6 A Service-oriented, Semantic Approach to Data Integration for an Internet of Things Supporting Autonomous Cooperating Logistics Processes

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Abstract The core vision put forward by the Internet of Things of networked, intelligent objects capable of taking autonomous decisions based on decentral information processing resonates strongly with research in the field of autonomous cooperating logistics processes. The characteristics of the IT landscape underlying autonomous cooperating logistics processes pose a number of challenges towards data integration. The heterogeneity of the data sources, their highly distributed nature along with their availability, make the application of traditional approaches problematic. The field of semantic data integration offers potential solutions to address these issues. This contribution aims to examine in what way an adequate approach towards data integration may be facilitated on that basis. It subsequently proposes a service-oriented, ontology-based mediation approach to data integration for an Internet of Things supporting autonomous cooperating logistics processes.

6.1 Introduction and Background

The concepts and technologies of the Internet of Things are rapidly becoming significant to challenges arising in the field of logistics. With today's globalised markets in a state of accelerating structural change, planning and control strategies need to be redefined, whilst traditional supply chains are evolving into complex networks of numerous stakeholders. The goods structure, logistics and structural effects identified by Aberle (2003) characterize these changes. The first describes a shift away from mass production towards a buyers' market, which creates a trend towards individual product customization and consequently a noticeable increase in per-unit shipments. The second effect describes a shift towards road freight transport which arises from the increasing demands for small shipments along with a high quality of service and due-date reliability. Finally, the structure effect indicates an individualization of transport on the micro-logistics level. Cooperation is required between otherwise competing logistics service providers to satisfy today's customer requirements. These three effects lead to a dramatic increase in the complexity and dynamics of transport logistics processes.

The core vision put forward by the Internet of Things of networked, intelligent objects potentially capable of taking autonomous decisions based on decentral information processing resonates strongly with research in the field of logistics aimed at addressing these effects. Autonomous cooperating logistics processes (Hülsmann et al. 2006) are a prominent example of such research. Here, "autonomous control" is understood as processes of decentralised decision-making in heterarchical structures. It anticipates interacting elements in non-deterministic systems, which possess the capability and possibility to render decisions independently (Böse and Windt 2007). Critical to this understanding is the decentralisation of decision-making responsibilities in contrast to traditional, hierarchical process control. This approach is motivated by an expected improvement in robustness and increase in scalability of process control, amongst other effects.

An example of the convergence of the concepts of the Internet of Things and autonomous cooperating logistics processes can be found in the use of software agents to implement information processing and decision taking entities (Timm 2006) for logistics processes, as described in Trautmann (2007) and Jedermann et al. (2008). In combination with an appropriate solution to mapping software agents as "digital counterparts" to physical logistics objects, using the auto-identification technology, middleware and standards of, for instance, EPCglobal (EPCglobal 2009) or ID@URI/Dialog (Främling et al. 2006), a foundation for an "Internet of Things for logistics" may be laid.

Research in autonomous cooperating logistics processes shows that different control problems arise from different applications of autonomous control, resulting in a wide spectrum of degrees of autonomy (Windt et al. 2008) with respective requirements towards the characteristics of the involved intelligent logistics objects as well as the underlying data processing, decision making and data integration strategies. This means that, in order for an Internet of Things to truly benefit the autonomous cooperating logistics processes on an operational level, the "things" therein not only need to be able to communicate with each other, but also be suitably integrated into the overall logistics IT landscape.

The IT landscape in logistics is already a highly complex, distributed and heterogeneous one even without taking autonomous cooperating processes into account. As shown in Fig. 6.1, significant effort was and still is spent in order to achieve at least integration between systems of certain business partners by bridging the technological islands through specific ICT solutions (Hannus 1996). However, most of these solutions sooner or later become obsolete due to the continuous development of the islands reflected by a steadily decreasing sea level as well as the highly dynamic partnerships within today's enterprise networks. Instead of developing solutions for 1:1 relationships a general solution must be found which allows a unique access to all relevant logistics data while accepting the diversity of existing systems and standards (Hans et al. 2008).

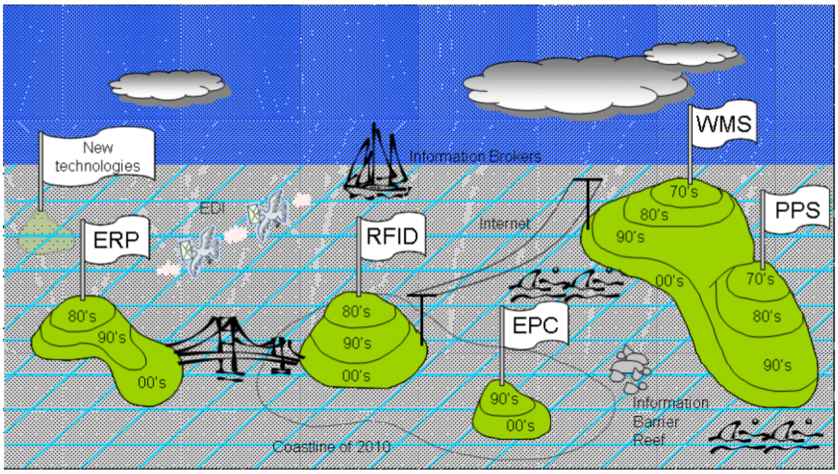

Fig. 6.1 The IT Landscape in Logistics – Bridging Islands (based on Hannus 1996)

This situation is exacerbated by developments in modern logistics such as autonomous cooperating logistics processes and the Internet of Things. Both developments lead to the creation of “new islands” of technology development in the IT logistics landscape. Depending on the application, relevant data may be stored in heterogeneous enterprise systems, such as Warehouse Management Systems (WMS), Enterprise Resource Planning Systems (ERP) or disposition systems. At the same time, data from item-level tracking and tracing systems needs to be taken into account, in particular that pertaining to RFID. Data may also be generated and stored in systems embedded into logistics objects such as trucks or containers, or be generated dynamically, for example by sensor networks monitoring the temperature of a refrigerated container. Whilst the specific requirements towards data integration differs according to the characteristics of each individual application of autonomous control, it can be said that, in general, digital counterparts representing individual logistics entities need to be able to access data relevant to their decision making processes, regardless which “island” that data may be located on.

The characteristics of the IT landscape underlying autonomous cooperating logistics processes outlined above pose a number of challenges towards data integration. The heterogeneity of the data sources, their highly distributed nature, along with their availability make the application of traditional approaches problematic. The field of semantic data integration offers potential solutions to address these issues. This contribution aims to examine in what way an adequate approach towards data integration may be facilitated on that basis. It subsequently proposes a semantic approach to data integration for an Internet of Things supporting autonomous cooperating logistics processes which combines ontology-based mediation with service-oriented integration.

6.2 State of the Art

The following sections outline the state-of-the-art in relevant areas of research. First, literature from the field of the Internet of Things is discussed in order to establish an understanding of the terminology used in the remainder of this contribution. Next, autonomous cooperating logistics processes are introduced and put into perspective with the perspective upon Internet of Things discussed in the previous section. Moving forward, approaches to data integration from two different areas are investigated. First of all, concepts and solutions for item-level information management for products and logistics objects are discussed. Secondly, approaches to traditional enterprise application integration are presented, which need to be combined with item-level information management approaches in order to facilitate intelligent data integration for an Internet of Things in logistics within the context of this contribution.

6.2.1 The Internet of Things

This section begins by clarifying the understanding of the Internet of Things used in the remainder of this paper, including a look at related developments in the field of Intelligent Products. It concludes outlining applications of the state-of-the-art to the field of logistics.

Terminology

The term “Internet of Things” was first used by the Massachusetts Institute of Technology in the year 1999. Here, it was used in the sense of a networked system of autonomously interacting and self-organising objects and processes, which is expected to lead to a convergence of physical things with the digital world of the internet (Brand et al. 2009). This extrapolates the idea of the Internet - a global, interconnected network of computers – to describe a network of interconnected *things* such as everyday objects, products, and environments. As such, the Internet of Things represents the common ground of a number of recent multi-disciplinary developments such as Ambient Intelligence (Ducatel et al. 2001), Ubiquitous (Weiser 1991) and Pervasive Computing (Gupta et al. 2001) and Auto Identification (Cole and Engels 2002). At the heart of the concept lies the idea that objects - *things* - are capable of information processing, communication with each other and with their environment, and autonomous decision taking.

Intelligent Products

One example of quite research towards the realisation of intelligent objects which exhibit the characteristics described above is the field of "Intelligent Products". Intelligent Products are physical items, which may be transported, processed or used and which comprise the ability to act in an intelligent manner. McFarlane et al. (2003) define the Intelligent Product as

> "...a physical and information based representation of an item [...] which possesses a unique identification, is capable of communicating effectively with its environment, can retain or store data about itself, deploys a language to display its features, production requirements, etc., and is capable of participating in or making decisions relevant to its own destiny."

The degree of intelligence an intelligent product may exhibit varies from simple data processing to complex pro-active behaviour. This is the focus of the definitions in McFarlane et al. (2003) and Kärkainen et al. (2003b). Three dimensions of characterization of Intelligent Products are suggested by Meyer et al. (2009): *Level of Intelligence*, *Location of Intelligence* and *Aggregation Level of Intelligence*. The first dimension describes whether the Intelligent Product exhibits information handling, problem notification or decision making capabilities. The second shows whether the intelligence is built into the object, or whether it is located in the network. Finally, the aggregation level describes whether the item itself is intelligent or whether intelligence is aggregated at container level.

The Internet of Things in Logistics

Concepts and technologies of the Internet of Things have previously been applied to problems in the field of logistics. For example, in the area of transport logistics, ten Hompel (2005) considers the autonomous transport of logistics objects from the sender to the delivery address an example of the Internet of Things. A further example is the discussion of the application of dynamic route planning algorithms in autonomous transport logistics networks (Berning and Vastag 2007). Besides basic, item-level tracking & tracing of goods along the supply chain and a general potential for the optimisation of processes (VDI/VDE 2008) and the improvement of Efficient Customer Response (ECR) (Gaßner and Bovenschulte 2009), the Internet of Things is of particular interest to the field of logistics.

The German national study QuinDILog, which focused on vocational qualification resulting from the implementation of IoT in logistics, identified a number of additional potentials of IoT for the field of logistics. For example, the granular, item-level documentation of supply chain events can allow for a greater transparency in contractual and legal matters (VDI/VDE 2008). Out-of-stock (OOS) situations may be avoided by automated positioning and warehouse management solutions (Gaßner and Bovenschulte 2009). Especially for critical goods such as foods or medicine, quality assurance (Jedermann et al. 2008), product pedigree and history traceability can be enabled using the Internet of Things. Protection against product theft and plagiarism (Staake et al. 2005) based on unique identification and positioning technologies is another example. Last, but not least, completely new business models like fourth party logistics (4PL) may developed on the basis of the Internet of Things (Schuldt et al. 2010).

Research in the field of Intelligent Products has also been applied to logistics. For instance, Kärkkiänen et al. (2003b) describe the application of the concept to supply network information management problems. Additional examples are the application of the Intelligent Products to the supply chain (Ventä 2007), to manufacturing control (McFarlane, et al. 2003), and to production, distribution, and warehouse management logistics (Wong, et al. 2002).

6.2.2 Autonomous Cooperating Logistics Processes

This section briefly introduces the research area of autonomous cooperating logistics processes. It furthermore presents the concept of intelligent logistics objects developed in that area of research. Subsequently, it puts the concept of intelligent logistics objects into perspective with the Internet of Things and intelligent products.

Terminology

In the context of this contribution, the term "Autonomous Control" is used following Böse and Windt (2007) to describe

> "...processes of decentralised decision-making in heterarchical structures. It presumes interacting elements in non-deterministic systems, which possess the capability and possibility to render decisions independently."

The research area of autonomous cooperating logistics processes (Freitag et al. 2004) aims to meet today's logistics challenges such as the goods structure, logistics and structural effects identified by Aberle (2003), by introducing autonomy and self-organisation into control, information processing and decision-making in logistics (Ehnert et al. 2006). The argumentation is that central control and planning of logistics processes has reached its limits in addressing these issues (Scholz-Reiter et al. 2004). Here, the term "autonomy" describes

> "...the capability of a system, process or an item to design its input-, throughput- and output-profiles as an anticipative or reactive answer to changing constraints of environmental parameters."

The application of autonomous control to logistics processes is expected to increase their robustness, flexibility, adaptability and reactivity to respond to changing business environments, requirements and to changing or partially conflicting objectives (Freitag et al. 2004). A prominent characteristic of this understanding is the decentralisation of decision-making responsibilities in contrast to traditional, hierarchical process control. A dynamic heterarchy in which otherwise passive logistics entities are equipped with the ability to process information, to render and execute decisions on their own replaces the strict centralised top-down management of traditional logistics processes. Artificial agents are entrusted to act in their own “best interest" within the bounds of their operational, tactical or strategic (Timm 2006) autonomies. The motivation for this approach is, amongst others, an expected improved robustness and increased scalability of process control.

Intelligent Logistics Objects

The concept of an intelligent logistics object is inherent in the understanding of autonomous control in logistics systems proposed by Böse and Windt (2007). Here,

> “...autonomous control in logistic systems is characterized by the ability of logistic objects to process information, to render and to execute decisions on their own.”

Logistics objects are defined in this context as both,

> “...material items (e.g. parts, machines or conveyors) and immaterial items (e.g. production orders) of a networked logistic system, which have the ability to interact with other logistic objects of the considered system.”

In Scholz-Reiter et al. (2007), the former are further differentiated as commodities and all types of resources and whilst constraining the immaterial logistics objects to orders.

According to this understanding, an intelligent logistics object is consequently either a material or immaterial logistics object which is capable of communicating and interacting with other logistics objects. It is a broader understanding than that of the Internet of Things which additionally encompasses autonomous objects without physical representations.

6.2.3 Item-level Information Management Approaches

Item-level information is that information which is specific to individual logistics objects or products. It is created in all processes a logistics object is involved in. These include, for example, production logistics processes as they occur in the beginning-of-life (BOL) phase of the product lifecycle (Hong-Bae et al. 2007), distribution (Hribernik et al. 2009) and service logistics processes as occurring during the middle-of-life (MOL) phase and reverse logistics processes which take place in the object’s end-of-life or EOL (Schnatmeyer et al. 2005; Schnatmeyer 2008).

Item-level information management can be based on standards for product information modelling and exchange. Existing standards, such those developed by ISO TC184/SC4 the technical committee, focus on product information and processes specific to BOL. The emerging standards ISO10303-239 (International Organization for Standardization 2009a) which defines Product Life Cycle Support (PLCS) and ISO 15926 (International Organization for Standardization 2009b) are exceptions, which deal explicitly with item-specific product information. Although PLCS is under continuously development to widen its scope of application, it currently focuses on specific maintenance processes in MOL. ISO 15926 caters for the oil and gas production domain but contains generic parts, such as the ISO 15926 Part 2 Data model, which is also used by other initiatives. However, both standards remain restricted to particular domains or processes. Moreover, information standards only address the information transfer and interpretations issues in the information management throughout the product life-cycle. Access to and consolidation of information is an issue to be solved for each inter-enterprise scenario.

Another prominent application domain is the area of shipment tracking. The tracking systems used by major forwarders or logistics service providers are perfectly engineered to suit situations where shipment is handled by a single organisation (Kärkkäinen et al. 2004). However, management of item-specific product information requires the support of multi-organisational networks, which is supported only by some approaches, i.e. the EPCglobal Architecture Framework, DIALOG, WWAI and the PROMISE Architecture. These approaches are introduced in the following sections in more detail.

EPCglobal Architecture Framework

The EPCglobal Architecture Framework (EPCglobal 2009) represents a collection of widely adopted industry standards in the field of auto-identification aimed at the coupling of information and material flows in retail logistics (cf. Fig. 6.2). It includes tag protocol standards for the physical and logical requirements of RFID systems and encompasses standards for the definition of item-level, unique identification codes, the Electronic Product Code (EPC). Of foremost interest towards data integration are the EPC Information Services (EPCIS) (EPCglobal 2007) and Object Name Service (ONS) standards specified in the framework.

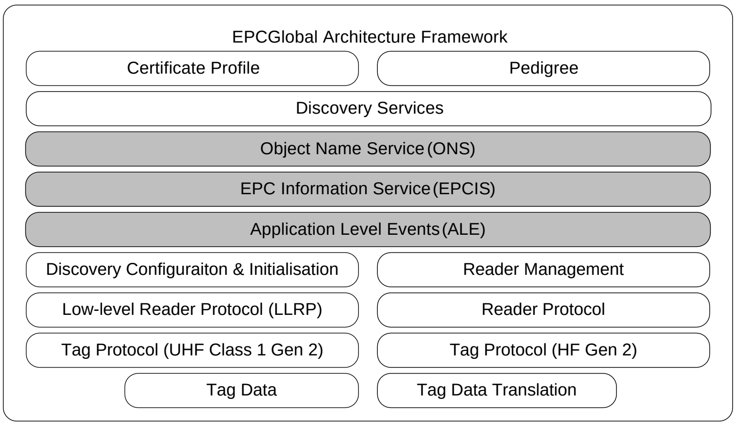

Fig. 6.2: The EPCGlobal Architecture Framework (EPCglobal 2009)

EPCIS is a standard that defines interfaces for the sharing of data among trading partners. Its aim is primarily to enable supply chain participants to gain real-time visibility into the movement, location and disposition of assets, goods and services throughout the world (Soon and Ishii 2007). EPCIS can be leveraged to track individual physical objects and collect, store and act upon information about them. By providing a standard interface to that information, EPCIS enable cooperation partners to seamlessly query such information throughout supply chains. At the present time, information service discovery operates at the product class level, and not the item level.

ONS defines a mechanism by which authoritative metadata and services associated with EPC Identifiers may be located in the network. Its function is to transform the EPC stored, for example, on RFID-Tags, via their corresponding Identity URI encoding into URLs, which may respectively point to a Web Service or other information resource. Performance and security issues have moved EPGglobal to develop alternative “discovery services” (Meyer et al. 2009).

Dialog

The Dialog system developed at Helsinki University of Technology aims at solving the challenges of item level information management without the need of developing new standards for product coding. In the DIALOG approach (Kärkkäinen et al. 2003a) an ID@URI notation is used as product identifier, where the ID part identifies the product item at the URI. The uniqueness of a URL is guaranteed by the Domain Name System (DNS) infrastructure. For an ID@URI to be globally unique, the ID part should be unique for that URI. The URI part of the Dialog product code indicates the location of the tangible object’s “agent”. The agent is a background service running at the computer indicated by the URI. It offers various interfaces for functionalities like location updates, product information requests, maintenance information requests etc. Each interface has its own characteristics concerning the information to exchange, restrictions on data security, authentication, authorization etc. Therefore security considerations can be treated in different ways depending on how “dangerous” the service provided by each interface is for the Dialog system itself and for the information systems of companies using the Dialog system (Kärkkäinen et al. 2003b).

World Wide Article Information

The World Wide Article Information (WWAI) approach, originally of the Trackway company, now a part of Elisa, provides an XML-based communication protocol for exchange and querying of product-related data. WWAI follows the structured peer-to-peer (P2P) approach and utilizes a hash algorithm to determine the node for the placement of data concerning a particular object, e.g. a product, in the network. This permits easy location of nodes potentially storing data for objects of interest. Furthermore, subscriptions can be specified for object IDs to automatically obtain new information on the objects. The main advantages of WWAI include an implementation of the protocol and the decentralized nature of the solution allowing for easy implementation and deployment. However, WWAI is a proprietary specification with currently little industry support. Furthermore, it is unclear how the approach addresses the critical issues of P2P networks, such as ensuring result quality and response time for queries, and limited querying capabilities confined to object ID exact matching (Do et al. 2006).

The PROMISE Architecture

The PROMISE Architecture is focussed on the concept of Product Embedded Information Devices (PEIDs). PEIDs (Jun et al. 2007) realise the concept of intelligent products and components acting as embedded information gathering devices linked to sensors, which are able to sense their environment and their condition wirelessly, for example via RFID or Universal Plug and Play (UPnP). PEIDs are categorised according to their capabilities with regards to data storage and data processing capabilities (cf. Table 6.1). In addition to the categories data storage and data processing shared with Böse and Windt (2007) the devices’ ability to integrate sensors as well as their options for network connectivity are used to differentiate different types of PEIDs. The sole common denominator of all types of PEID is, however, that they contain a global, unique identifier. This fulfils the most basic requirement towards integrating information with an intelligent object. PEID information is communicated to backend systems via a message and event based middleware (PROMISE Data Services) using a standardised and XML based PROMISE Messaging Interface (PMI) (Främling and Nyman 2008).

Table 6.1 PEID Classification according to (The PROMISE Consortium 2008)

Type	Identification	Data Storage	Sensors	Data Processing	Connectivity
Type 0	✓				Passive
Type 1	✓	✓			Passive
Type 2	✓	✓	(✓)	+	Wireless
Type 3	✓	✓	✓	++	Wireless
Type 4	✓	✓	✓	+++	Always

The PMI (Kärkkainen et al. 2003b) is an XML-based standard communication protocol linking the nodes of a PROMISE architecture implementation. An information model is instanced for each individual product on the basis of a semantic object model (Cassina et al. 2008). This is transformed into a semi-structured, syntactical model to define the information items related to each individual product (Främling and Nyman 2008), which in turn defines the structure and data types of the PMI messages. It provides functionality for the access to and management of item-specific product data in an expressive and generic way, and specifies both the syntax and semantics of a request and response pairs. Its main task is to represent item-level read requests and write commands from and to PEIDs and the other nodes in the PROMISE architecture. The InfoItem-Element is the central concept of PMI, representing the message payload used to fulfil queries. InfoItems use unique identifiers to address specific items and define both application and item specific data types. PMI supports event, message and subscription based communication between all nodes and forms the backbone of the PROMISE architecture.

6.2.4 Enterprise Application Integration Approaches

Taking into consideration the IT landscape in logistics as outlined in this contribution, approaches towards enterprise application integration need to be taken into account. This section outlines prominent approaches relevant to the problem area. First, traditional data integration approaches are outlined, with tightly coupled, loosely coupled and object-oriented approaches being discussed. Service-oriented architecture is briefly discussed and subsequently, the field of semantic mediation is introduced.

Traditional Data Integration Approaches

Whilst a tightly coupled approach can quickly be dismissed on grounds of its inflexibility, loosely coupled and object-oriented approaches cannot be adopted without critical analysis. An object-oriented approach generally provides good mechanisms for avoiding integration conflicts. However, when considering this approach, one must take into account that a single canonical model is required to describe the entire data model, which clearly restricts its flexibility and scalability. Each time a new stakeholder or data source enters the logistics system, the model needs to be extended. Depending on the dynamics of the logistics system, this may or may not be a disqualifying factor with regards to this approach. As the fluctuation of data sources, stake holders and systems in a complex logistics system with any degree of autonomous control can be assumed to be high, an object-oriented approach to data integration is likely to be unsuitable. A loosely coupled approach requires detailed knowledge of each of the heterogeneous data sources to be able to be successfully employed. With regards to complex logistics systems, further analysis is required to determine whether this is feasible or not. The possibility of requiring highly flexible, and thus possibly not always pre-determinable, context data, for example from sensor networks, may prove to be an argument against this approach.

Service-oriented Architecture

A software architecture is described as service-oriented when it uses loosely coupled software services to provide functionality (Stojanovic et al. 2004). Here, logic is not packaged as individual programmes, but is distributed across an amount of independent services. The actual implementation details of these services by their provider are completely transparent to the consumer. The most popular implementations of service-oriented architecture (SOA) are carried out using Web Services (Thoben et al. 2003), which are built using the combination of the XML standards, Simple Object Access Protocol (SOAP) (cf. Gudgin et al. 2003), Web Service Definition Language (WSDL) (cf. Christensen et al. 2001) and Universal Description, Discovery and Integration (UDDI) (cf. Clement et al. 2004). These standards, in combination with the Hypertext Transfer Protocol (http), provide a system independent approach to the discovery, identification, provision and consumption of services according to SOA. However, a SOA may also be built using other technology such as Common Object Request Broker Architecture (CORBA), Distributed Component Object Model (DCOM) or Enterprise Java Beans (Blanke et al.. 2004).

Semantic Mediation

Besides the traditional approaches to data integration, a number of predominantly semantic approaches remain to be taken into account. Here, the main concepts constituting architecture of such data integration systems are mediators (Ullman 1997; Wache et al. 2001 and Wache 2003). In this approach, both syntactic and semantic descriptions of the data to be integrated are applied. The semantic mediator is capable of extracting knowledge regarding the data structures of the underlying data sources and subsequently transforming, decomposing and recomposing data requests according to that knowledge. The mediator relies on semantic descriptions of the data sources. In the case of autonomous logistics processes, this implies a wholly semantic modelling of the relevant logistics information and data across the distributed, heterogeneous sources, for which a number of approaches, such as ontologies, may be chosen. Here, extensive research is required to determine whether such semantic descriptions of logistics data are feasible and adequate to address the requirements of autonomous logistics processes.

6.3 Problem Analysis

In the following, this contribution concentrates on examining how decentral data storage may be facilitated to support an Internet of Things for the autonomous control of logistics processes. It examines the advantages of combining a service interface with a semantic approach to data integration for solving this data integration problem.

The understanding of an Internet of Things for logistics presented in this paper so far contributes to the fulfilment of these criteria and consequently to an increase in the degree of autonomy of logistics processes. Firstly, the Internet of Things displays high degrees of data processing decentrality with Things explicitly required to be capable of local data processing. Furthermore, Things are expected to communicate with each other in order to coordinate their decisions.

Currently, the discussion of data integration from the perspective of the Internet of Things in logistics focuses mainly on the facilitation of information exchange between individual physical, intelligent objects. The reasoning behind this is to separate the operational level of control from the strategic in order to create more autonomous, robust and flexible operational systems. However, this is not always the most appropriate solution. Research in autonomous cooperating logistics processes shows that different control problems arise from different applications of autonomous control, resulting in a wide spectrum of degrees of autonomy (Windt et al. 2008) with respective requirements towards the characteristics of the involved intelligent logistics objects as well as the underlying data processing, decision making and integration strategies.

6.3.3 Logistics Systems Integration Targets

A market study of the current IT logistics system landscape was carried out by the authors in the context of CRC637 Autonomous Cooperating Logistics Processes in order to identify potential integration targets for intelligent logistics objects in autonomous cooperating logistics. The study covered 122 different IT systems on the market used in distribution, transport, retail, and warehouse logistics. It focused on identifying the foremost data exchange formats in the field by collecting information regarding the systems' interface capabilities. Additionally, database and ERP interoperability were examined alongside auto-ID support.

According to the study, the most prominent interface is EDIFACT EANCOM with 62% implementation, followed by SAP with 54%. Third is EANCOM XML with almost 39% use, closely followed by ebXML with almost 36%. To put this in perspective, almost 32% indicated the implementation of bespoke proprietary interfaces only.

The study reveals a large number of different IT systems, data models and exchange formats are employed to support logistics processes. Whilst a significant share of the market can be addressed by EANCOM, SAP and ebXML, still almost one third of all systems exhibit proprietary interfaces.

6.3.4 Integrating Intelligent Logistics Objects

Dynamic data sources in an Internet of Things in logistics are foremost material intelligent logistics objects themselves. The characteristics of intelligent logistics objects are quite close to those defined by Meyer et al. (2009) in their classification of Intelligent Products. Furthermore, the PEID classification scheme in Table 6.1 gives an overview of the types of technology and interface used to realise intelligence embedded into products. This classification is a good indicator to the requirements towards data integration for such devices. The following sections have been derived from the classification scheme and discuss the identification of intelligent logistics objects, data storage and connectivity issues and sensors. A section dealing explicitly with immaterial logistics objects concludes this discussion.

Identification of Intelligent Logistics Objects

In order to be able to make decisions regarding the entities within an autonomous logistics system, a mapping between the individual entities and their descriptive data is imperative. The study mentioned in the previous section shows the most supported auto-identification technology by logistics systems today is RFID (65%) with EAN and EPC numbering schemes, both exhibiting about 60% support. Alternative approaches should, however, not be discounted. Among these are the approaches discussed in "state-of-the-art", such as ID@URI/Dialog and WWAI.

Data Storage and Connectivity

With a mapping between the individual entities and their descriptive data facilitated using auto-ID technology, as described above, data in backend systems can be attributed to intelligent logistics objects by mapping an identifier to the data. This can, in principle, be applied to data stored on dynamic data sources as well. However, dynamic data sources bring with them added complication of not always being accessible, having data volume restrictions, and other hardware-related issues. Furthermore, the disparity of different implementations is a problem. From RFID via embedded systems to full-scale, integrated computing devices such as OBUs (On-board Units), the scope of systems to be integrated is wide. A number of existing approaches exist to overcome these limitations. RFID middleware such as the EPCglobal Architecture Framework can be used to abstract from RFID hardware. For PEIDs, the PMI standard can be used in combination with the PROMISE development CorePAC, which is a hardware abstraction layer for different PEID types. Other approaches in this area include the deployment of OSGi components, amongst a number of more proprietary solutions.

Sensors and Actuators

Sensors are of particular interest to autonomous cooperating logistics processes for their ability, for example, to monitor the condition of cargo. The integration problem with regards to sensors and sensor networks is similar to that of data storage above – sensors can simply be seen as a specific type of dynamic data source. On top of the approaches discussed above, such as PMI and OSGi, a number of standards for the description and communication of sensor data exist. Foremost amongst these is the work of the Open Geospatial Consortium, SensorML. SensorML provides standard models and an XML encoding for describing sensors and measurement processes.

Actuators are relevant to the field of autonomous cooperating logistics processes where intelligent logistics objects with capabilities for autonomous decision making are designed to directly act upon the physical logistics environment. Examples of these kinds of intelligent logistics objects include autonomous forklift trucks (Schuldt and Gottfried 2008) or intelligent production machines (de Souza et al 2008). Besides bespoke proprietry data exchange formats, a number of contributions towards the standardisation of interfaces towards actuators exist. Foremost are the contributions from OPC, ASAM-GDI and SAP. The OPC Unified Architecture (OPC UA) encompasses a comprehensive framework for the integration of automation technology including actuators. In contrast to the preceeding standard OPC Data Access (OPC DA), the Unified Architecture makes use of a service-oriented approach instead of the Microsoft Distributed Component Object Model (DCOM) interface. The standard General Device Interface (GDI), proposed by the Associsation for Standardisation of Automation and Measurement Systems (ASAM), and the related Open Robot Resource Interface for the Network API (ORiN) aim to provide platform and framework independent access to devices such as actuators, and has been adopted into the ISO standard 20242 on Industrial automation systems and integration (International Organization for Standardization 2009c). Finally, the SAP-driven SOCRADES initiative strives to establish a service-oriented integration architecture for manufacturing resources (de Souza et al 2008).

Immaterial Logistics Objects

In addition to the categories defined here, immaterial logistics objects need to be considered. This is, in fact, merely a formal amendment – immaterial logistics objects can be considered to be Intelligent Products with intelligence located in the network, but without a physical manifestation. Without having to resort to proprietary implementations, immaterial logistics objects may be handled using existing standards. For instance, orders, invoices and other data pertaining to this type of object can be interfaced using the relevant messages of the EDIFACT EANCOM standard data exchange format. Furthermore, as shown in Hribernik et al. (2009), immaterial logistics objects may be identified and described by participating stakeholders using URIs in EPCIS events. Purchase orders may be mapped to physical entities via the BusinessTransactionID vocabulary that may point to an URI describing the transaction.

6.3.5 Summary of Data Integration Requirements

The following table (Table 6.2) summarises the previous section by listing the major integration targets for autonomous cooperating logistics processes. Four types of integration target are differentiated between:

1. Logistics IT systems, describing IT systems in logistics such as ERP, WMS, disposition and other "traditional" enterprise systems used in logistics
2. Intelligent material logistics objects – which relate to material intelligent logistics objects, which exhibit characteristics of the PEID classification scheme
3. Digital counterparts – these relate to the decision making components of intelligent logistics objects, whether located in the object or in the network
4. Sensors and actuators – relating to sensors, sensor networks and actuators, which fall outside of the previous categories

A specific category has neither been defined for immaterial logistics object nor smart environments. If the former is "intelligent", it is merely a digital counterpart without a physical component. Consequently, the category "digital counterpart" suffices. Where a logistics object merely exists, e.g. as an order in an ERP system, the underlying logistics IT system is all that is needed to be taken into account.

With regards to the latter, intelligent logistics objects encompass not only goods but also logistics resources, such as machines, vehicles, transport nodes, etc. Consequently, data sources in a “smart environment” as suggested by ubiquitous computing and ambient intelligence are simply specific instances thereof and need not be treated separately. Examples are a warehouse with a sensor network installed or a truck equipped with an on-board unit. There is obviously some overlap between the categories, especially between “intelligent material logistics objects” and “digital counterparts”, depending on the implementation choices towards decision making and information processing. For example, it is quite possible to install software agents on OSGi components. These grey areas, however, do not affect the aim of identifying data integration requirements.

Table 6.2 Major integration targets in autonomous cooperating logistics processes

Integration Target	**Type(s)**	**Interface/standard**	**Type of interface**	**Importance (0-5)**
Logistics IT systems	General	EDIFACT EANCOM	Semi-structured text	●●●●●
		EANCOM XML	Semi-structured text	●●●
		ebXML	Semi-structured text	●●●
	SAP compliant	SAP RFC (Remote Function Call)	ABAP function interface (proprietary)	●●●●●
	Other	Bespoke proprietary	Misc. proprietary interfaces	●●●
Intelligent logistics objects	EPC compliant	EPCIS	Semi-structured text, service binding	●●●●●
	ID@URI compliant	Dialog	Services	●●●
	PEIDs	PMI	Semi-structured text, Service binding	●●●●
	OSGi-based	OSGi	Service	●●●
	Other	Bespoke proprietary	Misc. proprietary interfaces	●●●
Digital counterparts	Multi-agent based (e.g. JADE, PlaSMa, Dialog)	ACL (Agent Communication Language)	Agent language, onotlogy	●●●●
		Agent proxies	Services	●●●
		Dialog agent	Services	●●●
		EDIFACT EANCOM	Semi-structured text	●●
Sensors & actuators	Java-based	OSGi	Service	●●●
	OGC compliant	SensorML	Semi-structured text	●●●

PEIDs	PMI	Semi-structured text, service binding	●●●●
Other sensors	Bespoke proprietary formats	Mainly semi-structured text	●●●●●
OPC	OPC DA	MS DCOM	●●●
	OPC XML DA	MS DCOM, Semi-structured text, service binding	●●●
	OPC AU	Services	●●●●●
General	GDI	Remote procedure calls, GDI data types	●●●
	ORiN API	Service, DCOM, semi-structured text	●●●●
Smart Embedded Devices in Manufacturing	SOCRADES	Services	●●●
Other actuators	Bespoke proprietary formats	Misc. proprietary interfaces	●●

With regards to logistics IT systems, EDIFACT EANCOM and SAP RFC are the most prominent targets. However, the more than 30% systems with proprietary interfaces cannot be neglected. Consequently, a data integration approach must be able to cope with both semi-structured, standard data exchange formats as well as function interfaces and be flexible enough to cope with arbitrary proprietary interfaces.

To integrate intelligent material logistics objects, the support of RFID middleware standards such as the EPCglobal Framework Architecture, foremost EPCIS, is mandatory. In addition, a means to interfacing emerging standards for the integration of PEIDs and other embedded devices is necessary. PMI currently offers the most comprehensive and structured approach to this.

The field of digital counterparts is dominated by software agent technology. The PlaSMa platform is dedicated to the support of autonomous cooperating logistics processes and is consequently of highest priority. Other approaches favour service interfaces. The possibility of agent communication via EANCOM strengthens the need for EANCOM support, but is at the present time not widespread.

Sensor and sensor network integration is at the present time largely a case-by-case decision, with most interface using proprietary approaches. However, emerging standards such as PMI or SensorML are increasing in importance and should not be neglected. A data integration approach therefore needs to be highly flexible towards sensor data sources. With regards to actuators, a promising contribution can be found in the Unified Architecture standards put forwards by OPC. A proposed data integration approach should also take into account the standards emanating from ISO 20242 and factory automation initiatives such as SOCDRADES:

6.4 Solution Concept – A Service-oriented, Ontology-based Mediator

The following sections outline a solution concept for data integration for an Internet of Things for autonomous cooperating logistics processes. The concept describes a service-oriented, semantic approach to data integration which addresses the requirements outlined in the previous section. The concept consists of two main solution components – first is an ontology-based mediator, second a service interface layer defining logical views upon that mediator. These two components are described in the following sections.

6.4.1 Ontology-based Mediator

At the heart of the solution concept lies an ontology-based mediator component (Ullman 1997, Wache et al. 2001 and Wache 2003), which is capable of composing queries to any combination of relevant logistics data sources. It achieves this by semantic mediation. Each data source is fully described syntactically and semantically by an ontology, which can be mapped onto the others by the mediator. Wrapper components handle the transformation to and from the relevant data sources in a rule-based fashion.

The proposed system architecture illustrated in Fig. 6.3 follows the traditional pattern of a semantic mediator - besides the actual mediator component, which possesses an ontology of autonomous cooperating logistics processes, the wrapper components each contain extension ontologies, which fully formalize the data sources they are responsible for as semantic descriptions. Heterogeneity conflicts are solved either by the mediator component itself or by the respective wrapper, depending on the type of conflict

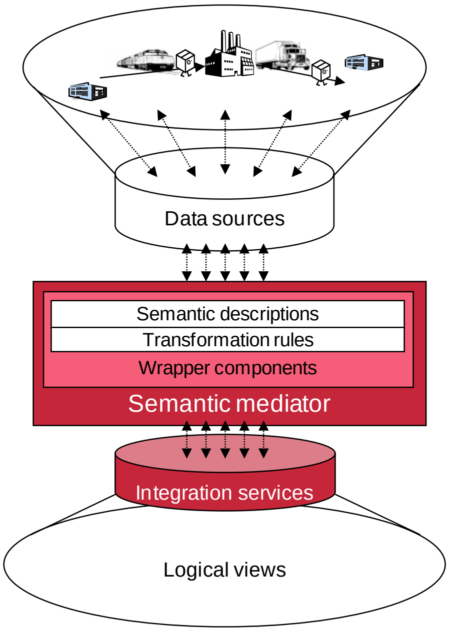

Fig. 6.3 Concept of a service-oriented, ontology-based mediator

The following sections describe the components of the ontology-based mediator in more detail, on the basis of a prototypical implementation of the solution concept.

Semantic Descriptions of the Data Sources

The Web Ontology Language (OWL-DL) (Smith et al. 2004) was used for the specification of the ontology, which describes the individual data exchange formats. OWL-DL was chosen for three reasons: first of all, it is used in the multi-agent system for the description of the domain of autonomous controlled logistics. Secondly, it was judged to be adequately expressive to cover the semantic description of both the standard exchange formats used in transport logistics and the overarching concepts of autonomous logistics processes. Finally, a number of Java libraries and reasoners are readily available for OWL-DL, which was expected to significantly accelerate the development of a prototypical implementation.

By implementing semantic descriptions and transformation rules for the major interfaces to IT systems in logistics and intelligent material logistics objects identified in Table 6.2, access to the majority of relevant data sources can be given. As a proof of concept, this was prototypically implemented as wrappers for both the EDIFACT EANCOM and EPCIS formats. Additional standards and proprietary data sources can be integrated easily by adding a new wrapper with the relevant semantic description and set of transformation rules, making the concept highly extensible. This approach also allows the service consumer to either easily integrate the required services into its own logistics IT landscape, or, for example, utilize thin clients to access a web-based GUI towards the cloud services.

Data Transformation in the Wrappers

The wrappers query data from the respective data sources and transform it via an internal format in order to enable the processing of data from heterogeneous data sources and formats. The transformation is carried out within the wrappers and is transparent to the actual mediator component. This allows for a complete abstraction from the data sources. Transformation in the wrappers is rule-based. A first prototypical realisation described and implemented these using to the business rule management system “Drools” (Drools Community 2009) (Drools - Business Logic Integration Platform). The use of Drools offered the possibility to react more quickly and flexibly to modifications to individual data sources. However, this approach proved slow and inaccurate in practice. A dedicated, generic algorithmic approach was specified and implemented, which makes use of transformation rules stored in XML-Files. Should a change be needed to be made, only the rule files would need to be updated. Modifications to the source code of the wrappers with subsequent recompilation and deployment can be avoided in this way.

Internal Query Interface

The query language “SPARQL” (Prud'hommeaux and Seaborne 2008) is used as the query language at the query interface of the system. It was specifically developed for querying ontologies and thus provides an adequate basis for queries to the semantic mediator. However, SPARQL only offers the possibility to query the system but not write to it. However, SPARQL alone doesn’t fulfill all of the requirements, because agents representing autonomous objects also need to be able to create messages and data. To extend the functionality to support bidirectional queries, the “SPARQL Update” (Seaborne et al. 2009) language was used to extend the SPARQL query language. This allows for the editing of ontologies with a similar syntax to SPARQL. A combination of both languages was specified and prototypically implemented as the query language of the semantic mediator.

Hardware Abstraction towards Dynamic Data Sources

The proposed concept also facilitates the direct integration of dynamic data sources used in logistics processes, such as RFID, sensors, sensor networks and other systems integrated into physical logistics objects. By abstracting from the physical interfaces towards these data sources, the semantic mediation approach may be applied in much the same way it is to static data sources. The abstraction layer is required to be able to provide a reliable interface, regardless of the physical accessibility of the dynamic data sources at any time. It is responsible for buffering, filtering and routing data to and from the respective data sources. It may consist of elements such as the FOSSTRAK (Floerkemeier et al. 2007), HAL towards EPC-compliant RFID, PMI (Främling and Nyman 2008) towards PEIDs (Jun et al. 2007) or OSGi towards sensor components (Ahn et al. 2006).

Interoperability with Existing Ontologies

The ontology used is a critical success factor of any semantic mediator. It has to reflect all the characteristics of the application domain and simultaneously has to be as simple and comprehensible as possible. Many existing onotologies may be taken into consideration for the semantic description of the entities in the given transport logistics scenario, such as those used in the fields of product lifecycle and data management as exemplified by (Terzi 2005; Tursi 2009 and Lee et al. 2009). However, none of these truly reflect the syntax and semantics of autonomous logistics processes whilst encompassing the syntax and semantics of standard logistics data exchange formats. Consequently, as a first step, a new ontology was designed based on both the application scenario and the top-level ontology of the multi-agent system, which describes basic concepts of autonomous logistics processes. It can be extended by incorporating additional ontologies into the system. One particularly interesting option is the alignment of the ontology with the PROMISE semantic object model, which already reflects many aspects of item-level information management of intelligent objects, albeit in the field of Product Lifecycle Management.

6.5.2 Service Interface Layer for Logical Views

A service layer is designed as the external query layer towards the semantic mediator. This design decision was made for three interrelated reasons. The first and decisive reason for a service-oriented interface layer lies in its ability to efficiently implement logical views upon the heterogeneous, distributed data made accessible by the semantic mediator. In this context, a logical view is a data model into which a subset, or even entirety, of the data made available by the semantic mediator may be transformed. In simple terms, the mediator pre-processes the queried data into that data model the recipient requires. The goal of the implementation of such logical views is to make the process of semantic mediation as transparent as possible to the consumers of the mediation service.

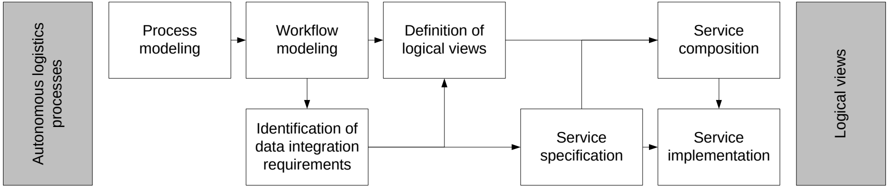

Fig. 6.4 Method for defining logical views and corresponding service compositions

Logical views upon mediated data may be designed effectively using the methods of service-oriented architecture. This also brings with it the distinct benefit of facilitating a process-oriented, model-driven approach to their design. The procedure sketched in (cf. Fig. 6.4) may be applied to design logical views for specific autonomous cooperating logistics. The first step is to model the autonomous cooperating processes, e.g. using EPK. From that model, a workflow model may be derived in a language facilitating the model-driven design of SoA, such as Business Process Modelling Notation (BPMN). On the basis of such a model, data requirements may be identified using e.g. UML sequence diagrams. Both the workflow model and the data requirements can be used to derive a logical view, which can be modelled e.g. as UML class diagrams. In the next step, services fulfilling the data requirements may be specified. The services are then implemented and mapped to mediator queries, in this case to SPARQL queries. Service compositions may be designed based on the defined logical views in e.g. Business Process Execution Language (BPEL), which can be mapped across from the BPMN workflow model. This mapping may be guided by the defined logical views.

The second reason for designing a service interface is that a number of major integration targets already at least optionally define service interfaces to their data. Especially for the most relevant service bindings, such as EPCIS and PMI, the addition of native service interfaces towards the mediator has several benefits. One advantage is that systems supporting these service interfaces gain native access to all data sources integrated by the mediator. They consequently inherit all of the advantages of semantic mediation for autonomous cooperating logistics processes in their specific application domain. Such service interfaces can simply be designed as logical views, as described above – using this mechanism, the mediator might, for example, provide the logical view of EPCIS events upon a subset of the available data.

Finally, to define the proposed internal SPARQL query layer as the external interface would effectively create a further “proprietary data source” in the IT landscape in autonomous cooperating logistics processes.

6.6 Conclusions and Outlook

In this contribution, requirements towards an adequate approach to data integration for an Internet of Things supporting autonomous cooperating logistics processes were discussed on the basis of both different types of intelligent logistics objects and the relevant IT systems in logistics. The requirements indicate that in order to successfully provide intelligent logistics objects with the data they need for varying degrees of autonomous control, a number of data integration targets need to be addressed. For the operational integration of IT systems in logistics into an Internet of Things supporting autonomous cooperating logistics processes, foremost specific data exchange formats, such as EDIFACT EANCOM and ebXML need to be taken into account besides SAP RFC. However, due to the fact that almost one third of logistics systems do not comply to standard interfaces, the data integration needs to be flexible enough to efficiently cater for arbitrary proprietary interfaces.

Besides interfacing such enterprise systems, an adequate data integration mechanism is also required to cater for the integration of dynamic data sources, foremost material and immaterial intelligent logistics objects and sensors. Here, the necessity for catering for a plethora of different semi-structured and service-based interfaces defined the data integration problem. Furthermore, abstraction towards the hardware platforms of the data sources is identified as a further problem to be tackled.

A service-oriented, ontology-based mediator is proposed as one approach to meeting these integration requirements. Ontology-based mediation brings with it a number of advantages when tackling the identified integration issues. For one, the heterogeneous data sources need not be touched. By defining wrapper components containing semantic descriptions of the data sources along with transformation rules, data sources may be integrated in a flexible fashion. Access to dynamic data sources can be ensured using hardware abstraction towards both, physical intelligent logistics objects and sensor components. Interfaces to existing hardware abstraction middleware, such as defined by PROMISE or EPCglobal may also be integrated. Finally, a service interface layer is proposed to provide logical views for consumers of the mediation service. By leveraging the strengths of service-oriented architecture, logical views can be developed for individual consumers, according to a model-driven method. Logical views can consequently be designed on the basis of models of autonomous cooperating logistics processes, for both, participating IT systems and intelligent logistics objects.

Validation of the prototypical implementation against exemplary application scenarios has demonstrated the applicability of the semantic data integration to an Internet of Things in the field of autonomous cooperating logistics processes (Hribernik et al. 2010). The semantic mediator proved capable of fulfilling bidirectional data integration in these scenarios. However, a number of issues remain to be tackled. Foremost is the better integration of sensors and sensor networks into the data integration approach. Here, work will be focused on the definition of a more comprehensive hardware abstraction layer for fulfilling all requirements towards the integration of dynamic data sources and sensors.

Future research will concentrate on leveraging the potential of using ontologies to semantically describe data sources. In order for the ontology-based mediator to react flexibly to changes in the autonomous cooperating process and IT landscape, methods of ontology learning may be applied to contribute to automating the currently manual process of data source description.

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