AN INTERNET OF THINGS FOR TRANSPORT LOGISTICS - AN APPROACH TO CONNECTING THE INFORMATION AND MATERIAL FLOWS IN AUTONOMOUS COOPERATING LOGISTICS PROCESSES

Hribernik, Karl A.[1]

Warden, Tobias[2]

Thoben, Klaus-Dieter[1]

Herzog, Otthein[2]

[1]BIBA - Bremer Institut für Produktion und Logistik GmbH

Hochschulring 20, 28359 Bremen, Germany

[2]TZI - Center for Computing and Communication Technologies

Intelligent Systems Department, University of Bremen

Am Fallturm 1, TAB (Entrance E), Room 2.61, 28359 Bremen, Germany

E-mail: hri@biba.uni-bremen.de,

Abstract:

This paper presents a standards-based approach to connecting the information and material flows in autonomous cooperating logistics processes. The information flow is represented by a multi-agent system (MAS) with capabilities for the autonomous control of transport logistics processes. The material flow consists of the actual physical logistics objects participating in these processes. By creating a connection between the two flows, an Internet of Things (IoT) for transport logistics may be created in which the logistics objects or "things" are capable of processing information, communicating with each other and taking their own decisions. The proposed solution concepts for connecting the flows are based on the EPCglobal Framework Architecture and consequently lends themselves to practical implementation in existing transport logistics infrastructures, suggesting the feasibility of an Internet of Things for Transport Logistics.

Keywords:

Internet of Things, Logistics and Supply Chain Management, RFID, IT Integration, Architectures and Reference Models

1. INTRODUCTION

The increasing pace of structural change in today's globalised markets bears significant implications for adequate planning and control strategies in transport logistics. Traditional supply chains are evolving into complex networks with numerous stakeholders. In this context, [Aberle] identifies three effects which characterize these changes: the goods structure effect, the logistics effect and the structural effect. 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 relates to 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 needed 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 today's transport logistics processes which poses a growing challenge for the traditional paradigm of centralized process management. The widespread spatial distribution of transport nodes within the networks as well as the link-up of competing logistics service providers in large supply-networks restrict or even inhibit the provision of crucial information for central decision-making instances. Multidisciplinary research in the context of the Collaborative Research Centre (CRC) 637 „Autonomous Cooperating Logistics Processes - A Paradigm Shift and its Limitations“ seeks to identify chances to cope with the highlighted challenges. It does so by promoting the paradigm shift towards decentralized control of logistic processes. For this paper, we focus on multiagent systems as one particular path to implement the novel control paradigm, which has already been found to yield promising results in multiagent-based simulation experiments. We are interested in challenges that arise when an agent-based control scheme is to be operationalized in a real logistics environment. The fundamental problem investigated in this contribution lies in connecting the actual logistics objects – whether they be physical such as goods, containers, trucks and transport hubs or immaterial such as orders – to the agents which are their “digital counterparts” in the MAS and to existing logistics IT infrastructure such as disposition, route planning and enterprise resource planning systems.

Here, the concept of the Internet of Things (IoT) becomes relevant, which 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 concept represents the convergence of a number of recent multi-disciplinary developments such as Ambient Intelligence, Ubiquitous [Weiser] and Pervasive Computing, Auto-Identification and Intelligent Products [Meyer et al.]. At the heart of the concept lies the idea that objects – “things” – are capable of information processing and communication with each other and with their environment. In autonomous cooperating logistics processes, the logistics objects are the “things” which the MAS enables to process information and communicate.

This paper investigates on the basis of an exemplary application scenario how an Internet of Things for transport logistics, viewed as a vision of the integration of autonomous control, auto-ID technology and ubiquitous sensorics, can be conceived and applied to current logistics environments. It takes into account current standards in the fields of auto-identification, RFID and sensorics to propose an approach to connecting the information flows in the MAS and logistics IT systems with the material flows.

2. Related Work

The following sections explore relevant related work in a number of areas. First, an underlying understanding of autonomous control in logistics is established. Next, relevant research towards the establishment of smart logistics entities is investigated including holonic manufacturing, smart resources and intelligent products. This section concludes with a discussion of the application and potential of the Internet of Things to the field of logistics.

2.1. Autonomous Control in Logistics

In the context of this work, *“Autonomous Control describes 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"* [Böse & Windt]. 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] levels of autonomy. The motivation for this approach is, amongst others, an expected improved robustness and increased scalability of process control.

2.2. Smart Logistics Entities

In autonomous control, particular focus is placed upon smart logistics entities which are able to interact with each other. These entities may be either material or immaterial items. Material logistics items may, for example, be vehicles, goods or conveyors whilst an example for an immaterial item could be a delivery order. The former can be further differentiated as commodities and all types of resources [Scholz-Reiter et al.]. Several prerequisites must be met to realise smart logistic entities which are able to process information, take decisions and interact with each other. Taking decisions implies a number of prerequisites. First, a decision making mechanism must be implemented. Second, that mechanism must be integrated into the object's logistic environment. That is, it must be able to assess its current situation by direct perception using sensors or indirectly by information acquired from other sources. Third, means to put decisions into effect by affecting the environment are essential, either physically via actuators or virtually via communication. The latter refers not only to information acquisition but also to the propagation of decisions to business associates or peers within the own organisation, as well as coordination among smart logistics objects to achieve common goals.

When reviewing suggestions for smart logistics entities in the technical literature, it is possible to distinguish two categories of smart logistics entities, namely smart resources and smart products/shipments. The following sections investigate these categories more closely.

2.2.1. Smart Resources – Holonic Manufacturing Systems

In the field of production logistics on the shop floor scale, holonic manufacturing systems (HMS) have been proposed as autonomous, co-operative building blocks of manufacturing systems for transforming, transporting, storing and/or validating information and physical objects [van Leuwen & Norrie]. Each HMS is thereby understood as a composite entity, referred to as a holon, which comprises an information-processing part and, optionally, a physical processing part. These parts may either be comprised of atomic components or subordinate, nested holons. Attention is directed towards the concept of autonomy as the capability of the holon to create and control the execution of its own plans and/or strategies [ibid.]. Holons do not act in isolation but interact with each other. The holarchy, or system of holons which can co-operate to achieve a goal or objective, generates mutually acceptable schemes in order to fulfill system goals [Wang et al.].

2.2.2. Smart Commodities – Intelligent Products & Product Avatars

McFarlane et al. define the Intelligent Product as *“a physical and information based representation of an item for retail 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”* [McFarlane et al.]. The degree of intelligence an intelligent product may exhibit varies from simple data processing to complex pro-active behaviour. It is thus the main focus of the definitions and classifications in [McFarlane et al.], [Kärkkäinen et al.]. Building on these, Meyer et al. introduce an extended classification scheme for intelligent products which additionally takes location and granularity of intelligence into consideration [Meyer et al.]. It encompasses three dimensions of product intelligence: *1. Level of Intelligence, 2. Location of Intelligence* and *3. Aggregation Level of Intelligence*. The first dimension describes whether the Intelligent Product exhibits information handling, problem notification or decision making capabilities. The second 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.

Research in the field of Intelligent Products has previously been applied to the field of logistics. For instance, Kärkkäinen et al. describe the application of the concept to supply network information management problems [Kärkkäinen et al.]. Additional examples are the application of the Intelligent Products to the supply chain [Ventä], to manufacturing control [McFarlane et al.], and to production, distribution, and warehouse management logistics [Wong et al.].

[Hribernik et al. 2006] propose an approach for semi-autonomous product-centric information management which is based on the concept of the Product Avatar. Here, individual products are viewed as intelligent entities throughout their entire lifecycles as defined in [Wong et al.]. Avatars might represent item-specific product information such as manufacturing master data but also context and handling information which accumulate across the product lifecycle. Based on the observation, that the amount of information relevant to each individual product as well as the number of disparate types, formats and systems involved is proportional to the amount of different stakeholders involved in each phase of the product’s life, the avatar constitutes an authoritative contact point for product information. From the information management point of view, product avatars act as mediators. In addition, they may also act on behalf of their associated physical product throughout the latter’s lifecycle.

2.2.3. Software Agents as Enablers of Smart Logistics Entities

Software agents constitute a suitable paradigm both for conceptual design and technical realization of the digital counterpart of smart entities. This is primarily due to the far-ranging concordance of the prerequisites for decision systems, and well-accepted notions of agency. Wooldridge defines that *”an agent is a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives.”* Wooldridge & Jennings propose the weak notion of agency which specifies the following minimum criteria for intelligent agents which immediately fit smart logistics entities as particular class of agents as well [Woolridge & Jennings]. These are: autonomy, reactivity, pro-activeness and social ability. Some researchers in the field of artificial intelligence adhere to a more precise conceptualization. According to this strong notion of agency [ibid.], an intelligent agent is conceptualized or implemented using concepts drawn from a human context. For instance, agents are characterized using mentalistic notions such as beliefs, desires, and intentions [Bratman]. When implementing digital counterparts as intelligent agents acting on behalf of their physical realizations, bounded rationality is also a fundamental agent characteristics, meaning that given its current beliefs about the state of the world and its idiosyncratic preferences, an agent should act in tune with its goals. The design of heterarchies of autonomous decision systems as multi-agent systems is facilitated through the natural mapping from real world actor or entity to representing agent and the availability of mature tools and agent development frameworks such as JADE [Bellifemine et al.]. Novel approaches to autonomous control which have been implemented in terms of agent behaviours can then be benchmarked using multiagent-based simulation to receive clues in which scenarios and to what extent autonomous control may be beneficially introduced for real-world operation.

2.3. The Internet of Things as an Enabler for Autonomous Control in Logistics

The augmentation of physical objects with decision systems, sensors, and actuators, as well as the permeation of the environment with IT is central to several multi-disciplinary, increasingly convergent fields such as Ambient Intelligence, Ubiquitous and Pervasive Computing. The autonomous control of logistics objects can be made possible by recent developments in these fields which culminate in the Internet of Things [Floerkemeier et al.

2008]. The principle idea is that things are capable of information processing and interaction with each other and their environment. Smart logistics objects can be viewed as such "things".

2.3.1. Application and Potential of the Internet of Things in Logistics

IoT concepts and technologies have previously been applied to problems in the field of logistics. In the area of transport logistics, the autonomous transport of logistics objects from the sender to the delivery address has been considered as a paradigmatic field of application [Ten Hompel]. A further example is the discussion of the application of dynamic route planning algorithms in autonomous transport logistics networks [Berning & Vastag]. Besides basic, item-level tracking and tracing of goods along the supply chain and a general potential for the optimisation of processes [VDI/VDE Innovation] and the improvement of Efficient Customer Response (ECR) [Gaßner & Bovenschulte], additional potentials for logistics have been identified in literature. For example, the granular, item-level documentation of supply chain events can allow for a greater transparency in contractual and legal matters [VDI/VDE Innovation]. out-of-stock (OOS) situations may be avoided of by automated positioning and warehouse management solutions [Gaßner & Bovenschulte]. Especially for critical goods such as foods or medicine, quality assurance via a tracing of product pedigree and history can be enabled using the IoT [Jedermann et al.]. Protection against product theft and plagiarism based on unique identification and positioning technologies is another example [Staake et al.]. 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.].

2.3.2. Standards in the Internet of Things – the EPCglobal Architecture Framework

The EPCglobal Architecture Framework defines a standard approach to providing item-level data visibility and integration throughout logistics processes. Whilst other, similar approaches are available, such as Dialog [Huvio et al.] or ID@URI [Främling et al.], this paper restricts its scope to the EPCglobal Architecture Framework [EPCglobal Inc. 2009] as an industry standard widely adopted in retail and distribution logistics. The Electronic Product Code (EPC) [EPCglobal Inc. 2008b] is a scheme for the universal identification of physical objects, primarily by Radio Frequency Identification (RFID). The standard tag encodings include an EPC identifier that uniquely identifies an individual object. EPC Information Services (EPCIS) constitute a standard that defines interfaces for sharing data among stakeholders on the basis of EPC [EPCglobal Inc. 2007]. It allows real-time visibility of the movement, location and disposition of assets, goods and services [Soon & Ishii]. The function of the Object Name Service (ONS) is to resolve the EPC into URLs, which may point to a Web Service or other information resource [EPCglobal Inc. 2008a]. The most common use for ONS is the discovery of specific services for an object class. ONS can be used to discover the EPCIS Capture and Query Interfaces for an object class.

3. RELATIONS BETWEEN PHYSICAL OBJECTS AND AGENTS IN AUTONOMOUS CONTROL IN TRANSPORT LOGISTICS – AN EXEMPLARY APPLICATION SCENARIO

An exemplary application scenario form the field of transport logistics is presented in the following on the basis of which the characteristics of the material and information flows to be connected can be studied. It has previously been used to demonstrate principles of implementing autonomous control using multi-agent systems (MAS) [Jedermann et al. 2006]. The scenario deals with the transport of foodstuffs. It has been specifically selected due to the necessity to monitor the quality of the transported foods e.g. using sensors [Jedermann et al. 2008a] and shelf-life prediction [Jedermann et al. 2008b]. With regards to the material flow, typical logistics objects such as storage facilities, means of transport, cargo containers, and delivery addresses are involved in the scenario. Concerning the information flow, the MAS comprises agents responsible for managing typical logistics tasks such as order, stock, storage and transportation management, freight monitoring and route planning. The scenario describes the representative autonomous cooperating processes beginning with the initial customer order all the way through to delivery. It is expected that, due to the generic nature of the processes, the relations between the material and information flows discovered by studying the scenario are transferable to other concrete transport logistics use cases.

First, a customer uses his ERP to order one crate of blueberries and two of raspberries by electronic transaction to an order management agent in the producer's multiagent-based ERP. The order management agent then queries an inventory management agent in the producer's MAS to check the available stock against the order. After acquiring the necessary information, supervision of delivery is delegated to a shipping agent, which first needs to identify a suitable means of transport for the delivery. It queries a brokerage agency, which provides an electronic marketplace where freight forwarders publish information about their transport capacities. The query includes information such as scheduling, delivery address and functional requirements like cooling or monitoring needs. The broker agent responds with the contact details of the agents of suitable transports. The shipping agent prefers options in which the crates can be transported together, and enquires with suitable vehicle agents for transport proposals. These agents bid for transport on the basis of their knowledge about their vehicles' status. The shipping agent selects the best bid according to weighted criteria such as cost, delivery speed or quality of service and submits the order to the chosen transport agent, which re-plans its current route to take the additional delivery into account. The refrigerated truck completes its pickup tour in the negotiated time, and signals that it is ready to collect the crates at the producer's outgoing goods. Prior to loading, the shipping agent checks with the sensor network running on a system embedded into the reefer to verify that the sensor network is configured as specified during negotiation and is working properly. The shipping agent then deploys a preconfigured shelf-life monitoring agent into the refrigerated truck's onboard MAS where it automatically connects to the sensor net. Loading is then approved by the shipping agent and delivery commences. The sensor agent monitors the cold chain throughout delivery. After some time, a temperature rise is detected where the fruit crates are loaded. The sensor agent assumes a fault in the cooling system. Its shelf-life prediction based on the sensor readings suggests an unacceptable degradation of quality has to be expected if delivery continues as planned. The situation necessitates intervention and the shipping agent is notified, which attempts find a solution. It first contacts the transport broker agent for a replacement transport. This query is unsuccessful, so it forfeits the single-transport strategy and considers single-hop alternatives with interim storage. Suitable warehouses are identified via a brokerage agency and storage is negotiated. The crates are temporarily stored in a refrigerated warehouse, preserving the cold chain whilst gaining an opportunity to negotiate the rest of the delivery. The autonomously controlled shipping process outlined above begins again, and continues until delivery is complete.

4. CONCEPT OF AN INTERNET OF THINGS FOR TRANSPORT LOGISTICS

As noted briefly in the introduction of the preceding section, the application scenario presented therein has been implemented as a hybrid demonstration system which coupled multiagent-based simulation of the transport scenario, based on the simulation system PlaSMA [Gehrke & Ober-Blöbaum] with physical aspects. Downsized versions of the perishable goods, equipped with RFID-tags, and an intelligent freight container equipped with sensors and an embedded agent platform [Jedermann et al. 2006] were used for a prototypical link-up of material flow and autonomous control which was shown to significantly enhance the basis of decision making of the software agents. The transfer of such an embedding from multi-agent systems realizing autonomous control in a self-contained, concerted simulation environment - i.e. under lab conditions - to those being deployed for operative use in enterprises, necessitates a careful re-assessment of requirements and an approach based on industry standards as constituted by the EPCglobal Architecture Framework.

By differentiating types of connection of the entities participating in the material flow, their agent counterparts orchestrating the information flow and the relations among entities in those two tiers, four solution concepts are proposed to represent these relationships. The concepts build upon on EPC as a scheme for the unique identification of both physical and virtual objects. Furthermore, EPC Information Services are used as a gateway between the MAS and the physical logistics objects in the material flow as sketched in Figure 1. Where applicable, standard EPCIS events are suggested to model the connections between the entities in question. In the cases in which the standard events provided by the EPCIS specification are not adequate, extensions are proposed encompassing both additions to standard event types as well as a new event type proposal. The problem of integrating sensor data is addressed using an extension to the ALE (Application Level Events) standard.

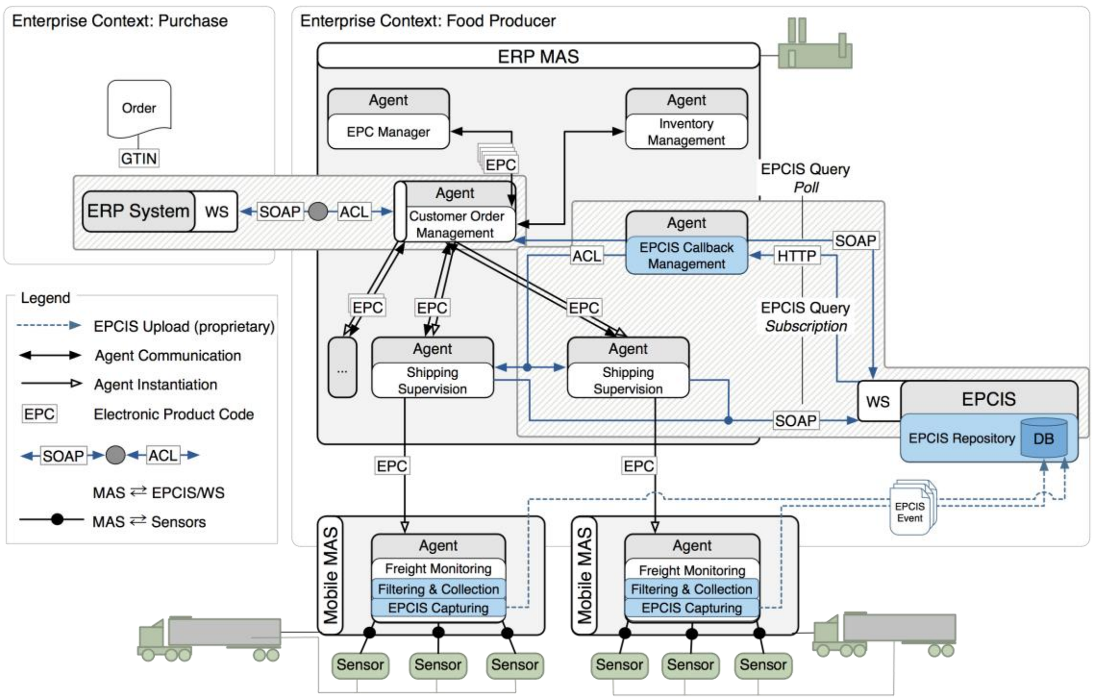

Figure 1: High-level concept for an EPCIS-enabled implementation of the MAS outlined in the application scenario.

By applying the widely adopted EPCglobal Architecture Framework to the problem, a standards-based solution may be derived which provides a solid basis for platform independent interoperability.A wide range of relevant logistics IT systems may be integrated into and make use of the resulting Internet of Things for transport logistics, consequently making autonomous cooperating logistics processes feasible in operational logistics environments.

4.1. Associating Agents with Physical Logistics Objects

The Internet of Things and here in particular AutoID technology can be leveraged to unambiguously associate software agents with physical logistic entities. With regard to the application scenario, consider for instance the fruit crates that comprise the customer order and the shipping agent orchestrating their transport. At the outset of the scenario, the two types of fruit ordered may be uniquely identified on the product-class level by GS1 global trade item numbers. Whilst this is sufficient for the order management agent to initiate shipping, the individual crates need to be identified during delivery. This can be achieved by attributing an EPC to each crate. An agent can assume the role of an EPC manager in the producer's MAS and issue EPCs to the goods. These can be communicated to stock and order management agents to retrieve tagged crates from storage and prepare them for transport. Delivery is delegated from the order agent to the shipping agent. The corresponding transport order communicates the EPCs of the crates in question. To express the relationship between the shipping agent and its freight, both need to be uniquely identifiable. Thus, an EPC is assigned to the agent. EPCIS events may be used to express relationships between individual EPCs. The *TransactionEvent* may be used to “highlight a specific EPC [...] as the preferred primary object but not imply a physical relationship of any kind” [EPCglobal Inc. 2007]. Consequently, the association of the shipping agent with the crates may be expressed by defining a *TransactionEvent* with the the freight's EPCs as EPClist and the shipping agent's EPC as ParentID (cf. Figure 2).

By issuing EPC to software agents and defining *TransactionEvents* with their EPCs and those of logistics objects, links between physical logistics objects and their digital counterparts may be expressed. Storing EPCIS events in stakeholders' repositories allows the handling history of logistic objects to be recorded throughout the product lifecycle. Another benefit lies in tracking liabilities and responsibilities of digital counterparts' operators; agents can be irrefutably linked to their operating companies via EPCIS master data and their associations documented. *TransactionEvents* may be further used to record when other agents carry out auxiliary functions on logistic objects. EPCIS extension mechanisms, namely the introduction of a new optional event field [EPCglobal Inc. 2007] can be used to distinguish both types of agent-to-object associations.

4.2. Associating Agents with Supervised Physical Logistics Resources

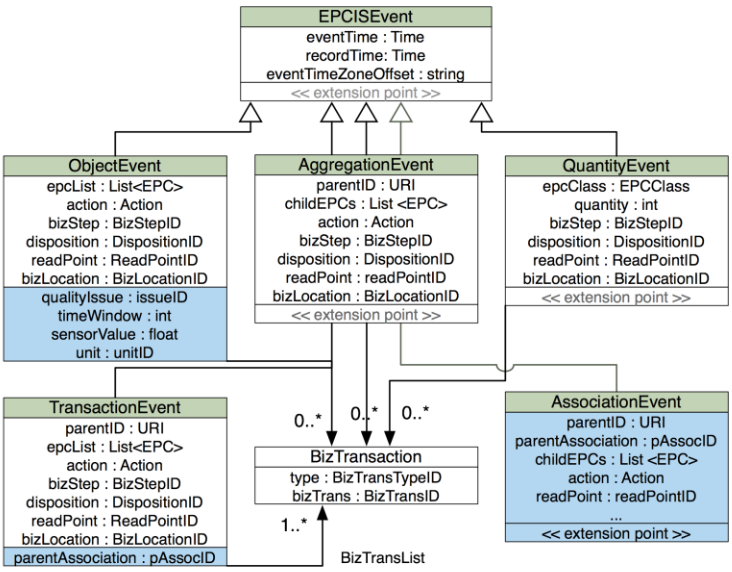

Figure 2: Core EPCIS event types, adapted from [EPCglobal Inc. 2007], including proposed extensions

Having proposed a means to represent agent-to-product associations, we now consider the complimentary case of agent-to-resource associations. As a paradigmatic example from our application scenario, we can consider the transport agents which each manage an individual truck in their freight forwarders vehicle fleet. This is a specific case of the general problem of associating software agents with resources. The solution proposed here assumes that both agent and resources are assigned EPCs. The association is made when the resource is deployed. In contrast to the first case, this need not take place within a transaction. Consequently, neither the *TransactionEvent* does not reflect this relation, nor do the remaining pre-defined event types (cf. Figure 2). The *ObjectEvent*, *AggregationEvent*, and

TransactionEvent reference material flow events whilst the *QuantityEvent* is suitable only for stock management purposes. However, the object-oriented EPCIS event definition is extensible by new classes. Thus, a solution lies in the introduction of a new class, specifically a variation of the *AggregationEvent* without restriction to the material flow context. Thus, a new *AssociationEvent* is proposed as illustrated in the bottom right of Figure 2, to represent the association of software agents to physical logistics resources.

4.3. Exploiting Information about Aggregation of Physical Logistics Objects

In the preceding sections, we have proposed an approach for the use of EPCIS events to represent the association of software agents as autonomous decision makers to managed products and resources. Now, we consider the aggregation of those logistic objects that have been linked with agents to another and other relevant items in the environment. Since physical aggregation is directly supported by the EPCIS specification via the *AggregationEvent* type, we concentrate on highlighting the implications for autonomous control when proper aggregation information can be retrieved from EPCIS systems.

As a first use case, we focus on the means of transport from our application scenario. In Section 4.2, we assumed that means of transport are atomic entities which may be consequently identified by a single EPC. Here, this assumption is put into perspective by taking a closer look at the actual state of affairs. Consider for instance an articulated truck which is a composite entity formed by a tractor unit and a trailer. In the simplified example above, both would share one EPC. However, both transport capacity and additional functionalities such as cooling are the trailer's characteristics. Separate identification of semi-trailers is consequently pertinent. The combination of tractor unit with trailer may be expressed using the *AggregationEvent* to put their EPCs into relation. Furthermore, a reefer carried by a semitrailer may carry functional components like sensors. Their association with the reefer can be represented by further *AggregationEvents* if they are also issued EPCs. The resulting aggregation trees that are formed by the *AggregationEvents* thus describe configurations of means of transport and functional components which characterise the resources. The storage of the events in EPCIS repositories allows for the documentation of such configuration trees over time. This principle can be equally applied to all types of resources in the application scenario, such as storage facilities.

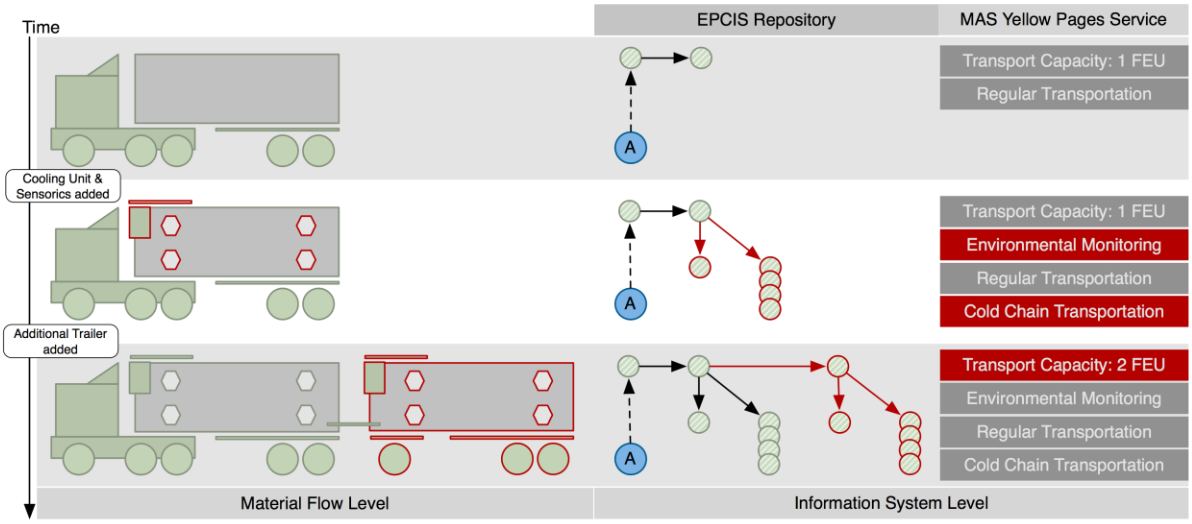

Figure 3: The physical reconfiguration of a truck is represented by suitable ECPIS events used by the managing agent to continuously update the truck service porfolio.

Agents can identify functional characteristics of logistics resources by querying their EPCIS repositories and parsing the trees of *AggregationEvents*. Transport agents can use that information to publish vehicle profiles with the transport brokerage agency (cf. Figure 3). Agents can ensure that they are kept up to date with changing functional characteristics, such as new sensors or the replacement of a trailer, via subscription to respective EPCIS events.

A second, more conventional use case for EPCIS *AggregationEvents* is related to those events which allow inferences on the handling of goods in procurement and distribution processes. Agents can monitor loading and stocking processes by subscribing to EPCIS events stored in freight forwarders' and warehouse operators' repositories. For instance, during transport or storage acquisition, the shipping agent is notified of the EPCs identifying the vehicles or storage facilities. These can be looked up in ONS to determine the respective EPCIS addresses. The agent may then subscribe to the EPCIS for notification about *AggregationEvents* regarding its managed goods. The shipping agent is thus kept up to date with the physical position of the goods it manages - it knows, for example, which vehicle the goods are currently in or where they are stored.

4.4. Assigning Condition and Quality Monitoring to Agents

Previously, it has been outlined how software agents can use EPCIS *AggregationEvents* in order to enable tracking and tracing of managed product throughout the ship- ping process. In addition, the EPCglobal infrastructure may also be used for condition monitoring of products that require careful control. For instance, temperature, humidity and released decay gases have been identified as key state variables for sustaining the quality of perishable goods. The application scenario shows interaction between the local quality monitoring and assessment agent in the refrigerated container and the shipping agent in the MAS of the food producer. The EPCglobal architecture framework currently makes no explicit provisions for sensor data tracking. However, it does present applicable mechanisms for the problem. The monitoring agent in the scenario filters and collects sensor data, which is close to the function ALE fulfils in the EPCglobal architecture framework (cf. Figure 4) in that it *"carries out processing to reduce the volume of EPC data"* by creating *"streams of events […] suitable for application logic"* [EPCglobal Inc. 2009]. Here, [Mitsugi et al.] have proposed extensions for the integration of sensors into ALE which adequately solve this problem for the monitoring agent.

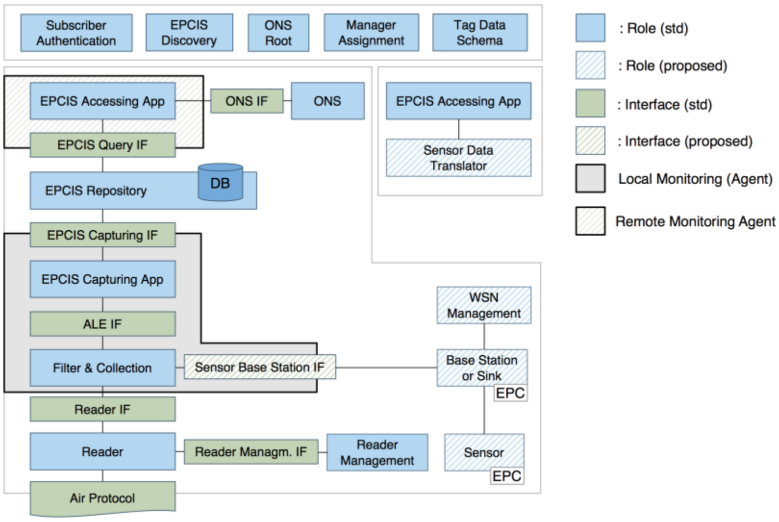

Figure 4: EPCglobal architecture reference model with proposed extension based on [Mitsugi et al.]

The shipping agent deals with process-specific aggregations of sensor data and quality information. This data is business process related and could be represented by EPCIS events. However, the basic EPCIS event model does not cater for sensor-related quality data. The EPCIS specification endorses the use of ObjectEvents *"for any event a capturing application wants to assert about"* [EPCglobal Inc. 2007]. Consequently, the authors propose an extension to the ObjectEvent [EPCglobal Inc. 2009]. The proposed extension encompasses fields for preprocessed sensor readings and quality assessments, for example, the shelf-life time left and detected quality issues (cf. Figure 2). The local monitoring agent can now create EPCIS ObjectEvents and store them in a repository, mirroring an EPCIS Capturing Application.

5. CONCLUSIONS

The proposed concepts illustrate how an Internet of Things for Transport Logistics may be created by a combination of MAS-based autonomous control integrated with the material flow of EPC-compliant transport logistics infrastructure. Together, they demonstrate an approach for a feasible embedding of autonomous control into well-established logistics IT infrastructures whose practical validation via a proof-of-concept implementation, however, is beyond the scope of this contribution. To that end, ongoing work by the authors includes a prototypical implementation of the proposed solution concepts on the basis of the multi-agent based simulation system PlaSMA[1] [Warden et al.], the FOSSTRAK Open Source implementation of the EPC Framework Architecture [Floerkemeier et al. 2007] and an ontology-based mediator [Hribernik et al. 2010] for the flexible integration of a broader range of logistics data sources. In parallel, other options for integrating the MAS with the material flow are being investigated based on, for example, ID@URI using the DIALOG system [Främling et al.]. Furthermore, in order to generate a deeper understanding of the types of relations between logistics objects and their digital counterparts in a MAS for autonomous control, a broader and more detailed study of specific use cases is necessary. In this context, a detailed categorization of the types of relations between physical is the aim of this work.

REFERENCES

Aberle, G. (2003). Transportwirtschaft: einzelwirtschaftliche und gesamtwirtschaftliche Grundlagen, Oldenbourg Wissenschaftsverlag GmbH, 4 edn.

Bellifemine, F., Caire, G., Greenwood, D. (2007). Developing Multi-agent Systems with JADE, Wiley Series in Agent Technologies, Wiley Inter-Science.

Böse, F., Windt, K. (2007). Catalogue of Criteria for Autonomous Control, in: M. Hülsmann, K. Windt (Eds.), Understanding Autonomous Cooperation and Control in Logistics. The Impact on Management, Information and Communication and Material Flow, Springer, pp. 57-72.

Berning, M., Vastag, S. (2007) Simulation selbststeuernder Transportnetze. In: Bullinger, H.-J., ten Hompel, M.(Hrsg.): Internet der Dinge. Springer, Berlin, Heidelberg, pp. 119–126.

Bratman, M. (1987). Intentions, Plans and Practical Reason, Havard University Press, Cambridge, MA.

EPCglobal Inc. (2007). EPC Information Services (EPCIS) Version 1.0.1 Specification, Standard Specification, EPCglobal Inc.

EPCglobal Inc., (2008). EPCglobal Object Name Service (ONS) 1.0.1, Standard Specification, EPCglobal Inc.

EPCglobal Inc., (2008). EPC Tag Data Standards Version 1.4, Standard Specification, EPCGlobal Inc.

[1] Platform for Simulations with Multiple Agents http://plasma.informatik.uni-bremen.de/

EPCglobal Inc. (2009). The EPCglobal Architecture Framework, 1.3, Standard Specification, EPCGlobal Inc.

Floerkemeier, C. , Lampe, M. and Roduner, C. (2007) Facilitating RFID Development with the Accada Prototyping Platform. In: PerCom 2007. White Plains, NY, USA: IEEE Computer Society, pp. 495-500.

Floerkemeier, C., Langheinrich, M., Fleisch, E., Mattern, F., Sarma, S. (Eds.) (2008). The Internet of Things. First International Conference, IOT 2008, Zurich, Switzerland, March 26-28, 2008, Proceedings, vol. 4952 of LNCS, Springer, Berlin Heidelberg.

Främling, K., Ala-Risku, T., Kärkkäinen, M. and Holmström, J. (2006). Agent-Based Model for Managing Composite Product Information. Computers in Industry, 57(1), pp. 72–81.

Gaßner, K., Bovenschulte, M.: Internet der Dinge-Technologien im Anwendungsfeld „RFID/Logistik (2009) In: Das "Internet der Dinge". Die Informatisierung der Arbeitswelt und des Alltags - Erläuterung einer neuen Basistechnologie. Düsseldorf. Nr. 176: pp. 15-29.

Gehrke, J., Ober-Blöbaum, C. (2007). Multiagent-based Logistics Simulation with PlaSMA, in: R. Koschke,O. Herzog, K.-H. Rödiger, M. Ronthaler (Eds.), Informatik 2007 - Informatik trifft Logistik, Band 1. Beiträge der 37. Jahrestagung der Gesellschaft für Informatik e.V. (GI), GI, Bonn, pp. 416-419.

Gehrke, J. (2008). Collaborative Experimentation Using Agent-based Simulation, in: Workshop on Building Computational Intelligence and Machine Learning Virtual Organizations, pp. 34-38.

Hülsmann, M., Windt, K., Wycisk, C., Philipp, T., Grapp, J. Böse, F. (2006). Identification, Evaluation and Measuring of Autonomous Cooperation in Supply Networks and other Logistic Systems, in: T. Baltacioglu (Ed.), Proceedings of the 4th International Logistics and Supply Chain Congress, Izmir, Turkey, pp. 216-225.

Hribernik, K.; Kramer, C.; Hans, C.; Thoben, K.-D. (2010). A Semantic Mediator for Data Integration in Autonomous Logistics Processes. In: Poppelwell, K.; Harding, J.; Poler, R.; Chalmeta, R. (eds.): Enterprise Interoperability IV. Making the Internet of the Future for the Future of Enterprise, Springer, London, pp.157-167.

Hribernik, K. A., Rabe, L., Thoben, K.-D., Schumacher, J. (2006). The Product Avatar as a Product-instance- centric Information Management Concept, International Journal of Product Lifecycle Management 1 (4), pp.367-379.

Huvio, E., Grönvall, J., Främling, K. (2002). Tracking and tracing parcels using a distributed computing approach, in: O. Solam (Ed.), Proceedings of the 14th Annual Conference for Nordic Researchers in Logistics (NOFOMA 2002), pp. 29-43.

Jedermann, R.; Antunez, L.J.; Lang, W.; Lorenz, M.; Gehrke, J. D.; Herzog, O: (2008) Dynamic Decision making on Embedded Platforms in Transport Logistics. In: Haasis, H.D.; Kreowski, H.J.; Scholz-Reiter, B. (eds.): Dynamics in Logistics. First International Conference, LDIC 2007, Springer, Berlin Heidelberg , pp. 191-200.

Jedermann, R., Behrens, C., Laur, R., Lang, W. (2007). Intelligent Containers and Sensor Networks, Approaches to Apply Autonomous Cooperation on Systems with Limited Resources, In: M. Hülsmann, K. Windt (Eds.), Understanding Autonomous Cooperation and Control in Logistics. The Impact on Management, Information and Communication and Material Flow, Springer, pp. 365-392.

Jedermann, R., Behrens, C., Westphal, D., Lang, W. (2006). Applying autonomous sensor systems in logistics; Combining Sensor Networks, RFIDs and Software Agents, Sensors and Actuators A (Physical) 132 (1) pp. 370-375.

Jedermann, R., Edmond, J., Lang, W. (2008). Shelf Life Prediction by Intelligent RFID, in: H. Haasis, H. Kreowski, B. Scholz-Reiter (Eds.), Dynamics in Logistics. First International Conference, LDIC 2007, Springer, Berlin Heidelberg, pp. 231-240.

Jedermann, R., Gehrke, J., Becker, M., Behrens, C., Morales-Kluge, E., Herzog, O., Lang, W. (2007).Transport Scenario for the Intelligent Container, in: M. Hülsmann, K. Windt (Eds.), Understanding Autonomous Cooperation and Control in Logistics. The Impact on Management, Information and Communication and Material Flow, Springer, pp. 393-403.

Kärkkäinen, M., Holmström, J., Främling, K., Artto, K. (2003). Intelligent products - a step towards a more effective project delivery chain, Computers in Industry 50 (2), pp.141-151.

van Leeuwen, E., Norrie, D. (1997). Holons and holarchies, Manufacturing Engineer 76 (2), pp.86-88.

McFarlane, D., Sarma, S., Chirn, J. L., Wong, C. Y., Ashton, K. (2003). Auto ID systems and intelligent manufacturing control, Engineering Applications of Artificial Intelligence 16 (4), pp.365-376.

Meyer, G. G., Främling, K., Holmström, J. (2009). Intelligent Products: A Survey, Computers in Industry 60 (3), pp.137-148.

Mitsugi, J., Inaba, T., Patkai, B., Theodorou, L., Sung, J., Sanchez Lopez, T., et al. (2007). Architecture development for sensor integration in the EPCglobal network. Auto-ID Labs White Paper, White Paper Series 2007.

Scholz-Reiter, B., Kolditz, J., Hildebrandt, T. (2007) Specifying Adaptive Business Processes within the Production Logistics Domain: A new Modelling Concept and its Challenges, in: M. Hülsmann, K. Windt (Eds.), Springer, Berlin, pp. 275-301.

Schuldt, A.; Hribernik, K. A.; Gehrke, J. D.; Thoben, K.-D.; Herzog, O. (2010) Cloud Computing for Autonomous Control in Logistics. In: 40th Annual Conference of the German Society for Computer Science (GI 2010). Gesellschaft für Informatik.

Soon, T. J., Ishii, S. (2007), EPCIS and Its Applications, Synthesis Journal, pp.109-124.

Staake ,T, Thiesse , F., Fleisch, E. (2005) Extending the EPC network: the potential of RFID in anti-counterfeiting, Proceedings of the 2005 ACM symposium on Applied computing, March 13-17, 2005, Santa Fe, New Mexico.

Ten Hompel, M. (2005) Das Internet der Dinge: Status, Perspektive, Aspekte der aktuellen RFID-Entwicklung. Vortrag. Dortmunder Gespräche 2005. Fraunhofer Symposium RFID, Dortmund.

Timm, I. J. (2006). Strategic Management of Autonomous Software Systems: Overview Article, Technical Report 35, University of Bremen, Center for Computing and Communication Technologies, 2006.

VDI/VDE Innovation + Technik GmbH: Intelligente Logistiknetze mit RFID (2008) Praxisnahe Informationen für Hersteller, Anwender und Dienstleister. Berlin, Bundesministerium für Wirtschaft und Technologie.

Ventä, Olli. (2007) Intelligent and Systems. Technology Theme - Final Report. VTT, Espoo: VTT Publications, 304pp.

Wang, F., Hou, Z.-G., Xu, D., Tan, M. (2005). An Agent-Based Holonic Architecture for Reconfigurable Manufacturing Systems, tY: CHAPTER; M3: 10.1007/11539902 75.

Weiser, M. (1991). The computer for the twenty-first century, Scientific American, Vol. 265 No. 3, pp. 94-104.

Wooldridge, M. (2002). An introduction to multiagent systems, Wiley.

Wooldridge, M., Jennings, N. (1995). Intelligent agents: Theory and practice, Knowledge engineering review 10 (2), pp.115-152.

Wong, C., McFarlane, D., Zaharudin, A., Agarwal, V. (2002). The Intelligent Product Driven Supply Chain, in: IEEE International Conference on Systems, Man and Cybernetics, vol. 4, Citeseer.

Warden, T.; Porzel, R.; Gehrke, J. D.; Herzog, O.; Langer, H.; Malaka, R.: Towards Ontology-based Multiagent Simulations: The PlaSMA Approach. In: Bargiela, Andrzej; Azam Ali, Sayed; Crowley, David; Kerckhoffs, Eugène J.H. (eds.): 24th European Conference on Modelling and Simulation (ECMS 2010). European Council for Modelling and Simulation, 2010, pp. 50-56

ACKNOWLEDGEMENT

This research was partially funded by the German Research Foundation (DFG) within the Collaborative Research Centre 637 Autonomous Cooperating Logistics Processes - A Paradigm Shift and its Limitations.