# 8 The Role of the Internet of Things for Increased Autonomy and Agility in Collaborative Production Environments

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**Abstract**. This chapter discusses the contribution of the Internet of Things for providing a fine-grained information infrastructure within collaborative production environments. Such infrastructure makes up-to-date information available to autonomous objects to render contextual decisions that evolve elemental agility. A technical discussion illustrates the feasibility of autonomous objects as well as their possible involvement in the Internet of Things. Additionally, a demonstrator is described, which exemplifies the effects of autonomous objects on agile processes within the automotive industry. Concluding, the chapter relevant research questions in the field of the Internet of Things and collaborative production environments are specified.

## 8.1 Introduction

Market structures underlie a continuous process of change, caused by innovations of enterprises, technical improvements, new market participants, amendments, or changes in society's values. The concerned enterprises need to react to these changes and need to adapt their services and products in a quick and adequate manner in accordance with the new market conditions. The rate of market changes grew steadily over the previous decades, especially due to the improvement as well as the development of existing and new information and communication technologies (ICT). Fulfilling the demands of the market is a bigger challenge than ever before – within very small time intervals a market can change fundamentally (Pavlou and El Sawy 2005). The automotive industry can serve as an example: within a few years the demand for powerful and fast cars has decreased significantly, while the customers' sensitivity for ecological fuel-saving cars has increased noticeably – that was much faster than the leading automakers had ex-

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pected and taken into account within their product ranges and corporate structures (Zalubowski 2008). Automotive supply chains are typical collaborative production environments, in which different companies participate in producing a final product. Hence, varying the product range or changing the corporate structure of a central supply chain member, like automakers, always affects the processes and structures of its supply chain partners. The transmission of the need for changes from partner to partner and the detection of the individual modifications in processes and structures require a long time. Thus, an improvement of the network-wide reaction time offers a high potential to save and to strengthen the market position. To reduce the time gap between the detection of change and the necessary adjustments in production, it is necessary to find technologies and methods which enable the production networks to react autonomously for developing an agile supply chain coordination design.

Potential technologies that can confer this behaviour to collaborative production environments are the Internet of Things and autonomous objects (Uckelmann et al. 2010). The Internet of Things underlies different definitions, but mainly the term describes the increasing interconnectedness of electronic devices, using a common information infrastructure. Sometimes the Internet of Things is depicted as an unclear vision of unknown technologies; but it is neither a future vision, which is far away like a utopia, nor a technological breakthrough, like the invention of the radio or television was; it is a realistic prediction of the future convergence of present technological developments, the infrastructural expansion and the general trend of ubiquitous online accessibility. The future Internet of Things will use protocols and algorithms which will be based on those we use in the Internet today; it will just extend the capabilities of a more extensive machine-to-machine and human-to-machine communication, resulting in a higher number of specialised communication participants within the Internet. Autonomous objects are objects which are equipped with intelligence (small central processing units (CPUs) and algorithms) to be capable of making contextual routing decisions or handling activities. Both, the Internet of Things concepts and the autonomous objects, are complementary. The Internet of Things acts as an infrastructure and helps to realise the new systemic characteristics of autonomy and agility by providing an object-oriented information architecture for precise real-time data and ubiquitous Internet access. When applying the described concepts consequently, several existing paradigms of production environments are affected. Paradigms like "Just in Time" are no longer applicable, for instance. Most of the existing paradigms have in common that they require deterministic environments. Introducing a high degree of freedom leads to non deterministic environments and, as a result, state-of-the-art methods have to be extended. This contribution investigates the suitability and cooperation of the Internet of Things and autonomous objects for autonomic and agile processes in collaborative production environments.

This chapter is structured as follows: Section 8.2 gives an overview of recent demands of networked enterprises. Following, section 8.3 explains the fundamental concepts of agility and autonomy. After that, section 8.4 demonstrates the suitability of the Internet of Things for implementing autonomic and agile production processes in networked enterprises. Section 8.5 describes the technical requirements for fulfilling the new demands in production logistics. A prototypical example of a production scenario in which autonomic products are administrating themselves is given in section 8.6. Section 8.7 derives fundamental research questions and challenges which arise from the development and potential integration of the Internet of Things. Finally, in section 8.8 a conclusion and an outlook summarise the results.

## 8.2 Emerging Challenges of Networked Enterprises

The basic challenges of enterprises are well defined by Porters *Five Forces*; those are the rivalry within an industry, the bargaining power of suppliers, the bargaining power of customers, the threat of substitute products and the threat of new entrants (Porter 1979). All together create the market environment, which shows an inherent trend of increasing dynamically, caused by a more comprehensive use of ICT (more extensive and precise information) as well as of the extension of the worldwide infrastructure (more efficient and reliable transports/material flows).

Even if markets work by the law of supply and demand, the market participants influence the market by using many different strategic measures to exploit this law for their own objectives. They challenge their rivals through product innovations, strategic partnerships, procedural efficiency, pricing policies, acquisitions or in exploring new market opportunities (Morgan and Strong 1998). Particularly enterprise networks, where the individual enterprises concentrate on their core competences, are established to evolve synergies and to strengthen their market positions. However, the more extensive an enterprise network is, the more complex are control, synchronisation, fault recovery and reorganisation of the overall process flow. If the networks are collaborative production environments with a physical exchange of objects, the process flow is divided into an informational and a material flow, resulting in combined management, which is even more difficult.

Resuming the example of automotive industry from section 8.1, which also consists of collaborative production environments, it can be noted that there are still other components apart from the rivalry of enterprises which can affect the market conditions. For example, automakers also have to regard changes in customer preferences as well as in legal frameworks of different countries/markets. Due to the financial crisis of 2008 and high fuel prices, the customer preferences for powerful cars slid, while the concerned automakers did not offer alternatives (Zalubowski 2008). The situation was intensified by the European Union, which had enacted more rigorous emission regulations for passenger cars (European Union 2007), as well as by car scrappage schemes of some countries that were bound to the purchase of low-emission cars (ACEA 2009). The product range of the concerned automakers did not meet the new demands of the market, which resulted in considerable losses in their sales figures and profits and, consequently, partly lead to bankruptcies (Isidore 2009). Even if the development portfolios of the automakers had contained fuel-saving cars, since their supply chains contain a high number of partners, a fast adoption of new car models, as a reaction to the new customer demands, would probably not have had the necessary celerity in terms of restructuring of material and information flows. Additionally, customers increasingly demand the possibility to influence the design of their ordered cars by customising the cars' configurations. The automakers fulfil this demand by variant management, which allows the usage of different types of the same component in production processes, regarding the individual custom order. This also affects possible process sequences and constitutes an enormous challenge in terms of storage and scheduling. The demonstrator of the Collaborative Research Centre (CRC) 637[89] in section 8.6 shows an innovative approach to this challenge.

Another reason why enterprises have to ensure their structural agility is the necessary preservation of their potential compatibility to other enterprises apart from their actual partners. In supply chains, a dominating partner often defines the standards for information and material exchange and beats down the prices as a result of his absolute monopsony. The exclusive focus on the structures and specifications of the main customer lead to dependencies in the enterprise processes and can be detrimental, if the enterprise wants to cooperate with new partners, whose specifications differ from that one of the main customer. Furthermore, incorporating a new partner into a supply chain, which is dominated by one company, also requires its adaptation in structures and processes; this can reduce the attractiveness of its dedication. Additionally, markets are not longer limited by country or continental borders. Globalisation has created an international competition of the cheapest production sites as well as very efficient global logistics providers so that distances do not play the same important role as before.

Taking these market developments into account, it can be summarised that enterprises have to observe and to forecast the market in much more detail than before – due to global markets and to the more extensive enterprise rivalries, the frequency of changes within the markets have increased. Additionally, focusing on the main customer leads to dependencies in structures and market activities. These conditions cause a general new need for agile enterprise structures to strengthen the systemic characteristic of agility for ensuring a fast and adequate process adaptation to new market conditions. For implementing agile enterprise processes and satisfying the demand for customised products it is not sufficient to have agile strategies and structures; it is also necessary to give the operational processes the capability of being agile. One possibility of creating agile processes is given by the concept of Autonomous Control, which defines autonomous objects that are able to make their own decisions on the basis of certain information. For the purpose of agile and autonomous processes, the enterprises have to integrate high-density informational and control networks, which provide extensive real-time

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[89] www.sfb637.uni-bremen.de

data and enable fine-grained controlling and objective specification for management. This feature can be served by the Internet of Things.

## 8.3 Fundamental Concepts of Agility and Autonomy

This section gives a detailed description of agility and autonomy, which will be the arising challenges of modern production and logistical systems.

### *8.3.1 Agility*

While the general linguistic usage relates the term “agility” to the ease of movement or the human behaviour of being quick, light, nimble or mentally alert, agile manufacturing implies a lot more. A general definition of agility in manufacturing, out of a market oriented view, is made by Bessant et al.:

> “Agility in manufacturing involves being able to respond quickly and effectively to the current configuration of market demand, and also to be proactive in developing and retaining markets in the face of extensive competitive forces.” (Bessant et al. 2001)

Another definition by Katayama and Bennett is also market oriented, but more focussed on the company’s capabilities as well as on the customer requirements:

> “Agility relates to the interface between the company and the market. Essentially it is a set of abilities for meeting widely varied customer requirements in terms of price, specification, quality, quantity and delivery.”(Katayama and Bennett 1999)

A more comprehensive definition is given by Yusuf et al., who have researched the drivers, concepts and attributes of agile manufacturing. They perceive the concept of agility as a system with input factors, operating mechanisms and outputs, and define it as follows:

> “Agility is the successful exploration of competitive bases (speed, flexibility, innovation, proactivity, quality and profitability) through the integration of reconfigurable resources and best practices in a knowledge-rich environment to provide customer-driven products and services in a fast changing market environment.” (Yusuf et al. 1999)

Furthermore, the agility can be classified into three levels: macro, micro and elemental agility. While elemental agility refers to individual resources like people, parts or machinery, micro agility denotes the enterprise perspective (Goldman et al. 1995). Macro agility extends this consideration to enterprise networks and is suggested by Yusuf et al. For receiving an agile collaborative production environment, it is important to note that these levels cannot be optimised separately, but they are built on each other and they need to be optimised in a harmonic way (Yusuf et al. 1999).

In order to develop the systemic capability of agility, an organisation has to pursue the four core concepts of agile manufacturing, which emanate from a strategic management perspective (Yusuf et al. 1999; Katayama and Bennett 1999; Gunasekaran 1998). Figure 8.1 illustrates these concepts; afterwards the core concepts will be described briefly.

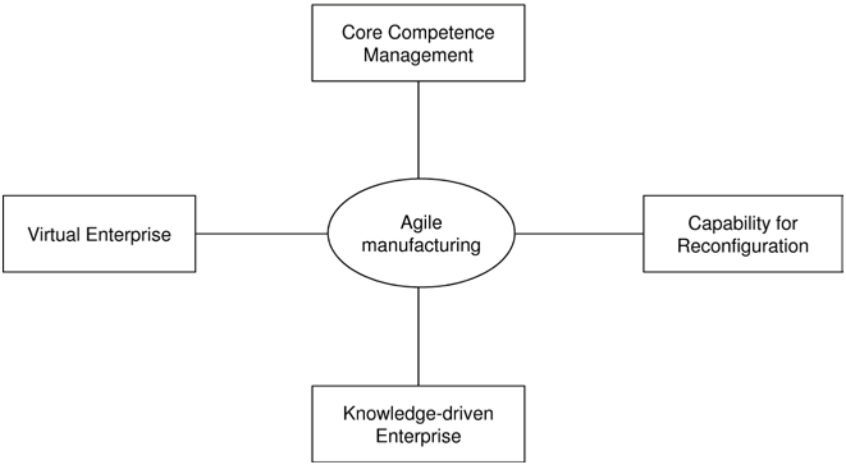

**Fig. 8.1** Core Concepts of Agile Manufacturing (Yusuf et al. 1999)

*Core Competence Management* comprises all measurements and methods for saving, intensifying and developing a company's core competences. Such competences are all "*...skills that enable a firm to deliver a fundamental customer benefit*" (Prahalad and Hamel 1990). They are also called the collective knowledge of an organisation, which mainly means the technological and organisational skills as well as the know-how of the employees about manufacturing techniques, project management, communication, product development, etc. The firm's core competences should be particularly strong compared to other firms in the same industry.

A detailed understanding of the core competences enables organisations to interact in a *Virtual Enterprise*. Within virtual enterprises, organisations complement each other by providing competences which are necessary for their partner's production, but missed or outmatched by their counterpart. Participating organisations are still legally independent and their respective employees, who work for the virtual enterprise, are still placed in the organisations premises; the co-operation and communication within virtual enterprises take place by using modern ICT, mainly the Internet. Hence, usage of the Internet of Things offers an improvement of the potential co-operation, since it prolongs the informational range into the partner organisation. Virtual enterprises are often temporary organisations, which are built for a special purpose. Due to low effort for building a virtual enterprise, the possibility of an uncomplicated and flexible concentration of high qualified employees as well as the purposeful construction give organisations an extensive potential for creating agile structures.

The *Capability of Reconfiguration* is probably the most intuitive one in conjunction with the term agile manufacturing. It contains the structural and operational flexibility to shift the enterprise's focus and realign its business to the changed market environment. Additionally, it capacitates the enterprise to lead the way in competition (Yusuf et al. 1999). Realising this competence is a two-step process with a top-down approach. It starts with the development of a strategic architecture that features a corporate wide map of core skills (Prahalad and Hamel 1990), which enables the management to react fast to a necessary change by a quick identification of the corresponding elements. The second step concerns the implementation of modern ICT into the operational processes for achieving operational flexibility; only with executors, who have access to reliable real-time information and who receive their commands without delay, the *Capability of Reconfiguration* can be achieved.

The concept of the *Knowledge-driven enterprise* is based on the increasing acceptance of inimitable knowledge and information as the source of corporate success. The owners of this knowledge and information are mainly the employees. They generate the enterprise's success by transferring their collective knowledge into saleable products. To enable an agile enterprise, it is necessary to build up a knowledge-rich workforce, which is able to react quickly and adequate to the need for change in structures and products (Yusuf et al. 1999). For that purpose the enterprises have to integrate a knowledge management, which tasks are the

- prevention of knowledge loss by employee turnover,
- extension of the collective knowledge through further education,
- execution of workshops for cross-generation knowledge transfer as well as
- the arrangement of structured knowledge documentation.

The management of an enterprise can use these four concepts as a tool set for developing agile strategies (Gunasekaran 1998). Due to the difficult prediction of change they have to be very generic; not until the occurrence of change they will be instanced and specified by the individual parameters of the situation.

There are two comprehensive suggestions for determining the agility level reached by an enterprise. The first is from Yusuf et al., who categorised enterprises with agile attributes which are grouped in decision domains (Yusuf et al. 1999). Exemplary decision domains are

- competence (attributes: multi-venturing capabilities, developed business practice difficult to copy),

- technology (attributes: technology awareness, leadership in the use of current technologies, skill and knowledge enhancing technologies, flexible production technology),
- partnership (attributes: rapid partnership formation, strategic relationship with customers, close relationship with suppliers, trust-based relationship with customers/suppliers) or
- market (attributes: new product introduction, customer-driven innovations, customer satisfaction, response to changing market requirements).

The second suggestion is from Gunasekaran. He defined agility enablers as well as corresponding metrics (Gunasekaran 1998). The enablers are

- virtual enterprise formation tools/metrics;
- physically distributed teams and manufacturing;
- rapid partnership formation tools/metrics;
- concurrent engineering;
- integrated product/production/business information systems;
- rapid prototyping tools and
- electronic commerce.

The objective of this explanation was to describe the concept of agility in manufacturing process as well as to depict potential starting-points for a supportable concept integration of the Internet of Things.

## *8.3.2 Autonomous Control*

The idea of Autonomous Control of making decisions and solving problems on the locality and within the environment where the objects are pending (the context) enables robust logistic processes. This has a significant impact on generating the elemental agility, which is immanent for achieving the integrated system agility.

The CRC 637 "Autonomous Cooperating Logistic Processes – A paradigm Shift and its Limitations" at the University of Bremen, has been analysing Autonomous Control since 2004. The CRC 637 defines the Autonomous Control as follows:

> "Autonomous Control describes processes of decentralized decision-making in heterarchical structures. It presumes interacting elements in non-deterministic systems, which possess the capability and possibility to render decisions independently. The objective of Autonomous Control is the achievement of increased robustness and positive emergence of the total system due to distributed and flexible coping with dynamics and complexity." (Hülsmann and Windt 2007)

The constituents of the definition can be divided into characteristics (autonomy, heterarchy, decentralised decision-making, interaction and non-deterministic system behaviour) and objectives (increased robustness and positive emergence). All of them are also discussed by Hülsmann, Windt and Böse (Hülsmann and Windt 2007, Böse and Windt 2007). For a better understanding of Autonomous Control, there will be a summary in the following section.

### Characteristics

*Autonomy* describes the ability to make own decisions, independent from any external influence (Probst 1987). For autonomous objects those are mainly decisions which result in a physical handling activity of themselves. This can be a logistical decision, like a route or a transport mean or a production decision about the sequence of individual process steps like milling before drilling or vice versa.

*Heterarchy* is a form of a system in which its elements are theoretically on the same level of power and authority and where there is no entity which permanently dominates the others (Probst 1992). The elements have just a few relationships of superordination and subordination, so that controlling mechanisms are mostly executed by the elements themselves. That means that all system elements have the same organisational chance to take part in the interactions of the system (Hejl 1990). Thus, a heterarchical system design is closely related to the concept of Autonomous Control: while Autonomous Control describes the object behaviour, the heterarchy describes the characteristic of a system which is formed by the behaviour of the associated elements.

A heterarchical system with autonomous objects implicates *decentralised decision-making*. That means that the decisions on the operative level are not taken by a central co-ordinating instance, but the decision power is transferred to the elements themselves. They take contextual decisions between alternative actions on the basis of the environmental conditions or available information in line with their instructions and the predefined systemic objectives (Frese 1998). The capability of decision competence requires the presence of appropriate algorithms and methods.

Autonomous objects need exchange with their environment (e.g., other objects or sensors) for gathering crucial information, sending status messages and triggering actions. For these reasons they have to be capable of interacting with other system elements for co-operation and co-ordination. The *interaction* activity is the successful contact between systems or their elements, which is either intended by the object itself or induced by receiving a request from another object.

*Non-deterministic system behaviour* describes the unpredictability of a system's output despite having definite input variables, information about the system state as well as knowledge about the systemic transformation rules. Rerunning the system with identical input variables can cause different output results (Pugachev and Sinitsy 2002).

A prerequisite for achieving autonomous objects is to implement or to enhance some kind of intelligence into objects. The concept of the Intelligent Product pursues this approach and enhances products of today by adding competencies to them. Requirements of Intelligent Products are often verbalised as high level requirements and reflect the demand of autonomous products. McFarlane and Wong describe the Intelligent Product as a physical and information based representation of an item (McFarlane et al. 2003, Wong et al. 2002), 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.

Definitions from Kärkkäinen et al. (2003) and Ventä (2007) reflect very similar properties of an Intelligent Product. They differ in the perspective from which they look at the Intelligent Product. While Ventäs point of view is a technical and systemic one, Kärkkäinen has a logistics focus. Based in this focus, he describes the Intelligent Product in a supply chain.

Similar to this, the Internet of Things concept formulates its requirements on intelligent items, which is highly congruent to the above mentioned description of Intelligent Products. There are key functionalities that are required to enable the interaction between items (Fleisch and Thiesse 2008):

- Identification: Objects in the Internet of Things are precisely identifiable by a defined scheme.
- Communication and Cooperation: Objects are capable to interact with each other or with resources across the Internet.
- Sensors: Objects can collect information about their environment.
- Storage: The object has an information storage that stores information about the object’s history or/and its future.
- Actuating elements: Objects in the Internet of Things are capable to act on their own without having a super ordinate entity.

- User Interface: Adapted metaphors of usage have to be made available by the object.

Having in mind the definitions of the Intelligent Product as well as the aforementioned research field of Autonomous Control, in section 8.6 we will come up with an implemented application of these concepts.

**Objectives**

As Hülsmann and Windt explains, the Autonomous Control has two main objectives: increased robustness and positive emergence of the overall system.

The objective of *increased robustness* is based on the assumption that autonomous objects can react much faster to unforeseen events than higher planning and controlling instances (see also section 8.3.1 in terms of necessary agility in manufacturing). The direct concernment within the situation enables the objects to calculate their position and to react in a contextual manner, still in line with their instructions. If all incidents were solved by a higher instance, decisions and instructions would take longer to reach the executors and the system resources would have to handle a higher fluctuation in the number of objects.

*Positive emergence* means that the sum of the individual and context dependent decisions, which are made by autonomous objects, gain a better achievement of the total system objectives than it can be explained by the behaviour of every single element (e.g. lower delivery times and higher adherence to delivery dates) (Böse and Windt 2007).

**Degree of Autonomous Control**

The concept of Autonomous Control can be used in different degrees of intensity. An intuitive criterion for dividing the behaviour of logistical systems into those of a higher and those of a lower level of Autonomous Control is the proportion between autonomous controlled and conventional managed objects. But this is a very abstract criterion, due to the difficulty of deciding whether an object is autonomous or not. For a detailed categorisation of the system's level of Autonomous Control, Böse and Windt defined an extensive catalogue of criteria in the form of a morphological scheme, which tries to determine the property values of the overall system and the range of the object capabilities. Exemplary criteria are the organisational structure, the location of storage, the interaction ability or the resource flexibility (Böse and Windt 2007).

The consequences of the different degrees of Autonomous Control on the achievement of the logistic targets are not proportional. That means a higher level of Autonomous Control does not automatically lead to a better achievement of the logistic targets; additionally, they also depend on the complexity of the logistics systems. Philipp et al. showed that the concept of Autonomous Control helps to achieve the logistics targets within complex systems, but this support just endures until a specific level of Autonomous Control. If that limit is exceeded, the achievement of logistic targets will decrease markedly, as the system behaviour will increasingly resemble a state of anarchy (Philipp et al. 2007).

The correlation between the characteristics and objectives of Autonomous Control as well as their impact on agility are summarised in figure 8.2.

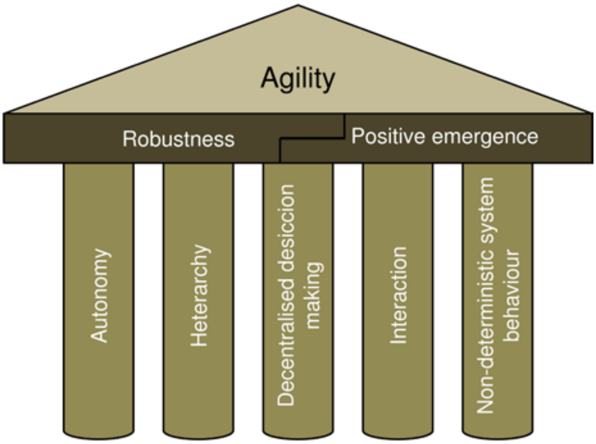

**Fig. 8.2** Correlation between Characteristics and Objectives of Autonomous Control

## 8.4 Enabling Autonomy and Agility by the Internet of Things

Assuming that the runs of individual processes in a collaborative production environment are built and structured in an agile way (e.g., people are trained to switch between different activities, or changeability of process sequences is possible, etc.) and that the processes have a high level of ICT integration, the Internet of Things can constitute an agility enabler by providing the necessary communication infrastructure (compare to section 8.3.1). This impact occurs on two different ways: the managerial and the operational way. Both are shown in figure 8.3.

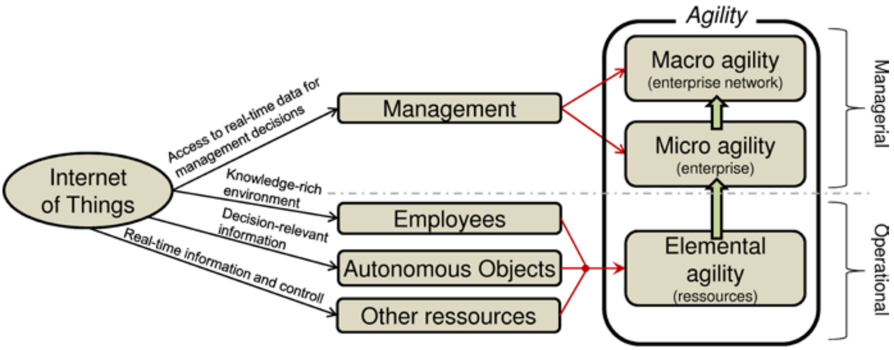

**Fig. 8.3** Ways of Impact of the Internet of Things onto the Systems Agility

The managerial way takes effect about the human as a high level decision maker. By providing extensive real-time data out of the working environment through the Internet of Things, filter mechanisms can aggregate the relevant information and observe thresholds for critical processes, so that responsible persons receive their individual management status views with important exception messages. If necessary, the manager can take counteractive measures by using the Internet of Things as an instruction bearer. Due to the possibility of multidirectional communication, the instructions can reach all people and objects that are connected to the Internet of Things. An example for an unexpected event with market evidence is a product recall. After an enterprise has discovered a significant deficit within the product quality, it has to initiate several measurements in terms of its production processes. First of all, it is necessary to stop the current production of the defective product. While the development department remedies the products deficit, the management identifies the necessary changes within the production processes and adjusts the capacities for the reparation of the returning products. All these steps are supported by the infrastructure of the Internet of Things. If the product recall concerns an enterprise network, the Internet of Things demonstrates another advantage: standardised interfaces and protocols; the measurements in terms of the production processes would be the same. In this way the Internet of Things offers a kind of high-level controlling with shorter delays and thus enables faster reactions to unexpected events as well as quicker executions. Hence, agility on the level of enterprises and enterprise networks can be achieved.

The operational way of generating an agile system by the usage of the Internet of Things is through autonomous objects, operative employees and Internet connected resources. Autonomous objects are characterised by making their own decisions. Those decisions can just result from a reliable, accurate and actual information basis. If decision-relevant information is not in the proximity of the autonomous object, it can use the Internet of Things as an information provider to contact spatially distributed databases, objects and resources, which are connected to the Internet of Things architecture. The equipment of the objects with a long-range communication module (e.g., mobile communications) would offer another way to connect spatially separated sources of information, but it is still too expensive in terms of money and energy consumption in relation to the object values and realisable energy capacities. In contrast, the use of the Internet of Things architecture, which is embedded in the objects environment, causes adequate costs and enables autonomous objects to make decisions on the best available information with less energy expenditure for communication. For example, the occurrence of unexpected events (e.g., missing deliveries) could be automatically detected, the information could be provided to the autonomous objects for a situation dependent decision (e.g., changing their processing sequence due to missing parts) by using enterprises' intranets. There is also the usage of the Internet of Things as an instruction bearer, e.g., by triggering a handling activity on the autonomous object itself, like discharging it on a conveyer.

In this situation, operative employees work in knowledge-rich production environments, which are characterised by a high ICT integration within the working processes. The connection of the work stations to the Internet of Things achieves that the employees receive all the necessary information on their screens, regarding those product components which are relevant to their job. For example, these can be job lists with the product components' status (e.g., position, degree of completion), the next object individual work step (important in job shop manufacturing with a high number of product variants) or safety instructions. If a fast reaction to market changes is required, the management can send decisions concerning production changes directly to the employees' work station; employees, who are trained for changeability, can execute the new instructions instantly in their sequence of work. Internet connected resources are able to provide information about their environment based on a time interval, a threshold or by receiving a request. A good example is warehouse management. Within a collaborative production environment each enterprise owns warehouses and all of them depend on each other. The Internet of Things enables a permanent, network wide stock management and reduces the uncertainty about available goods; reliable data can be used for a better synchronisation of the processes as well as for a reduction of overstocking and understocking for cost savings, thus potentially reducing the bullwhip effect. Another example is the tracking and tracing of items like tools or products. The Internet connected resources do not influence the agility directly, but they provide a data base of reliable and actual information, thus enabling faster and more adequate reaction to a need for change.

On the operational side the individual non-human resources, which are able to act autonomously, the trained employees as well as the information transparency, provided by Internet connected resources, generate the elemental agility.

The influence of the Internet of Things on the agility of collaborative production environments can be summarised as an allocation of a close meshed information and control network, which obtains decision-relevant data of the participating objects and humans in real-time and offers an infrastructure for the quick and direct transmission of production instructions by determining the need for change.

## 8.5 Technical Requirements for Satisfying the New Demands in Production Logistics

Using the Internet of Things for optimising collaborative production environments with an increased autonomy and agility requires the development of hardware and software. Two main challenges can be derived from this need. First: the whole Internet of Things needs the ability to handle data from sensors, real-time location systems and other pervasive technologies available in the future (Thiesse et al. 2009). Second: the economical development and production of software for agents and hardware, such as sensors, actuators or dynamic material handling equipment. These challenges need to be coped in order to enter the available data in the Internet of Things and to make them accessible to objects for rendering their own decisions (Fleisch et al. 2005).

Bridging the gap between the real and the virtual world, the Internet of Things is the technological requirement for achieving an autonomous and agile collaborative production environment. In this environment all objects (whether humans or machines) can communicate with each other without the need of deliberate manual interaction. Currently, the Radio Frequency Identification (RFID) technology is penetrating different businesses and thus blazes a trail for the communication between objects and companies (Fleisch et al. 2005).

The Internet of Things is more than communication, the Internet of Things goes beyond communication; it equips the individual object with intelligence. This intelligence can be placed on the object itself or by representing the object in an IT-infrastructure, which can be near or far away from the object and which is linked to the object permanently or temporarily by the Internet of Things. By using available standard RFID technology, the object can only be identified and linked with information about the environmental conditions at the locations of the RFID-interrogators. Until now, the storage and processing of the data, which the object generates during its lifecycle, could be realised by the usage of IT-infrastructure, which is not physically linked to the object. The current Electronic Product Code (EPC) network architecture is designed to store the information an object collects during its whole lifecycle in IT-systems, which are placed at the supply chain partners, who have handled the object (EPCglobal 2009).

### *8.5.1 The Evolution from the RFID-based EPC Network to an Agent-based Internet of Things*

For having a fully capable Internet of Things, every object should have the capability to process data in order to handle available information and to make decisions based on them, if necessary. This could be done by implementing Software agents and Multi-Agent Systems (MAS), which are common for implementing autonomous and interacting software systems. Agents are autonomous decision makers acting on behalf of physical objects implemented as a software program running in an MAS environment. These agents have sensors for perceiving their environment and actuators to act based on the results of reasoning processes. Moreover, agents are able to communicate with each other in an MAS to coordinate their actions. This results in an even better target achievement of each agent. Based on Knirsch and Timm (1999), agents are situated in an environment, act autonomously, and are able to sense and to react to changes.

In most conventional test scenarios the objects' agents are just running on server platforms. That implies the physically linkage of the agents to the objects, because embedded systems do not have enough computational power for running agent platforms. In the majority of scenarios the objects are connected to their intelligence, which is provided by the agent programs, by attaching unique identifiers, like RFID or barcode tags. These unique identifiers are detected when passing an RFID interrogator. The aim of a future Internet of Things is having the agents physically linked to most of the objects - especially the ones where it makes economical or strategic sense, like valuable goods or production relevant components. Moreover, Jedermann and Lang explain that it could be cheaper to attach intelligence to the object, instead of having much communication between the information technology infrastructure and the object (Jedermann and Lang 2008). To achieve this level of autonomy, computational hardware needs to become smaller and inexpensive, so that even everyday objects could be equipped with intelligence. Based on Moore's law, Mattern says that in the long term almost every object could be equipped with intelligence to run agents on its embedded system (Moore 1998, Mattern 2005). Not only the computational power is important when thousands of intelligent objects are produced every day, even economical and ecological aspects need to be considered. One step towards the production of cheaper and more environmental friendly tags offers the development of chips based on polymer electronics technology (CERP-IoT 2009).

### Energy Supply for Embedded Devices

In addition to the capability of decentralised computational power, energy supply is an important topic. Unfortunately, the development of energy supply could not keep up with the development in processing technologies (Mattern 2005). Nevertheless, the ongoing miniaturisation of integrated circuits (ICs) and the software development have led to their reduced energy consumption by constant computational power. But there is still a need for innovative concepts regarding the energy supply. That does not necessarily mean energy storage; it also means to do research on approaches like energy harvesting. Sources for energy harvesting could be for example: vibration/motion, temperature difference, light or RF (electromagnetic waves). Combined with temporary storages and ultra low power micro control units these techniques can lead to a new ubiquitous sensor generation for the Internet of Things (Raju 2008).

## Sensors for Collecting Information

Getting towards the future Internet of autonomous and agile Things, objects need to have information concerning their present situation. The agents running on IT-systems, which are physically or remotely linked to the objects, need this information for their decision making processes. Typical sensors could detect light, acceleration, temperature, their location or humidity (Mattern 2005). Currently, research is investigating new small sensors to analyse even liquids or gases. An example is the miniaturised gas chromatography system for detecting volatile organic compounds developed at the Institute for Microsensors, -actuators and -systems (IMSAS)[90] at the University of Bremen (Stürmann et al. 2005). Information about fresh products is collected by these small sensors by analysing the air which surrounds the products. This could be used by the object agents for calculating dynamic best-before dates. Based on that, approaches like "First Expires First Out" in supply chains could be implemented in new warehousing concepts for reducing losses due to a bad quality of perishable goods (Jedermann and Lang 2008).

One of the most important pieces of information, which is decision relevant for intelligent objects, is their location. The reason for this is that the majority of the objects will be mobile so that the objects themselves need to know about it (e.g., if the logistical object has reached its destination). Aside from the absolute position, the relative position might also be of interest. An example is the transport of fresh fruits: bananas should not be stored next to apples because this would lead to a fast ripening of the bananas. Currently, positioning systems are big, expensive, have high energy consumption and do not have the required accuracy. This is going to change (Mattern 2005). Location-sensing techniques like triangulation, proximity or scene analysis can be combined with different transmitting technologies based on radio, infrared light, magnetism, ultrasound or vision for designing location-aware objects (Hightower and Borriello 2001).

## Communication

When the Internet of Things will consist of billions of objects (COMMISSION OF THE EUROPEAN COMMUNITIES 2009), this will result in extensive network traffic and will need a high number of network addresses. The communication needs of intelligent things could not be handled completely by common communication technologies: on the one hand, wired networks need further development for handling the increased network traffic over long distances. This will boost for example, the change from copper wires to fibre optics for long distance communication. On the other hand, the majority of objects will be mobile within the Internet of Things, so that wireless technologies for short- and long-distance communication need to be extended and developed further. Hence, technologies like ultra wide band (UWB), universal mobile communication system (UMTS), Zigbee or Long Term Evolution (LTE) will have to be even more common. But there will be

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[90] www.imsas.uni-bremen.de

also a demand for special technologies, which consist of cheap components that are using low level protocols or need very low energy to bridge the gap between broad band networks and sensor networks. In order to handle all intelligent objects, being present in the Internet of Things, an address protocol with a wide address space is needed. An option is presented by the Internet Protocol version 6 standard (IPv6) for Internet communication (CERP-IoT 2009), which allows $2^{128}$ addresses.

### Task Specific Degrees of Object Capabilities

In the future Internet of Things the technological equipment of (autonomous) objects will differ in its functional range, depending on the context in which the object acts as well as on its tasks. In the following, two opposed scenarios will be described, nevertheless, a lot more scenarios are possible in between these extremes:

In the first scenario the object presents a swap body with valuable goods inside, which carries a transponder for its identification, a general packet radio service (GPRS) module for long-distance communication, an embedded micro-controller for the agent platform as well as sensors for temperature and position measurement. This full capable object can act autonomously in offline cases and has an agent replica hosted in the Internet of Things.

The second scenario includes a box, which is used for the transport of low-cost items in automotive industry. This box is just equipped with a transponder, which enables its identification for the company´s load carrier management. An agent could be realised on a server within the Internet of Things, but not on the object itself. For receiving corresponding information, it would be conceivable to use the EPC network to find out more about the identified object. Equipment with only identification technologies could make sense, especially for linking low price products to the Internet of Things or for locations without a permanent network access.

This subsection explained the technological needs to enable an Internet of Things in collaborative production environments. An overview about the hardware status, necessary improvements and developments is illustrated in Table 8.1.

| | Available technologies | Necessary improvements | Technologies in development |
|---|---|---|---|
| Identification | Barcode, OCR, RFID | RFID needs suitability for daily use | Polymer electronic (RFID) |
| Short distance communication | Zigbee, Bluetooth, WLAN, UWB, RFID | Reducing energy consumption, Simplify communication protocols | Bluetooth low energy, 6lowpan |
| Long distance communication | Copper wires, Fibre optics, GSM, UMTS | Expand the availability of broad band accesses | LTE, Smart Grid |
| CPU | Standard Silicon Technology e.g. ARM, Low voltage CPUs | Reducing energy consumption, Improving environmental friendliness | Photonic computing, Polymer electronic |

| | | | |
|---|---|---|---|
| Energy supply | Batteries (Lithium etc.), Capacitors | Higher energy density, Improving environmental friendliness, Extending life time, Fast battery charging | Energy harvesting, Polymer electronic, Novel batteries (Lithium-metal-air battery), Resonant energy transfer |
| Sensors | Small variety of miniaturised sensor types, e.g. temperature, acceleration | Developing more different sensors, Integration into embedded systems | Miniaturised sensors for e.g. gases and enzymes |

**Table 8.1** Capabilities of Autonomous Objects and Their Realisation by Technologies

### 8.5.2 Agents for the Behaviour of Objects

After describing the hardware which is needed to fulfil the needs of the Internet of Things, the development status of software technology will be illustrated:

For implementing the Internet of Things in collaborative production environments with increased autonomy and agility, it is necessary to go beyond standard centralised software architectures. To attend to this challenge, agent technology offers a promising approach.

Different agent platforms are available for programming agents, representing the objects in the Internet of Things. Two platforms which are used at the CRC 637 are the well known JavaAgentDEvelopment framework (JADE) as well as the Open Services Gateway initiative framework (OSGi) (Jedermann and Lang 2008). They are theoretically usable, but a wider usage of agents within the Internet of Things needs improved software for the setting up of agents. In a world of billions of Internet connected objects, many people, including the consumers, want to have the possibility to design and develop their agents; hence, the enhancement of the user-friendliness for agent software is very important (Mahmoud and Yu 2006).

Based on Uckelmann et al. different options are possible for implementing the agents in the Internet of Things (Uckelmann et al. 2010); the basic idea is using the EPC network as a standardised and well accepted structure. The already existing network needs to be extended by the following abilities: the capturing of dynamic data, the autonomous processing of data and the integration of intelligent material handling systems. These ideas are still not implemented. For a realisation the following questions need to be answered amongst others:

*Where will the software agents work?*
This is mainly influenced by the available techniques and whether it makes sense in an economical way to attach intelligence to an object. Based on these premises it is possible to integrate an agent on central IT-systems at the objects manufacturer or on an embedded system, which is physically linked to the object. In-

between these contrasts, the agent could be implemented on a local IT-system, which is named Internet of Things Information System (IoT IS). This IoT IS, which is described by Uckelmann, is hosted at logistical objects like warehouses or trucks and provides the computation capability for the agents of the logistical objects inside these objects. This enhanced system, based on the already existing standards of the EPC network, consist of the Query Interface with data synchronisation capabilities, the Repository that stores data as well as decisions, software-agents and preference sets, and the Capturing Application. This makes sure that the generated data is exchanged with the global Internet of Things in a correct and secure way (Uckelmann et al. 2010). Every option has its pros and cons. The main differences are whether the object needs network connectivity as well as the price and complexity of the hardware. In Table 8.2 possible locations for hosting agents are compared with each other.

| **Location of process capability** | **Technical requirements at the objects** | **Pros** | **Cons** |
|---|---|---|---|
| Central IT-system | Object has a unique ID | No computational power at the object needed, Permanent access to agents, Cheap tags sufficient | No offline decision possible, Increased network traffic |
| Local IoT IS | Object has a unique ID | No computational power at the object needed, Cheap tags are sufficient, Agent is nearby the object | Agent has to transfer itself to the next IoT IS's |
| Embedded system | Object has a micro controller, Sensors and network connection | Offline decisions are possible, Low network traffic | Complex embedded hardware is needed, Synchronisation with agent replicas |

**Table 8.2** Comparison of Possible Hosting Locations in the Internet of Things for Agents

Additionally, figure 8.4 illustrates the two dimensions of an object's intelligence as well as the physical distance between the object and the location of its intelligence and shows some exemplary technology equipments. The rising level of intelligence by an increasing distance is due to the higher computational power of central IT and the ability of using more complex algorithms and heuristics.

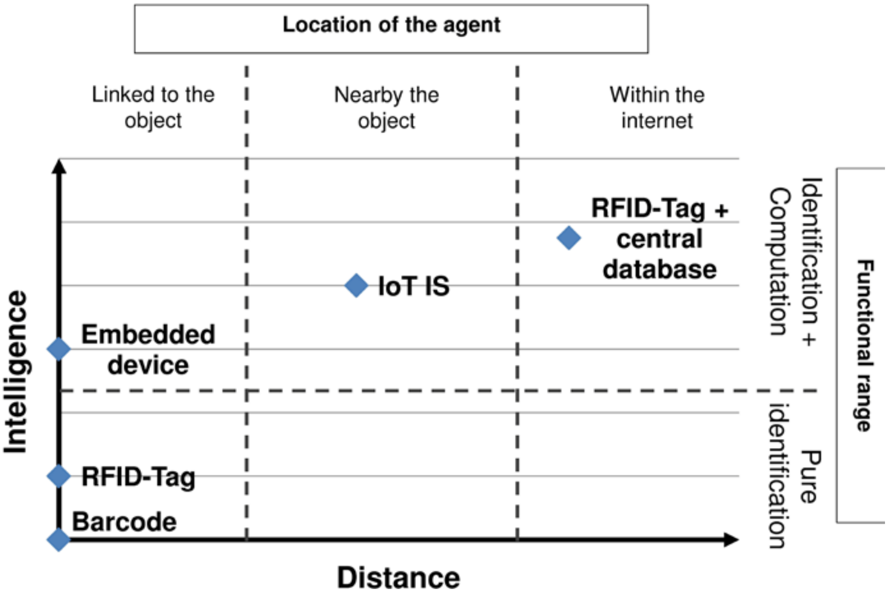

**Fig. 8.4** An Object's Intelligence as well as Its Proximity to the Object

*Who will be responsible for the agents on the organisational level?*
Additionally, the localisation of agents implies questions of data security, product lifecycle responsibility and other social requirements. It is obvious to leave the agent in the sphere of the manufacturer. This solution includes the following advantages:

- It enables the manufacturer to collect a multitude of data about the lifecycle of the product, which could be used for product development.
- Moreover, the manufacturer can offer more services by using the data about the products available through the Internet of Things.
- The users of the product do not need to think about the agent's hosts.
- The manufacturer can easily refinance the costs for hosting the agent by including these costs into the price.

There are still some open issues, like the influence on the customer relationship, legal protection or the already mentioned data security.

**Agent Replicas**
The exclusive running of the agent on one IT-system or on the object itself seems impractical. There will be objects, which need both, an agent located on the object or in an IoT IS next to the object (depends on the functional range of the

object) and an agent replica continuously connected to the Internet of Things. The replica is needed if the agent has to make decisions without having network connectivity (e.g., if an object is standing in the corner of a warehouse without Wi-Fi coverage and needs to make sure being just in time at the customer's). This will result in additional challenges. The most important one is how to implement a reliable synchronisation of the agents being responsible for the same object (Uckelmann et al. 2010). Making objects capable of rendering decisions without being connected to an agent in the Internet of Things needs some rules which determine the authority of the agent next to the object to come up with decisions. This is needed to make sure that both agents responsible for the same object do not make different decisions.

In terms of the software, there are still some other necessary developments and open questions, beside the necessary enhancement of the user-friendliness of agent platforms, the agent location and the authorisation between the object's agent and its replica. These are, for example, the energy consumption of embedded devices (i.e., so that they consume energy depending on the context of the devices) or decision algorithms. A lot of applications should be improved in the near future, but there is still a long way to implement software agents on every level of product environments, especially in which real time control is needed.

## 8.6 Application Field: Automotive Tail-lights – Intelligent Product

The high complexity of logistics networks makes it more and more difficult to meet the demands of logistics. Having the right product at the right time at the right place – this is becoming very challenging with conventional planning and control methods. Thus, aspects such as agility, flexibility, proactivity and adaptability are in the focal point of the current research. This is done by applying concepts of decentralisation and autonomy on the logistics decision-making process.

These concepts that concentrate mainly on the methodology, require an information infrastructure they can rely on. The Internet of Things concept is deemed to act as an enabling infrastructure for distributing the information to items and logistics objects. As a future autonomous logistics object, the Intelligent Product is being introduced. The Intelligent Product will be presented in a production logistics scenario and is capable of acting autonomously through an assembly process. This assembly process is part of a production scenario designed to investigate the applicability in the domain of production logistics. The scenario illustrates an autonomous assembly system for an automotive tail-light. The whole equipment is tailored to communicate over the Internet, and, as a consequence, we can imagine extending this scenario in order to consider more than one location of the supply chain.

This section reflects an ongoing work on implementing Autonomous Control methods on logistics systems, specifically in production logistics, where the Intelligent Product plays a central role. The previously mentioned CRC 637 ‘Autonomous Cooperating Logistic Processes – A Paradigm Shift and its Limitations’ hosts this work in a technical subproject.

### *8.6.1 Assembly Scenario*

A production scenario is being implemented for investigating the applicability of Autonomous Control methods in the domain of production logistics. The scenario illustrates an autonomous assembly system for an automotive tail-light. The autonomous aspects refer to the decision-making and all related processes of transport of the components, etc.; the assembly itself is still designed to be a manual task.

The assembly scenario is originally designed to be a flow shop system that does not allow any flexibility within the sequence of processes. Today, automotive tail-lights are produced with variant types to meet the customer configuration demands. Due to this fact, variant flow shop systems evolved from the inflexible systems. However, these systems are still controlled centrally with a limited and predefined space of variants that are determined and scheduled beforehand. This realistic scenario was taken as a starting point to derive the introduced scenario with Autonomous Control by implementing variant types of the finished product which have to be chosen by the product itself. Figure 8.5 shows the assembly process and the related parts.

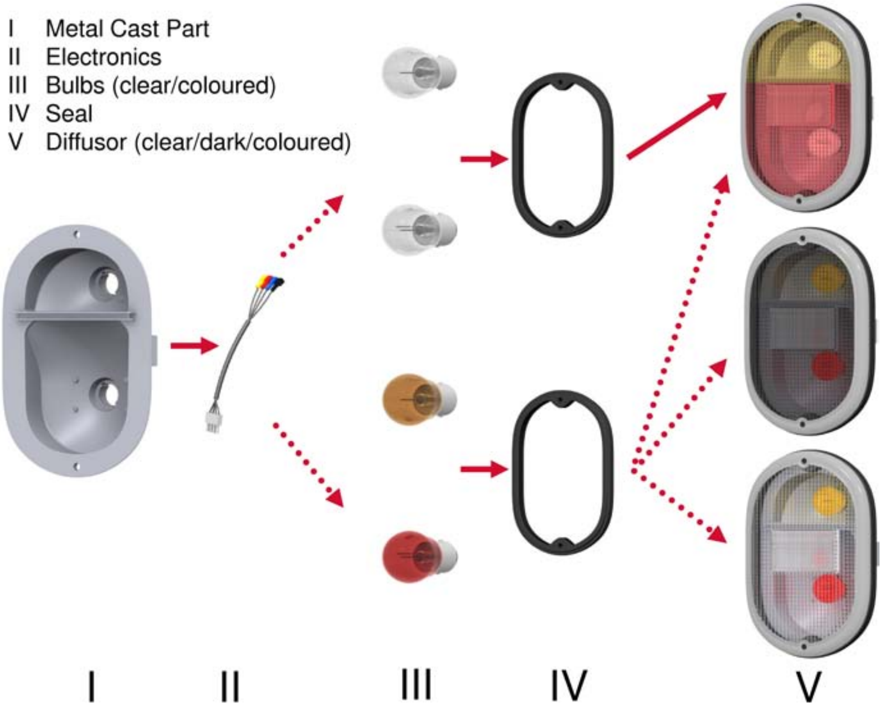

**Fig. 8.5** Assembly Process of the Tail-light

## 8.6.2 Layout

The scenario consists of six stations; five of them are assembly stations, while one station is implemented as an input/output station to insert the semi-finished parts and also to take out the assembled/finished products. The assembly process consists of four stages, which are depicted in figure 8.5. The process starts with the insertion of the semi-finished metal-cast part into the material-flow system (compare to figure 8.6). The implemented assembly stations correspond to the five-stage assembly process and are designed to assemble bulbs (coloured and clear), seals and three types of diffusers.

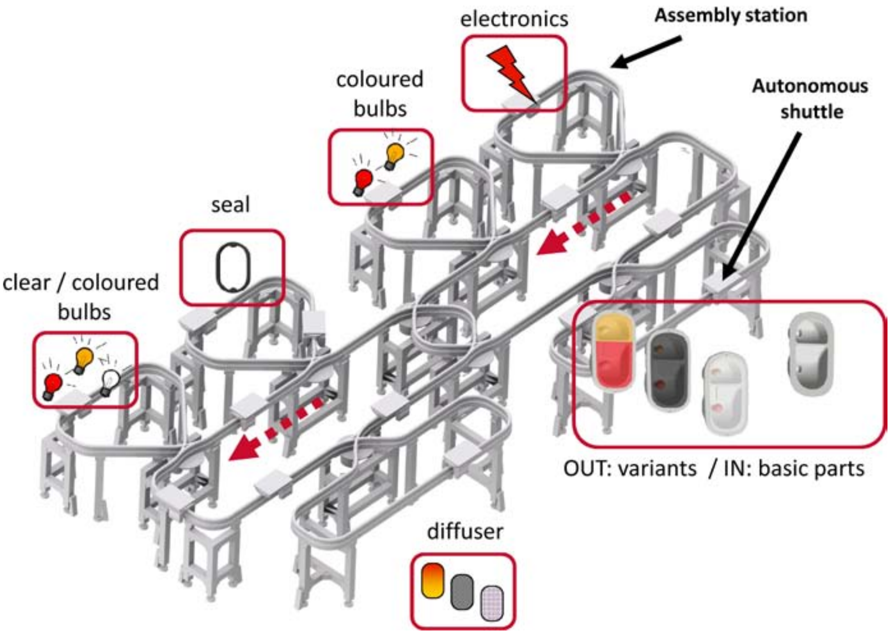

**Fig. 8.6** Assembly/Production Scenario (Morales Kluge and Pille 2010)

To allow Autonomous Control, potential flexibilities have to be enhanced to the assembly process. This is realised by allowing the metal-cast parts with in-process-embedded RFID tags (Morales Kluge and Pille 2010) (basic structure for the automotive tail-lights) to choose which type variant to target. The variants require specific parts during the production process.

There are logical constraints that exclude products to choose the next assembly processes by chance. The currently available and feasible variant as well as the scheduling to the next assembly step is determined by the implemented decision methods.

## *8.6.3 The System*

The actual set-up of the assembly scenario at the shop-floor of the Bremer Institut für Produktion und Logistik GmbH (BIBA)[91] allows the product to act flexible and to change the planned route by using the system integrated monorail-switches that offer multiple paths (compare to figure 8.7). The product has the ability to remain on the main line or to deviate to a bypass.

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[91] www.biba.uni-bremen.de

The monorail system works with self-propelling shuttles with a mounting capable of carrying loads of up to 12kg. It is a modular system and gives the freedom of future extensions.

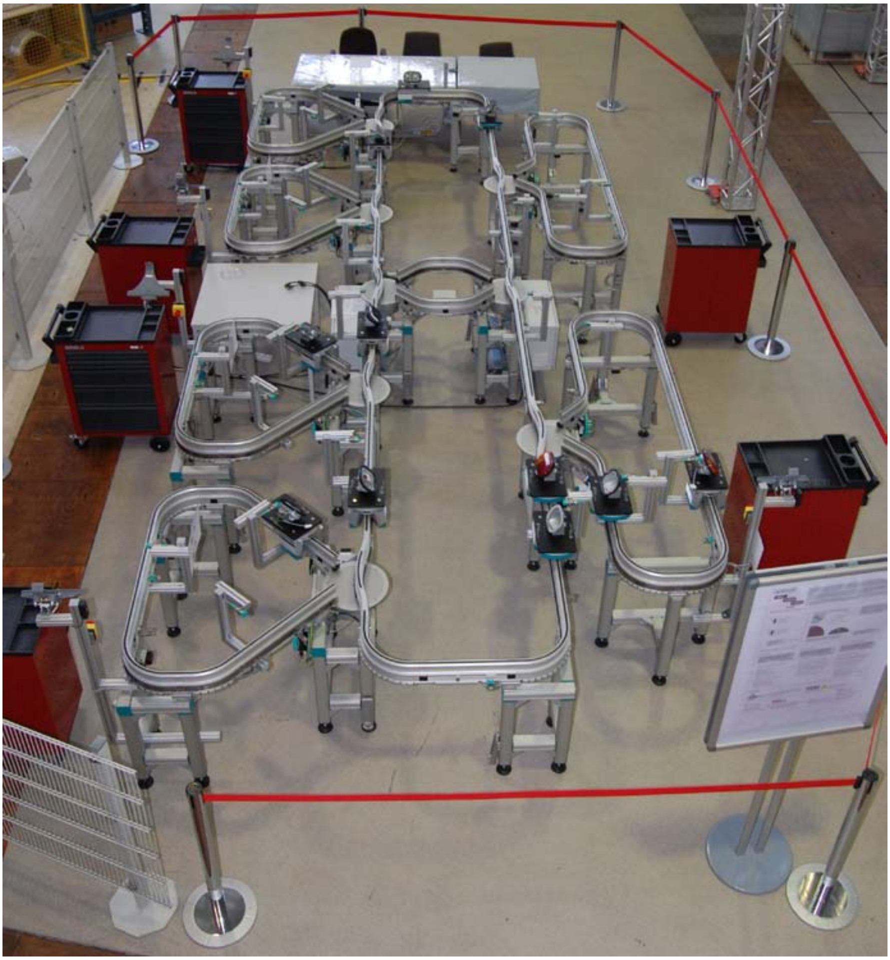

**Fig. 8.7** The Monorail System (compare to Morales Kluge et al. 2010)

**Fig. 8.8** Shuttles with Intelligent Products (Morales Kluge et al. 2010)

## 8.6.4 Technological Prerequisites

**Hardware Abstraction Layer**

The probably utmost important and especially relevant requirement of Autonomous Control is the ability of individual logistics entities to access to contextual as well as environmental data. Thus, the ability to understand and to compute the data from information sources is the prerequisite to build local decision-making systems (Hans et al. 2008). For this purpose a “Hardware Abstraction Layer” (HAL) was used, which was developed for having a structured access to nearly every hardware component of the system. It represents a layer that accesses hardware through the IP protocol, thus every brick of hardware had to be enabled to communicate over IP, beforehand. The HAL also takes into account the findings from the perspective of data integration. This facet goes beyond the usual HAL concepts but becomes necessary in this heterogonous context. Hans et al. as well as Hribernik et al. examined this from the point of view of data-integration in autonomous logistics networks (Hans et al. 2008; Hribernik et al. 2009). It also gives freedom in terms of future extensions of the system.

### Metal Cast RFID

An automotive tail-light was tailored to be the Intelligent Product for the implementation scenario which has the feature of having an integrated 125 kHz RFID tag, enabling the identification of each item. Today's automotive parts are not equipped with material inherent Auto-ID Systems. This means that the tag is being inserted while producing the tail-light in a casting process. Morales Kluge and Pille describe the objectives of this approach (Morales Kluge and Pille 2010). They focus on enabling the products to be exactly identifiable and also to be autonomous from the beginning of their life. Pille also describes how to cope with related challenges of this engineering process (Pille 2009).

### Multi-Agent-System

Even physical objects, which are equipped with Auto-ID technology, have to be made intelligent somehow. By linking the physical object via their unique identifier (RFID) with an agent system, decision-making processes can be set-up. For this reason, an MAS, which is based on JADE, is introduced for enabling the identifiable product to act in a complex network of autonomous objects. The distributed software agents represent the logistics objects and interact in a standard way, which is defined by the Foundation for Intelligent Physical Agents (FIPA) (Gehrke et al. 2006; Foundation for Intelligent Physical Agents 2002). The MAS represents the infrastructure in which decision algorithms can be implemented.

### Decision Algorithms

By implementing decision-making algorithms in an MAS environment, physical objects can be enabled to act autonomously in a network. Such an algorithm is based on the "Product Type Corridor". The product moves along this corridor during the manufacturing and assembly process (Windt and Jeken 2009). This allows the Intelligent Product to make decisions online which variant type to choose by considering its degree of assembly. A decision algorithm becomes necessary when the order of demanded products changes during the assembly process. The decision affects also the next possible production steps, which are identified then. Thus, it is required to analyse the all-up situation, which induces the evaluation of every operation alternative (Ludwig 1995). This concept is a precondition for going into decision-making. For this concept a model is used which is able to evaluate multicriterial states. This approach is based on the fuzzy hierarchical aggregation (Rekersbrink et al. 2007). Exemplary criteria are waiting time at potential assembly stations, material in stocks of the stations and current customer orders.

The presented implementation is being developed in the course of the CRC 637, which undertakes basic research in the field of Autonomous Control in logistics. The CRC 637 considers technological innovations and rules like Moore's Law (Moore 1998), so that this research concentrates on the basic issues logistic objects have to be aware of. This means, we assume that necessary technological improvements, like miniaturised processing power, will be available in the near future. This approach allows us to perform research on topics and create results that will be applied when technology is available. Thus, we developed, e.g., decision methods and customised Multi-Agent-Systems and algorithms for decentralised Autonomous Control of logistics objects by using state-of-the-art Internet technologies. We always assume that a bigger framework will be available that allows the interaction of objects and allows our developed methods to be implemented in a big network that goes beyond the used Internet infrastructure. The Internet of Things is deemed to be the complementary part to our research that is working on enabling objects to communicate, while we perform research on how to enhance objects with competencies for acting in this totally networked environment. The presented implementation shows clearly that merging the Internet of Things concept with our research findings can create a positive emergence.

## 8.7 Challenges by Developing the Internet of Things

Before the Internet of Things can unfold its full potentials in collaborative production environments (e.g., the connectivity of each electronic device), further scientific research is necessary. This section gives an overview of the general challenges as well as necessary developments for a full reliable, secure and all demands satisfying Internet of Things:

**Authenticity, Encryption and Integrity of Data**
There are already algorithms for the encryption and verification of data in use in the Internet. It will be necessary to check their transferability to the Internet of Things. Especially the encryption of object communication needs further research: symmetric encryption algorithms seem not realistic, due to the necessary exchange of a common decryption key to all objects. However, the usage of the public key cryptography, which does not require an exchange of a secret key, claims comprehensive computing time – potentially more than autonomous objects can offer or than their energy capacities can provide.

**Authentication**
The Internet of Things will be mainly used for the exchange of object bounded data and instructions. Since the majority of the objects will be non-public objects, significant amounts of sensitive information and execution power will exist. Access to these pieces of information and instruction possibilities need authentication mechanisms, which ensure the determination of the identity and access authorisation of the requesting humans or objects. In collaborative production environments the access authorisation will be very important, due to the enterprise partners, who are still legally independent and who may be still in competition to each other in other markets. The rights for reading and execution need a precise definition so that they can be defined for each single object and resource connected to the Internet of Things. Another option is to design a role model, which can be used for defining the access authorities for groups of users.

**Legal Safety for Data Protection**

The data exchange within the Internet of Things will be comprehensive and international. Partly these data will consist of sensitive information; their protection is very important for their owners. Existing approaches, which are in use in the Internet, must be checked as to their adaptability to the scenario of an Internet of Things. For that purpose further research about the probably content of data as well as the international cooperation in law is necessary.

**Scalability**

Billions of objects will communicate across the Internet of Things and will put a strain on its technical infrastructure (COMMISSION OF THE EUROPEAN COMMUNITIES 2009). For a reduction of the data throughput, the Internet of Things needs scalability mechanisms, which enable a data reduction without a loss of important information. Such mechanisms can be provided by clustering methods, which have been developed in the research of Wireless Sensor Networks. However, sensor nodes differ from autonomous objects or intelligent resources (e.g. movement behaviour, energy supply, objectives) so that further research for object clustering in the Internet of Things will be necessary.

**Billing and Business Model**

The development and operation of the Internet of Things infrastructure cause high costs, which allocation to the beneficiaries have to occur in a comprehensible way, according to the costs-by-cause principle. Additionally, it is necessary to determine the monetary value of individual information, which enables the financial evaluation of the information exchange between objects. This data can be used for the development of billing models. Furthermore, the Internet of Things will offer the chance of a wide range of novel business models, which will provide new services like the innovation of the Internet did (compare to Amazon, eBay or YouTube).

**Data Management and Synchronisation**

Autonomous objects and intelligent resources are often free in move; they are not bound to a fixed location partly disconnected from the Internet of Things. For that reason they need a representing replication which is permanently connected to the Internet of Things. Another very important question, which has to be answered, is about the storage location of data, which an agent produces during its whole life.

During the offline time the object can make decisions, gather data or change its status; there can be also new instructions or objectives, which are sent to the objects replication. In terms of a previous offline case, the reconnected object requires to synchronise these changes with its replication within the Internet. Moreover, two agents which are responsible for the same object (i.e., within the Internet of Things/on the object itself) need predefinitions about their competences as well as their range of authorisation; this will be necessary in order to enable each agent's autonomy without being connected to each other and to avoid inconsistent decisions.

**Human-to-machine Communication**

While machines can communicate to each other very quickly via electronic interfaces, humans do not have such interfaces. The communication with humans always requires an access via senses like visual, acoustic or vibration/mechanical signals as well as corresponding input possibilities. The Internet of Things will produce a significant higher degree of human-machine-communication. Especially autonomous objects, which can be offline and which decisions may trigger a human activity in their environment (e.g., if a parcel wants to join a truck load and the employee has to carry it onto the truck), usually are not equipped by a human communication possibility. For those issues developments in wearable technologies as well as in the field of dialogues for reaching a quick, understandable and fault reduced Human-machine-communication will be needed.

**Technological Improvements**

The main technologies are already available to make the first steps towards the Internet of Things. But there is still a lot of research necessary to achieve a world of real autonomous and agile objects, which represent almost every commodity item in the Internet.

Especially the following improvements are necessary: The energy supply and the energy consumption of the devices, hosting the agents platforms, need to be improved. This could be done for example by developing energy harvesting technologies combined with smaller ICs, consuming less energy as well as energy efficient software algorithms. Moreover, the communication infrastructure needs two main improvements. On the one hand, broad band is needed almost everywhere to handle the increasing network traffic resulting from the high number of intelligent objects. On the other hand, wireless communication technologies are required, which consume less energy and are easily attached to embedded systems to bridge the gap between moving objects and the cable based Internet of Things.

## 8.8 Conclusion and Outlook

This chapter attends to the benefits of the Internet of Things for a higher degree of autonomy and agility in the processes of collaborative production environments. For that purpose the mutual suitability and synergetic potentials of the concepts of Autonomous Control and Agility in manufacturing were demonstrated. A discussion about the technical implementation and integration of autonomous objects into the Internet of Things showed the theoretical feasibility, but also the necessary improvements. The description of the CRC 637 demonstrator illustrated the potential of a combination of Autonomous Control and a fine-grained informational infrastructure in realising agility on the elemental level of processes and resources.

As mentioned before, the Internet of Things is no unrealisable vision; it will build on the present infrastructure of today's Internet and will include technologies which are currently under development. First steps of evolving the Internet of Things are already in progress, like smartphones, UMTS, LTE, and so on.

Due to the significance of the Internet of Things for globalisation, the research aspects from section 8.7 should be investigated by international research clusters. This will help to evolve common standards and methods within the Internet of Things and will avoid national or continental solos. The research clusters should unify research institutes and companies from those industries which will mainly influence the rising trend of an Internet of Things. Collaborative research in step with actual practice is a promising approach for a wide standardised, accepted and used Internet of Things.

### Acknowledgements

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## References

ACEA (2009) Vehicle Scrapping Schemes in the European Union. http://www.acea.be/images/uploads/files/20090406_Scrapping_schemes.pdf. Accessed 21 May 2010

Bessant J, Francis D, Meredith S, Kaplinsky R, Brown S (2001) Developing manufacturing agility in SMEs. Int J Manuf Technol Manag. doi: 10.1504/IJMTM.2000.001374

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

CERP-IoT (2009) Internet of Things Strategic Research Roadmap. http://www.grifs-project.eu/data/File/CERP-IoT%20SRA_IoT_v11.pdf. Accessed 21 May 2010

COMMISSION OF THE EUROPEAN COMMUNITIES (2009) Internet of Things - An action plan for Europe. European Commission. http://ec.europa.eu/information_ society/policy/rfid/documents/commiot2009.pdf. Accessed 21 May 2010

EPCglobal (2009) EPCglobal Architecture Framework – Version 1.3. http://www.epcglobalinc.org/standards/architecture. Accessed 21 May 2010

European Union (2007) REGULATION (EC) No 715/2007 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 June 2007. Off J Eur Union. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:171:0001:0016:EN:PDF. Accessed 21 May 2010

Foundation for Intelligent Physical Agents (2002) FIPA standard status specifications. http://www.fipa.org/repository/standardspecs.html. Accessed 20 June 2010

Fleisch E, Christ O, Dierkes M (2005) Die betriebswirtschaftliche Vision des Internets der Dinge. In: Fleisch E, Mattern E (eds) Das Internet der Dinge. Springer-Verlag, Berlin-Heidelberg

Fleisch E, Thiesse F (2008) Internet der Dinge. In: Kurbel, K., Becker, J., Gronau, N, Sinz, E., Suhl, L (eds), Enzyklopädie der Wirtschaftsinformatik – Online Lexikon.

http://www.enzyklopaedie-der-wirtschaftsinformatik.de/wi-enzyklopaedie/lexikon/technologien-methoden/Rechnernetz/Internet/Internet-der-Dinge/index.html/?searchterm=internet%20der%20dinge. Accessed 31 May 2010

Frese, E (1998): Grundlagen der Organisation : Konzepte – Prinzipien – Strukturen. 7th edn., Gabler, Wiesbaden

Gehrke JD, Behrens C, Jedermann R, Morales Kluge E (2006) The Intelligent Container - Toward Autonomous Logistic Processes. KI 2006 Demo Presentations. http://www.intelligentcontainer.com/fileadmin/template/main/files/pdf/gehrke Demo.pdf. Accessed 31 May 2010

Goldman SL, Nagel RN, Preiss K (1995) Agile Competitors and Virtual Organisations: Strategies for enriching the customer. Van Nostrand Reinhold, New York

Gunasekaran A (1998) Agile manufacturing: enablers and an implementation framework. Int J Prod Res doi: 10.1080/002075498193291

Hans C, Hribernik K, Thoben K-D (2008) An Approach for the Integration of Data within Complex Logistic Systems. In: Dynamic in Logistics - First International Conference 2007. Springer, Heidelberg

Hejl PM (1990) Self-regulation in social systems. In: Krohn W, Küppers G, Nowotny H (eds) Self-organization: Portrait of scientific revolution. Springer, Berlin

Hightower J, Boriello G (2001) Location Systems for Ubiquitous Computing. Comput. doi: 10.110910.1109/2.940014

Hribernik K, Hans C, Thoben K-D (2009) The Application of the EPCglobal Framework Architecture to Autonomous Control in Logistics. Proceedings of the 2nd International Conference on Dynamics in Logistics, Bremen

Hülsmann M, Windt K (eds) (2007) Understanding Autonomous Cooperation and Control in Logistics. Springer, Berlin et al.

Isidore C (2009) GM bankruptcy: End of an era. http://money.cnn.com/2009/06/01/news/companies/gm_bankruptcy/index.htm. Accessed 21 May 2010

Jedermann R, Lang W (2008) The Benefits of Embedded Intelligence - Tasks and Applications for Ubiquitous Computing in Logistics. In: Floerkemeier C, Langheinrich M, Fleisch E, Mattern F, Sarma SE (eds) The Internet of Things. First International Conference, IOT 2008. Springer, Berlin-Heidelberg

Kärkkäinen M, Holmström J, Främling K, Artto K (2003) Intelligent products: a step towards a more effective project delivery chain. Comput Ind. doi: 10.1016/S0166-3615(02)00116-1

Katayama H, Bennett D (1999) Agility, adaptability and leanness: A comparison of concepts and a study of practice. Int J Prod Res. doi: 10.1016/S0925-5273(98)00129-7

Knirsch P, Timm IJ (1999) Adaptive Multiagent Systems Applied on Temporal Logistics Networks. In: Muffatto M, Pawar KS (eds) Proceedings of the 4th International Symposium on Logistics. Florence

Ludwig B (1995) Methoden zur Modelbildung in der Technikbewertung. CUTEC-Schriftenreihe Nr. 18, Clausthal-Zellerfeld

Mahmoud QH, Yu L (2006) Making Software Agents User-Friendly. Comp. doi: 10.1109/MC.2006.239

Mattern E (2005) Die technische Basis für das Internet der Dinge. In: Fleisch E, Mattern E (eds) Das Internet der Dinge. Springer-Verlag, Berlin-Heidelberg

McFarlane D, Sarma S, Chirn JL, Wong CY, Ashton K (2003) Auto ID systems and intelligent manufacturing control. Eng Appl Artif Intell. doi:10.1016/S0952-1976(03)00077-0

Moore G (1998) Cramming more components onto integrated circuits. P IEEE. doi: /10.1109/JPROC.1998.658762

Morales Kluge E, Pille C (2010) Autonome Steuerung - Intelligente Werkstücke finden selbstgesteuert ihren Weg durch die Produktion. RFID im Blick, Sonderausg Brem 1:44-45

Morales Kluge E, Ganji F; Scholz-Reiter B (2010) Intelligent products - towards autonomous logistic processes - a work in progress paper. PLM 10. 7th International Product Lifecycle Management Conference, Bremen. To appear.

Morgan RE, Strong CA (1998) Market orientation and dimensions of strategic orientation. Eur J Mark 32: 1051 - 1073. doi:10.1108/03090569810243712

Pavlou PA, El Sawy OA (2005) Understanding the 'Black Box' of Dynamic Capabilities 1. ManSci http://agsm.ucr.edu/faculty/papers/pavlou/ms_pavlou_elsawy_rev3%201.pdf. Accessed 21 May 2010

Philipp T, de Beer C, Windt K, Scholz-Reiter B (2007) Evaluation of Autonomous Logistic Processes - Analysis of the Influence of Structural Complexity. In: Hülsmann M, Windt K (eds) Understanding Autonomous Cooperation & Control in Logistics - The Impact on Management, Information and Communication and Material Flow. Springer, Berlin

Pille C (2009) Produktidentifikation, Intralogistik und Plagiatschutz – RFID-Integration in Gussbauteile. In: BDG-Fachtagung Gussteilkennzeichnung. Methoden und Datenmanagement - Praxisberichte. VDG-Akademie, Essen

Porter M (1979) How competitive forces shape strategy. Harv Bus Rev. doi: 10.1225/79208

Prahalad CK, Hamel G (1990) The core competence of the corporation. Harv Bus Rev. doi: 10.1225/6528

Probst GJB (1987) Selbst-Organisation: Ordnungsprozesse in sozialen Systemen aus ganzheitlicher Sicht. Parey, Berlin

Probst GJB (1992) Organisation. Strukturen, Lenkungsinstrumente und Entwicklungsperspektiven. verlag moderne industrie, Landsberg

Pugachev V, Sinitsy, I (2002) Stochastic systems: theory and applications. World Scientific, Singapore

Raju M (2008) Energy Harvesting, Whitepaper, Texas Instruments Inc. http://www.ti.com/corp/docs/landing/cc430/graphics/slyy018_20081031.pdf. Accessed 21 May 2010

Rekersbrink H, Wenning B-L, Scholz-Reiter B (2007) Entscheidungen selbststeuernder logistischer Objekte. Ind Manag 23:25-30. http://www.sfb637.uni-bremen.de/pubdb/repository/SFB637-B1-07-009-IJ.pdf. Accessed 31 May 2010

Stürmann J, Benecke W, Zampolli S, Elmi I, Cardinali GC, Lang W (2005) A micromachined gas chromatographic column to optimize the gas selectivity for a resistive thin film gas sensor. Proceedings of the 13th International Conference on Solid-State Sensors, Actuators and Microsystems. Seoul

Thiesse F, Floerkemeier C, Harrison M, Michahelles F, Rodunes C (2009) Technology, Standards, and Real-World Deployments of the EPC Network. IEEE Internet Comput. doi: 10.1109/MIC.2009.46

Uckelmann D, Isenberg M-A, Teucke M, Halfar H, Scholz-Reiter B (2010) An integrative approach on Autonomous Control and the Internet of Things – Increasing robustness, scalability and agility in logistics networks. In: Ranasinghe D, Sheng Q, Zeadally S (eds) Unique Radio Innovation for the 21st Century: Building Scalable and Global RFID Networks. Springer, Berlin

Ventä O (2007) Intelligent Products and Systems. Technology Theme - Final Report. VTT Publications. http://www.vtt.fi/inf/pdf/publications/2007/P635.pdf. Accessed 31 May 2010

Windt K, Jeken O (2009) Allocation Flexibility – A new Flexibility Type as an Enabler for autonomous control in production Logistics. 42nd CIRP Conference on Manufacturing Systems, Grenoble

Wong CY, McFarlane D, Zaharudin AA, Agarwal V (2002) The Intelligent Product Driven Supply Chain. Proceedings of the IEEE International Conference on Systems Man and Cybernetics, Hammamet

Yusuf YY, Sarhadi M, Gunasekaran A (1999) Agile manufacturing: the drivers, concepts and attributes. Int J Prod Res. doi: 10.1016/S0925-5273(98)00219-9

Zalubowski D (2008): Gas prices put Detroit Big Three in crisis mode - U.S. consumers are moving to hybrids, high mileage models at a fast pace. Associated Press. http://www.msnbc.msn.com/id/24896359/. Accessed 21 May 2010