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Autonomous Logistic Processes – New Demands and First Approaches –

B. Scholz-Reiter (2), K. Windt, M. Freitag
University of Bremen, Bremen, Germany

Abstract
Due to the dynamic and structural complexity of today's logistics systems and networks, central planning and control of logistic processes becomes increasingly difficult. Thus, decentralised and autonomous control of logistic processes is required. Based on recent IC technologies such as RFID and wireless communication networks, intelligent items, which can communicate and coordinate each other, are possible. These technological developments require novel concepts and strategies to implement autonomy in logistic processes.
This paper sketches the vision of autonomy in logistics, describes the new demands on autonomous logistic processes and introduces a new German Collaborative Research Centre, which investigates autonomy as a new control paradigm for logistic processes.

Keywords:
Production, Control, Autonomy

1 INTRODUCTION

There is an ongoing paradigm shift from centralised control of 'non-intelligent' items in hierarchical structures towards decentralised control of 'intelligent' items in heterarchical structures in logistic processes. Those intelligent items could either be raw materials, components or products as well as transit equipment (e.g. pallets, packages) or transportation systems (e.g. conveyors, trucks). Reichl describes such items as things that think [1]. The main characteristic of an intelligent item is its capability to control itself, which means that these items act autonomous in their planning and production processes.

Autonomy in general means the capability of a system, process or an item to design its input-, throughput- and output-profiles as an anticipative or reactive answer to changing constraints of environmental parameters. One specific criterion of autonomous processes or items is to render a decision by itself on the basis of parameters, which can lead to different but in principal predetermined process or order fulfilment steps. The dynamic development of information and communication technologies, e.g. the RFID (Radio Frequency Identification) technology, makes intelligent processes (and therefore intelligent items or autonomy) possible.

Since January 2004, a German Collaborative Research Centre (CRC 637) funded by the German Research Foundation (DFG) has been established at the University of Bremen. It is named "Autonomous Cooperating Logistic Processes – A Paradigm Shift and its Limitations". The interdisciplinary project with the participating faculties of engineering technology, economics, informatics, mathematics and electrical engineering concentrates on modelling of autonomous cooperating logistic processes, designing methods and adequate tools as well as on evaluation for practical use.

This paper will explain the meaning of autonomy in logistic processes on different examples and will give an overview of possible logistics applications in the near future. One key problem of autonomy is the detection of borderlines from conventional management to autonomy.

The next chapter will give a description of the actual situation of logistic processes. The dynamics in logistics structures are characterised and the new technologies, important for autonomous logistic processes, are addressed. Next, a vision of autonomous processes is formulated in response to existing and emerging problems.

The new demands on logistic processes are derived and structured in technological, organizational and process related demands followed by an overview of the organisational and topical structure of the collaborative research centre 637.

The ideas and research objectives of the different sub projects of the CRC will be presented in chapter 5. The paper ends with first approaches demonstrated on an example of a production process and with a closing summary.

2 CURRENT SITUATION IN LOGISTICS

2.1 Increasing Dynamics and Complexity

The more and more rapidly changing conditions in present markets have an extensive impact on logistic processes. The worldwide presence and market development of a growing number of companies implicate the development of global and complex intra- and inter-corporate logistics networks [1].

The shift from seller to buyer markets pushed by the emergence of the internet economy and the increasing importance of customer orientation and individualisation involve a simultaneous atomization of payloads and increase of shipment frequency as well as overall transport volume [2].

There are naturally and economically limited infrastructure expansion possibilities. In such an environment, today's concepts of planning and controlling of logistic processes are starting to fail. The complexity and dynamics of widely ramified and distributed value chains complicate the supply of all relevant information to a central entity.

This development requires new methods of planning and control in production, transportation and procurement, which means that instead of having central control of complexity and dynamics, decentralized autonomous logistic processes are implemented. One assumed characteristic of autonomous processes or items is the adaptation of its behaviour in a more effective manner on changing constraints. Due to this development, the achievement of

This example demonstrates the combination of logistics structures and new technologies to carry out autonomous logistic processes and to comply with demands of today's markets.

4 NEW DEMANDS ON LOGISTIC PROCESSES

Establishing autonomous logistic processes requires a set of general conditions on the logistics system, which must be fulfilled. Figure 3 gives an overview of these demands according to the holistic perspective on logistics.

Logistic System / Task Layers	New demands on Logistics Processes
Decision System / Organisation and Management	**Organisational demands** • Definition of autonomous logistics processes • Definition of limits of conventional and autonomous control • Availability of adequate information at the correct place in time • Ability to measure and evaluate autonomous logistics processes • Design and structuring of dynamic distributed targets • Management strategies to consider external and internal risks • Methods to establish efficient distributed Quality Management Systems
Information System / Informatics Methods and I&C Technologies	**Technological demands** • System items' ability to communicate and cooperate • Distributed data management and date handling • Mobile data communication technologies • Data security guidelines regarding establishing mobile data communication • Localisation's ability • Mobile hardware components (transponder etc.) • Software requirements (new PPC-/ERP-functions)
Execution System / Material Flow and Logistics	**Process-related demands** • Development of autonomous decision algorithms • Development of strategies to use the process immanent intelligence • Ability to model autonomous logistics processes • Adaptation/development of PCS- and logistics-functions • Robustness (resource, object, part) • Divisibility of orders / mergence of intelligent items (e.g. assembly stage) • Logical and physical reactivity

Figure 3: System layers and their demands.

As shown in the figure above, the new demands on logistic processes can be assigned to the system layers such as the decision system, information system and execution system and its task layers such as organisation and management, informatics methods, I&C technologies and material flow and logistics. As a result, the demands can be categorised in organisational demands, technological demands and process-related demands.

4.1 Organisational demands

The creation of some new organisational general conditions is essential to be able to establish autonomous logistic processes. First of all, a definition of the term autonomous logistic processes and dissociation from conventional logistic processes are necessary to get a consistent understanding of this paradigm. Based on this definition, the limits of conventional and autonomous control must be investigated to be able to identify possible applications.

Characteristic for autonomous logistic processes is an increased distributed information demand. So the availability of adequate information at the correct place in time is one of the main organisational demands of autonomous logistic processes.

The main target for establishing autonomous logistic processes is an increased efficiency of the logistics system. Therefore, it is necessary to develop an evaluation system that considers the changes in order processing due to autonomy. It will enable the user to evaluate autonomous processes against conventionally managed processes. Furthermore it is necessary to define limitations of management and autonomy, to integrate different autonomy views (resource, object, part) within the system structure. So dynamical targets can be defined and new characteristics of autonomy can be considered.

Autonomous control of logistic processes contains the ability to react to special and unanticipated events. Concerning the scheduling of appropriate activities adequate management strategies are required to avoid or minimise the risk. Another organisational requirement is the development of a local quality management, where several parts control their own quality management or that of other items.

4.2 Technological demands

Regarding the information system layer there are some new technological demands that must be considered with respect to the paradigm shift. New or changed technological demands result from a relocation of planning and control functions to parts or resources, especially regarding the data management (consistency of data, high amount of memory, etc.), data handling (coverage of information overload, standardised interfaces etc.) as well as the ability of the system items to communicate and to cooperate. The parts' mobility makes new demands on data communication and localisation. Technologies like Bluetooth or WLAN were suitable for mobile data communication, radio communication based or satellite based positioning systems for parts' localisation. Because of the employment of mobile data communication technology, it is important that the data security guidelines are observed. The hardware demands will also change. The importance of transponder technology will increase, especially concerning the mentioned amount of memory. An autonomous planning and control of production systems at a lower level like subsystem or part level contains relevant demands on used or new software systems in the form of new functions.

4.3 Process-related demands

In addition to the organisational and technological demands, certain process-related demands on the material flow system and logistics system must be fulfilled to enable autonomous logistics processes.

A development of strategies is needed to use the process immanent intelligence of subsystems and system elements, to reach autonomous decisions to achieve own or predetermined aims. Therefore the intelligent items of the system are able to execute independent problem solving algorithms. By developing necessary software tools and by evaluating the system in simulations it should be possible to model the selected system with its corresponding processes. Currently existing planning and control systems have to be adapted to the new demands. New planning and control methods and their functions have to be developed. By the implementation of autonomous logistics processes the robustness of the logistics system must be warranted to achieve undisturbed production. A further requirement on the logistics system is the divisibility of orders. This is necessary to enable autonomous control of single processes in general. Maybe the autonomous items have to influence each other. A fundamental requirement to ensure the use of autonomous processes is the warranty of logical (as described above) and physical reactivity of the involved systems. These include e.g. materials handling, application technique and all other productive units.

5 COLLABORATIVE RESEARCH CENTRE (CRC 637) FOR AUTONOMY IN LOGISTICS

5.1 Idea of CRC 637

Since the beginning of the year 2004, the new German Collaborative Research Centre "Autonomous Cooperating Logistics Processes: A Paradigm Shift and its Limitations" (CRC 637) has been established at the University of Bremen [13].

The objective of the CRC 637 is the systematic and broad investigation and application of "autonomy" as a new control paradigm for logistics processes. For this, appropriate concepts and models as well as methods and tools are being researched and developed in twelve scientific subprojects. Thereby, the general idea of autonomy in logistics includes concepts of management theory, computer science as well as technical autonomy concepts from the divers engineering domains. The CRC 637 uses a system concept by Ropohl [14], who divides a system into an execution system, an information system and a decision system. The outcomes are three task layers of the CRC 637, depicted in figure 4.

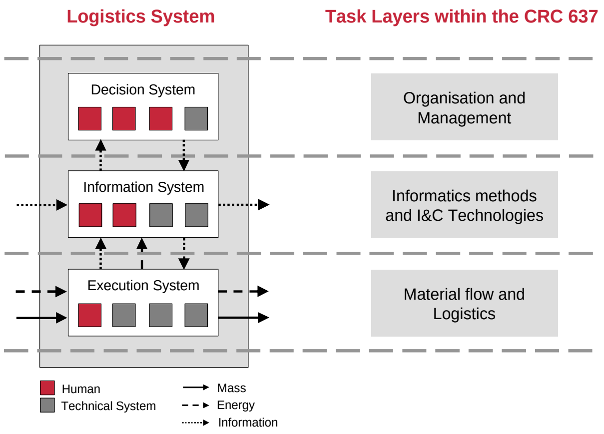

Figure 4: Holistic perspective on logistics and resulting task layers within the CRC 637.

Resulting from figure 4, the objects of research are

- the autonomous physical material flow,
- the realisation of autonomy in the information system,
- the management of autonomous logistics processes.

To guarantee this holistic view on logistics and to cover the three task layers depicted in figure 4, the CRC 637 encompasses researchers from the scientific disciplines manufacturing engineering, business studies, computer science, electrical engineering and mathematics.

For a structured investigation and application of the paradigm "autonomy", the CRC 637 is divided into three project domains.

Project domain A "Modelling Foundations for Autonomous Logistics Processes" will investigate the theoretical basis of autonomy as well as modelling techniques for autonomous logistics processes. Thus, project domain A provides a general foundation for the other research activities of the CRC 637.

Project domain B "Methods and Tools for Autonomous Logistics Processes" uses the theoretic concepts and modelling techniques from domain A or other related research areas to develop methods and tools for efficient and dynamic autonomous logistics processes. During the first phase of the CRC 637, the applicability of already established methods for autonomous issues will be investigated und applied. In the second phase, domain B will focus on finding synergy effects between the divers concepts developed in Project Domain A. The aim is the realisation and implementation of methods and tools and their transfer into practical projects.

In project domain C "Applications for Autonomous Logistics Processes", the results from domain A and B will be used to solve specific practical problems. Insofar, project domain C is based on the other two project domains and will start in the second phase of the CRC 637. The subprojects in this domain will search for potential logistics application fields for autonomous logistics processes.

These project domains form the structure of the CRC 637, which contains twelve subprojects (figure 5). Each subproject considers a certain problem from the viewpoint of the particular scientific discipline, so that the holistic view of autonomy in logistics is guaranteed.

Collaborative Research Centre 637 Autonomous Cooperating Logistic Processes: A Paradigm Shift and its Limitations		
A: Modelling Foundations for Autonomous Logistic Processes	**B: Methods and Tools for Autonomous Logistic Processes**	**C: Applications for Autonomous Logistic Processes**
A1 Fundamental Studies *(Manuf.Engin.)* A2 Sustainable Management *(Econ.)* A3 Monitoring of Autonomous Systems *(Econ.)* A4 Rule-based Graph Transformation *(C.Sc.)* A5 Dynamics of Autonomous Systems *(Manuf.Engin. / Math.)*	B1 Reactive Planning and Control *(Manuf.Engin. / Elec.Engin.)* B2 Adaptive Business Processes - Modelling and Methodology *(Manuf.Engin.)* B3 Mobile Communication Networks and Models *(Elec.Engin.)* B4 Knowledge Management *(C.Sc.)* B5 Risk Management *(C.Sc. / Manuf.Engin.)* B6 Sensor Systems *(Elec.Engin.)* B7 Autonomous Adaptation of Vehicle Schedules *(Econ.)*	Planned for the 2nd and 3rd phase of the CRC
Central Application Platform and Demonstrator		

Figure 5: Structure of the CRC 637.

5.2 Subprojects from manufacturing engineering

Five subprojects will next be described which are related to manufacturing engineering and technology.

The subproject A1 "Process-Oriented Fundamental Studies of Autonomous Logistic Processes" is motivated by the main questions:

- Where do conventionally managed and autonomous processes differ?
- What changes will autonomy cause in order processing?
- Which methods are suited?
- How are autonomous processes measured and evaluated?

As the project title points out, one aim of this project is to define fundamental knowledge concerning autonomous logistics processes, especially concerning the production processes and the production planning and control procedure. The second aim of the project is to develop an evaluation system in order to measure the achievement of logistics targets. Therefore, the project currently consists of two parts: The fundamental studies and the development of the evaluation system.

The subproject A5 "Modelling and Analysis of Dynamics of Autonomous Logistics Processes" looks for autonomy in self-organising systems e.g. biological systems and wants to apply such natural autonomy concepts to logistics processes. The central questions to be answered are:

- How to design the local autonomy to reach a desired global behaviour?
- How to design the global structure to enable local autonomy?

To answer these questions, this subproject is arranged in a dual way. The faculties of Mathematics and Manufacturing Engineering cooperate to analyse the system's dynamics as well as the system's performance. The mathematicians focus more on the dynamics, while the production engineers focus more on the performance of autonomous logistics processes. Based on differential-equation systems, the mathematical side uses analytical models and analyses the dynamic behaviour. The logistics side uses discrete-event simulation and analyses both dynamics and performance by statistical methods and time series analysis. The dual way provides the possibility to evaluate and improve the different models by comparing each other.

The subproject B1 "Reactive Planning and Control to Support Autonomous Objects in Multi-Modal Transportation Processes" is motivated by constraint like varying environmental conditions, inadequate knowledge and atomisation of load units, which appear in multi-modal transportation networks.

machine's capacity, for example, by increasing its performance and to counteract the bottleneck of the process step turning.

Conclusion: In contrast to conventional control, where generally the machine breakdown is recognised manually by a worker, who takes necessary steps especially an adaptation of the centrally planned PPC, autonomous control is characterised by independent and immediate reaction to unanticipated events. In this case, the machine recognises its breakdown and takes necessary actions. The basis for all further actions is the adjusted PPC of the work step turning, which generates a set of information flows to several system elements. Every system element (resources, parts etc.) has got its own PPC or necessary PPC-functions and so the ability to react fast and flexible to changing general conditions. By means of this simple scenario it becomes apparent that a focused, fast and flexible reaction to unexpected disturbance in the form of individual, self initialised adaptations of processes is possible by dislocating the planning and control functions as well as embedding of partial intelligence to separate subsystems or system elements. In this case, positive effects of autonomous logistic processes compared with conventional controlled logistic processes could be less down time because of minor response time, a decrease of personnel costs as one result of an increased level of automation and improved machine's efficiency due to decentralised, autonomous capacity planning. Those and other effects will be analysed in the near future in more detail with the help of simulation and process studies.

7 SUMMARY

The idea of autonomous logistic processes is presented in this paper. Autonomy can occur as intelligent items, parts, resources or processes. The main characteristic is that those intelligent things are able to decide on their future "life". The described vision combines the current logistics developments with new technologies. The RFID technology enables logistic processes to become autonomous in the future. To use this new technology requires the fulfilment of several demands such as defining what kind of information is needed to save on a possible RFID-tag of an item. Those questions and others will be answered in a new German Collaborative Research Centre (CRC 637) established at the University of Bremen since January 2004. The main targets as well as the subprojects related to manufacturing engineering and technology are presented. In order to demonstrate the achieved results of the CRC 637, an application platform will be provided.

First approaches are shown on the example of a production process, in which a resource disturbance demands new planning and control strategies in order to fulfil the order procedure with its given logistics targets. The aim is to show the differences in information flows between centralised PPC systems and the idea of decentralised and autonomous acting items and processes.

Future work will focus on the definition of autonomy in logistic processes, its major characteristics as well as on the development of new methods for autonomous logistic processes. One key question to be answered concentrates on the limitations of autonomy: How much autonomy is useful and how much of conventional management is still necessary? The new CRC 637 with its interdisciplinary view will find answers to those questions in the future.

8 ACKNOWLEDGMENTS

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