Agent-Based Management Systems in Logistics

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Abstract. In logistics of today's economy we have to deal with distributed systems. To support the demanding management task the multi-agent approach offers promising perspectives. For human organizations a socio-technical system is to be handled. The theory of organizational cybernetics provides basic knowledge about structure-theoretic foundations to reach organizational fitness. For the design of management systems based on a multi-agent concept, we try to adopt as much as possible of the insight valid for human based socio-technical systems to the agent world. We particularly focus on identifying the main characteristics for design of management systems in order to achieve the ability to master a system in a dynamic environment evolving in a short and long-term horizon.

1 Introduction

Tasks in production and distribution logistics have to be accomplished within networks on the physical as well as on the informational level in today's global economy. On the physical level systems are locally distributed over large areas, sometimes worldwide, the information system is based on an intra or internet data network anyway. This system layout is a particular challenge for the control task, a distributed system has to be controlled in a dynamic fast changing environment. This requires the ability to react to events and evolutions in the system's environment as well as within the system itself in the short and long time range in a way to guarantee the envisaged short- and long-term goals of the system.

We have to deal with the control of distributed systems in which a larger number of actors (individuals) and agents (software objects) have to take decisions. These decisions have to be co-ordinated and directed towards the global goals of the system. If we consider actors, a socio-technical system has to be handled. For the planning and control task the theory of organizational cybernetics provides basic insight, whereas for automated systems or computer-based decision support tools, the multi-agent approach offers promising perspectives.

System control as we have in mind for logistics systems embedded in a dynamic environment is a management task. Satisfactory solutions can't be obtained by viewing the control task simply as a sequence of single decisions. Therefore we propose to design multi-agent systems in logistics as similar as possible to socio-technical systems with human actors and rely on the available theoretical background of organizational cybernetics.

2 Logistics

Our envisaged application field is logistics. We define logistics as the control of material, capital and information flow within an enterprise in view directed towards their global goals.

As to their formal structure logistics systems have a lot of similarities. The following abstraction covers a wide range of practical examples in economy in the field of production, distribution and services.

The purpose of the system is well defined, the goals are specified on a strategic and operational level. The operational task consists in fulfilling a list of orders according to their requests in time and product specification. To process these orders operations according to a specified process flow have to be accomplished consuming determined scarcely available resources. These operations have to be executed in a locally distributed system. As to material, information and capital flow within the system their routing has to follow given directives. The logistics system is embedded in a dynamic environment, where a permanent interaction between the logistics system and the environment takes place.

3 Cybernetical Management Theory

Our approach for an appropriate handling of the management task is based on organizational cybernetics in management theory. Organizational cybernetics is a science, which applies principles and models of cybernetics for designing, controlling and developing organizations of all kinds. We refer as theoretical foundation for a cybernetic structure to the combination of the Model of Systemic Control (MSC) developed at the University of St. Gallen [12] and the Viable System Model (VSM) by Stafford Beer [3].

3.1 Model of Systemic Control

The developed model suggests that the management task has to be accomplished on different logical management levels, called operational, strategic and normative level. A system has to evolve continuously to meet short- and long term goals. Different control variables have to be considered in order to pursue these different goals. While steering a system by controlling the lead time on the operational level might be sufficient, it is not an adequate orientator for the long time horizon of the system. This leads to the introduction of the three management levels. The levels are tied together through an feed-back control cycle, where control variables and parameters of the higher logical level exert a pre-control function in relation to the lower ones.

3.2 Viable System Model

Beer pointed out, that a system is only viable if it has a specific management structure (Invariance Theorem). According to the proposed Viable System Model a set of management tasks is distributed to 5 systems ensure the viability of any social system. The 5 systems can be summarized as follows:

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System V is the top normative decision level (policy-making) of the whole (logistics) system. The main roles of Policy are to provide clarity about the overall direction, values and purpose of the organizational unit.

System IV is the link between the primary activities and its environment. On this level the future developments according the systems capabilities and changing of the environment (customer demands) are planned.

System III is the controlling unit of the operational level (System I–III). It has to assure the internal stability and to optimize the allocation of resources.

System II co-ordinates and regulates the partly autonomous subsystems.

System I controls and optimize the performance of the partly autonomous sub-systems on the short-term basis.

System I–III forms the operational management level, whereas system IV is the strategic and system V the normative one. Finally the management system comprises three logical management levels (cf. section 3.1).

3.3 Impact on Agent Technology

The inherent complexity of current systems leads to systems of embedding autonomous tasks within autonomous tasks, rather than to a system of delegating responsibilities from one level to the next (see[5]). For this reason recursively structured multi-agent systems as part of a socio-technical management system should be build, where autonomous units within autonomous units pursue a specific task.

A framework for establishing such viable control systems is provided by the cybernetical management theory, which defines a generic structure for embedding all activities in the management context. Viable in the context of logistics means the capability of a multi-agent system to adapt to changes of its environment (e.g. new order arrival) in order to meet the requirements of customers in the best possible way.

The prerequisite of a system to maintain viability is self-control. Agents can control processes on the basis of actual values compared to target values. In other words, agents are regulators, taking actions, if the output values differ substantially from the target value. This feedback control cycle can only be applied for variables which are controllable (e.g. lead times). In the case of non-controllable variables (i.e. frequency and mix of new order arrivals) a feedforward mechanisms such as demand forecasting models for anticipating this kind of disturbances have to be developed.

The feedback control cycle should also be applied for controlling the performance of agents by agents on a higher logical level (e.g. co-ordinating agents of System II of the VSM model). Furthermore, through this established control flow an agent can inform an agent on a higher logical level about the intractability of a task with respect to the system goals. In this case the informed agent has to handle the problem (e.g. by adjusting the target values).

4 Multi-Agent Systems in Logistics

[6] reviewed various definitions of the term agent. The most general way to describe the notion is derived as stated below:

Agents are software entities, which are dedicated to a specific purpose and carry out some set of operations in order to accomplish tasks.

From a logistics management perspective this definition is too simple. Agents taking responsibility in fulfilling the operational goals as well as agents supporting these tasks in a computational way are needed. These thoughts motivate the introduction of two generic meta types of agents in the logistic domain. *Management agents* pursue goals with respect to their environment and their defined action space, whereas their contractors, the *service agents* solve well specified tasks autonomously. Management agents need various algorithmical problem solving methods, such as scheduling of tasks with respect to certain conditions, so it makes sense to delegate these kind of tasks to computational agents particularly designed for such purposes. With this task distribution, management agents are able to focus on decision related problems.

4.1 Management Agents

4.1.1 Basic Description

Management agents are the central part of a management system and defined[2] as follows:

Management agents in logistics are software entities for meeting operational goals on behalf of a human actor or another managerial agent with some degree of independence or autonomy, and in so doing employ some knowledge or representation of the user's goals or desires.

More explicitly: management agents are goal directed, pro-active, take goal responsibility, make decision, and have a model of their environment. They act autonomously, but the actions are constrained by the provided information and models[3](e.g. from a supervising agent). A management agent needs, therefore, the following information:

- a goal to pursue
- its skills and behavior
- model of its environment
- its role in the agent community (e.g. supervising agent, its sub-agents, collaborating agents)
- communication and co-operation protocols

Since we are in a logistic domain, where the co-ordination of joint actions play an important role, a management agent must exhibit the following properties:

- act in a collaborating manner
- apply various problem solving strategies
- communicational abilities
- methods for solving conflicts among its sub-agents
- capabilities for goal and model building, which are used by its sub-agents

4.1.2 Instances of Management Agents in Logistics

We are introducing 3 types of agents (similar to [13]), which have all in section 4.1.1 mentioned properties.

Resource Agents A resource is an abstraction of the production facilities and requisites, such as machines and raw materials. A resource can be either allocated by applying simple rules or managed in a more sophisticated manner by resource agents. The agent has knowledge about methods to allocate and control the production resources.

[2] This definition was adapted from the IBM definition for intelligent agents (see [6]).

[3] [7] outlined the benefits of using models in DAI Systems.

Product Agent A product agent holds all process information. It knows the components needed to be able to complete a task. Furthermore it has to assure that a task is correctly and in a sufficient way done.

Order Agent A flowing entity in a logistics network can be represent by an order agent. It holds all relevant customer specific data, such as due dates. It keeps track that logistical task is performed within the time-frame.

4.2 Service Agents

As mentioned earlier in this paper instances of this agent type mainly work on behalf of managerial agents:

Service agents are contractors of other agents with special computational capabilities without having any representation of their client's goals.

Typical tasks for service agents in the domain of logistics are:

- computing schedules
- monitoring the logistic system for special events, e.g. machine breakdown
- computing performance data related to logistics such as machine utilization

Moreover, service agents are free to split tasks among subcontractors.

5 Management Systems with Agents

5.1 Architecture

Agents are responsible for the management tasks on the operational level. As software artifacts, they are restricted in their activity range by the capacity they get by the implemented software procedures they are equipped with. Only formally comprehensible activities can be executed within our system. We concentrate therefore on technical aspects of management, nevertheless we try to profit as much as possible from the basic experience of management in human organizations. We will base our approach on the management concepts of organizational cybernetics described in section 3.

For a management system comprising an agent community we have conceived two management levels, an upper and a lower level.

The 5 systems of a Viable System Model (VSM) comprise the necessary functionality of a management system. These 5 systems we allocate to our two management levels in the following way:

System V and IV, the normative and strategic tasks, we assume to be given by an external system user, a formal handling of these task will be hardly ever possible.

To the upper management level, we allocate system V, IV and the inner supervising functions of system III. The functionality consists on the one hand in co-ordinating externally the system with its environment on a long-term basis and on the other in co-ordinating internally the actors of the lower level in their effort to reach their operational goals. In doing this, the effort to fulfil the global system goals should always be the guideline.

To the lower management level, we allocate the systems I–III. It comprises the operational management skill to solve specific tasks in the running process in view of the given operational goals and the reaction to events in the environment on a short- term basis. The link to the upper level is established by system III as already mentioned.

Finally, we propose the following generic structure for the agent community on the lower management level:

Planning corresponds to System III of the VSM and represents an interface of the autonomous agent system to the higher recursion level. A planning agent has to assure the internal stability (e.g. by adjusting the work load) and optimize the performance of the system with respect to the given operational goal by actors of the same recursion.

Scheduling corresponds to System II of the VSM and co-ordinates the actions of the executional part by applying a co-ordination mechanism[4] like Kanban or heuristics like shifting bottleneck procedure (see [1]).

Execution and controls either a machine or represent an autonomous sub-system.

5.2 Design parameters

The internal design of a management system in a human environment is disputed fundamentally in the economy. Different organization concepts for a management system are investigated. This discussion is also relevant for mechanical systems up to a certain point. The realization of those concepts implies a specific internal design of the management system. In the following we try to identify the most important design characteristics. An important issue for a performance analysis is the variation of these characteristics in order to find out which characteristics is the most effective for a given practical case. The following design parameters characterize a management system in its most important aspects:

5.2.1 Organizational Structure

In a management system the actors with their task to accomplish and their competence within the decision process are members of an organization, which is structured as to ranking levels and functional connections. The lay-out of this structure determines essentially management activities, a strictly *hierarchical* order tends towards a centralized control concepts whereas a *heterarchical* order favors de-central concepts.

5.2.2 Management Technique

For the way management tasks are handled in human organizations different techniques exist. They differ mainly in the part the top management level takes. If it acts only in a passive supervising function, concepts as *Management by Exception* or *Management by Delegation* are to be considered, whereas if the top management level takes an active directing part *Management by Objectives* is a more adequate concept. For a proceeding according to these concepts, in management theory for human organization exists a detailed literature (e.g. [4, 14]), which offer a lot of insight valid for an agent community as well.

5.2.3 Co-ordination

Like a human organization an agent community needs co-ordination of actions for performing their task effectively. Co-ordination can be realized in different ways. According to their individual operational goals, autonomous units can either co-operate or compete with each other. A co-operative society tries to solve their problems by mutually supporting each other with an open information exchange. A society with a competitive culture is based on competition for scarcely

[4] [2] gives a survey of control algorithms which can be implemented in a multi-agent heterarchy.

resource or orders and only the fittest survive. Problem solving is an individual task, information exchange takes place only on a low level basis.

In logistics, in the case of production or procurement of standard products with frequent repetition and fixed batch sizes, the Kanban technique can be applied (see [11]. The key to Kanban is that once it is installed, a very limited exchange of information is necessary for co-ordination. The mutual provision of information is, as it were, ’materialized’ in the Kanbans [5].

5.2.4 Control Concept

The traditional controversy in planning and control is the question how to execute these tasks, in a centralized or de-centralized way. In a centralized concept the upper management level is directly involved in the operational process directing actively the activities towards the global goals. In a de-centralized concept, decision competence is associated mainly to the lower level, the upper level is not directly involved in the operational process and has in maximum a function as supervisor.

5.3 Application Concepts

We are focussing on Management systems run by a community of agents in the field of logistics. These management systems can be applied in different ways. As agents are part of a software program we have to deal with representations of logistics systems, in which the management system functions in a mechanical way.

For analysis purposes we can distinguish two types of applications:

Either we have a model representation of a socio-technical system on a relatively high level of abstraction. We are interested only in technical aspects of management and neglect to capture the purposeful, intentional and also largely voluntaristic character of individuals and groups, which constitute modern human organizations. In this context agents represent directly human decision-makers and determine the performance of the system. The logistics system to manage has to be linked as simulation model to the developed management system.

Or we have an agent-based management system as decision support tool, which is running besides a human organization. Agents in this tool propose solutions to well-defined decisions or take even decisions autonomously as far as decision competence is delegated to agents. The link of the management system with its logistics system to control can be realized in two ways, either to a representation in a simulation model or directly to the real world system. With a simulation model, off-line analyses “what happens if?” are possible, otherwise linked directly to the real world system, we get real-time support.

6 Application

In this section we give a brief description of the utilized test bed and we outline the proposed management concept.

6.1 Test bed

We consider a shop-floor as it can be found in the semi-conductor industry. The manufacturing process takes place in several automated work-cells embedded in the shop-floor. A work-cell supports four steps in the assembly process. On the die-bonder the electrical devices are picked from a wafer and glued on a metallic strip (the leadframe). A typical strip carries up to 15 devices. That semi-finished product goes to an oven where the glue is dried. Afterwards the electrical connections (gold wires) between the device and the leadframe are bonded on the wire-bonder. On the die-bonder the strips are filled into magazines and the finally the leadframes are pressed into a plastic form on the mold.The transport of these magazines within the work-cell is automated and is performed by a robot.

The main characteristic for the four equipment types are:

Die-Bonder: needs setup when the product changes, can produce approximately 1500 devices per hour, has a limited output buffer where magazines can wait to be moved to the oven if there is no capacity available.

Oven: has a limited number of oven chambers that can hold one magazine simultaneously, has no input or output buffer, the duration each magazine has to stay in the oven is product independent.

Wire-Bonder: needs setup when the product changes, can produce up to 300 devices per hour, has a limited input and output buffer. Modern wire-bonders can make up to 10 connections per second.

Molding: needs setup when the product changes, can produce up to 500 devices per hour, has a limited input and output buffer.

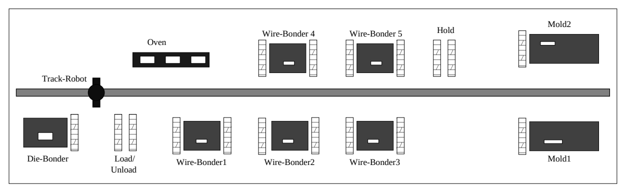

Figure 1. The Automated Work-Cell

Due to the different performances of the equipment a work-cell normally contains one die-bonder, several oven chambers, several wire-bonders and two molds.

6.2 Applied Management Concept

The above described logistics system contains two recursion, the shop-floor and the work-cells. A further recursion could be obtained, if machines of the same type but with different specification are regarded as unit. Since the utilized machines of the same type don’t differ in their configurations, they are regarded as a simple group represented by an agent.

6.2.1 Hierarchical Approach

A shop-floor agent receives a shop order from an actor (e.g. by terminal input) and configures the shop order (lot sizing), determines the due date by lead time scheduling and releases the order to a specific work-cell. Then, a work-cell agent is responsible for the scheduling (sequencing of the lots) with respect to the given due dates. Finally, a machine agent execute the task given from its work-cell agent.

6.2.2 Market Mechanism

The order of task to be executed (from order configuration to job processing) are similar to the centralized concepts, but the decision are taken in a de-centralized way. On the recursion shop-floor the agent has to configure the order and announce the lots with due dates to the work-cells. The planning part of a work-cell formulate a tender depending on:

- the announced lots (quantity, due dates, etc.)
- the arising costs: executional agents can influence the tender by varying their cost models
- demand forecasting model (feedforward): a more lucrative lot could be announced soon
- given operational goals (e.g. quantity of work in process)

The approval of a tender depends, in turn, on its quality (e.g. meeting the due dates), price, offers from other competitors and its own demand forecasting model.

After a bid is accepted, the work-cell and to be more precise the scheduler, continues with the internal planning with respect to the operational goals (e.g. target lead time) and the current situation on the executional level (e.g. amount of work in process). The scheduling agent decides about releasing a lot for its execution and the kind of applied coordination and control concept for the agents on the executional level. As mentioned above, this executional level can be another recursion (e.g. wire-bonder level) and in principal the same procedure can be applied on this recursion.

6.2.3 Heterarchical Approach

A pure de-centralized concept means eliminating the work-cells and the emergence of a 'sea of machines'. For each machine an agent is introduced, who competes with other machine agents of the same type for new orders represented by order agents. In principal distributed markets emerge. The difference to the approach outlined in the previous section is, that each machine agent includes the function of planning, scheduling and execution. Moreover, the actions of the agents aren't co-ordinated by a common body.

6.3 Evaluation Tool

The simulation platform HIDES (cf. [8]) is particularly designed for the simulation of logistics systems. The most important characteristics of this discrete-event simulator are the reference model for logistics systems providing a small number of simple generic elements as modeling basis and the strict separation of physical and logical level in the modeling process. In order to be able to test various management concepts the simulation kernel was extended by introducing a management level [9]. This management level comprises a management system including an agent community, where agents are in charge of the operational tasks in the logistics system.

7 Summary & Outlook

The approach to adapt cybernetical management concepts to multi-agent systems in the case where a close intercation between actors and agents are neccessary is quite promising, because

- the agent organization is structured compliant to a socio-technical system, which hopefully improves the understanding of decisions taken by agents for actors[5]
- the suggested organizing principles are generic for any logistics system and allows an fast adaptation to changing conditions

Further information about the ongoing research project are provided on the Web: http://www.ifor.math.ethz.ch/research/mgmt

[5] Several authors in [10] give examples in which traditional PPS-Systems fail due to the fact that computer-based planning decisions aren't well understood by the operators.

REFERENCES

[1] Joseph Adams, Egon Balas, and Daniel Zwack, 'The shifting bottleneck procedure for job shop scheduling', *Management Science*, **43**, 391–401, (1988).
[2] Albert D. Baker, 'A survey of factory control algorithms which can be implemented in a multi-agent heterarchy: Dispatching, scheduling and pull', *Journal of Manufacturing Systems*, (1998).
[3] Stafford Beer, *Brain of the firm*, John Wiley & Sons, Cichester, 1981.
[4] K. Bleiker, *Das Konzept integriertes Management*, Campus, Frankfurt a.M., 4 edn., 1996.
[5] Raul Espejo, Werner Schuhmann, Markus Schwaninger, and Ubaldo Bilello, *Organizational Transformation and Learning*, John Wiley & Sons, Cichester, 1996.
[6] Stan Franklin and Art Graesser, 'Is it an agent, or just a program?: A taxonomy for autonomous agents', in *Proceedings of Third International Workshop on Agent Theories, Architectures, and Languages*. Springer, (1996).
[7] Les Gasser, 'An Overview of DAI', in *Distributed Artifical Intelligence: Theory and Praxis*, eds., N.M. Avouris and L. Gasser, chapter 1, 9–30, Kluwer Academic Publishers, (1992).
[8] A. Graber, Heinz Ulrich, D. Schweizer, and A. Zimmermann, 'A Highly Interactive Discrete Event Simulator designed for Systems in Logistics', in *European Simulation Symposium Proceedings*, ed., E. Kerckhoffs A. Verbraeck, (1993).
[9] Jens Henoch and Heinz Ulrich, 'HIDES: Towards an Agent-Based Simulator', in *Proceedings of Workshop 2000 on Agent-Based Simulation*, ed., Christoph Urban. SCS European Publishing House, (May 2000).
[10] *Shop Floor Control - A Systems Perspective: From Deterministic Models towards Agile Operations Management*, ed., Eric Scherrer, Springer, 1998.
[11] Paul Schönsleben, *Integral Logistics Management - Planning and Control of Comprehensive Business Processes*, CRC/ St. Lucie Press, Boca Raton, FL, USA, 2000.
[12] Markus Schwaninger, *Management-Systeme*, Campus, 1994.
[13] Hendrik Van Brussel, Jo Wyns, Paul Valckenaers, Luc Bongarts, and Patrick Peeters, 'Reference architecture for holonic manufacturing systems: PROSA', *Computers In Industry, Special Issue on Intelligent Manufacturing Systems*, **37**(3), 225–276, (1998).
[14] H.P. Wiendahl, *Betriebsorganisation für Ingenieure*, Hanser, München, Wien, 4 edn., 1997.