Published in: Proceedings of 8th MITIP Conference, Budapest, 2006, pp. 341-346.

MODELLING OF AUTONOMOUSLY CONTROLLED LOGISTIC PROCESSES IN PRODUCTION SYSTEMS

Felix BÖSE, Katja WINDT, Michael TEUCKE

University of Bremen
Bremen Institute of Industrial Technology and Applied Work Sciences (BIBA)
Department IPS
Hochschulring 20, 28357 Bremen
Germany
E-mail: boe@biba.uni-bremen.de

Abstract:

The increasing complexity in order processing of today's logistics systems requires a reorganisation of existing planning and control systems, which do not allow a fast and flexible adaptation to changing environmental influences. Autonomously controlled logistics processes seem to be an appropriate approach to meet these new demands. In the context of this paper the changes in modelling of autonomously controlled logistics processes are investigated. At first a definition of autonomous control in general and within the scope of engineering science is introduced and its main criteria are described. Based on this changes in order processing by establishing autonomous control are investigated and exemplarily illustrated in several views of a business process model.

Keywords:

Autonomous Control, Modelling, Logistic Processes

1. INTRODUCTION

Rapidly changing conditions of present markets lead to an increasing complexity of logistic systems and require innovative approaches to organisation and control of logistic systems. Typical examples of market-driven changes are the increasing importance of customer orientation because of the shift from seller to buyer markets, shorter product life cycles and decreasing lot sizes with a simultaneously rising number of product variants as well as higher product complexity [13]. As a result new demands were placed on competitive companies, which require innovative logistic concepts and planning and control methods to ensure a high flexibility and adaptability of the logistics system to changing environmental influences [8]. Conventional production systems are characterised by central planning and control methods, which show a wide range of weaknesses and cannot fulfil these demands. Conventional planning and control methods are based on simplified premises (predictable throughput times, fix processing times of production orders etc.), which lead to an inadequate and unrealistic description of the production system. The different centralised planning steps of the traditional ERP respectively MRP based PPC-Systems are run sequentially, therefore the adaptation to changing boundary conditions (e.g. planning data) is only possible within long time intervals. This means that changes of the job shop situation cannot be considered immediately, but the next planning run at the earliest. As a result the current planning is based on old data and the needed adaptation measures cannot be performed in time for a proper reaction of the discrepancy between the planned and the current situation [14]. In case of disturbances or fluctuating demand centralised planning and control methods are insufficient to deal with the complexity of centralised systems, which rises disproportionately to their size and heavily constrains the fault tolerance and the flexibility of the overall system [3], [9].

These weaknesses of conventional logistic planning and control systems require a fundamental reorganisation. In scientific research recently the concept of autonomously controlled logistics systems as an innovative approach of a decentralised planning and control system is investigated, which meets the increasing requirements of a flexible and efficient order processing [1], [7]. To establish the logistic concept of autonomous control adequate modelling methods are needed, which allow an exact description of autonomously controlled logistics processes. In this paper a definition of the term autonomous control in logistics and a specification of its main criteria are introduced. Based on this changes in order processing by establishing autonomous control are investigated and are exemplary illustrated in several views of a business process model. The paper ends with a short summary and an outlook in respect of further research activities.

This research is funded by the German Research Foundation (DFG) as part of the Collaborative Research Centre 637 “Autonomous Cooperating Logistic Processes: A Paradigm Shift and its Limitations” (SFB 637) at the University of Bremen.

2. AUTONOMOUS CONTROL IN LOGISTICS SYSTEMS

2.1. Definition of autonomous control

The idea of autonomously controlled logistic processes is to develop decentralised and heterarchical planning and controlling methods in contrast to existing central and hierarchical aligned planning and controlling approaches [14]. According to the system theory, there is a shift of capabilities from the total system to its system elements [4]. Consequently decision functions are transferred to autonomous logistic objects, which are defined as physical items (e.g. part, machine, conveyor) or logical items (e.g. production order) of a networked logistic system. Autonomous logistic objects have the ability to interact with other logistic objects of the considered system and are able to act independently according to their own objectives and to navigate through the production network themselves [15]. To achieve this, logistic objects are enabled to render decisions by themselves in a complex and dynamically changing environment by using new technologies and methods.

Based on the results of the work in the context of the Collaborative Research Centre (CRC) 637 “Autonomous Cooperating Logistic Processes - A Paradigm Shift and its Limitations” at the University of Bremen [13], autonomous control can be defined 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.” [2]

Based on this global definition of the term autonomous control a definition in the context of engineering science was developed, which is focused on the main tasks of logistic objects in autonomously controlled logistics systems:

“Autonomous control in logistics systems is characterised by the ability of logistic objects to process information, to render and to execute decisions on their own.” [16]

2.2. System Layers and Main Criteria of Autonomous Control

Based on the definition of autonomous control in the context of engineering science its main characteristics are the ability of logistic objects to process information and to render and execute decisions. Each characteristic can be assigned to different layers of work in an enterprise. In accordance with Ropohl [10], different layers of work can be classified in organisation and management, informatics methods and I&C technologies as well as in flow of material and logistics, each concerning decision, information and execution system. Figure 1 presents the assignment of the characteristics to the system layers, illustrates their correlations and introduces the main criteria of autonomous control.

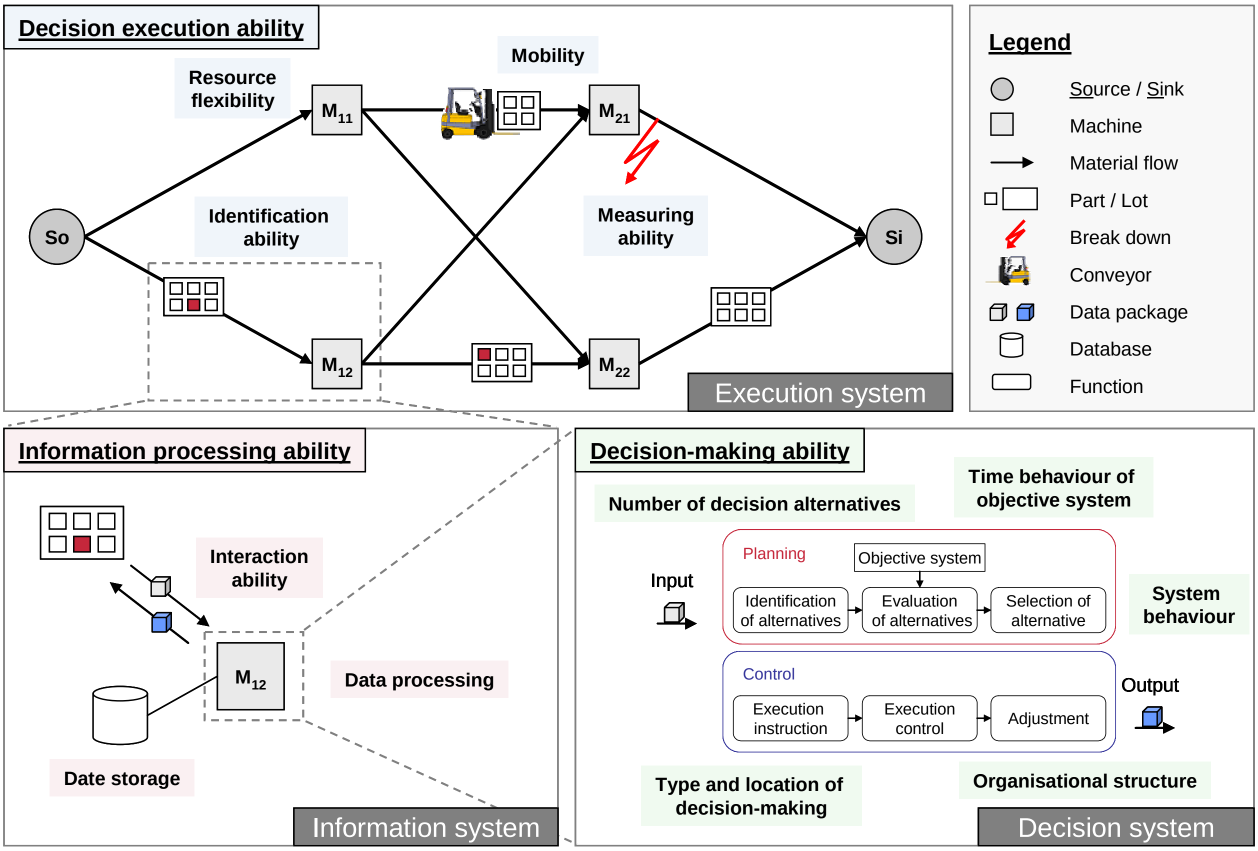

Figure 1. System layers and criteria of autonomous control

The decision system is characterised by the decision-making ability. As mentioned before in autonomously controlled production systems decision functions are shifted to logistic objects, which are aligned in a heterarchical organisational structure. These functions contain planning and control tasks and enable logistic objects to assign their progression. The decision-making process includes the identification and evaluation of decision alternatives on the basis of an own, decentralised objective system, the selection, instruction and control of the best rated alternative as well as possibly adjustments.

The basis for decision-making is the information processing ability on the information system layer. In autonomously controlled production systems logistic objects must be able to interact with each other as well as to store and to process data.

The execution system layer is characterised by the decision execution ability of logistic objects. Autonomous logistic objects are able to measure their current state and react flexible to unforeseeable, dynamic influencing variables. Mobility and high flexibility of the resources are other main criteria of autonomous control in production systems.

3. MODELLING AUTONOMOUSLY CONTROLLED PROCESSES

The definition of the term autonomous control in logistics and the description of its main criteria are the basis of a comprehensive investigation of the changes in order processing caused by establishing of autonomous control. Focus of interest is the question, to what extent existing models of logistic order processing are suited for modelling autonomously controlled logistic processes respectively which modifications are necessary. The range of required modifications depends on the level of autonomous control of the considered production system. The definition of autonomous control explained in the preceding chapter describes the maximum level of imaginable autonomous control. But autonomously controlled logistics systems will probably contain both: conventionally managed and autonomously controlled elements and sub-systems. To answer the question concerning the suitability of existing models to describe autonomously controlled logistic systems several process studies using the ARIS (Architecture of Integrated Information Systems) concept are conducted by means of existing reference models of the logistic order processing [5], [6], [11], [12]. The ARIS concept as an integrated method for the modelling of processes and information systems provides several views on a system: the data view, the function view, the organisational view and the control view, which uses the EPC (Event-driven Process Chain) as modelling notation. In the following essential modifications of existing reference models because of changes in logistic order processing caused by establishing autonomous control are introduced. For this purpose the modifications in every single view are exemplary illustrated (compare figure 2) and shortly described.

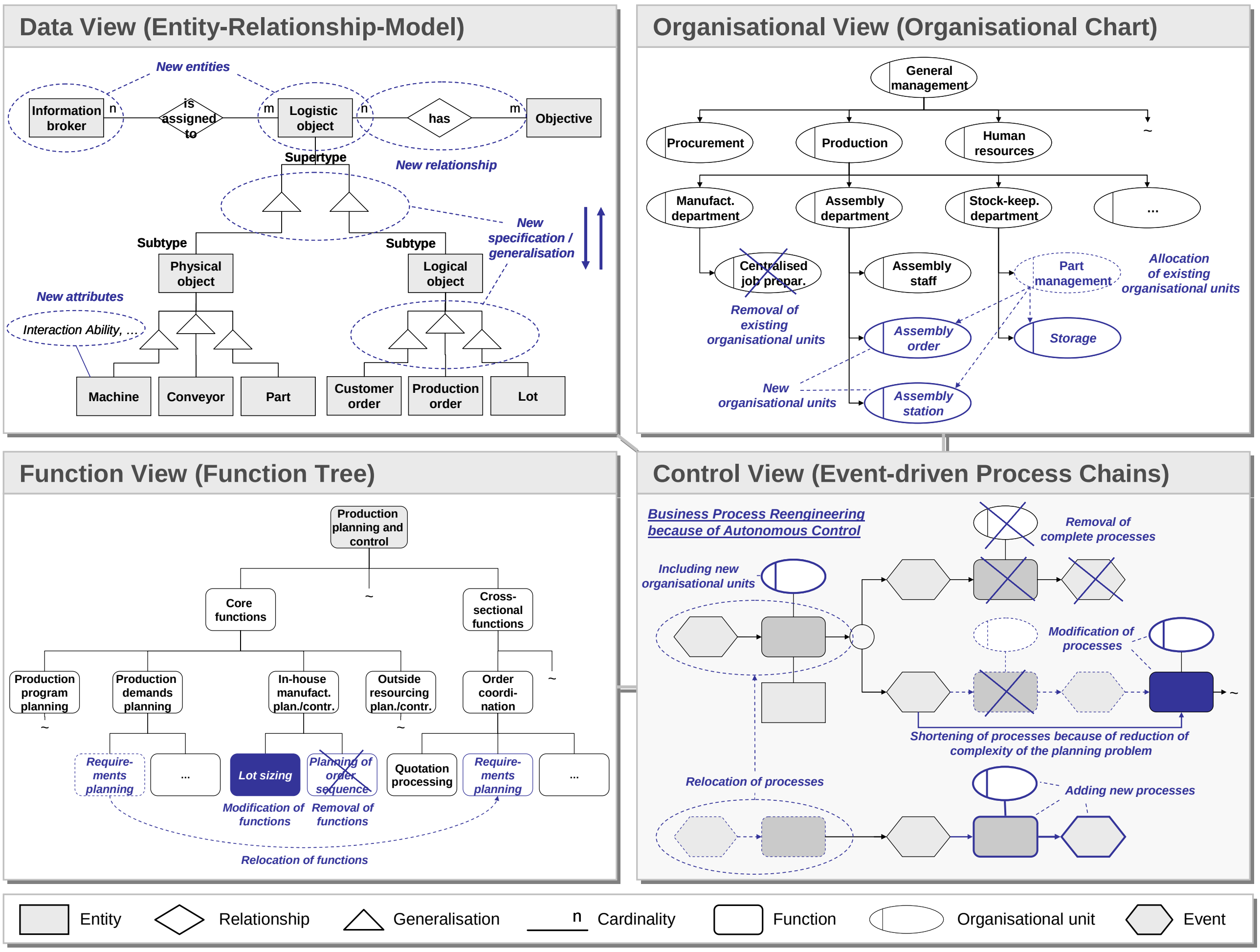

Figure 2: Modelling views of autonomously controlled logistics processes

3.1. Data View

Existing data models, for example in the form of an ERM (Entity-Relationship-Model), are not sufficient to describe adequately entities in autonomously controlled logistics systems, but have to be extended by new entities, attributes, relationships as well as specification / generalisations. As described in the chapter before in autonomously controlled systems autonomous logistics objects, both physical and logical objects, have the ability to interact with other logistic objects of the considered system, to act independently according to their own objectives and to navigate themselves through the production network. Considering these criteria of autonomously controlled logistics systems the *logistic object* as well as the *physical* and *logical object* has to be added as new entity just as the belonging generalisation between these new entities. Furthermore there is a new relationship from the entity *objective* to the new entity logistic object. A new entity *information broker* is introduced to represent special information broker objects. These objects are needed in autonomously controlled systems to register the logistic objects prevalent at certain process stations and to provide communication links between them. Also the *interaction ability* has to be added as an attribute of an entity, for example as attribute of the entity *machine*. Accordingly complexity of data models of autonomously controlled systems rises because of adding of new entities, attributes, relationships as well as specifications / generalisations.

3.2. Function View

The modifications of the function models, pictured in the form of a function tree (compare figure 2), are determined by the decentralisation of the planning and control functions to the logistic objects, that requires a relocation respectively reorganisation of several functions. For example in autonomously controlled logistic systems there is no longer a centralised *requirements planning*. Rather this function is moved from the centralised system to the logistic object order and with it assigned to the superior function *order coordination*. Some functions of conventional planning and control systems, which are executed centralised for several logistic objects, are removed. For instance the function *planning of order sequence* in the field of *in-house manufacturing and control* in no longer needed, because the control of order sequence happens at run time by the machines themselves. Other functions still remain, but require an alteration. For example the activities within the function *lot sizing* is simplified due to the fact that based on the decentralisation of the planning and control functions there is no longer a centralised lot sizing, but a local lot sizing coordinated by a single machine.

3.3. Organisational View

There are several changes concerning the organisational structure caused by establishing autonomous control in order processing due to the fact that in autonomously controlled systems logistic objects are able to initiate and execute functions. Because of the relocation of functions to the logistic objects some centralized organisational units are no longer needed, for example the organisational unit *centralised job preparation*. Some organisational units are substituted by other, partly new organisational units. So the organisational unit *part management* is replaced by several logistic objects like *storage*, *assembly order* and *assembly station*, which are added as new organisational units. Thus a logistic object can function both as an entity and an organisational unit. Even though in autonomously controlled logistic systems logistic objects are able to initiate and execute functions within order processing, it is highly doubtful, whether they can take on a responsibility for the related functions. On the contrary it makes sense, that not the single logistic object but rather the superior “human” organisational unit is responsible for the results and (unintended) effects of the functions.

3.4. Control View

The modifications of the data, function and organisation view are reflected in the control view, which contains the adaptations of the business processes of the planning and control system caused by establishing autonomous control. As the wide range of manifold modifications of the several views result in a corresponding number of modifications in the control view, in the context of this paper only a common illustration of the changes is introduced (compare figure 2). As described above new organisational units as well new entities have to be included because of the existence of autonomous logistic objects. The decentralisation of planning and control functions to the logistic objects causes relocations of processes within the work flow, removals of complete processes as well as shortenings and modifications (modifications of functions, replacing organisational units, adding new entities etc.) of logistic processes. This results in two different effects on the complexity of the business process model. The decentralisation of the planning and control tasks reduces the need for long and complicated process chains of planning and control tasks. However it also results in an increasing number of (redundant) processes and thus leads to a higher complexity of the business process model.

4. CONCLUSIONS

In the context of this paper the concept of autonomously controlled logistics systems was investigated as an innovative approach of a decentralised planning and control system, which meets the new requirements of a flexible and efficient order processing. Based on the definition of the term autonomous control within the scope of logistics and the constitutive criteria it has been shown, that existing models of logistic order processing are not sufficiently suited for description of autonomously controlled logistic processes. Manifold modifications of existing models are necessary, which depend on the level of autonomous control of the considered production system. Using the ARIS concept several modifications were introduced from data, function, organization and control view. Future research is focused on the detailed investigation and modelling of changes in logistic order processing by establishing autonomous control. Main objective is the development of a reference model of the autonomously controlled logistic order processing using the example of a job shop manufacturing scenario.

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