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Autonomous Logistic Processes in Manufacturing – A Challenge for Configuration and Management

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ABSTRACT

The integrating function of logistics leads to varying requirements on the involved systems. The implementation of logistic processes in the material flow is dominated by optimization tasks. However, the management aims at strategic competition leading to a two-fold consideration of information logistics: either as assistance function for the management or as a control function on the material level. Within this paper, we are proposing contradiction management for an integration of the conventional approaches.

INTRODUCTION

Modern approaches in the area of operations research and logistics are increasing the problem complexity for more realistic logistic models (e.g. Urban/Reese (2005)). Modern approaches in research and application, try to transfers the functionality resp. quality of autonomy to logistical processes. According to the interdisciplinary definition by Hülsmann and Windt (2006) autonomous processes are described as processes of the decentralized decision finding in heterarchical structures. It presupposes the ability and possibility of interacting system elements for the autonomous meeting of *goal-orientated*, *wanted* (resp. positive effect) and *conscious decisions*. Autonomy is applied to gain more robustness by distributed mastering of dynamics and complexity of non-deterministic systems in the form of a higher flexibility and autonomy in the decision finding. The features of autonomous processes (e.g. complexity, dynamics, non determinism, autonomy, redundancy, interaction and emergence) promise autonomous processes as a beneficial approach for handling the increasing and changing requirements in logistics. The interactions between autonomy, contradictions and knowledge will be introduced in more detail in the full paper. The realization of autonomy conditions knowledge of the complex, context sensitive decision finding on the one side. An explicit analysis of contradictory requirements becomes necessary on the other side which are immanent in the concept of autonomous processes. In Dembski & Timm (2005), we analysed the implications of autonomy in logistic processes. As a result, we stated, that it is required to integrate aspects of the strategic management in operational decision making. The integration of these aspects should be performed on the level of information flows. The interdisciplinary analysis of intelligent representatives (computer & information science) and strategic management (business administration and economy science) leads to a shift of the conventional consideration interface. In this paper, the requirements which emerge from autonomous logistical processes are analysed. Knowledge and knowledge management is identified as a challenge, starting out from the analysis of contradictory requirements and from contradiction management. The automation degree in addition is taken into account in the production logistics and intelligent representatives are discussed for the realization of autonomy resulting from it. Contradiction management and knowledge management are integrated in a conceptual framework to make a complex decision finding possible in autonomous processes. Based on this a concrete approach, contradiction management is established by context-explication and decentralized conflict management. This approach is evaluated using a prototypical implementation.

CONCEPTUAL FRAMEWORK

The key challenge in autonomous logistic processes can be found in the treatment of contradictions and the resulting conflicts on the process level. Within this section, the necessary concepts on contradictions and knowledge in regard of autonomous logistic processes are analyzed. The integrated analysis of the decision- and information level contains aspects from the areas of autonomous processes, contradiction and knowledge management.

The requirements to focus more and more on autonomy in logistics show the management of today's enterprises among other things the inconsistency between outside control and autonomy which is necessary to handle systematically for using the advantages of autonomous processes efficiently.
In very complex decision situations there often is no uniform and consistent solution. An area of conflict can rather arise by the fact that developing new advantages is accompanied by the loss of existing ones. So enterprises cannot obtain cost advantages by a central storekeeping and effect simultaneously disposition and transaction advantages by decentralized organization of the store. The optimal consideration of all decision relevant criteria doesn't solve the contradiction which exists in the central or decentralized organization at this example. The available -- rather central -- decision structure of the enterprise changes autonomous logistics processes for the management with a greater decentralized information processing capacity (by the implementation of information and communication technologies). A higher standard of autonomy then means a delegation of decision competences. While autonomy enables faster and more flexible decisions, a stronger outside control allows more intensive regulation of the behaviour of the decision makers. The increase of this principle logically leads to a reduction of the possible application of the contrary principle now, however. For dealing with contradictions in this context knowledge is required, which arises on the one hand in a logistical process and is used as well as developed from the protagonists involved and therefore is process specifically. On the other hand methodological knowledge of dealing with contradictions is required which the individual abilities to handle contradictory requirements, includes. The delegation of decision competences (e.g. men, machine) requires a high quality of available knowledge for realising and implementing autonomy in logistic processes. This necessity arises particularly from the demand that logistic processes must stay efficient even if the conditions change or the dynamics of the environment leads to changed situations.

Summarizing the various requirements in the logistics domain introduced within the last sections, it is obvious, that knowledge is core element of an approach to autonomous logistics, as it enables sophisticated decision-making within the agents. In conventional approaches, the implementation of a knowledge management system within a company could help to improve the situation for local decision making. However, we assume that it is impossible to establish a single knowledge management system within an open network of autonomous decision makers of various enterprises. Therefore, we are in need of an innovative approach to knowledge management. The infrastructure for knowledge management has to integrate aspects of cooperation and competition with regard to the relationships of the corresponding enterprises. As knowledge is one of the key factors for establishing efficient logistics, knowledge is considered as a resource. This includes the ability to use knowledge as a tradable good, such that even competing enterprises may share knowledge in a concrete situation. Following this assumption, knowledge may also be used for establishing trust networks or new cooperation relations between enterprises dynamically and autonomously. Obviously, agents resp. autonomous decision makers in the logistics domain can use knowledge in different ways, e.g., using

knowledge from another agent, providing knowledge to another agent, etc. Furthermore, intelligent agents have the ability to reason on knowledge and infer new knowledge form current situations. This ability can also be used for trading new knowledge within the systems.
The challenge of interdisciplinary consideration of knowledge and contradictions in autonomous decision-making is to enable actors in processes and enterprises represented by agents and the management together resp. provide those information which are necessary for sustainable decisions. However, there are parts of the knowledge, e.g., strategic knowledge, which have to be transferred to an agent of the company but which have to be kept as a secret to other companies.

CHALLENGES OF AUTONOMOUS PROCESSES FOR MANUFACTURING

In the previous section, we discussed the role of knowledge and contradictions for autonomous logistic processes. The implementation of such processes requires the solution of the following challenges:

- contradictional requirement
- intelligent agents
- management of contradictions
- integration of intelligent agents and management of contradictions

The framework has to integrate sophisticated decision making on an operational and strategic level. The approach is based on two aspects: context management and decentralized conflict management. In conventional systems, e.g., organizations, there is a management defining the strategic context for the actors and solving the contradictions with respect to predefined situations. The approach of autonomous processes restricts the management to the definition of context, which has to be that restricting that the actors are acting within a predefined economic scope and has to be that flexible, that the actors are gaining a positive emergent effect. The consequence of this approach is, that not all of the contradictions are handled by the management anymore. Thus, the agents are in need of capabilities for handling contradictions in concrete situations. In a situation, a contradiction is materialized as a conflict. In our research, we developed an automated approach for handling conflicts within computational agents. In the paper, we would like to provide more details on the technical issues of our approach, which is based on intelligent agents.

EVALUATION

Agents seem to be a promising approach for realization of autonomous systems. Supporting tasks like the management and integration of planning, scheduling, and controlling processes they can be used as *enterprise delegates*. In our research, we introduced a new approach to identification of synergy and conflicts of interest in the desires as well as intentions. On this basis, a conflict resolution mechanism is applied for minimizing conflicts and maximizing synergy. In this step, new goals as compromises of desires might be created. The agent which is using the innovative algorithm resp. a comparison algorithm represents a machine tool (resource) within a shop floor. Here, order agents which represent manufacturing orders negotiate with resource agents to implement an integrated process planning and production control. In this setting, the resource agent is responsible for its own schedule as well as the negotiation with the order agents. There is an explicit probabilistic failure model for the resource included. In order to assess the behaviour of the decision algorithm, an evaluation with 1700 experiments and 163.200 decision cycles has been performed (Timm 2004). Additionally, a state-of-the-art intention-selection algorithm based on dynamic priorities has been implemented in order to benchmark the cobac-algorithm. The comparison algorithm is based on the assumption that the management provided conflict resolution rules in advance to the agent. In direct comparison of cobac and the priority-based agent, cobac is beneficial in any of the five experiment

groups. The priority-controlled agent shows a significant statistical spread in the success parameters. Especially the number of accepted but not processed orders is a major problem for the priority-based agent, since it fails to handle the backlog when it reaches a certain amount. The agent using the complex algorithm appears to be more stable and overall more superior to the priority-based agent. The benefit is supported by the statistical analysis where the deviation of the new algorithm to priorities is highly significant ($p<0.0001$) with respect to the indicators money, maintenance level, production, and order list.

CONCLUSION

The transition of centralized to autonomous internal production logistics moves the decision competence and the resulting contradictory requirements increasingly on the process level. In this paper we proposed a conceptual framework for the treatment of contradictions on the process level. Our approach of the implementation contains the consideration of context-explication and decentralized conflict management in the context of a multiagent system. The conflict management follows interpersonal research results so that the results get comprehensible for man and that such an integration of social and information system is made easier. Within an extensive simulation could be proved statistically and significantly that this approach with context-explication and conflict management is superior to a from outside control with a dynamic priority calculation. The advantage founds itself in the possibility of being able to form dynamic compromises between conflicting goals.

At present, an agent cannot modify its target system e.g. by the generation of new permanent aims durably, however. An efficient adaptation of the strategic behaviour to new market situations is therefore only restrictedly possible. This aspect should be examined more and more in an improvement of the approach. We see further steps in the arrangement of the conceptual frame and the transfer of the implemented approach on hybrid processes in which both people and technical systems interact. Building upon this the concretizing of the context-explication as well as the operationalization in particularly should be carried out and should be supported by a corresponding management approach.

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