The Application of the EPCglobal Framework Architecture to Autonomous Controlled Logistics

Karl A. Hribernik, Carl Hans, Klaus-Dieter Thoben
BIBA - Bremer Institut für Produktion und Logistik GmbH
e-mail: {hri, han, tho}@biba.uni-bremen.de

Abstract In this paper, the authors explore the how the Electronic Product Code EPC standard along with its supplementary architecture framework components can be judged to support autonomous controlled logistics. Initially, the paper introduces the problem area, being the field of data integration in the context of autonomous controlled logistics. It then reflects the motivation for examining the EPC family of standards in this context. Subsequently, the paper introduces the relevant standard components, with a focus on describing the mechanisms which are applicable to the unique identification of logistics entities, the discovery of software services relevant to that identification and the standardised storage of and access to data connected to that identification. It then discusses criteria from literature towards the appraisal of the information layer of autonomous controlled processes as well as differentiating different types of autonomous controlled logistics objects required to be considered by that layer. A critical appraisal of the application of the EPCglobal Framework Architecture within the context of autonomous controlled logistics concludes the paper.

Keywords

Autonomous Controlled Logistics, EPC, ONS, EPCIS, Data Integration, standards

1 Introduction

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 (Böse and Windt 2007). The requirements set by complex logistics systems towards the integration of data regarding the individual entities within them prove immensely challenging. In order to implement complex behaviour with regards to autonomous control, dynamism, reactivity and mobility, these entities, including objects such as cargo, transit equipment and transportation systems but also software systems such as disposition, Enterprise Resource Planning (ERP) or Warehouse Management Systems (WMS) require the development of innovative concepts for the description of and access to data. (Hans et al. 2007) One recent standard approach to providing data visibility and integration throughout complex logistics processes on an item-level is defined by the EPCglobal Architecture Framework. This paper aims to evaluate whether the framework can be applied to successfully support autonomous controlled logistics and where the limitations of the current set of specifications lie in this regard.

2 The EPCglobal Architecture Framework

Fig. 1 shows the principle components of the EPCglobal Architecture Framework, as defined by EPCglobal (Armenio et al. 2007). The Tag Protocol standards (UHF Class 1 and HF Generation 2) define the physical and logical requirements for RFID systems operating in the ultra-high and high frequency ranges respectively. The Low-level Reader Protocol (LLRP) deals with the standardisation of the network interface of RFID readers. The Reader Management standard is the wire protocol used by management software to monitor the operating status and health of RFID Readers. The Application Level Event standards (ALE) specifies an interface through which clients may obtain filtered, consolidated RFID data whilst abstracting from the underlying physical infrastructure. The EPC Information Services (EPCIS) represents an event-based service interface for the distributed, inter-organisational sharing of application-level EPC data. The Object Name Service (ONS) defines a mechanism by which authoritative metadata and services associated with EPC Identifiers may be located in the network. In the following sections, those components most relevant to data integration are described in more detail – the EPC Identifier itself, followed by the ALE, ONS and EPCIS standards.

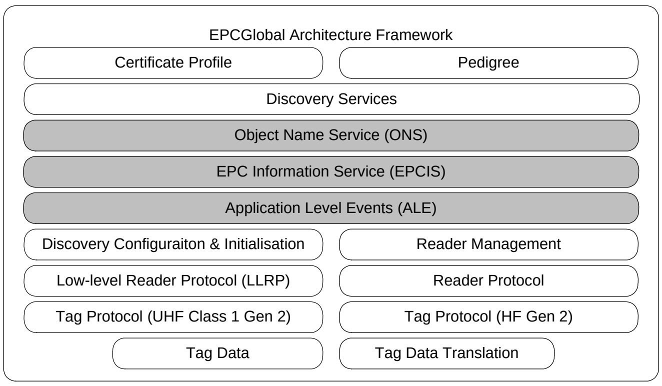

Fig. 1. The EPCGlobal Architecture Framework (Armenio et al. 2007)

2.1 The EPC Identifier

In (EPCglobal Inc 2008), the Electronic Product Code (EPC) is described as a scheme for universally identifying physical objects. The media targeted foremost by EPC is Radio Frequency Identification (RFID) tags but other means are not excluded. The standard tag encodings consist of an EPC (or EPC Identifier) that uniquely identifies an individual object, as well as a filter value, if necessary, to enable effective and efficient tag reading. Within the EPC Identifier scheme, “Pure Identity” refers to the abstract name or number used to identify an entity, regardless of the media used to encode it, such as barcode, RFID or a database field. The Pure Identity may be represented as an Identity URI (Uniform Resource Identifier). The General Identifier, for example, consists of three fields. Encodings of the GID include a fourth field, the header, to guarantee uniqueness within the EPC namespace. The General Manager Number identifies an organizational entity (company, manager or other organization) responsible for managing the subsequent fields. The General Manager Number is assigned by GS1. The Object Class identifies a class or “type” of thing. The Serial Number code, or serial number, is unique within each object class and denotes a specific, individual physical entity.

2.2 ALE

The Application Level Event standard specifies interfaces for the communication between multiple devices and clients which exchange EPC data, and facilitates the abstraction of logical readers from the physical infrastructure. ALE allows a client application to subscribe to a network of readers for read events. The term “readers” is not restricted to RFID readers as such, but may be interpreted as any device capable of capturing EPC data.

2.3 EPC Information Services

EPCIS stands for Electronic Product Code Information Services. It is a standard that defines interfaces for the sharing of data among trading partners. Its aim is primarily to enable supply chain participants in the EPCglobal network 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. The EPCIS standard consists of three layers. The first is the Abstract Data

Model Layer, which specifies the generic structure of EPCIS data. The second is the Data Definition Layer, in which the syntax and semantics of the data exchange via EPCIS are defined. In this layer, the concept of EPCIS Events is defined and the Core Event Types Module specified. The third layer is the Service Layer, which specifies the service interfaces for both querying and capturing EPCIS Events. On top of these three layers, recommendations for bindings are given which exemplify how the specifications may be implemented in practice.

2.3.1 EPCIS Events

The individual EPCIS Event classes inherit their basic structure from the parent EPCIS Event following the Object Oriented paradigm. Object Events are the simplest type of EPCIS event, and are used to capture and communicate information about objects identified by an EPC. They can, for example, be used to document that a specific object has been observed at a specific position and time, or capture changed to the status of that object. Aggregation events are used to document events in which an object identified by an EPC is brought into relation with a number of other such objects. In the example presented in this paper, it is used to capture which component parts of are installed into which overall product. It can be used to both create and destroy such relations. Quantity Events are specified to document events which influence a set of objects which can be identified as belonging to a common class. An example for such an event could be the change of price for an entire assortment of products. Transaction Events can be employed whenever an event triggers a business transaction. The mapping of these events is facilitated by means of a business transaction list, which is a core element of the suggested specification of this event.

2.3.2 EPCIS Capture and Query Interfaces

The standard defines two services - EPCIS Capture Interface and the EPCIS Query Interfaces. The latter consists of two services, the Query Callback Interface and the Query Control Interface. The capture interface consists of only one method, “capture”. This method is responsible for accepting EPCIS Events and storing them in the respective repository. It accepts a list of EPCIS Events as its sole argument and returns no results. The Query Interfaces only provide a general framework for the definition of an interface by which applications may query EPCIS data. The interface caters both for on-demand queries via the Query Control Interface and standing queries via the Query Callback interface.

2.3.3 EPCIS Event Data Storage

The EPCIS standard only specifies event types and the interfaces to arbitrary systems capable of storing such events. It neither makes a statement about the characteristics of the system used to store EPCIS event data, nor about the representation in which the events are stored. ERP systems, tracking and tracing applications, or warehouse management systems are examples of systems which might implement one or both of the EPCIS interfaces (EPCglobal Inc 2007).

2.4 ONS

The function of the Object Name Service (ONS) is to transform the EPC stored, for example, on RFID-Tags, via their corresponding Identity URI encodings into URLs, which may respectively point to a Web Service or other information resource. First, the EPC read from the RFID tag is transformed into its standard URI encoding. The next step is to rewrite the given URI into a DNS name, which is accomplished using a simple regular expression. Then, the DNS name is resolved into a valid URL. This is accomplished by using a DNS Type Code 35 (Naming Authority Pointer - NAPTR) request, which offers a number of different options for specifying the type of URL to resolve the DNS name into. Neither the method for carrying out this request nor the specification of the DNS resolver is within the scope of the ONS specification (EPCglobal Inc 2008). The most common use for ONS is the discovery of specific services for an object class. For example, Web Services may be discovered using this mechanism. Similarly, ONS can be used by an application to discover the EPCIS Capture and Query Interfaces responsible for the object class. The application may then bind to the identified EPCIS services.

3 Integrating EPCIS into Autonomous Logistics

According to (Böse and Windt 2007), “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.” They furthermore define logistics objects in this context as “as material items (e.g. part, machine and conveyor) or immaterial items (e.g. production order) 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. In (Windt et al. 2005) a catalogue of criteria for autonomous cooperating processes is suggested. Within this catalogue, three criteria explicitly address the “information system” layer, as illustrated in Fig. 2 below. Specifically, these criteria deal with the properties of data storage, data processing and the system’s interaction ability. The first two criteria are directly related to the problem of data integration. These criterias´ properties make apparent that the higher the less central the data storage and processing of an information system is, the higher the level of autonomous control. The third criterion, interaction ability, relates implicitly to the data integration problem, in that the interaction ability of the information system in question is based upon its ability to access and process data stored according to the initial two criteria.

System layer	*Properties*				
Information system	*Data Storage*	*Central*	*Mostly central*	*Mostly decentral*	*Decentral*
	Data Processing	*Central*	*Mostly central*	*Mostly decentral*	*Decentral*
	Interaction Ability	*None*	*Data allocation*	*Communication*	*Coordination*

Increasing level of autonomous control

Fig. 2. Information System Layer Criteria for Autonomous Cooperating Processes (Windt et al. 2005)

Consequently, an IT architecture can be said to contribute to the autonomous control of a logistics system if it provides support for information processing and decision-making on the part of logistics objects, both material and immaterial. Furthermore, the information system is required to exhibit the properties data storage, data processing and interaction ability with respect to these types of logistics objects. The following sections examine the EPCglobal Framework Architecture in its support for the criteria shown in Fig. 2 from the perspective of material and immaterial logistics objects.

3.1 Material Logistics Objects

Auto-identification, that is a method for the unique, item-level identification of material objects coupled with a mechanism for the automated retrieval of that identity, forms the basis of any data processing operation with regards to individual material objects. This has been extensively shown for the Intelligent Product, a class of autonomous object similar to the material logistics object discussed here, in (McFarlane et al. 2003), (Wong et al. 2002), (Kärkkäinen et al. 2003) and (Ventä 2007). The discussion with regards to the Intelligent Product encompasses the entire product lifecycle, from the production, distribution, and use to the disposal of the products. This includes autonomous controlled logistics processes, for example, increased intelligence in supply chains (Ventä 2007), manufacturing control (McFarlane et al. 2003), production, distribution, and warehouse management (Wong et al. 2002). Consequently, the findings with regards to auto-identification in the field of Intelligent Products are applicable to that of the autonomous control of material logistics objects. The EPC identification schema fulfils that requirement by providing a standardized means for the unique identification of individual physical logistics entities. Along with the specifications for the encoding of EPC on media such as RFID, the EPCglobal Architecture Framework provides the foundation for processing information regarding individual physical entities. An EPC may be associated with each individual material logistics object within an autonomously controlled logistics system. Leveraging the standard structure of, for example, the general identity type General Identifier (GID-96) allows for a rough classification of logistics objects at the identifier level with the possibility of the expression of ownership relations (General Manager Number) and type of logistics object (Object Class). The Serial Number can then be used to uniquely identify the logistics object within that structure.

The low-level standard specifications along with the ALE components support basic auto-identification mechanisms which satisfy the needs outlined above. Building on the unique identification and hierarchical structure provided by the EPC itself, ONS offers a mechanism for the automated discovery of arbitrary services on the Object Class level. Within the context the autonomous control of logistics system, that means each type of logistics object can be associated with a specific set of services using ONS. The types of services exposed by the logistic objects types are not restricted by the standard, although recommendations are given and all further services are to be considered experimental. The recommended use encompasses html, wsdl and epcis. The second of these is relevant to autonomous control due to the fact that by means of wsdl and methods of automatic service discovery and composition, logistics objects may be enabled to expose, discovery and consume information services, facilitating data processing and providing a basis for their ability to interact with each other. The third option allows for logistics objects in Autonomous Controlled logistics systems to access standard EPC Information Services. Furthermore, the design of this service discovery functionality anticipates the ad-hoc integration of stakeholders into a trading network as opposed to the traditional, pre-arranged approach (Soon and Ishii 2007).

The service interface and event model of EPCIS provide a modular, extensible and decentral means of storing and exchanging data pertaining to the uniquely identified material objects. According to (EPCglobal Inc 2007) the perspective EPCIS takes is “visibility of the physical world, incorporating common notions of What Where When and Why.” Each EPCIS event represents data corresponding to a unique spatio-temporal constellation of one or more physical entities associated with an EPC. (Hribernik et al. 2007) demonstrates the applicability of EPCIS events to seamlessly modeling, tracking and tracing products and their subcomponents throughout their life-cycles, including logistics processes. Attributes of physical logistics objects such as the time, position, status and the current related business transaction can be modeled using the basic event objects. Further attributes, such as the properties of autonomous controlled material logistics objects like speed, weight, enterprise affiliation, as well as capabilities such as transportation or storage capabilities, or sensors for measuring humidity as described by (Langer et al. 2006) may be modeled by extending the basic objects with user vocabulary extensions.

3.2 Immaterial Logistics Objects

Not all events related to logistic objects take place on the level of the material flow of specific physical entities. In (Scholz-Reiter et al. 2007), the kinds of logistics objects with relevance to autonomous control are identified as commodity, all types of resources and orders. The former two kinds are readily addressable by EPCIS as they refer to specific, individual physical entities which may be identified using an EPC as discussed above. Commodity and resources types are also addressable using EPC´s object class hierarchy level. The latter kind of logistics object, the order, corresponds to the immaterial logistics object according to (Windt et al. 2005). Whilst Pure Identity types of EPC Identifier generally deal with the unique identification of physical objects, types such as the Global Document Identification Number GDI, which can refer to both a physical document as well as, for example, a database entry, demonstrate that unique identification in the EPCglobal Architecture Frame is not conceptually restricted to physical objects.
As a standard dealing solely with the handling of RFID capture data, the ALE component has no relevance to immaterial logistics objects. Furthermore, whilst EPCIS does not directly support the modeling of orders, it does facilitate the association of order information to identifiable, physical entities on the material flow level. As soon as an order is explicitly related to physical logistic objects, an EPCIS event may be generated to exchange information about it. This is the aim of EPCIS transaction events. Here, immaterial logistics objects may be identified and described by participating stakeholders using URIs. Purchase orders may be mapped to physical entities via the BusinessTransactionID vocabulary which may point to an URI describing the transaction. A schema for the unique identification of such transactions is, however, not specified by the standard. Furthermore, Master Data attributes are not given by the standard (EPCglobal Inc 2007). Ultimately, even with regards to Transaction Events, the event data handled by EPCIS is always based upon physical handing steps (SupplyScape 2008), meaning the relevance of the event object model is to the material flow of individual physical entities.

4 Summary and Conclusions

The EPCglobal Framework Architecture provides explicit technical support for the first type of autonomous logistic objects defined by Böse and Windt (2007) – the individual physical entity. The EPC identification schema provides a means for the unique identification of individual physical logistics entities. Along with the specifications for the encoding of EPC on media such as RFID, it provides the foundation for processing information regarding individual physical entities. ONS supports automated service discovery on the basis of that unique identifier. The discovery of standard EPC Information Services for each individual physical logistics entity is also facilitated in this way. The service interface and event model of EPCIS provide a modular, extensible and decentral means of storing and exchanging event data pertaining to the identified entities. EPCIS Events are proficient at capturing, storing and providing access to event information regarding material logistics objects in a decentral fashion. This distributed, fine-grained event data is based upon physical handing steps (SupplyScape 2008), meaning the relevance of the event object model is primarily to the material flow of individual physical entities. Attributes such as the time, position, status and the current related business transaction can be modeled using the event object model. Whilst the abstract data model can be extended in a modular fashion by user vocabularies to encompass application-specific attributes, the event-driven concept imposes restrictions upon the applicability of EPCIS and does not explicitly support the interaction of autonomous controlled logistics objects. The EPCglobal Architecture Framework focuses on providing support for data exchange centred on identifiable, physical entities. Immaterial logistic objects such as orders are indeed considered by the architecture and its data structures, for example, in EPCIS transaction events and their related properties, or in specific EPC Identifier types. However, the perspective of the framework upon immaterial logistics objects is always from the material object to which they are related.

From the perspective of the Information System Layer Criteria for Autonomous Cooperating Processes, through the EPC Identifier and EPCIS the Framework Architecture explicitly fulfills the requirements towards a high level of autonomous control for decentral data storage pertaining to the visibility of individual physical logistics objects. With regards to the second criterion, decentral data processing, it provides implicit support by specifying standard interfaces by means of that data may be discovered and accessed, whereas the specification of actual data processing facilities for autonomous control are outside the scope of the standards. The third and final criterion, the interaction ability of autonomous controlled logistic objects lies well outside of the scope of the specifications. To conclude, the EPCglobal Architecture Framework´s contribution towards the standardization of auto-identification technology and increased visibility of the material flow represent a significant step towards a platform capable of functioning as a foundation for the requirements of autonomous controlled logistics objects.

References

Armenio, Felice et al. *The EPCglobal Architecture Framework.* Lawrenceville, New Jersey: EPCglobal Inc, 2007.

Böse, Felix, and Katja Windt. "Catalogue of Criteria for Autonomous Control in Logistics." In *Understanding Autonomous Cooperatoin and Control in Logistics - The Impact on Management, Information and Communication and Material Flow*, by Michael Hülsmann and Katja Windt, 57-72. Berlin: Springer, 2007.

EPCglobal Inc. *EPC Information Services (EPCIS) Version 1.0.1 Specification.* Lawrenceville, New Jersey: EPCglobal Inc, 2007.

EPCglobal Inc. *EPCglobal Object Name Service (ONS) 1.0.1.* Lawrenceville, New Jersey: EPCglobal Inc, 2008.

EPCglobal Inc. *EPCglobal Tag Data Standards Version 1.4.* Lawrenceville, New Jersey: EPCglobal Inc, 2008.

EPCglobal Inc. *EPCIS (Electronic Product Code Information Service) Frequently Asked Questions.* Lawrenceville, New Jersey: EPCglobal Inc, 2007.

Hans, Carl, Karl Hribernik, and Klaus-Dieter Thoben. "An Approach for the Integration of Data within Complex Logistics Systems." *LDIC2007 Dynamics in Logistics: First International Conference. Proceedings.* Heidelberg: Springer, 2007. 381-389.

Hribernik, Karl A., Martin Schnatmeyer, Andreas Plettner, and Klaus-Dieter Thoben. "Application of the Electronic Product Code EPC to the Product Lifecycle of Electronic Products." *RFID Convocation.* Brussels, Belgium: European Commission, 2007.

Kärkkäinen, Mikko, Jan Holmström, Kary Främling, and Karlos Artto. "Intelligent Products - A Step Towards a More Effective Project Delivery Chain." Edited by J C Wortmann. *Computers in Industry* (Elsevier) 50, no. 3 (February 2003): 41-151.

Langer, Hagen, Jan D. Gehrke, Joachim Hammer, Martin Lorenz, Ingo J. Timm, and Otthein Herzog. "A Framework for Distributed Knowledge Management in Autonomous Logistic Processes." *International Journal of Knowledge-Based & Intelligent Engineering Systems, 10*, 2006: 277-290.

McFarlane, Duncan, Sanjay Sarma, Jin Lung Chrin, C Y Wong, and Kevin Aston. "Auto ID Systems and Intelligent Manufactring Control." *Engineering Applicaitons of Artificial Intelligence*, 2003: 365-376.

Scholz-Reiter, Bernd, Jan Kolditz, and Thorsten Hildebrandt. "Specifying adaptive business processes within the production logistics domain – a new modelling concept and its challenges." In *Understanding Autonomous Cooperation & Control in Logistics – The Impact on Management, Information and Communication and Material Flow*, by Martin Hülsmann and Katja Windt, 275-301. Berlin: Springer, 2007.

Soon, Tan Jin, and Shin-ichii Ishii. "EPCIS and Its Applications." *Synthesis Journal*, 2007: 109-124.

SupplyScape. *Combining EPCIS with the Drug Pedigree Messaging Standard.* Woburn, MA: SupplyScape, 2008.

Ventä, Olli. *Intelligent Products and Systems. Technology Theme - Final Report.* VTT, Espoo: VTT Publications, 2007, 304 s.

Windt, Katja, Felix Böse, and Thorsten Phillipp. "Criteria and Application of Autonomous Cooperating Logistic Processes." *Proceedings of the 3rd International Conference on Manufacturing Research - Advances in Manufacturing Technology and Management.* Cranfield, 2005.

Wong, C Y, Duncan McFarlane, A Ahmad Zaharudin, and V Agarwal. "The Intelligent Product Driven Supply Chain." *Proceedings of IEEE International Conference on Systems, Man and Cybernetics, 2002.* Tunisia: IEEE, 2002.