Patterns for Managing Data in Complex Automatic Identification and Data Capturing Environments

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1. Introduction

Nowadays production and distribution processes are controlled to a large extent by information processes. Interconnecting the flow of material and information promises to increase efficiency and quality of business activities while reducing costs. Production planing and control systems and enterprise resource planning systems can optimize processes within companies.

Supply chain management comprises the whole process of planning, implementing, and controlling the operations within a supply chain. The overall goal is to satisfy customer requirements as efficiently as possible while saving time and resources on the other hand. Controlling all logistic processes from raw materials suppliers to manufacturers and retailers to the consumer needs transparency of the process steps. Managing the whole product life cycle from point-of-origin to the point-of-consumption and disposal or recycling needs accurate information about products in each process state and at the appropriate location.

Automatic Identification and Data Capture (AIDC) or Automatic Identification (AutoID) comprise techniques to automatically identify objects, to collect associated product data, and to propagate that data to back-end software applications like Enterprise Resource Planning systems. Typical automatic identification technologies are bar codes, Radio Frequency Identification (RFID) and smart cards. These techniques identify assigned properties while biometrics, optical character and voice recognition utilize natural properties.

RFID has its origins more than fifty years ago. But due to recent developments this technique is now available with higher quality and more functionality at lower costs. Especially in logistics a large-scale commercial application is expected. In [Hen09] an worldwide market increase of 25% p.a. is expected.

RFID technology comprises several aspects: infrastructure and architecture, hardware like tags or transponders and readers, integration on the physical layer up to IT system integration: SCM, ERP, MES and warehouse management systems.

System architects, technology integrators, process designers and engineers in charge of implementation and system integration face several challenges. On the physical level first of all "material things" have to be identified. Then the captured data can be processed, filtered and forwarded to applications which perform planning and controlling tasks. Questions concerning appropriate data formats, efficient data transfer, data integration, lookup mechanisms, and others arise in AutoID environments. This pattern collection introduces patterns dealing with aspects of those problems.

This collection is a continuation and extending of a work starting with "A Pattern Language for Process Optimization with Smart Object Identification" at EuroPLoP 2005 [Bie05] and "Patterns for Unique Product Identification" [Bie08].

2. Overview

Figure 1 illustrates the relationships among the patterns presented in this collection. Starting point of this collection is the need for centralized product data management as a basis for planning and controlling systems. The pattern Identifiers Point To Data introduces a solution to that problem. Applying the pattern may result in situations where new challenges arises: capturing identification data of each individual product at many process steps and at several times bears the risk of producing a large amount of data at low information level. A solution for that problem is described in the pattern Business Events.

A decentralized data storage has benefits in applications where access to a network infrastructure is temporarily or in principle not available. In such scenarios Data Accompanying Products is an appropriate solution. Storing product data decentralized attached to the product and at the same time centralized on servers can easily result in data inconsistencies. Synchronised Data Location explains how to cope with that problem.

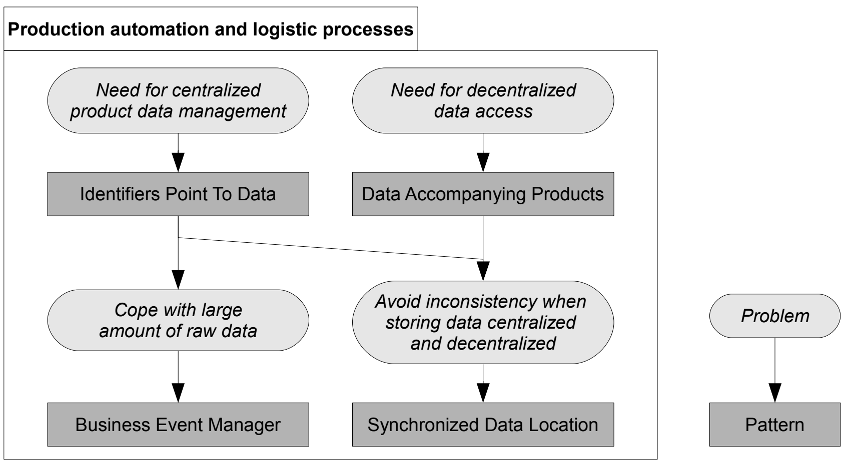

Figure 1 – Overview Graph

Identifiers Point To Data

Context Identifiers Point To Data is necessary to enable seamless access to product data within a single company's internal production processes as well as in case of supply chains where several companies are involved.

Problem ***How to give access to detailed product data in distributed production and logistic networks while only an identifier is attached to the product?***

Forces

- In production and distribution processes several partners needs to gain access to detailed product data. If the product data representation is attached to the product itself the describing information can only be obtained when the product is present.
- Product data not only has to be accessible but also has to be updated and maintained during the whole product life cycle from raw material suppliers to customers and finally to disposal or recycling. Optical data representations are printed once and afterwards unchangeable. Modifications can only be done by replacing an old label or product accompanying description by a newer one.
- Machine readable data has to be stored in such a way that it is assigned to the describing product. Typically a label is fixed on a product or it's packaging. Alternatively the product itself is marked (Direct Part Marking) e.g. by means of laser engraving. Relatively cheap RFID transponders store about a hundred Bits (EPC specifies a 96 Bit encoding) up to one or two kBits. The amount of data is restricted.
- An unique identifier allows distinction of product types or even individuals. But this is not sufficient if a detailed product description is necessary e.g. for customers or due to documentation reasons.
- Increasing complexity of several companies spanning production processes and deep supply chains raise the demand for product data accessible beyond company internal and isolated IT systems like Production Planing Systems (PPS) and Enterprise Resource Planning (ERP) Systems.

Solution ***Establish a network-based infrastructure that consists of components providing services for registering resources with an associated data lookup service which enables storage and query of data along with their identifiers (keys). The services may be be folded into one single piece of software or can be distributed over the Internet.***

In real world physical objects populate the environment. Products or transport units are a specific type of physical objects as results of planed and controlled production processes or as part of such processes or as elements of transportation and storage.

Information technology supports controlling of technical or administration processes. Processing and storing data about the real world needs abstract model of reality. Objects of the real world are abstracted in the information systems through the use of symbols (names, labels).

Abstraction is necessary because the real world cannot be represented in each detail, but relevant sections of reality have to be chosen. Data describing properties of the physical objects may be extensive. Often several parts of organisations or individuals especially customers and users are interested in the data belonging to a product or transport unit, even if the physical object itself is not present.

Rationale Accessibility to product data can be gained by saving and processing the data in decentralized databases. If these databases can be accessed over the Internet most of the involved partners will find the data easily. An identifier has to be assigned to products or transport units and to be carried along with them which works as a "pointer" to it's belonging data. In this sense the identifier externalises the identifier that is necessary internally in databases to mark each entry uniquely. RFID is seen as an enabler so that things of the real world have a representation in the "virtual" world of the Internet [KBM+00], [Bie05].

Consequences

Benefits

- Product data can be accessed independently of the products presence.
- Only the identification number has to be represented or stored. Hence printed labels or inexpensive passive RFID tags are sufficient.
- Generation, representation and assignment of identifiers for products or transport units is well standardized. The standards specified for reading devices, middleware, and data manipulation grant compatibility and ensure a long-term use of AIDC technologies like barcode, two-dimensional symbologies and in an increasingly regarding RFID.

Liabilities

- Data accessibility is highly dependent on the availability of network infrastructure.
- Centralized data storage and processing has to be reachable from every decision point within the production or logistic processes. Failure of the centralized IT system or network components result in a stop of the process. Redundancy can reduce the risk of system standstills, but raises costs.
- Network traffic increases with the number of items which are stored and have to been searchable. The effort of resolving identifiers, searching the data and delivering it to the requester grows proportional to the amount of item records.
- Centralized data processing induces demands for data access regulations. Security issues may be raised by producers and customers as well: To avoid business espionage producers need to hide product details from their competitors. On the other hand customers have concerns that their consumer's behaviour may be recorded and then misused by unauthorized parties.

Known Uses

A well known use are cash registers at checkout points in supermarkets which scan the bar code on products to obtain data like price or weight. The data can be stored decentralized at the cash register itself or is stored on a centralized system for the reason of easier updates.

In logistics nearly each returnable transport item like pallets or containers are assigned a global shipping item number such that the transport units can be tracked. Interoperability and ease of use need standardisation. Global Standard 1 (GS1) has defined a scheme for globally applicable identifiers for trade items (products and services), the Global Trade Item Number GTIN. A whole family of data structure are specified for different application areas. In case of consumer products the EAN-13 bar code is very popular especially in Europe [GS1]. The symbol encodes 13 numbers and is divided into four parts:

- System code: two or three digits representing the country where the manufacturer is registered. To cover the International Standard Book Number ISBN and the International Standard Serial Number ISSN the starting three numerals 978 resp. 979 are used.
- Manufacturer code: four or five digits such that system code and manufacturer code are 7 numerals in sum.
- Product code: five digits given by the manufacturer (normally the serial number).
- Check digit: one digit for the check sum.

Figure 2 gives an example of a EAN bar code (code generator available on the Internet: http://www.barcoderobot.com)

Figure 2 – Example of an EAN-13 Bar Code

The EAN identifier can be scanned to look up product information especially a description and the product price in a database. As a service for consumers GS1 provides a web site on the Internet (`http://directory.gs1.org/gtin/search`) where the product code owner and item information can be searched for.

Figure 3 shows the result of looking up the EAN number 4006381105262 which the author found on a pen. (The Look-up tool is available on the Internet: `http://directory.gs1.org/gtin/search`)

Figure 3 – EAN-13 Item Number Resolved

Several courier-, express- and parcel (CEP) service provider offer customers freight tracking services. In each relevant step in the logistic chain from sender to handler and finally the the recipient is documented by capturing identification data and associating it to the fulfilled transaction. As a service customer can look up information about their shipments.

Data Accompanying Products

Also Known As: Data-on-Tag

Context Application of Data Accompanying Products enables process automation where data about physical objects like products or pallets is necessary.

Problem ***How to provide machines access to product data without presence of a network infrastructure?***

Forces

- A centralized data storage allows data access from several distributed decision points in production and logistic processes. If the necessary network is not available or if the centralized data storage and processing system fails the whole process stops.
- Identifiers attached to physical objects in the real world operate as pointers to resource in the "virtual " world. If the only information carried along with a physical object is the identifier then no detailed data can be obtained between points with no network access.
  But in case of unplanned events more detailed data like product contents may be necessary which cannot be obtained abroad from the normal process paths.
- Network traffic and lookup times increase with the amount of items for which detailed data is requested.

Solution ***Use a machine readable representation or storage technique carried along with the product itself such that product related data accompanies the physical object.***

In order to attach data to a physical object in a machine readable manner an appropriate representation is necessary which is capable to store data and allows at least a reading access.

Read only techniques can be distinguished due to the used storage media and communication method. The most common solutions are:

- Optical representation with transfer in the frequency range of visual light. Data is encoded as linear or two dimensional arranged geometrical patterns like rectangles, squares or circles. The encoding is based on the shape of the geometrical element and/or it's location.
  Typically the patterns are printed on adhesive labels which are then attached to the physical object. Alternatively a direct part marking by means of Laser engraving or other surface processing is applied to prevent removing of the data.

- Data storage in digital memories and communication devices on chips. Data transfer is performed via radio frequencies. On principle, storage capacities of digital memories can be very large but data transfer then is time consuming. While printed or directly marked symbologies are immutable except for replacing the label or modifying the marked surface, digital memories provide the opportunity of not only reading from but also writing to the chip.

Rationale Product data accompanying the the product itself grant access to information without a network infrastructure and a centralized data processing [DMS07].

Attaching human readable information to products is well established for decades. Examples are product sheets or instructions for use which are printed separately and packaged together with the product. Shorter instructions and descriptions are printed on labels and fixed on the product. Textual representations are not obsolete and to be replaced by machine readable data. In fact machine readable information augments the "audience" such that devices can get read the data which is then can be exploit to automatically control process steps or is displayed to humans. Attachment of data beyond simple identifiers raise the demand for higher storage or representation capacities. In case of optical identification techniques data capacity was stepwise enhanced in the evolution from linear codes – bar codes – to stacked codes and then to two-dimensional symbologies. A widely used two-dimensional symbology is the Data Matrix code which can contain up to 3116 numeric or 2335 alpha-numeric characters.

The digital memory integrated in RFID transponders feature a capacity of typically about 100 Bit sufficient for identifiers up to several kBit. It is guessed that Moore's Law just begins regarding RFID transponders.

Consequences

Benefits

- Access to product data can be accessed independently of the products presence.
- In case of re-writeable data storage labels like RFID transponders relevant data can be collected on the path a product is undergoing.
- Object related data allows managing of processes without a centralized controlling system.
- Data is available without an IT infrastructure and without the need for a centralized storage and processing system.

Liabilities

- Detailed data is only accessible when the described physical object is present.
- Data storage capacities limit the amount of information. The level of details hence is restricted and not all relevant data might be kept.

Known Uses

Automation of Production Processes

Siemens Amberg produces transformers which can be individually customized. Figure 4 shows a transport unit used in the transformer production process at Siemens Amberg. Individual configuration data and necessary production steps are stored in the transponder at the beginning of the production line. After that the transport unit is directed through the production and the specified steps are performed automatically without a centralized production execution system.

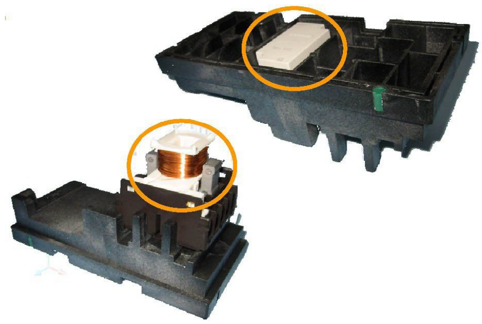

Figure 4 – Transponder storing configuration and production related data attached to transport unit. (Source: Siemens)

Further applications of RFID in process automation are Ford's manufacturing process at the Essex Engine Plant in Windsor, Ontario, and the aircraft maintenance at Boeing and Airbus [ZGYP03], [ZGP03].

Tracking and Tracing of Pharmaceutical Products

In the United States the Food and Drug Administration (FDA) forces the introduction of a so called *ePedigree* for pharmaceutical products. In California by law prescription drugs have to be accompanied by an electronic pedigree.

In the US RFID is the preferred tracking technology. Due to problems of wide spread application of RFID transponders, hybrid pedigree systems incorporating paper and automatic identification technologies like RFID or optical codes are in use as shown in figure 5.

Figure 5 – RFID label attached to a pharmaceutical package

Synchronized Data Location

Context Synchronized Data Location is needed if data is alterable at both the data carrier attached to the product and in centralized storage.

Problem ***How to avoid data inconsistencies if product data accompanying a physical object itself and the mirrored data on centralized servers are changed independently?***

Forces

- A centralized data storage allows data access from several distributed decision points in production and logistic processes. But if the infrastructure is not available or if the centralized data storage and processing system fails the whole process stops.
- Carrying product data along with the product itself provides access to that information independently from a network infrastructure – stand-alone reader devices are sufficient. But due to the decentralized storage technique necessary information is not permanently and accurately available for tasks on a system wide level like production planning and controlling.
- Integration of all reader devices in a network infrastructure can help to forward product related data to centralized processing services. In this case data is pushed forward each time a physical reading process happens. On the level of business-logic applications the need for information about the status of physical components is triggered by software execution. Hence, data generation and information processing are not synchronized. But the ability to react immediately to physical events needs accurate process data.
- Storing product data in both ways – attached to the product itself and on centralized servers – often results in data inconsistency. E.g. updating the product data attached to the product at each process steps provides detailed information about a product's history at any time and anywhere just having a mobile reader device at hand. But that information tends to differ increasingly from the centralized stored data.

Solution ***Synchronize product data carried along with the product and the centralized stored data by means of synchronization rules.***

Such rules define actors and execution details of data interchange processes. Important actors are data producer and consumers who are assigned updating and writing access rights. Synchronisation with the centralized system is mostly based on data versioning and event-based rules.

Rationale

In automation and logistics planning and controlling applications need data related to products and process progress. Modern AutoID technologies support those applications. The overall aim is efficiency based process transparency: to know as much as needed about state and location of products or transport units. Traditional identification data like Barcode labels or imprints are unchangeable. Hence no data inconsistency can occur (expect in case of damage or replacement of the ID). Radio-frequency identification allows storage of data far beyond simple identification numbers. DATA ACCOMPANYING PRODUCTS explains benefits of decentralized data storage. The resulting risk of inconsistent contents between separately located data not only arises in the case of modern automated identification and data capturing technologies: it is a general problem that occurs in backup scenarios and distributed systems. Hence AutoID infrastructures can benefit from solutions established in other IT application areas.

Consequences

Benefits

- Centralized stored data can more accurate represent the actual state of physical things within the monitored process.
- Decision and controlling systems can react more promptly to occurring changes within processes.
- In case of writeable storages attached to products like writeable RFID transponders central data updates can be downloaded and deployed to the de-centralized memories on-site.

Liabilities

- Data consistency is determined by the completeness of the synchronization rules. Unaccounted exceptions may still result in data inconsistencies.
- If the necessary network infrastructure is not available no synchronisation can be performed. Data accuracy and hence quality on the centralized storage is dependent on refresh periods.

Known Uses

Based on [Sch02] researchers at University of Bremen / BIBA developed the concept of "Data Contracts" for AutoID applications. Data Contract specify how to update and match data between locally and centralized stored data during a product's life cycle.

Updating and synchronisation of product data during its whole life cycle is the aim of Product Lifecycle Management PLM. From production to distribution, reselling, consumption and recycling all generated and necessary data about the products of a company have to be managed consistently and have to be provided to controlling and planning systems [AG06]. Automatic identification techniques contribute to PLM on the narrow layer of plant automation and production or distribution logistics.

BUSINESS EVENT MANAGER

Context BUSINESS EVENT MANAGERS bridge the gap between streams of raw sensor data and applications on the business-logic level.

Problem ***How to perform process controlling efficiently while on-site reading devices can only deliver raw sensor data which might even be redundant?***

Forces

- Automatic identification techniques sense physical properties of things like given properties or attached identifiers. Controlling of production and logistic processes is based on logical rules which determine control flows.
- Auto-ID technologies will enable businesses to move from linear and manual supply chain planning and execution to an event-driven, adaptive supply network. But devices like bar code scanner and RFID readers can generate multiple readings of the same physical object.
- The occurrence of a reading event is not necessarily a business relevant event.
- Propagation of each single reading event to the planning system may result in high network traffic.

Solution ***Augment the automatic identification and data capturing infrastructure by additional on-site software that performs a preprocessing of the raw data and propagates business relevant events to the process controlling applications. Such software components act as business event managers.***

Business event managers have to react on real-time events and information, to propagate alerts, and to provide services for essential reading and - if applicable – writing of information to other information systems. As shop-floor near components they have to provide interfaces for reader devices like scanners or RFID readers and other devices like sensors. To be easily integrable those components need standardised network interfaces. To be accessible from the business-logic level business event managers have to support standard communication protocols like Simple Object Access Protocol (SOAP).

Possible field of applications raise with abilities of general-purpose event routing, collating, and filtering.

Rationale Business event extractors and managers hide hardware specific interfaces and extensive streams of raw data. Furthermore, they can accomplish hardware configuration tasks and maintenance related services.

From the physical layer consisting of hardware devices like scanners and readers only physical signals can be obtained. Devices on this layer have to been managed e.g. by providing appropriate software like drivers.

Signals have to be transformed into data due to specific protocols and grammars in order to be transferred to the next layer. So at least two tasks have to be done on the hardware layer: device management and data extraction and communication [GH06].

The top layer of business process management can be seen as the opposite of the hardware related layer on the bottom. Back-end systems like Enterprise Resource Planning (EAI) solutions, Manufacturing Execution Systems (MES) or Supply Chain Management (SCM) systems need to know the status of the underlying processes from a business perspective. Hence business process relevant events or alerts are necessary for decision making and then commands are sent down to the active process elements to control progress. So extraction of business relevant events and command propagation are the tasks to link the business controlling layer and the layer of process near sensors like readers and actors.

Consequences

Benefits Assignment of specific tasks and functionality to specialized components supports flexibility and re-usability. Especially in case of multi-tier architectures the necessary processing power is at the point where the relevant data has to be captured and preprocessed.

Liabilities The increasing amount of components and communication overhead are time costly and decrease performance. Since more processing power is allocated at distributed hardware components the installation costs of the whole infrastructure grow.

Known Uses

In case of complex production processes or supply chains several distributed and heterogeneous components have to be integrated. This is the task of middleware which is referred to as Enterprise Application Integration (EAI). In between of those layers several functionality is necessary:

- Preprocessing of the raw data received from devices,
- data filtering and aggregation,
- context-based event extraction,
- propagation of business relevant events and
- connectivity components for communication.

This intermediate layer, which might be subdivided, is known as "edgeware". On the edgeware layer several tasks have to be done. Devices are distributed at decision relevant points of the process. Often inhomogeneous hardware components are in use. Software components specialized in those different tasks and adapted for the different hardware devices are the constituent parts of the edgeware layer.

Edgeware software is a good example where to apply the LAYERS [BMR+96] and PIPES AND FILTERS [BMR+96] architectural patterns.

Distinct parts work different levels and specific protocols can be used to access the services contained at each layer.

In case of a single tier architectural approach all software functionality for data and device management is integrated as a single software component with a layered internal structure. Figure 6 illustrates a single-tier edgeware architecture.

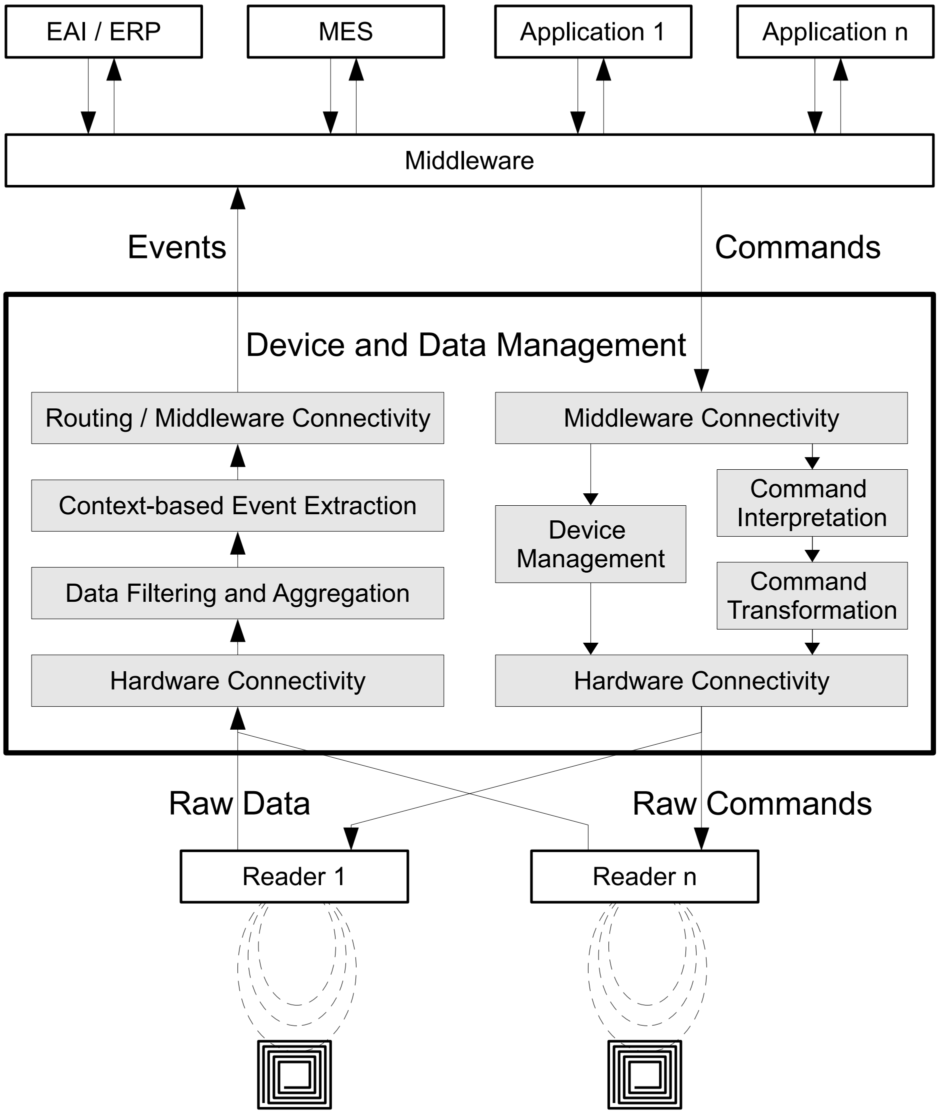

Figure 6 – Single-tier Edgeware Architecture

In production plant automation and in logistic applications reading devices are distributed. In such a setting a multi-tier architecture is more appropriate, as shown in figure 7. In this architecture an additional service bus separates command interpretation and event extraction from hardware specific functionality. The latter consists of command transformation into device specific formats as well as data filtering and aggregation. In [Lea04] several industrial applications of one-tier and multi-tier architectures are introduced.

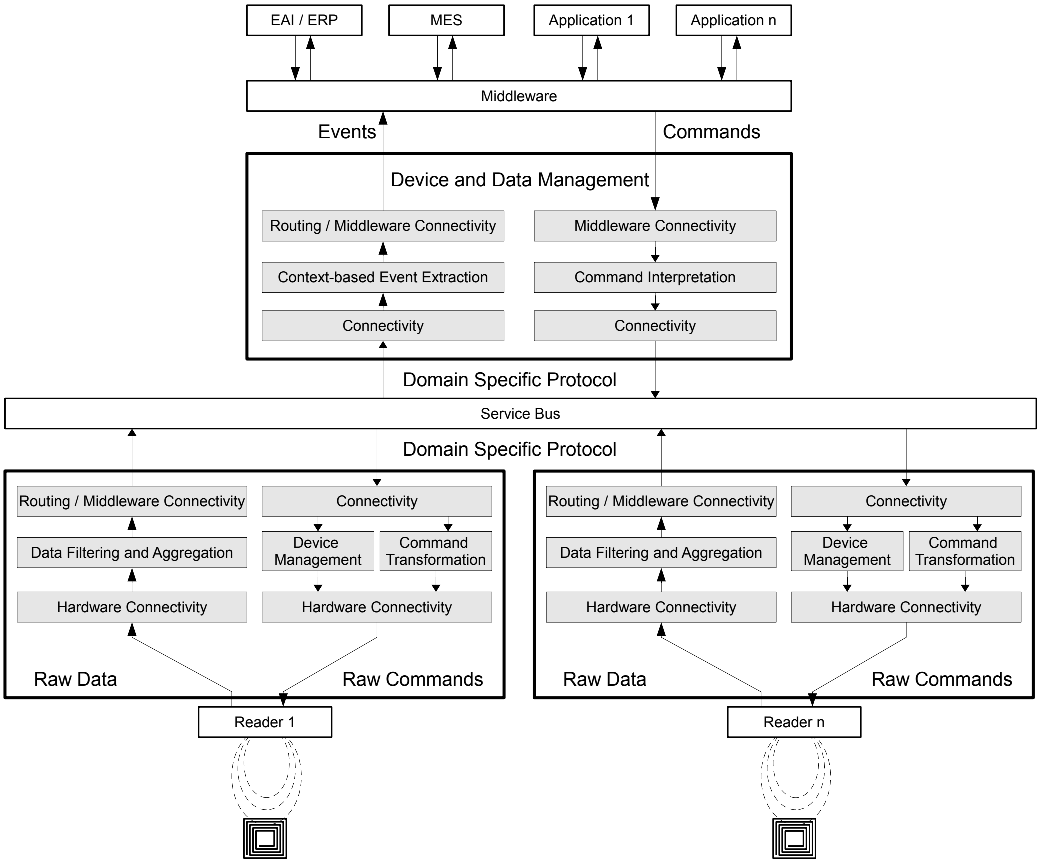

Figure 7 – Multi-tier Edgeware Architecture

GS1 aims on a standardisation of integration architectures. That standardisation defines the *The Savant Architecture* [LNE05], [CTAO03] where interface components on the hardware near layer perform simple data processing in order to extract *Application Level Events* from raw sensor data.

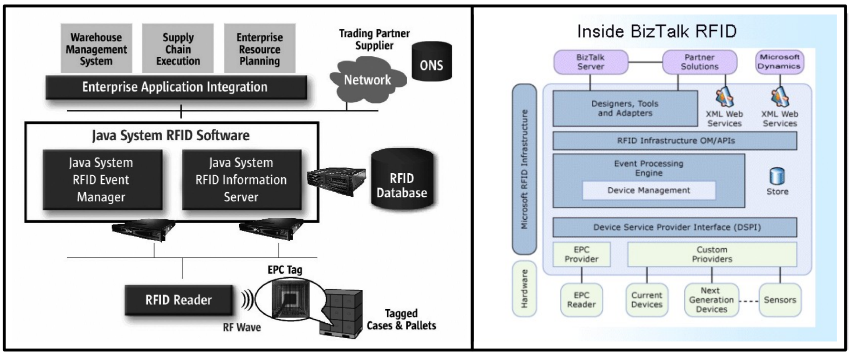

Figure 8 – Event Manager Software Components in RFID Middleware
Left: Sun's RFID Middleware (Source: Sun Microsystems)
Right: Microsoft's BizTalk Architecture (Source: Microsoft)

The architectural approach of extracting business events is implemented in middleware platforms like Microsoft BizTalk [Sch06] or Sun's RFID middleware [Sun05]. In both architectures specialized software components ("Event Managers") gather information from the RFID Readers, filter the information, and provide information as messages to systems on the business layer like ERP systems. Figure 8 illustrate how the Event Manager and Information Server fit into a network-based AutoID architecture.

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