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PAMAS: Agent-Based Supply Chain Event Management System

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Abstract

The complexity and the dynamic behavior of fulfillment processes in supply chains define the need for innovative Supply Chain Event Management (SCEM) systems. Based on a generic concept for an agent-based SCEM system the realization of a prototype for a logistics service provider is presented. The proactive design of the order monitoring using adaptive order profiles and the integration of heterogeneous data sources from different supply chain partners ensure an optimized management of events during supply chain fulfillment.

Keywords: Supply chain event management, multi agent systems, adaptive behavior, order tracking

Introduction

Complex supply chains (SC) consisting of networks formed by different enterprises nowadays face continuous optimization efforts using e.g. advanced planning systems (APS). In the face of dynamic environments and uncertainties of the fulfillment processes, events such as irregularities and disruptions threaten the benefits of optimized plans for supply chains. Therefore the need for communication of information on such events across the supply chain is imminent. The growing market for "Supply Chain Event Management (SCEM)"[1] systems addressing these problems is an indicator emphasizing this circumstance (Bretzke et al. 2002). Two factors add complexity to the need for inter-organizational SCEM (see figure 1). First every supply chain consists of autonomous participants that are characterized by a heterogeneous structure with regard to their processes, products, company size and management style. Secondly the integration of processes in supply chains is very tight today (e.g. just-in-time relationships). They depend on tight delivery schedules with minimum stocks to buffer the following processes (e.g. in the automotive industry). Besides benefits regarding responsiveness and overall costs of the supply chain processes, an increasing vulnerability to irregularities and disruptions can be identified. Inter-organizational SCEM systems have to take these factors into account.

In this paper an agent-based SCEM concept and a prototypical realization of such an agent-system is presented. Software agents inherently meet the requirements for local autonomy and enable the consideration of inter-organizational interdependencies by means of advanced communication capabilities and flexible integration into existing IT-systems. The prototype was developed in cooperation with a business partner to ensure practical relevance of the system. The agent-based approach adheres to the following requirements:

- *Consideration of interdependencies in supply chains*
  The relationships between orders and suborders that are the result of division of labor have to be taken into account by inter-organizational SCEM solutions. Otherwise effects of events on the network cannot be reflected adequately.

- *Primacy of local data storage*
  As a consequence of taking inter-organizational dependencies into account, the data sources that are available at each supply chain partner are not to be replicated unnecessarily elsewhere. Data between supply chain partners is only to be exchanged upon request or when critical situations call for an alert of affected partners.

[1] SCEM systems monitor events in a supply chain (e.g. milestones, disruptions) and react according to predefined business rules (e.g. sending alert emails).

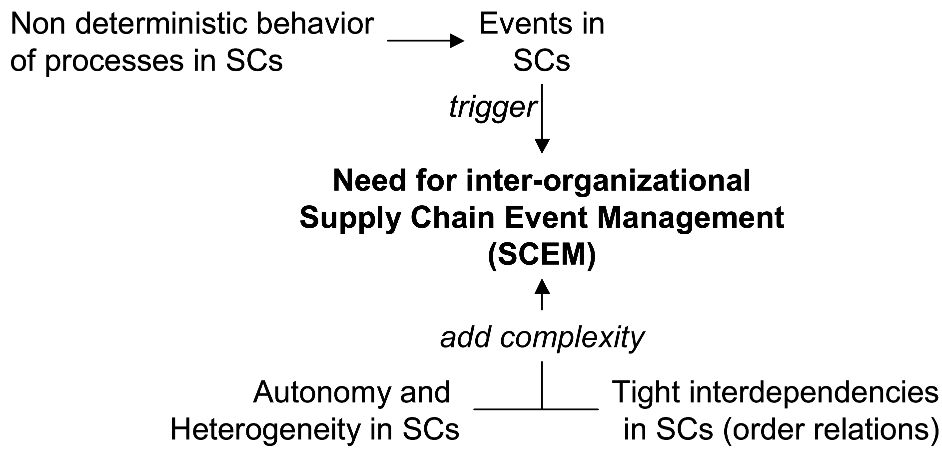

Figure 1. Factors Influencing SCEM

- *Proactive monitoring of potentially critical orders*
  Monitoring orders incurs cost that cannot be neglected. Therefore the identification of orders with a high probability of encountering events that threaten proper fulfillment is needed. With this knowledge a more focused proactive monitoring is enabled thereby optimizing the cost-benefit-relation of an SCEM solution.

- *Adaptability to new conditions in supply chain processes*
  The intensity of monitoring efforts has to be adapted to the likelihood of disruptive events. In dynamic supply chains especially error-prone order types may over time evolve into reliable ones that need not be monitored as closely as newly evolving focus points.

- *Autonomous interpretation of gathered information*
  The data gathered from internal and external sources regarding the status of an order and its suborders has to be interpreted. In a first step the complex dependencies between orders and suborders have to be considered while aggregating the respective information. In a second step an evaluation of the situation is necessary to generate a basis for taking decisions on possible reactions.

- *Intelligent generation of alerts*
  Based on the interpreted information a SCEM system has to be able to communicate with internal and external systems and users to inform them of important developments, to trigger reactions and to enable decision making.

Related Work

Classical tracking systems that are widely implemented within logistics service providers' (LSP) networks (Stein et al. 1998) and similar approaches of production control (Teufel et al. 2000) can be characterized as isolated and centralized systems without event management capabilities. Most of the SCEM systems available today have been developed by adding event management capabilities (e.g. rules for event handling) to existing centralized Enterprise Resource Planning (ERP) systems. Their perspective is primarily internal with a potential extension of external communication with supply chain partners. In addition some vendors of APS-systems offer SCEM solutions with a focus on the entire supply chain (Bretzke et al. 2002). Those systems have very rigid functionalities that do not allow to realize adaptive behavior in the face of environmental changes which results in extensive customization efforts to set-up such systems. Hence an agent-based approach is proposed that enables to conform to the requirements.

Typical applications of software agents in the supply chain domain focus on optimizing schedules through decentralized coordination mechanisms (e.g. (Wagner et al. 2002)). Other approaches to supply chain management suggest a wide array of different types of software agents that cover planning and execution of actions (e.g. (Fox et al. 2000)).

For an agent-based SCEM system insights on information gathering agents in supply chains can be of interest although they are generally concerned with searching for information in internet resources especially to prepare a transaction (e.g. comparing and combining offers) (Wagner et al. 2001). In contrast, the approach presented in this paper focuses on the monitoring of individual orders already issued.

Generic Agent-Based SCEM Concept

Today order tracking in SCEM systems is mostly limited to single enterprises. Suborders issued by an enterprise during procurement are not taken into account despite the interdependencies mentioned before. In essence each enterprise has to check its suborders that correspond to its monitored orders. The different functionalities needed for proactive SCEM to conform to the requirements defined above can be integrated in a generic algorithm (see figure 2). The monitoring of an order is triggered by either a query for information from a customer (respectively its software agent), an event signal (e.g. a disruption signal) from internal or external systems or – most importantly – by a critical order profile that matches a newly arrived order. An order profile describes a certain order type on the basis of common characteristics. For instance if deliveries to a certain destination frequently lead to delays during fulfillment, an appropriate order profile contains the name of this destination. The aim is to restrict the monitoring of orders to those with a high probability of facing irregularities during their fulfillment.

Besides querying external supply chain partners, data concerning internal processes of e.g. production has to be collected. Therefore the agent system needs access to internal data bases, for instance an enterprise resource planning system like SAP R/3. After receiving information from the supply chain partners concerning relevant suborders the current status of the monitored order has to be determined. Followed by the aggregation of data and an interpretation, alerts can be generated to inform affected actors or planning systems of the supply chain (internal and external).

This SCEM algorithm can be mapped to an agent architecture consisting of three layers of agents (Zimmermann et al. 2002a) (see figure 2). Each participant of a supply chain provides at least one such agent system with a set of instances of these agents. The technical link between these agent systems is realized via internet connections.

The first layer is characterized as the external communication layer which is represented by the discourse agent. It is concerned with communicating the monitoring information across the supply chain by interacting with the agent systems of other supply chain partners. This is needed when information on suborders is gathered (pulled) and when important status information is proactively distributed (pushed) in the supply chain.

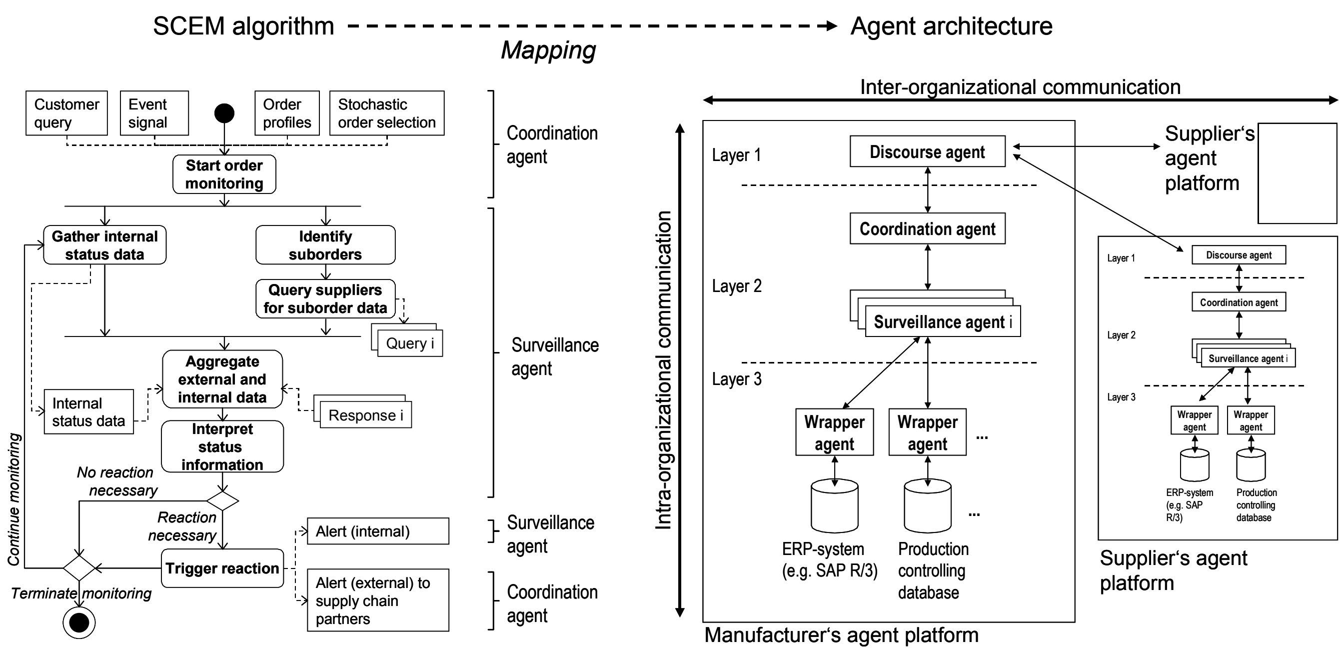

Figure 2. Mapping of SCEM Algorithm to Agent Architecture

Layers 2 and 3 host the tracking functionality. They are responsible for gathering and aggregating the desired tracking information from internal and external sources. In Layer 2 the coordination agent hosts, beside others, the order profiling functionality and thereupon decides autonomously which orders are to be monitored. In addition the request from a customer (agent) for status information will also force the coordination agent to trigger the monitoring of an order as long as the respective order is not yet monitored.

For each monitored order of an enterprise, a dedicated surveillance agent is triggered. It searches internally for desired status information (e.g. in the SAP R/3 system) and it communicates with other enterprises with the help of the discourse agent regarding the suborders of its monitored order. In addition, it aggregates the gathered information and interprets it. This information is related to the coordination agent, which in turn decides on an appropriate action if the situation calls for an external alert to a customer or supplier. However, simple internal alerts (e.g. an update of a graphical user interface (GUI)) are realized by the surveillance agent itself.

At the third level wrapper agents act as the interfaces to proprietary data sources, e.g. they enable the query of internal databases (e.g. an ERP system). Other types of wrapper agents can enable the query of internet resources, e.g. conventional tracking systems of carriers. In this way an integration of conventional – non-agent-based – external resources is also available, which facilitates the adaptation of the agent-based SCEM concept.

The PAMAS-prototype[2] is a realization of the basic agent architecture mapped to the detailed needs of a LSP. In this prototype the discourse agent has not been integrated, as the agent architecture of the business case does not include further agent-platforms at the suppliers' sites.

Business Case

The LSP handles approximately 200,000 to 250,000 orders per year at the facility analyzed in the business case. It receives orders from its customers which have to be fulfilled from stock. Therefore picking and packaging processes determine its process model. After releasing the orders to a carrier responsible for transportation, further milestones can be identified as depicted in figure 3.

The PAMAS system covers the whole process from warehousing to transportation, integrating information from different supply chain partners as needed.

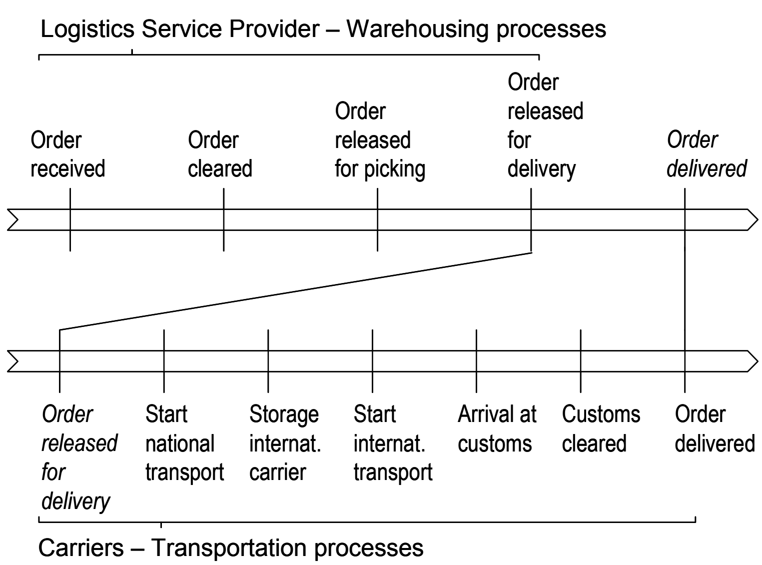

Figure 3. Milestones of the Business Case

[2]PAMAS = Proactive Order Monitoring Multi-Agent System (= „Proaktives Auftragsüberwachungs Multi-Agenten-System" [German]).

PAMAS Prototype

The architecture of the prototype is very similar to the generic agent architecture (see figure 4). The PAMAS system is based on a FIPA-OS platform that implements the FIPA standards. The system is FIPA-compliant using FIPA-ACL as the communication language.

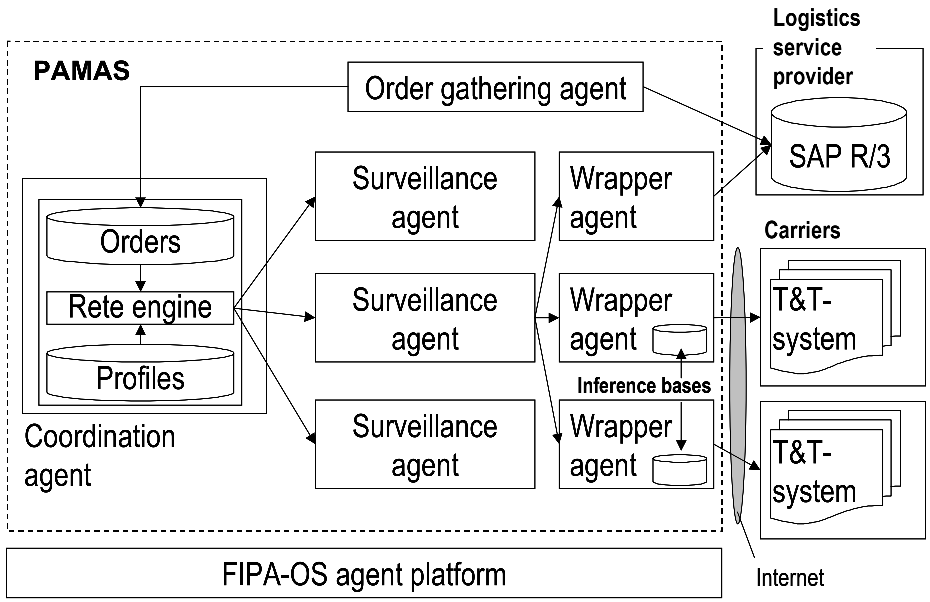

Figure 4. The PAMAS Architecture

Coordination Agent

The order profiling functionality of the coordination agent is realized by an integrated rule-based expert system called Java Expert System Shell (JESS)[3] with an internal knowledge base and an inference machine, which is based on the so-called Rete Algorithm, a very efficient mechanism to solve the "N:M comparison problem". (Forgy 1982), (Winston 1992). JESS continuously compares the incoming orders, which are conveyed by the order gathering agent from the SAP system, with the internal order profiles and thus identifies orders which have to be controlled. In case of a matching profile the coordination agent starts a surveillance agent dedicated to this order that monitors the fulfillment process across the entire supply chain from order reception to order delivery. The relevant milestones (see figure 3) and their planned dates of achievement are calculated (considering weekends and holidays) and communicated from the coordination agent to the respective surveillance agent. As a basis for this calculation a set of standard durations for different types of fulfillment processes (e.g. varying destinations) has been identified during interviews with experts of the LSP as well as some critical profiles.

Besides interviews with experts to define such critical profiles, the use of data mining methods allows to identify patterns in existing data pools (e.g. operational data from an ERP system) that can be condensed to profiles (Matheus et al. 1993). Since these algorithms are very complex an internal implementation was not intended for the prototype, but existing data mining tools as well as other agents can be integrated using a message interface. In addition, a randomizer generates new profiles from time to time, e.g. a profile consisting of shipments to Mexico with a certain carrier. All inserted profiles are managed by the coordination agent including the dynamic adaptation of profiles. A dynamic profile rating, evaluation of profile priority and automatic profile generation are the means to autonomously adapt profiles to the dynamic environment of a supply chain. For example if disturbances arise during the monitoring of orders the respective profile rating is increased otherwise reduced (see figure 5). Profiles, which in most or all cases lead to an error-free surveillance, are removed when they fall below a predefined limit. On the other hand profiles that uncover critical disturbances in the supply chain are monitored more intensely (e.g. queries for new tracking data are generated every hour instead of every three hours).

[3]**http://herzberg.ca.sandia.gov/jess/**, 2003-03-03.

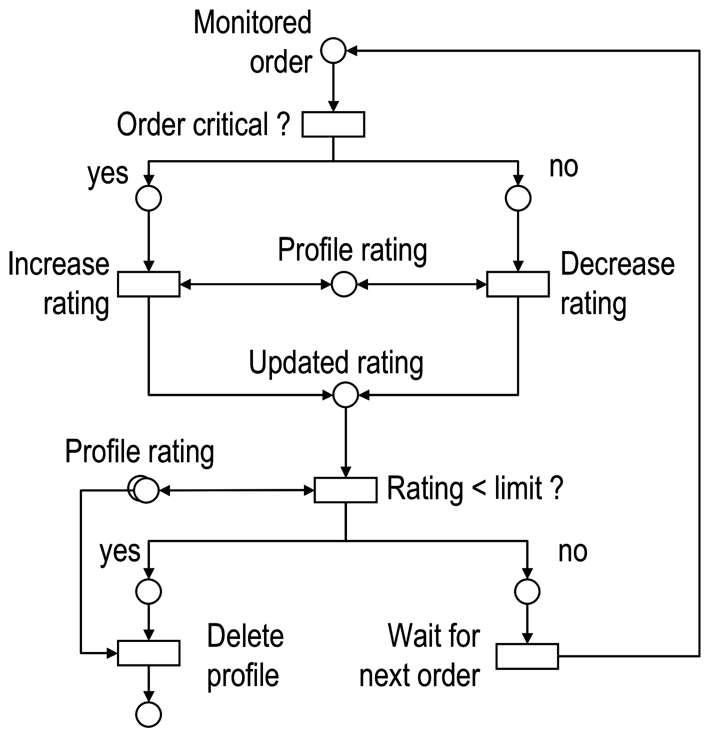

Figure 5. Dynamic Profile Rating

The coordination agent also offers a graphical user interface, which allows the user to monitor and manage the state of the entire tracking system from the point of view of the LSP (see figure 6). The user can configure the properties of the whole system, new surveillance agents can be started and managed, new profiles can be added etc.

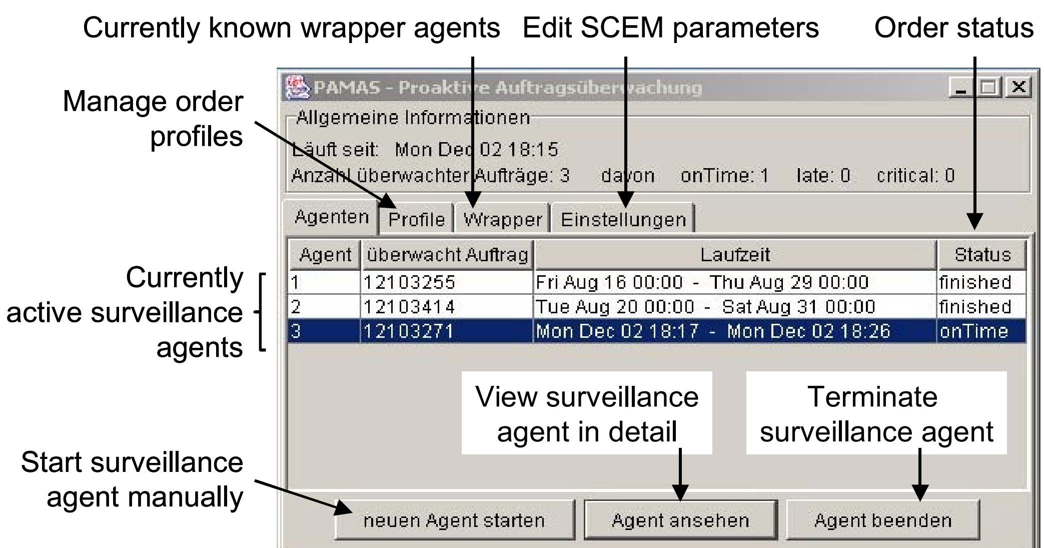

Figure 6. GUI of the Coordination Agent

Surveillance Agent

A surveillance agent is dedicated to monitor a single order of the LSP and the related (sub-) order(s) to carriers. The planned dates of achievement of the milestones are the basis for a temporal control and the quantities ordered by the customer are used for a quantitative control. The surveillance agent measures the current cycle-time of the order and continuously compares this with the planned date of the next milestone to be achieved. Via dedicated wrapper agents the surveillance agent periodically tries to gather the needed information from in-house systems (intra-organizational tracking) as well as from internet-based tracking systems of carriers (inter-organizational tracking).

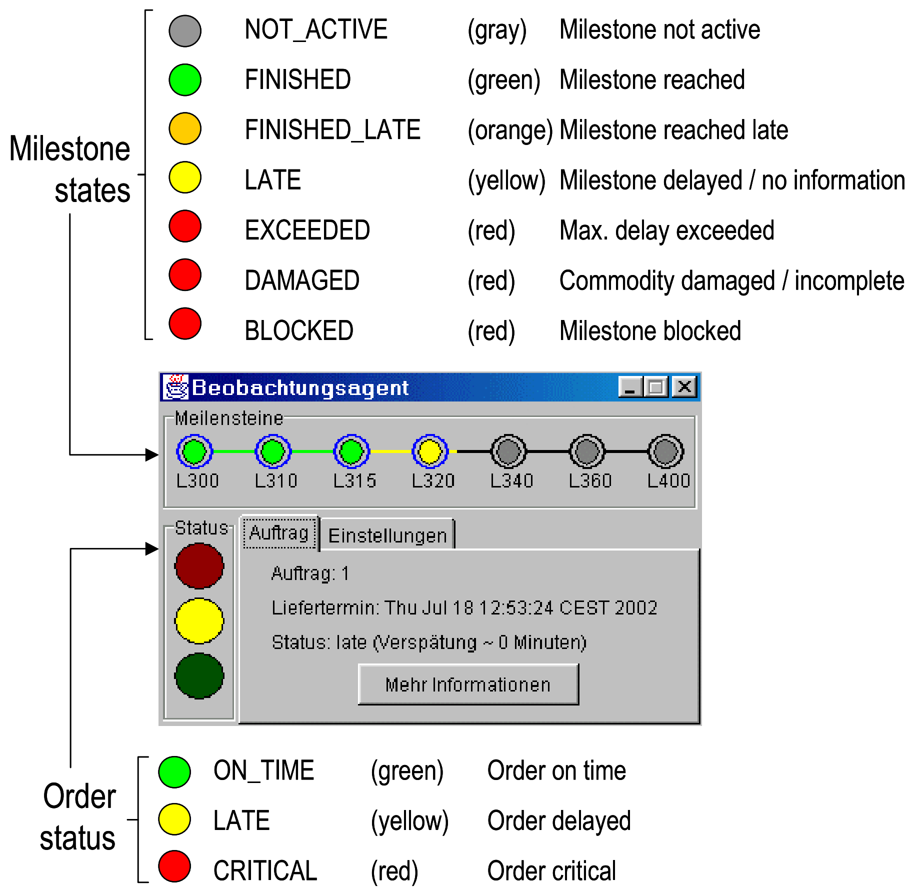

Figure 7. GUI of a Surveillance Agent

To indicate the status of a monitored order PAMAS differentiates between the states of single milestones and an aggregated status of an order. The states are defined as depicted in figure 7. Within the sequence of milestones the individual states of the already achieved milestones form a history, which is used for the calculation of an aggregated current order status. The order status indicates, whether an order is fulfilled properly, late but not critical or critical.

If a maximum delay is exceeded, the surveillance agent automatically sends a warning email to a person specified by the user of the PAMAS system. In addition the GUI of the surveillance agent is displayed to the user at the LSP ("pop-up"). Further SCEM functionalities for triggering specialized alerts can be added to the PAMAS system as needed.

Wrapper Agent

Because the monitoring data is collected from existing IT systems, e.g. a SAP R/3 system, other databases or internet based T&T systems, wrapper agents are needed. These offer a uniform and transparent access interface for the surveillance agents. Thus they hide the heterogeneity of the data sources from PAMAS.

Data offered by supply chain partners is available in different formats. Source documents based on XML or described by other types of meta data (e.g. an ontology or a Semantic Web document) are easily parsed, transformed into a uniform output and interpreted. This data can be accessed directly with existing query languages, e.g. Xpath/XQuery and the transformation can be accomplished with mapping concepts (Paschke, Hümmer 2002). In the business case the carrier's internet tracking systems only offer text based (HTML) documents without explaining tags. Therefore the wrapper agent needs exact knowledge concerning the structure of the document for parsing through the HTML code and searching for the desired information. It additionally needs syntactic and semantic knowledge for interpretation and transformation of the data. For this purpose each wrapper agent has an internal inference base that enables it to map milestone data of the carriers to the milestone definitions of the LSP.

Conclusion and Potential for Development

The PAMAS prototype implements most of the requirements defined above needed for an effective SCEM system. The main focus is on proactive gathering of order data from distributed local data sources across a supply chain with an additional attention to the adaptive behavior of the agent system. Regarding the other SCEM functionalities an autonomous interpretation of the data in the business case has been realized and basic alert mechanisms have been integrated. So far these are limited to the reporting of exception messages via email and via pop-up features of the surveillance agents. In addition, another more generic prototype is currently realized that implements an advanced fuzzy-based mechanism for aggregation and interpretation of data along with an enhanced alert-generator.

The prototype presented in this paper is able to work in a real-life context at the LSP. It is able to query the internal SAP-database as well as distributed tracking-databases of different carriers via their web interfaces. PAMAS can cope with a daily amount of orders reaching the magnitude of 30,000 orders that are inserted into the fact-base of the coordination agent. The coordination agent also possesses mechanisms to delete outdated facts which are needed for permanent operation of the SCEM system.

Web Services as an evolving e-business technology offer the potential to enhance the capabilities of the agent-based SCEM system. A web service is a modular application that delivers a service by means of the internet. It is developed in accordance to existing standards regarding self description, publication, localization and call, communication and data exchange. Especially for supply chain partners that do not want to implement an agent system but rather stick to their existing internal systems for tracking orders, the addition of web services to their existing functionalities is viable. This will allow flexible and efficient access for systems like PAMAS to relevant information regarding the monitored orders.

The agent system can be further supported with modern technologies for identification of goods called radio frequency identification (RFID) technology. An integrated approach using RFID technology and software agents for supply chain monitoring has been presented in (Zimmermann et al. 2002b). In addition, the information gathered during the SCEM process can be used for tactical and strategic supply chain performance measurement.

The integration of SCEM systems such as the PAMAS system into the planning and execution environment of a supply chain will allow to use simulations and optimization calculations to reduce the effects of unanticipated events. To enable a closed-loop agent-based supply chain management, an integration with other agent systems covering a variety of supply chain management tasks is addressed in the joint project "Agent.Enterprise"[4] (Frey et al. 2003).

[4]**http://www.realagents.org**, SIG Manufacturing Logistics.

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