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4 Autonomous Control Methods and Examples for the Material Flow Layer

4.1 Approaches to Methods of Autonomous Cooperation and Control and Examples for the Material Flow Layer

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One aim of the working circle “Autonomous Cooperation and Control” within the Cooperative Research Center 637 was to ensure that the developed definition (chapter 1 Introduction) will be on the one hand precise and valid for an interdisciplinary view, and on the other hand realistically based on production and logistic scenarios. A production scenario is represented by machines, orders, transportation systems, storage areas and the interconnecting material flow. The material flow in conventional production planning and control (PPC)-systems has to be planned, controlled and to be under surveillance. Material flow means the execution of the physical movement of parts and products through production and logistic systems. In order to cope with a wide range of logistic applications, transport and production processes are considered within selected scenarios. High relevance–and therefore logistic potentials–especially for the application of autonomous cooperation and control is offered by the job shop production principle. This is characterized by a functional organization whose departments or work centres are organised around particular types of equipment or operations. Work pieces are transported through the departments in batches (Hernández 2002).

The main challenges of the implementation of autonomous control methods for the material flow layer lies in:

- The ability to model autonomously controlled logistic processes;
- The realization of communication between intelligent items;
- The development of decision algorithms and therefore evaluation systems for the relevant intelligent items;
- The identification of important information for every intelligent item,
- The determination of the anticipation horizon for the selection of important information;
- The feasibility of divisibility of orders or of mergence of intelligent items (e.g. assembly stage);
- The derivation of requirements on production and transportation systems suited for autonomous cooperation and control.

Another challenge concerns the necessity to regard the environment at any one time as a dynamic one. Even during the decision-making process of single logistic objects the environment may be changed. This means that decisions of single logistic objects need to be executed swiftly, especially the decision influences other logistic objects (which will be the case for the majority of logistic objects) (Windt and Freitag 2004).

Finally, the process flow of order processing will change. The identification of these changes is one assumption in order to adapt the appropriate planning and control systems to the new requirements resulting from autonomous cooperation and control.

The aim of this chapter is to show the applicability of the theoretical structures for autonomous cooperation and control. Different logistic scenarios are described: One of the logistic scenarios integrates production and transportation processes on the example of an automobile distribution logistic provider. The transportation processes of cars in automobile terminals as well as the delivery processes are combined with production processes at the terminal, for example car washing and unwaxing, or the assembly of navigation systems (Böse et al. 2005).

The second logistic scenario presented in this edited volume concentrates on the implementation of information and communication systems as one condition for autonomous cooperation and control. In this case the prototype of an ‘intelligent container’ (Jedermann 2006).

One of the above mentioned challenges of autonomous cooperation and control is addressed in the article from Thorsten Philipp, Christoph de Beer, Katja Windt, Bernd Scholz-Reiter and is entitled **“Evaluation of autonomous logistic processes – Analysis of the influence of structural complexity”**.The coordination of intelligent objects requires advanced planning and control concepts and strategies to realize the autonomous control of logistic processes. In order to prove that the implementation of autonomous control in production systems is more advantageous than conventionally managed systems and to show where the limits are, the development of an adequate evaluation system is essential. This system reflects the degree of achievement of logistic objectives related to the level of autonomous control and the level of complexity. The evaluation system consists of three main components: The correlation between logistic objective achievement and level of autonomous control is heavily dependent on the complexity of the system in question. A measurement and control system for logistic performance was developed for the measurement of the logistic objective achievement. Furthermore, a complexity cube was developed in order to characterize the complexity of production systems and a catalogue of criteria can be used to determine the level of autonomous control. Within this article a vectorial approach to measure the achievement of logistic objectives together with a feedback loop for autonomous processes is introduced. By means of a complexity cube it is possible to operationalize the complexity of production systems with regard to different types of complexity.

Bernd-Ludwig Wenning, Henning Rekersbrink, Andreas Timm-Giel, Carmelita Görg and Bernd Scholz-Reiter concentrate on transportation processes in their article **“Autonomous Control by Means of Distributed Routing”**. To deal with dynamic problems in routing and assignment in logistics the subproject B1 “Reactive Planning and Control” investigates an approach that considers vehicles and packages to be intelligent and autonomous. These logistic items are able to decide about routes and loads by themselves based on local knowledge. This requires replacement of the centralised decision-making approach by a decentralised, distributed autonomous control approach. For this approach, methods and algorithms from other domains of science and technology are evaluated for their suitability for application in transport logistics. One promising technology domain is the wide range of routing algorithms used in communication networks. Distributed routing has already been successful in communication networks for several decades. For a transfer of routing methods from communication networks to logistic networks, it is necessary to identify where these networks are similar and where they exhibit differences. The two kinds of networks are comparable, both involving payloads which have to be transported from a source to a destination. They both have the possibility of resource reservation and are comparable in size and dynamics. But there are also differences in physical existence as well as amount limitations. Handling of loss is completely different in transportation and communication networks. The two networks also use different scales of time. This leads to the conclusion that routing methods from communication networks cannot be transferred directly into logistics. Nevertheless, routing approaches in communication networks can provide inspiration in devising routing approaches for logistic networks. Consequently, a concept for distributed routing in a logistic network is presented. In this concept, vehicles as well as packages are considered as autonomous. They have sufficient intelligence and communication capabilities to obtain their information and to decide on the next steps to be undertaken. The Distributed Logistic Routing Protocol (DLRP) presents a fully distributed routing concept for dynamic logistics. In this concept a vertex is a knowledge broker for the vehicles and packages. Before deciding about a route, a vehicle/package requests current information from the current or next vertex. Each vertex includes relevant information available from its current knowledge-base and forwards the request to neighbour vertices.

The concept has been implemented into a logistic simulation environment to prove its feasibility.

Bernd-Ludwig Wenning, Henning Rekersbrink, Markus Becker, Andreas Timm-Giel, Carmelita Görg and Bernd Scholz-Reiter present a **"Dynamic Transport Reference Scenario"**. Reference scenarios are a common technique in simulations allowing the evaluation and comparison of different algorithms and approaches. For transport logistic processes these approaches can be, for example, different strategies to select the packets to be loaded. Traditional logistic scenarios are not suitable for the investigation of dynamic transport processes. Therefore new reference scenarios are generated which can be used for the evaluation of approaches in these dynamic networks. The components for the modelling of dynamic logistic networks are introduced and evaluation parameters are listed. Based on the definitions of components the scenarios comprise all relevant components, such as location and functionality of vertices, edges, type and initial position of vehicles and distribution of packages. Two selected scenarios, the small 4-vertex scenario and the larger Germany scenario, are described.

When investigating the quality of an approach, there is the need to evaluate its performance levels with respect to the aspired goals. Therefore a set of evaluation criteria is required. Considering transportation logistics, the goal is to achieve a high logistic efficiency, i.e. high performance at low cost. Two sets of possible evaluation measures are introduced: The volume-related measures (consisting of queued packages, inactive vehicles, vehicle utilisation) and the process-related measures (comprising throughput time, punctuality rate per package, trans-shipments per package). The above mentioned combined scenario of transportation and production processes is described by Felix Böse and Katja Windt within the article **"Autonomously Controlled Storage Allocation on an Automobile Terminal"**. In the context of this article a new approach of an autonomously controlled logistics system is introduced, considering as example the storage allocation processes at the E.H.Harms Auto-Terminal Hamburg. The vehicle movement processes at the automobile terminal provide many opportunities for improvement. Based on the described business processes of the conventionally controlled as well as the autonomously controlled storage allocation, two simulation scenarios are developed and evaluated. By establishing autonomous control, vehicles are enabled to render decisions on their own and according to this to determine their way through a logistics network on the basis of an own system of objectives. As result of recent developments in the field of information and communication technologies, the implementation of such an autonomously controlled logistics scenario for an automobile terminal is now feasible.The object of investigation of the simulation study is the transfer times of the vehicles in the automobile terminal. As a main result of the presented simulation study, the new paradigm of autonomous control in logistics provides significant opportunities of time saving in the field of vehicle movement in automobile terminals. Due to the fact that the simulation study was strongly focussed on the storage allocation process as a single part of the vehicle management process chain of automobile terminals, further research is directed to the enlargement of the considered application scenario.

The article **"Intelligent Containers and Sensor Networks – Approaches to Apply Autonomous Cooperation on Systems with Limited Resources"** by Reiner Jedermann, Christian Behrens, Rainer Laur and Walter Lang focuses on RFIDs, sensor networks and low-power microcontrollers are increasingly applied in logistics. They are characterized by restrictions on calculation power, communication range and battery lifetime. The article considers how these new technologies can be utilized for autonomous cooperation and how these processes could be realized in systems with limited resources. Besides tracing of the current freight location by RFID technologies, the monitoring of quality changes that occur during transport is of growing importance. The demand for improved and comprehensive supervision of goods could be best fulfilled by distributed autonomous systems. The prototype of the 'intelligent container' demonstrates how autonomous control could be implemented on a credit-card sized processor module for integration into standard containers or transport vehicles. RFID technologies are used to control the transfer of this mobile freight agent. The implementation of the local data pre-processing and an example quality model for vegetables are described. If the supervision system predicts that the freight quality will fall below an acceptance threshold before arrival, it contacts the transport manager. Furthermore, the extended agent platform for further transport planning is shortly introduced. Sensors that are attached to the freight have to link themselves 'ad hoc' into the communication network of the vehicle. Therefore the text gives an overview of the design, configuration and control of the implementation of a wireless sensor network.

Then architectures, examples and further demands on autonomous cooperative processes running on low-power microcontrollers are discussed. Finally, approaches for future implementations of an autonomous decision system on small battery-powered sensor nodes and logistical freight objects are summarized.

The last article of chapter 4 by Reiner Jedermann, Jan D. Gehrke, Markus Becker, Christian Behrens, Ernesto Morales-Kluge, Otthein Herzog and Walter Lang represents a **"Transport Scenario for the Intelligent Container"**. The article describes how the intelligent container is linked with an agent system for transport coordination including communication gateway and vehicle location. The scenario itself consists out of a traffic network, trucks and loads with their respective positions. It concentrates on the automated monitoring and management of perishable goods. The hardware setting is presented, e.g. sensor configuration, as well as the used controlling methods, e.g. transport coordination and route planning, within the scenario. The article shows how autonomous cooperating and control may improve the processes of supply chain management.

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