# Intelligent Products - Towards Autonomous Logistics Processes - A work in progress paper

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**Abstract:** Intelligent products moved into the research focus of several research domains. These domains are Product Lifecycle Management, Internet of Things and Logistics, to name a few. They all have a quite common understanding of the intelligent product and their envisioned abilities. A key finding of the autonomous logistics research is the demand for positive emergence that should arise out of the global system when applying decentralized intelligent products. This paper concentrates on the first integration attempts of intelligent products in the context of autonomous logistics processes and presents a demonstration platform which assembles automotive tail-lights autonomously.

**Keyword:** Intelligent Product, Positive Emergence, Lifecycle, Autonomous Logistics

## 1 Introduction

Having the right product at the right time at the right place – these are the well-known requirements for logistics and transportation in general. Highly dynamic markets and the increasing complexity of logistics networks make it more and more difficult to reach these requirements with conventional planning and control methods. Therefore aspects such as flexibility, proactivity and adaptability are in the centre of attention in the current research by applying concepts of decentralization and autonomy on the logistic decision-making process.

Bringing up autonomous cooperating logistics processes seems to be an answer to the mentioned demands. The main idea behind autonomous cooperating logistic processes is to develop decentralized and heterarchical planning and control methods by shifting autonomous decision competencies to logistic objects.

Having in mind recent research in the field of PLM and considering above mentioned research focuses in the field of autonomous logistics, it turns out that both concepts converge in the demands of "intelligent objects" and also in their interpretation. The authors think that PLM could be enriched by methods developed in the context of autonomous logistics.

This paper reflects an ongoing work on implementing autonomous control methods on logistics systems, specifically in production logistics, where the Intelligent Product plays a central role. This work is being performed in a technical subproject which also develops an application and demonstration platform as a part of the Collaborative Research Centre 637 ‘‘Autonomous Cooperating Logistic Processes—A Paradigm Shift and its Limitations”. Through the course of the paper production scenario will be presented for investigating the applicability in the domain of production logistics. The scenario illustrates an autonomous assembly system for an automotive tail-light.

## 2 Related Work

### *2.1 Autonomous Logistics and PLM*

Cooperation and control are general requirements for complex systems in order to facilitate them to work. In the field of autonomous logistics where a high number of logistics objects are supposed to interact, some key definitions were developed. Scholz-Reiter and Höhns [1] and also Windt and Hülsmann [2] define autonomous cooperation and 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.*

*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.*

One of the key elements of this definition is derived from the concept of positive emergence [3]. Emergence can be understood as the development of new structures or characteristics by the concurrence of simple elements in a complex system. As a consequence, positive emergence means that the concurrence of single elements leads to a better achievement of objectives of the total system than it is explicable by considering the behaviour of every single system element [3, 4]. Positive is meant to be an emergence that acts positive in the sense of the logistics system.

Since PLM is a holistic approach and is also understood as a strategy [5, pp1-4], we state that positive emergence has to be an objective for PLM. Recent research focuses on this topic and is reflected in research projects like the PROMISE[1] Project. These approaches investigate on how to enhance “traditional” PLM with ICT considering e.g. sensor data. These concepts require besides an open infrastructure also products that have the ability to interact. These products are often called “intelligent products” or “smart products”.

[1] PROMISE: Product lifecycle management and information tracking using smart embedded systems, http://www.promise.no/

### *2.2 Internet of Things*

The strongly growing interconnectivity not only between people, but also between "things" is called the "Internet of Things" (IoT) and has become a new paradigm in the recent years [6]. It started with a vision driven mainly by technologies and concepts like pervasive and ubiquitous computing. Today there are several drivers pushing the IoT. There are firstly the research institutions, universities and authorities that are funding this research topic. Secondly there are associations like EPC-Global[1] that work on industry driven standards on electronic product code with the perspective on implementing RFID[2] in the supply chain. The IoT can be understood as convergence of technologies and as a bundle of heterogeneous objects that are enabled to interact with each other. There do exist some key functionalities that are required to enable the interworking [7]:

- Identification: Objects in the IoT are precisely identifiable by a defined scheme.
- Communication and Cooperation: Objects are capable of interacting with each other or with resources in the net.
- Sensor: 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: IoT Objects are capable of acting on their own without having a superordinate entity.
- User Interface: Adapted metaphors of usage have to be made available by the object.

### *2.3 Intelligent Products*

A concept of the Intelligent Product is to enhance products of today by giving them competencies. Several authors mention requirements of Intelligent Products that are high level requirements and reflect the demand on autonomous products. McFarlane [8] and Wong [12] describe the Intelligent Product as a physical and information based representation of an item which:

- possesses a unique identification
- is capable of communicating effectively with its environment
- can retain or store data about itself
- deploys a language to display its features, production, requirements, etc…
- is capable of participating in or making decisions relevant to its own destiny

Definitions from Kärkkäinen [9] and Ventä [10] reflect very similar properties of an Intelligent Product. They differ in the perspective from which they look on the Intelligent Product. Kärkkäinen has a logistics focus from which he describes the Intelligent Product in a supply chain.

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[1] EPC-Global: Electronic Product Code, http://www.epcglobalinc.org/home/
[2] RFID: Radio Frequency Identification

### *2.4 Positive Emergence as a conclusion to the related work*

The main objective of local autonomous control is an increased robustness and flexibility of complex systems by distribution to subsystems managing decomposed subtasks. Hereby, new properties of a larger system may emerge by local interaction of subsystems. A key characteristic of emergence is that its effects are hard to anticipate due to complexity resulting from subsystem interaction. Emergence may concern organizational structures or even problem solutions. Emergent organizations are evolving and thus able to adapt themselves to modifications in the environment and their members' goals. Positive emergence means that subsystem interaction leads to a better achievement of objectives of the total system than it is explicable by considering the behaviour of every single system element. In the context of autonomous logistics, these effects are incorporated by implementing logistic objects (e.g., means of transport, freight, parts) as decentralized subsystems that dynamically coordinate with other subsystems to manage logistic processes and reach their respective goals (e.g., on-time delivery or minimization of delivery times).

Three aspects were treated in this paragraph to illustrate how close to each other different research domains are investigating. Concluding these research activities, we can observe that although the domains of PLM and IoT are not explicitly naming the positive emergence as their main research goal, it holds true for them.

## 3 Methods

This paper addresses an ongoing implementation of a bundle of methods that were developed in a research initiative, called Collaborative Research Centre (CRC 637). As a part of this CRC, we present implemented methodologies coming out of the CRC. For this purpose, a material flow system with an applied production scenario is being introduced to ensure industrial conditions. Here, the challenge is to survey the capability of the methods with real material flow machinery. Hribernik et al. give an in depth insight into the methods that are mentioned below [22].

### *3.1 Hardware Abstraction Layer*

The most important and especially relevant requirement by autonomous control is the ability of individual logistic entities to access context and environment data. Thus the ability to understand and process the data from data sources is the condition to build local decision-making systems [14]. For this purpose we used a "Hardware Abstraction Layer", which was developed for having a structured access to nearly any hardware of the system. The Hardware Abstraction Layer considered the findings from the point of view of data integration. Hans et al. [14] and also Hribernik [13] examined which aspects have to be considered from the point of view of data-integration in autonomous logistics networks. This gives freedom in terms of future extensions of the system.

### *3.2 Metal Cast RFID*

The intelligent product used for the implementation-scenario is an automotive tail-light which has the unique feature of having an integrated low frequency RFID Tag at 125 kHz. Firstly unique because today's automotive parts are not equipped with material inherent AutoID[1] Systems that are designed to cover all PLM-phases from beginning of life to end of life phases. Secondly the RFID Tag was inserted while producing the tail light in a casting process. Pille [16] describes the objectives of this approach and focuses on enabling the products to be exactly identifiable and also to be autonomous from the beginning of processing. He also describes how to solve related challenges of this engineering process [15].

### *3.3 Multi-Agent-System*

For enabling the exactly identifiable product to act in a complex network of autonomous objects and to implement decision-making processes, a Multi-Agent-System (MAS) is being introduced.

The deployment of MAS imply capable agents as well as simple agents for distributed control in logistic systems and is one of the basic principles of the CRC 637. The distributed software agents represent the logistics objects and interact in a standard way, which is defined by FIPA[2] [17, 18]**.**

### *3.4 Decision Algorithms*

In order to facilitate physical objects to act autonomously in a system, decision-making algorithms have to be implemented. Such an algorithm is basing on the “Product Type Corridor”. The intelligent product agent for instance can, depending on the degree of assembly, make a decision which variant-type to target. The product is using the introduced method of autonomous product construction cycle for assembly systems. The product moves along the product type corridor during the manufacturing and assembly process [19]. This concept describes the available type variants that are currently possible considering the progress of production. By deciding for a final type variant the next possible production steps are identified. Therefore it is necessary to analyze the all-up situation, which calls for evaluation of every operation alternative [20]. This concept is prerequisite for going into decision-making that is done with a model, which is capable of evaluating multicriterial status. This approach makes a multicriterial mathematical evaluation possible and is based on the fuzzy hierarchical aggregation [21]. Criteria are for instance waiting time at potential assembly stations, material in stocks of the stations and current customer orders.

### *3.5 Material Flow System*

For setting up a scenario that is comparable to real life machinery a monorail conveying system is being introduced that works with self-propelling shuttles with a work piece holder capable of carrying loads of up to 12kg. It is a modular system and gives the freedom of future extensions.

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[1] AutoID: AutoID stands for Automatic Identification
[2] FIPA: Foundation for Intelligent Physical Agents

## 4 Results

### *4.1 Hardware*

The actual set-up of the monorail conveying system allows products to act flexible and to change the planned route by using the system integrated monorail-switches that offer multiple paths (Figure 1). It is then possible for the product to remain on the main line or to deviate it to a bypass. The implemented 125 kHz RFID technology was customized for our purposes to work with the casted RFID tag.

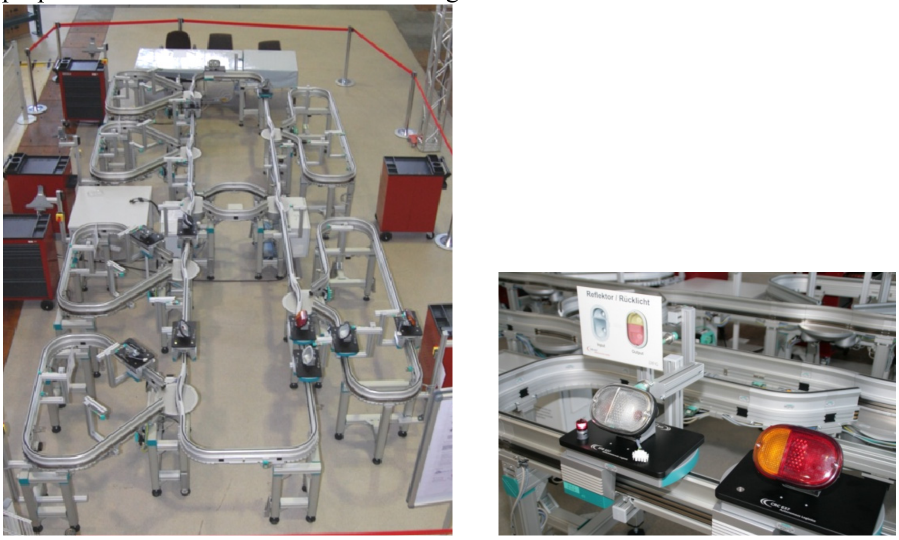


Figure 1: Mono-rail System (left), Shuttles with Intelligent products (right)

### *4.2 The scenario*

A production scenario is being implemented for investigating the applicability 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 work piece etc., the assembly itself is still designed to be a manual task. To allow autonomous processes, potential flexibility has to be implemented in the production process. This is realized by allowing the metal cast parts with in-process-embedded RFID tag [16] (basic structure for the automotive tail-lights) to choose which variant-type to target. The variants require specific parts during the production process; the variants are depicted in Figure 2.

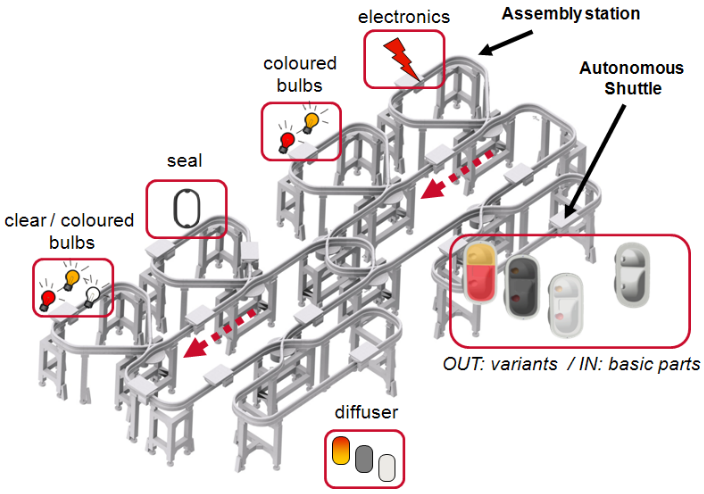


Figure 2: Assembly/Production scenario

There do exist logical constraints that forbid products to choose the next production processes randomly. The currently possible variant and the scheduling to the next production step is determined by the implemented decision methods.

### *4.3 Demonstrator and application platform*

In this paper we describe an implementation of autonomous control for manufacturing systems. Considering the size of the CRC 637 research initiative and the amount of results produced in it, it became evident to develop a framework platform that incorporates hardware such as RFID readers and also a material flow system to illustrate and validate manufacturing scenarios. On top of the hardware a software framework is being developed in order to integration different methods, research results and also different hardware in a flexible manner. It is designed to have a user friendly design, for editing other scenarios that can be defined by using the operator interface whereby the XML based configuration data can be edited and handled. Editing a scenario includes the definition of final products to be manufactured, the manufacturing steps to be processed respectively the corresponding assembly stations, needed parts, type of hardware (e.g. AutoID Systems) and finally the material flow layout. Other objects such as machines, workstations or hardware are also represented as software agents. Figure 3 shows the design of the platform

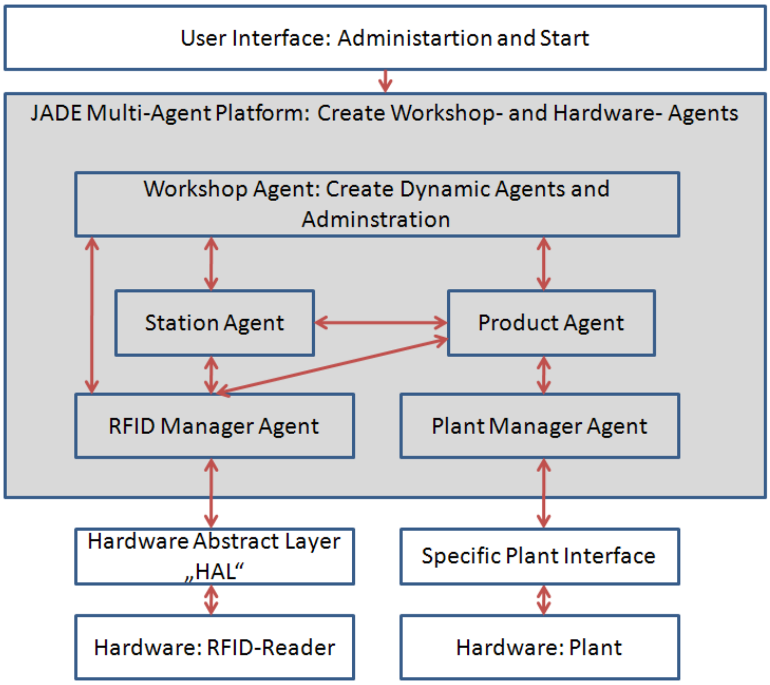


Figure 3: Design of the platform

### *4.4 Real time hardware signal processing via software agents*

The real time hardware signals such coming from the RFID systems have to be processed promptly. Considering the design of the platform, basing on a MAS it seems to be appropriate to implement the hardware manager also as a software agent that picks up the signals, processes them and communicates the information to other relevant agents. Up to now there are two hardware manager agents created, firstly for RFID-Reader and secondly for the material flow system. These agents will be created automatically by starting the scenario. They receive also the configuration data to have the context information.

### *4.5 The intelligent product software agent*

The implementation of the product agents is based on the described method of the autonomous product construction cycle for assembly systems [19]. The agents have the challenge to decide for the optimal product type considering different context factors. The decision-making is in fact focused on choosing between the three product variants, which directly affects the next targeted production step respectively assembly station. These agents have to rerun the decision making process after each manufacturing step.

## 5 Conclusions and Discussion

The first implementation shows that it is possible to control an industrial material flow system with autonomous control methods that are implemented through a multi agent system. The product becomes the centre of attraction and is enabled to make own decisions. It also becomes clear that an emergence arises out of the decentralized approach. This becomes evident when applying intended malfunctions or failures to the system. The products are able to react to the new situation without a central re-planning. We can state qualitatively that an increased robustness can be observed. Future will show more quantitative results, when metrics and operating figures, such as cycle times, will be elicited with the system.

### *5.1 Implications to the domain of PLM*

The concepts of autonomous logistics can be directly applied to the domain of PLM. Considering recent research in the domain of PLM, which works on integrating embedded systems into products, our results show that the findings and developed methodologies fit into the concept of PLM. Combining PLM and autonomous logistics seems to create new opportunities for both domains: The autonomous logistics can benefit from the structured approach of PLM to handle product data, while PLM could be enriched by products that can “think” and are capable to act accordingly to their goals.

The implementation in this demonstration platform shows that when having a product centric approach and not only having the control over the product, positive effects can be observed. It becomes obvious that the basic technology fundamentals for Intelligent Products do already exist and PLM could take advantage out of these developments in order to widen their perspective by integrating the concept of autonomous products.

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