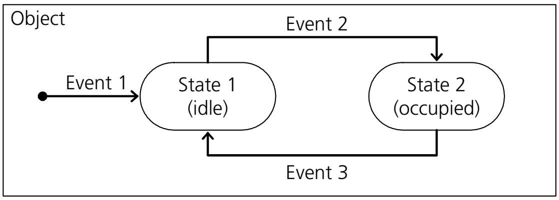

Fig. 2-1. UML state chart of an abstract object

The term "occurrence" can be illustrated by a few examples which highlight different types of events:

- "A disturbance occurred at machine X at time Y"

- "The milestone 'Delivery to customer' was achieved on date Z"
- "Measurement of production tolerances indicates a deviation of X % from the required
  tolerances"
- "Company XY has issued an order for Z pieces of product P"

These types of events change the states of different objects. A machine failure results in the state *blocked,* whereas the achievement of the final milestone of an order changes the order's state to *finished*. Not every type of event is important from the SNEM problem's point of view. If the occurrence of an event is certain, it is irrelevant whether it has a negative impact on processes in a supply network or not. It can be assumed that in such a case the event is integrated into any kind of plan and schedule, and processes are already optimized under the restriction of this event occurring at some point in time. However, if an event in a supply network is uncertain but has no impact or at least no negative impact on the performance of the network's processes there is no need to communicate such events to other network partners or to take any managerial actions. The only case where an information logistics solution is required, is characterized by an uncertain event that has a negative impact on processes of a supply network.

Disturbances, disruptions, malfunctions and other concepts for describing uncertain events with a negative impact will be referred to as *disruptive events*. They can propagate across many levels of a system (see section 2.1.1.1). Consequences of a specific disruptive event will affect only certain orders. Any order is characterized by different attributes (e.g. order quantity, destination, planned milestones, price) which are affected by disruptive events. Two scenarios illustrate the relationships:

- A traffic jam during transportation results in a delay with the consequence of an exceeded time-limit of the milestone for delivery of an order.
- Quality defects due to a lack of maintenance are identified during quality control, and only part of the ordered quantity is released for actual delivery.

Diagnosis of such consequences (e.g. a delay of an order) can point to disruptive events that are not identified explicitly (e.g. a slowdown of a machine). Indirect identification of disruptive events based on measurements is considered to be a disruptive event itself that has to be taken into account by an information logistics solution for the SNEM problem.

2.1.2 Supply Networks

2.1.2.1 Fulfillment Processes

To further analyze the SNEM problem, a characterization of the supply network domain is necessary. A supply network consists of all processes necessary to supply goods and services to customers and markets (*Klaus 1998, p. 434*). On a short- to medium-term basis these networks are mostly stable regarding their main participants, but changes of participants occur in the long run (*Marbacher 2001, p.19*). Supply networks in industrial environments are characterized by three main operational process types: demand communication, fulfillment and payment (*Klaus et al. 2000, pp.17*) (see fig. 2-2). Triggered by customers, the demand - articulated via orders that are placed with wholesalers, manufacturers or service providers - is propagated throughout the network and triggers suborders where necessary. Fulfillment of the orders is characterized by the physical processes of production, warehousing and transportation that "head" towards the final customers who articulated the initial demand. Payment processes finalize the transactions with the transfer of funds to the vendors of the goods and services.

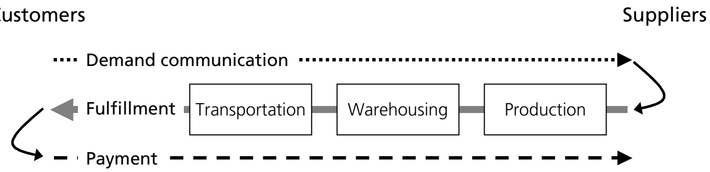

Fig. 2-2. Supply network processes (*Klaus et al. 2000*)

The examples of disruptive events (see section 2.1.1.1) which propagate in supply networks mainly occur during fulfillment processes. Although demand fluctuations are serious phenomena that amplify across supply networks (e.g. the bullwhip-effect as the most famous phenomenon (*Lee et al. 1997*)), a focus on fulfillment processes is chosen. Research on effects of demand fluctuations and on optimized methodologies for demand communication management has been conducted intensively (e.g. research related to the ECR- and CPFR-Initiatives[3]), whereas the execution of these plans and related controlling activities are often neglected (*Bretzke et al. 2002, pp.29*).

In the following the SNEM problem is analyzed with a focus on the information logistics tasks which arise in the fulfillment processes of supply networks - namely production, warehousing and transportation.

2.1.2.2 Relationships between Orders

Supply networks can be characterized as a special form of an institutionalized division of labor (many different enterprises cooperating under market conditions to produce goods and services). Here, division of labor is established by means of placing orders with suppliers or other types of enterprises that fulfill certain activities needed to produce a good or service. These activities encompass e.g. procurement of parts by a producer that are manufactured by a supplier and transported by a logistics service provider to the producer. Such (sub-)orders are characterized as pre-conditions which have to be fulfilled before certain other (value-adding) activities (e.g. the assembly of parts at the producer's site) can be initiated.

A supply network consists of a number of enterprises that may have different relationships at different times with each other. This results in a general supply network structure as depicted in fig. 2-3 (left side).

---

3. ECR = Efficient Consumer Response (http://www.ecrnet.org/) and CPFR = Collaborative Planning Forecasting and Replenishment (http://www.cpfr.org/)

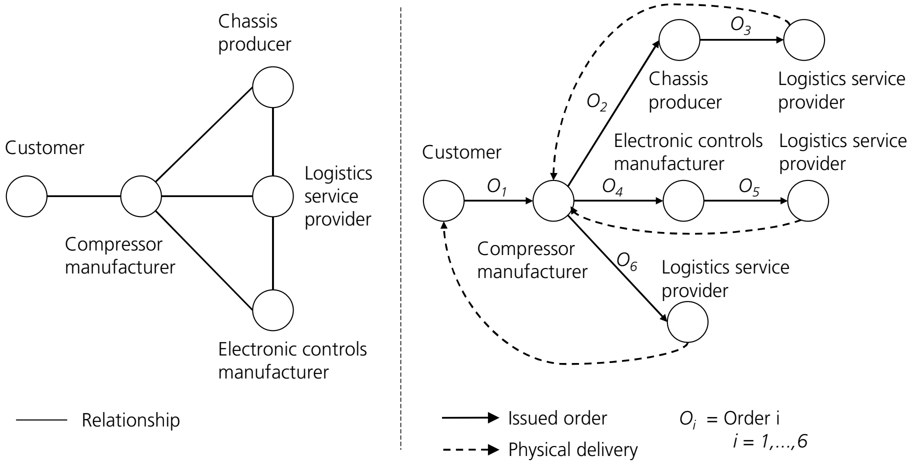

Fig. 2-3. Graphical representations of supply networks

However, the examples mentioned in section 2.1.1.1 refer to specific instances of orders and their related suborders, because disruptive events directly threaten certain orders while other orders between the same enterprises may not be affected at all. For instance, a different product for the same customer produced at a different site will not be affected by a specific machine breakdown.

To analyze the effects of events on certain orders, actual instances of orders O_i and their relationships have to be identified. As suborders represent pre-conditions for their superorders, the relationships between orders can be depicted as a directed graph (see fig. 2-3 right side): Suborder O_2 issued to the chassis producer has to be fulfilled before the compressor manufacturer can complete order O_1. However, the chassis producer itself can only fulfill his order O_2 completely, when suborder O_3 to the logistics service provider (LSP) has been fulfilled. This order relationship implies that the chassis has to be delivered by the LSP to the compressor manufacturer to complete order O_2.

Although in the example of fig. 2-3 all three manufacturers have relationships with the same logistics service provider (left side), the three different orders placed with this LSP by the manufacturers to deliver parts and products to their customers (O_3, O_5, O_6) have to be reflected separately in the directed graph of order relationships. The LSP appears three times in the directed graph and as a result the complex network structure is reduced to a sequenced "order-tree" which is the basis for further analysis.

2.1.2.3 Effects of Disruptive Events in Supply Networks

Effects of disruptive events are analyzed with regard to the complex structures in supply networks (see section 2.1.2.2). Since the SNEM problem is the result of an information deficit concerning these events, a need for information management is established (see section 2.1.1.2). Consequently, the effects of disruptive events in supply networks are analyzed in scenarios with and without an information logistics solution. In the following, three scenarios are developed in a thought experiment and analyzed as depicted in table 2-2. A "certain world" is assumed in the first scenario and all events that might occur in the future are known. In consequence, ideal plans can be devised for a supply network by taking into account every possible situation (compare section 2.1.1.3) and information logistics is not required. Efficient value creation in the supply network is possible. No measures have to be taken when an event occurs, because it has already been incorporated into every schedule (e.g. work plans and transportation plans) in the supply network.

However, in reality the assumption of complete certainty is, of course, not tenable and therefore abandoned in scenario 2. It is assumed that no communication on disruptive events within a company and between the partners of a supply network is possible (no information logistics). In this situation, order relationships have to be taken into account (see section 2.1.2.2).

Scenario	**Assumptions**	**Effects on supply network**	**Possible counter measures**
1	Certain world; No information logistics provided	Ideal Plans - No deviations - Efficient value creation	Not necessary
2	Uncertain world; No information logistics provided	Worst Case - No advance information on events - Propagation of events in supply network - No event-specific management actions possible to forestall negative consequences	Buffers - Physical stock (parts, goods) - Assets (machines, personnel) - Time (buffers in processes) - Money (liquidity)
3	Uncertain world; Ideal information logistics on disruptive events in real-time	Improved Situation - Advance information on events result in more reaction time - Propagation of events can be decreased/stopped - Event-specific management in advance of effects	Replace buffers with information - Alternative processes - Dynamic rescheduling - Controlling activities

Table 2-2. Scenarios for uncertainty of events

A disruptive event such as a machine failure might propagate in the network along the path defined by the relationships and amplify over time (see fig. 2-4). As no communication concerning disruptive events that occur is possible during fulfillment, no advance information on the consequences to be anticipated by supply network partners is available. Managerial actions can only be taken when negative effects have ultimately reached the partners (i.e. a delay is recognized). Even then decisions on corrective actions can hardly be attained because information on the type and consequences of the unknown event (e.g.

when the delayed delivery will ultimately arrive) is lacking. The only appropriate measures to forestall such consequences consist in increasing buffers of inventories, resources, time and liquidity in the fulfillment processes of a supply network. In consequence, negative effects of propagating disruptive events can be reduced only at the huge expense of costly buffers.

The third scenario assumes perfect information logistics regarding any disruptive event that occurs in a supply network. Timely identification and communication of event-related information is facilitated across the whole supply network. Gain in reaction time for affected supply network partners due to advance notice of events enables them to forecast consequences on their own processes and opens up alternatives to handle arising problems. Besides alternative processes, a dynamic rescheduling of orders is enabled. The increase in available event-related information will be accompanied by a decrease in the necessary buffers. To sum up, the uncertainty of disruptive events induces expensive buffers of different kinds in fulfillment processes of supply networks. Buffers can be reduced if information logistics can effectively provide information on disruptive events to supply network partners.

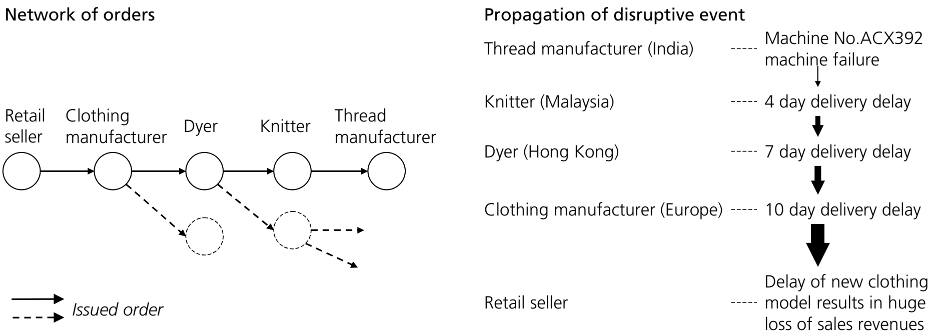

Fig. 2-4. Amplification of a disruptive event in a supply network (*Radjou et al. 2002*)

2.1.2.4 Autonomy of Supply Network Partners

The current situation in supply networks presumably lacks effective event-related information logistics (see section 2.1.1.1). A structural factor adds complexity to the development of an information logistics solution: the autonomy of the supply network participants (see fig. 2-5).

Every supply network partner is (in most cases) an independent enterprise with individual goals (e.g. "maximize individual gain"). Depending on its organization an enterprise can follow different behavior patterns that are developed to accomplish its individual goals. Cooperation of enterprises in supply networks due to the division of labor cannot prevent that conflicts between goals of different partners arise (e.g. a supplier minimizes quality control efforts to reduce its costs while the customer wants reliable products without rising prices for the service). Consequently, the behavior patterns of individual companies influence each other because every partner is trying to accomplish its own goals while interacting with other partners. That situation can result in a desire to hide information from partners, to act strategically or even opportunistic.

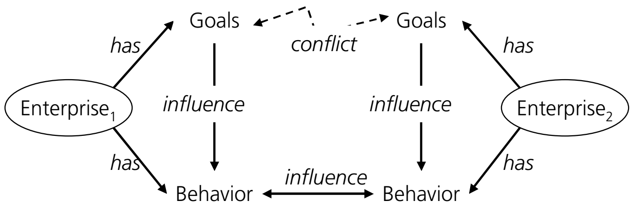

Fig. 2-5. Autonomy of supply network partners

An information logistics solution for the SNEM problem has to accept individual goals and behavior of the supply network partners and must not interfere with individual strategies. Therefore, each company has to be able to adapt its information logistics services to its own goals and strategies (e.g. define an information policy) as well as govern the behavior of these services (e.g. host its own information logistics solution, implement individual strategies, restrict data availability for external partners in specific cases).

2.1.2.5 Heterogeneity of Supply Network Partners

A second structural factor which adds even more complexity to the information logistics task is the heterogeneity of different partners involved in a supply network. Dimensions such as products, processes, size of companies and differences in management culture influence each other already within a company (e.g. a certain product type requires specific processes that are designed according to the management culture in the company). The more so they vary between supply network partners. Partners like logistics service providers cooperate in supply networks with producers of various goods, which can range from raw material (e.g. oil) to industrial products (e.g. electronic parts). In addition, small and medium enterprises with a simple organizational structure often supply to larger corporations that use sophisticated tools and methods in their complex organizations. And every industry has specialized processes and different management cultures that affect the way information is exchanged internally and externally with partners. As a result very different informational needs evolve in a supply network with respect to the information which is to be provided by an information logistics solution (e.g. a producer requires quality measures on product specifications of an order whereas a logistics service provider focuses on transportation milestones). Such needs have to be considered in a generic yet open and flexible solution for the SNEM problem.

2.1.3 Formal Specification of the Problem

The findings in section 2.1.1 and section 2.1.2 are summarized in a formalized model of the SNEM domain and the SNEM problem. It serves both as the starting point for further analysis and for the development of an information logistics solution for the SNEM problem[4].

2.1.3.1 Definitions

- *Legal Entity* - a *Legal Entity* LE_k with $k \in N$ is an entity which can enter into a legal contract. It is either a person or a corporation.
- *Disruptive Event* - a *Disruptive Event* DE_h with $h \in N$ is the term for any kind of disruption, malfunction or anomaly of behavior with a probability of occurrence between zero and one and a negative effect on the fulfillment processes of a supply network. A DE_h originates at a certain legal entity LE_k and occurs at a point in time T_t and is written as $DE_h(LE_k;T_t)$.
- *Order* - an *Order* O_i with $i \in N$ is a legally binding contract concerning a transaction between two or more legal entities LE_k. It is issued by one LE_k and received by another which is written as $O_i(LE_k;LE_{k-x})$ for $x \in N$ where LE_k issues and LE_{k-x} receives the order O_i.
- *Order Relationship* - division of labor results in suborders that have to be fulfilled before a superorder can be fulfilled. An *Order Relationship* OR_{ji} between a superorder O_j and a suborder O_i is defined as $OR_{ji} = (O_j;O_i)$.
- *Order Attribute* - an Order O_i has one or more characteristic *Order Attributes* OA_n with $n \in N$. Some of the OA_n have a constant value while others may change during the fulfillment of O_i. Therefore, $OA_n(T_t)$ is the value of an order attribute OA_n at a certain point in time T_t. An $OA_n(T_t)$ can also represent an aggregated value calculated from different $OA_{n-x}(T_t)$ for $x \in N$. A value of an order attribute OA_n is characterized by the parameters order O_i and time T_t: $OA_n(O_i;T_t)$.
- *Order Status* - the situation depicted by the values of all order attributes $OA_n(O_i;T_t)$ of an order O_i at a certain point in time T_t is defined as the *Order Status* $OS_i(T_t) = \{OA_n(O_i;T_t)\}$ for $n \in N$.
- *Location* - any legal entity LE_k has a *Location* L_r which defines where and how it can be contacted with the help of communication technology.
- *Activity* - an *Activity* A_v is something that is executed over a certain interval of time, with "something" referring to physical and/or mental tasks that are conducted by some entity.

The following basic definitions are detailed in statements defined in section 2.1.3.2:

- *Demand* - a *Demand* D_q is the need of an actor (e.g. a *Legal Entity*) for goods or information.
- *Message* - a written or spoken piece of information that is sent from one actor to another is defined as a *Message* M_s.
- *Content* - the *Content* C_p is defined as the subject contained in a piece of information (e.g. in a *Message*).
- *Reaction* - an *Activity* that is a direct result of some event (e.g. a *Disruptive Event*) is a *Reaction* R_u.
- *Consequence* - a *Consequence* CSQ_w is a result of a particular *Reaction* that is executed.

---

4. An information logistics solution for the SNEM problem is referred to as a *SNEM solution* or *SNEM system*.

2.1.3.2 Statements

The following statements are based upon the concepts defined above and characterize the SNEM problem:

A disruptive event $DE_h(LE_{k-x};T_1)$ that occurs at time T_1 and originates at legal entity LE_{k-x} will affect one or more orders O_i which results in a change of values of order attributes OA_n (depicted as $\Delta OA_n(O_i;T_1)$) and a change of order status $OS_i(T_t)$ represented by $\Delta OS_i(T_1)$.

(1) $DE_h(LE_{k-x};T_1) \Rightarrow \{\Delta OA_n(O_i;T_1)\} \Rightarrow \Delta OS_i(T_1)$ for $n \in N$ (read as $IF \Rightarrow THEN$)

The information concerning the relationship between the disruptive event DE_h and the changed order status $\Delta OS_i(T_1)$ is defined as the potential *Content* C_p of a message.

(2) $C_p(DE_h;\Delta OS_i(T_1))$

As for the interdependencies that exist between orders and their suborders, the change of order attributes $\Delta OA_n(O_i;T_1)$ and the respective change of the order status $\Delta OS_i(T_1)$ will affect a related superorder O_j of legal entity LE_k at some future point in time T_y.

(3) $((OR_{ji} = (O_j;O_i)) \wedge (\Delta OS_i(T_1) \neq 0)) \Rightarrow \{\Delta OA_n(O_j;T_y)\} \Rightarrow \Delta OS_j(T_y)$ for $n \in N$ with $T_y > T_1$

With the deviation $\Delta OS_i(T_1)$ in (1) an implicit *Demand* D_q for information arises at time T_1 at the supply network partner that will eventually be affected by the disruptive event DE_h in the future as described in (3). This demand D_q cannot actually be articulated, because it is unknown to the partners at the time of occurrence of the disruptive event DE_h. This implicit demand D_q is located at the legal entity LE_k that issued the suborder O_i and that has to fulfill its superorder O_j. The content C_p defined in (2) is required at time T_1 (as soon as the DE_h has occurred), and it is needed at the *Location* L_r of the recipient LE_k.

(4) $((OR_{ji} = (O_j;O_i)) \wedge (\Delta OS_i(T_1) \neq 0)) \Rightarrow D_q(LE_k;C_p;T_1;L_r)$ with $O_i(LE_k;LE_{k-x})$

Ideally, the demand D_q is satisfied by a *Message* M_s that is communicated from the legal entity LE_{k-x}, where the event occurred, to the potentially affected legal entity LE_k. It contains the content C_p and is transmitted at time T_2 to location L_r from sender LE_{k-x} to recipient LE_k.

(5) $D_q(LE_k;C_p;T_1;L_r) \Rightarrow M_s(C_p;T_2;L_r;LE_{k-x};LE_k)$ with $T_2 > T_1$

Based on the content C_p communicated in message M_s the recipient LE_k is able to react upon it in order to reduce the potential negative effects that will propagate from the suborder O_i and affect its own order O_j negatively. The *Reaction* R_u is characterized by the parameters LE_k depicting the actor, an *Activity* A_v, the order O_j that is the target of the activity, and a time-stamp T_3.

(6) $M_s(C_p;T_2;L_r;LE_{k-x};LE_k) \Rightarrow R_u(LE_k;A_v;O_j;T_3)$ with $T_3 > T_2 > T_1$

Any reaction R_u as defined in (6) will have a *Consequence* CSQ_w regarding the order status $OS_j(T_t)$ of the order O_j. The consequence is described by the remaining negative effect $\Delta OS_j(T_y)$ at time T_y of the disruptive event DE_h on the superorder O_j. This effect is eliminated or at least reduced to a minimum with respect to the chosen reaction R_u.

(7) $R_u(LE_k;A_v;O_j;T_3) \Rightarrow CSQ_w = \Delta OS_j(T_y) \rightarrow min!$ with $T_y > T_3 > T_2 > T_1$

2.1.3.3 Implications

The goal of minimizing the negative effects of disruptive events on supply networks, by using communication of event information to enable precautionary actions, is defined in formula (7) in section 2.1.3.2 with the term $\Delta OS_j(T_y) \rightarrow min!$. An analysis of the preceding formulae regarding potential problems in the sequence of statements puts forth one obvious critical fact: the "implicity" of the demand $D_q(LE_k;C_p;T_1;L_r)$ experienced by an affected partner LE_k in the supply network (see formula (4)). This actor cannot specify its actual demand for information on a disruptive event at time T_1 when a new disruptive event DE_h occurs. Although this information is already available as content $C_p(DE_h;\Delta OS_i(T_1))$ at LE_{k-x}, the potential sender of the information LE_{k-x} is not queried by LE_k for information concerning the disruptive event DE_h. An information deficit at LE_k is the consequence - the SNEM problem. Therefore, a proactive management of the information flow is needed that satisfies the implicit demand D_q defined in formula (4) in a timely manner. This is the information logistics task to solve the SNEM problem.

The relatively vague need for proactive information logistics management in a supply network, which became visible in statement (4), is refined in formula (5) by defining the necessary message $M_s(C_p;T_2;L_r;LE_{k-x};LE_k)$ to satisfy the implicit demand D_q. M_s includes the content C_p and several parameters which are the starting point for identifying requirements of a SNEM solution to solve the SNEM problem (see section 2.2).

The formalized model presented above considers the autonomy of supply network partners (see section 2.1.2.4): This autonomy is reflected in the notion of different legal entities LE_k who willfully enter into contracts by means of orders. Implicitly, the model also considers the heterogeneity of the participants and their different information needs (see section 2.1.2.5), since the demand D_q is defined without any data restrictions. It is to be satisfied with content C_p that contains changes in an order status OS_i. An order status itself is based on a flexible number of order attributes OA_n. Since both restrictions of heterogeneity and autonomy are reflected in the formal model of the SNEM problem, the model is used as the basis for further analysis of the SNEM domain.

2.2 Requirements of an Event Management Solution

Both, formulae (4) and (5) in section 2.1.3.2, which define the implicit demand D_q and the necessary message M_s to satisfy this demand, are used to identify relevant aspects of the information logistics task as depicted in fig. 2-6.

Three main fields of requirements are distinguished:

1. Since demand D_q is not apparent to a potential recipient of event information ("implicity"), a behavioral framework is needed to which supply network partners commit themselves. Basic behavioral agreements are addressed as general requirements of a SNEM solution in section 2.2.1.
2. Information that can satisfy the implicit demand D_q is defined in the content C_p of a message M_s. This content consists of various types of data relevant to the SNEM problem. Therefore, a data model is needed for a SNEM solution. Certain requirements for this model are identified in section 2.2.3.
3. To generate and transmit a message M_s, different information logistics activities have to be performed. Three basic types of functions are common to information logistics solutions: content, time and communication management (*Lienemann 2001, pp.4*). Within these limits, specific functional requirements of a SNEM solution are determined in section 2.2.2.

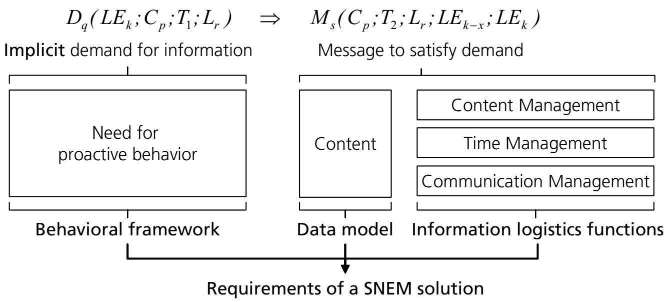

Fig. 2-6. Areas of requirements

An overview of all requirements for the three main fields is depicted in fig. 2-7. The requirements are subsequently defined in detail.

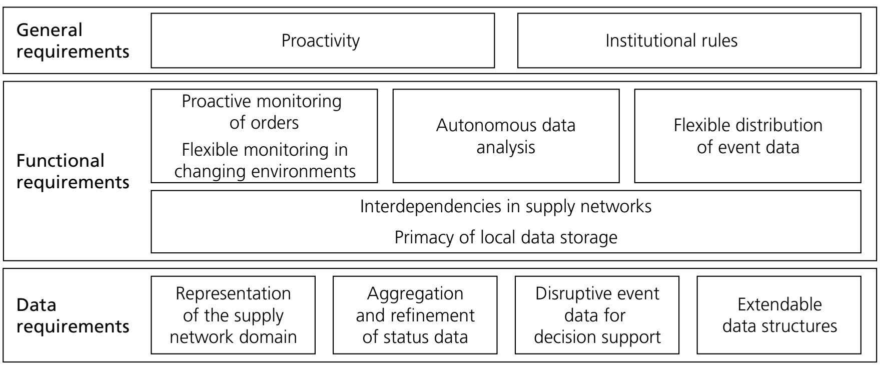

Fig. 2-7. Requirements of a SNEM solution

2.2.1 General Requirements

2.2.1.1 Proactivity

The main objective of event management in supply networks is to overcome the "implicity" of demand D_q since D_q cannot be made explicit (see section 2.1.3.3). Thus, supply network partners ought to act proactive: First, partners in the network have to "sense" what kind of information might be needed by themselves in the future and act proactive by pulling information from all available data sources including related network partners. Second, information on disruptive events identified by a network partner should be communicated to potentially interested network partners proactively (information push). In consequence, a supply network partner has to act proactively in at least two roles it is adopting at different times: as a sender it has to distribute information concerning disruptive events and as a receiver it will gather information on orders proactively given the assumption that otherwise important information might be identified too late. A SNEM solution has to enable and support both types of proactivity.

2.2.1.2 Institutional Rules

Autonomy of supply network partners as outlined in section 2.1.2.4 determines the behavior of actors in a supply network. As they pursue individual goals, conflicts are inevitable. The information logistics task of a SNEM solution has to consider these individual behaviors that are dependent on individual goals and strategies of the participants. To ensure effective SNEM processes and facilitate proactive behavior, some basic behavioral rules have to be established for a SNEM solution. Such a system of rules is called an "institution" and is used as a framework for the behavior of different actors (*Esteva et al. 2002*). This concept borrows from the idea of human institutions like a society or business organizations. An institution defines rights and obligations of actors that want to participate in such an institution (e.g. in a state or a company) and are regarded as the macro-framework in which each actor is allowed to act as long as it complies with the institutional rules. The idea of an institution can be transferred to electronically supported institutions that also need rules of behavior, if different participants with individual behaviors have to cooperate (*Esteva et al. 2001*). This is the case for a SNEM solution which is based upon information technology. Some important aspects that have to be defined as institutional rules of a SNEM solution are:

- Roles in the institution and hierarchies between roles
- Communication types and interactions between actors
- Allowed statements and vocabulary
- Costs of service provision
- Behavioral assumptions (benevolence vs. opportunism)

2.2.2 Functional Requirements

The process of managing the information logistics task to satisfy the implicit demand D_q is similar to a typical fulfillment process where a product or a service is supplied to a customer (in this case to supply network partner LE_k with its demand D_q).

The widely accepted supply chain reference model SCOR (*SCC 2005*) differentiates three main process types: *Source* (procurement), *Make* (transformation/production) and *Deliver* (distribution of goods/services) to define a fulfillment process. With regard to the information logistics domain *Source* refers to the process of gathering information and *Make* refers to an aggregation, interpretation and rearrangement of information. Both process types are part of the content management function (see fig. 2-8) identified as one major area for functional requirements (see also fig. 2-6). The output of the *Make* process is an information product. Distribution of this product, which contains SNEM data, is related to time and communication management functions of information logistics solutions. These functions are mapped to the *Deliver* process (see fig. 2-8).

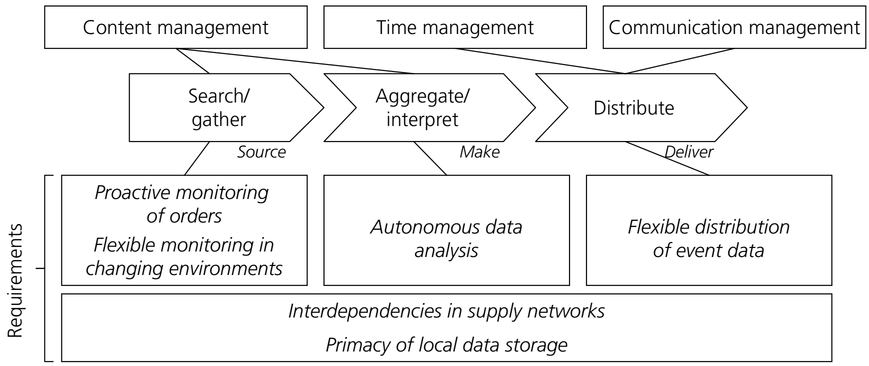

Fig. 2-8. Functional requirements of a SNEM solution

Similar models from other domains concerned with management of information underpin the general applicability of this process model (e.g. *Eisenbiegler et al. 2003*). For instance, the content lifecycle model relevant to the domain of web content management (*Buechner et al. 2000, pp.83*) is based on similar processes: During the *Source* process content is created and information gathered. In the next step it is edited until it is released for publication.

The basic SNEM process model which consists of searching/gathering, aggregation/interpretation and distribution activities is used to derive detailed requirements for the functions of a SNEM solution. Two basic requirements that have consequences in every process step are caused by order relationships and the structural factors of autonomy and heterogeneity in supply networks: *Interdependencies in supply networks* and *Primacy of local data storage* (see fig. 2-8).

2.2.2.1 Interdependencies in Supply Networks

During the search process order relationships OR_{ji} between orders and suborders have to be taken into account. Information on suborders has to be gathered in addition to the reception of event information communicated from network partners regarding suborders. In the aggregation and interpretation process data from different network partners has to be aggregated and interpreted to evaluate effects of disruptive events that occurred in the network. In the distribution process order relationships determine potentially affected network partners that have to be informed proactively.

2.2.2.2 Primacy of Local Data Storage

The second basic requirement is established as a consequence of taking inter-organizational dependencies (see above) into account. Considering autonomy of supply network partners (see section 2.1.2.4), a replication of all SNEM data in a centralized data storage system for a supply network is neither acceptable to autonomous enterprises in general nor is it feasible. Otherwise, a huge amount of redundant data would have to be communicated, filtered, matched and stored for every supply network partner in one central data base. In addition, heterogeneity of partners regarding data and technological infrastructures makes centralized data storage extremely difficult and complex. In consequence, data sources that are available at each supply network partner should not be replicated unnecessarily elsewhere. Data between network partners shall only be exchanged upon request or when critical situations call for an alert of affected partners.

2.2.2.3 Proactive Monitoring of Orders

The first requirement regarding the "search/gathering" process concerns activities of gathering information. They have to be fulfilled proactively (see also section 2.2.1.1) and in a timely manner to provide a data basis for the next process steps. However, gathering information on monitored orders always incurs costs (e.g. communication costs, infrastructure costs, activity costs associated with personnel) that cannot be neglected. Therefore, identification of orders with a high probability of encountering disruptive events is needed. With this knowledge a more focused proactive monitoring has to be realized with the result of an improvement of a SNEM solution's efficiency regarding operational costs.

2.2.2.4 Flexible Monitoring in Changing Environments

Intensity of monitoring efforts has to be adapted to the likelihood of disruptive events (see section 2.2.2.3). In dynamic supply networks error-prone order types may evolve over time into reliable ones that need not be monitored as closely as newly evolving critical types. A proactive SNEM solution autonomously adapts to such new conditions in its environment and gathers SNEM data accordingly.

2.2.2.5 Autonomous Data Analysis

The set of data gathered from internal and external sources regarding the status of an order and its suborders has to be interpreted automatically by a SNEM solution. In a first step, dependencies between orders and suborders have to be considered while aggregating available SNEM data and calculating effects of deviations on a superorder's fulfillment that are encountered during suborders' fulfillment. In a second step, an evaluation of the