A Simulation Platform for Multiagent Systems in Logistics

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Summary: The challenges in today's global economy are flexibility and fast reactions to customer requests. To cope with these requirements there is a need for intelligent adaptive planning and control systems. The multiagent approach offers favorable prospects for adequate solutions. A simulation platform for the development of multiagent systems in logistics is presented. Logistics is viewed as socio-technical which enables to take into account human resources within the design process explicitly according their importance. This simulation platform is based on the discrete-event simulation environment HIDES developed at our institute. The modeling bases of the simulation is a reference model of logistics comprising few specific basic elements to be used according to a well-defined syntactical structure. To realize multiagent systems a particular management level is added, where the agents and the interfaces to human resources are located. The platform is intended to provide a substantial support for developing multiagent systems.

Keywords: Production Management Systems, Multiagent Systems, Simulation

1. Introduction

The rapid development of economy and technology of the recent years influenced logistics management fundamentally. On the one hand problem dimension and complexity increased on the other hand the potential for problem solving increased as well if we consider the progress in Information technology as to its performance in data-processing and communication.

In economy the changes are caused by a growing globalization of the markets and an increasing extension of the business network which created new challenges for logistics management. At the same time information technology, partly a catalyst in economic development, provided new facilities for communication and data processing which open new perspectives for an efficient decision support in logistics management. The mentioning of Internet and the impressive performance of Deep Blue in competition with the world champion in Chess may suffice to illustrate the inherent potential.

2. New Characterization of Logistics Problems

Dealing with logistics problems, it is fairly obvious, that in a certain level of abstraction we basically are always meeting similar problems, be it transportation, production or inventory systems. Under the new circumstances the general abstraction of logistics problems could be characterized as follows: We distinguish between the system and its environment. The environment defines targets for the output of the system consisting in quantitative demand and delivery performance required. The system itself can be characterized as distributed system which means, system elements (e.g. resources, facilities) are locally distributed over a large area. But the distribution not only concerns resources and facilities, management and information processing is also distributed within the system. Dynamics within the system is expressed by processes designed to accomplish the given tasks. They interact and share the same scarce resources. Logistics management consist in directing the system's processes in a coordinated way to fulfill the given targets in the best possible way. The system is to view as socio-technical system, besides automated data processing human resources are involved directly in the decision process.

3. Today's Requirements

The tasks within Logistics Management are focused on planning and control, today's requirements may be summarized as follows.
An efficient use of scarce resources alone doesn't suffice any longer, dynamic aspects are the longer the more decisive. High flexibility and fast reactions to internal and external changes are important qualities. As to the design of computer supported planning and control systems, *adaptability* is required which means, planning and control directives have to be permanently updated to guarantee a remaining on track with the development of the system's environment. This concerns not only the system state, but also the knowledge about the future, expressed in forecasts. The quality of the computer support in the decision process should be *intelligent.* Considering today's potential in information technology, a support should provide more than data administration, an active direction towards goal fulfilling solutions is expected which implies a certain degree of intelligence. Not only the environment is changing fast, the system itself is subject of changes. A system design is therefore never finished, future changes and extensions have to be easy to implement, the system has to be *extendible.*

4. Multiagent Systems

Planning and control systems meeting today's requirements have to be conceived therefore as intelligent distributed systems. The artificial intelligence community proposes agent based concepts which seem to be promising in our context. Agents are software artifacts which are able to act. autonomously without assistance of the user. They react to system states and pursue defined goals. In a distributed environment a community of agents are introduced, the system is then called multiagent system.

4.1 The Agent Concept

For our purposes we use the term agent in its the weak notion according to M. Wooldrige and N.R. Jennings [1]:
Definition:
An agent is an entity in a software-based computer system with the following properties:

- *autonomy:* agents operate without the direct intervention of humans or others, and have some kind of control over their actions and internal state;

- *social ability:* agents interact with other agents (and possibly humans) via some kind of agent-communication language;

- *reactivity:* agents perceive their environment (which may be the physical world or the model),and respond in a timely fashion to changes that occur in it;

- *pro-activness:* agents do not simply act in response to their environment, they are able to exhibit goal-directed behavior by taking the initiative.

These agents need a quality we usually call intelligence. The exact definition of intelligence is still controversial, the following limited definition seem to be useful in our context:
We distinguish between the following two degrees of intelligence:
Reactive intelligence bases on knowledge which is represented in rules or in decision trees. The solution process provides an adequate reaction to the actual situation and consists of a search procedure on the individual knowledge base. Reactive Intelligence comprises all the well known-conventional automation where an apparatus reacts to input signals according to well-defined rules The possible outcome is selected among a number of predefined actions. (e.g. finite state automata)
Cognitive intelligence includes reactive intelligence but in addition more demanding problem solving procedures are at hand A base of methods offers a selection of methods ready for use. These methods can be applied in a problem solving procedure where solutions are generated in view of explicit goals, valued according to relevant criteria to choose finally the best one for realization.
Corresponding to the above definition of intelligence we define agents with different levels of intelligence:
The reactive agent
Reactive agents are provided with an intelligence of reactive quality, that is they act using a stimulus/response type of behavior and are able to respond to the present state of the environment in which they are embedded. They do not have a representation of their environment in their knowledge base.
The cognitive agent
Cognitive agents are provided with an intelligence of cognitive quality, that is they are driven by intentions, i.e. by explicit goals that conduct their behavior and make them able to choose between possible actions. They have a symbolic and explicit representation of their environment in their knowledge base on which they can reason and from which they can predict future events.

4.2 Internal Structure of an Agent

In agent's design we propose a general internal structure for each agent containing the following elements:
Characterization:
The characterization comprises individual name and localization within the system
Intelligence degree:
The competence of an agent as to its intelligence is indicated by his association to one of the two agent types (cognitive or reactive)
Position:
Each agent has a well-defined position in the management hierarchy level within the agent community and the communication links with other agents are determined
Information base:
An agent has a individual information base which can be extended by the defined communication

links. The information base contains knowledge, methods and information about the system state within the running process.

Task: Each agent has well-defined responsibilities and herewith related specific tasks he has to complete alone or in cooperation with other agents.

Goals: Related to his responsibilities an agent has his given goals he is able to adapt to operational goals for his specifique tasks. The coordination of the individual goals of the agents is performed within the management process and is a crucial problem of its design.

Capabilities

For problem solving each agent has his individual problem solving engine designed to solve his individual tasks. His capabilities are in correspondence with his available degree of intelligence. In case of a cooperative problem solving each agent may use his engine in a problem solving cycle several times, until the common solution promises satisfactory results.

4.3 Problem Solving Engine

Each agent is able to solve problems independently. The proceeding for their problem solving is called engine. A problem solving engine is designed according to a general problem solving proceeding in management science e.g. Systems Engineering [2]. The following cycle for problem solving is proposed:

1. Problem definition:	Analysis of the present state in search for problems which need to be solved.
2. Search for goals:	Among the given goal or goal hierarchy choosing the most adequate operational goal to be addressed in the above identified problem.
3. Search for solutions:	Based on the available potential on knowledge and methods possible solutions are generated.
4. Final decision:	The generated solutions are valued according to criteria corresponding the operational goal determined in step 1.

In case of the lower intelligence level of the reactive type, the last two steps are reduced to one single step, a simple search procedure.

4.4 Agent Types

In our view logistics systems are sociotechnical systems. Especially in logistics management human resources are involved in various functions and responsibilities within the decision process, this interference has to be taken into account in the modeling environment. We therefore conceived the following two types of agents:

The control agents have to accomplish management tasks corresponding to those in a human environment. Therefore, capacities for problem solving are required which include in their turn a certain degree of intelligence. These agents dispose of general procedures for problem solving, the so-called

'engines', which have to be specified individually for each application case.
The interface agents establish the necessary interface for the interaction with human resources. They are built up according to a general scheme as the control agents with individual specification according to their specific task. They don't have any direct control duties, these functions are delegated to the control agents, therefore they lack the ability for problem solving. Their duty consists in establishing the necessary communication links and in procuring the required information concerning the actual state of the system. By means of these interface agents a human operator or manager is able to interact within the running process, she/he can stop the simulation run, insert her/his instructions and continue the run afterwards.

4.5 Agent Communities

In a multiagent system several agents form a community which has to be organized. We suggest a structure following as close as possible human management organizations as guidelines with their internal communication and hierarchy. These agents have each their specific planning and control task which they fulfill together in a well defined and cooperative way.

5. Architecture of a Simulation Platform for Multiagent Systems

In logistics management system design is a process which proceeds from concept to realization in several steps including iterations if required. Before final implementation dynamic aspects of the system can only be tested in a model by simulation in an experimental environment. The final validation of a concept for practice will be given by its success in application.
Simulation is therefore an important method applicable in various contexts [3]. The development of simulation models is a very time-consuming job, especially the necessary frequent adaptation of the models within a dynamic development process demands a well-designed flexible model base to perform this task efficiently. That is the reason why we try to define an architecture for a simulation platform which is able to support the design process for multiagent systems in logistics substantially.

5.1 Reference Model

The architecture of a simulation platform in a specific application field should be based an a meta model of this environment, so called "reference models" as Schmidt [4] proposes. As reference model for logistics systems we propose the following abstraction:
We define three levels a physical, a logical and a management level. This distinction allows a separation of the physical part of the system from its planning and control part. As we focus in logistics management on planning and control, the physical level often remains unchanged whereas model modifications are necessary only on the other levels. By this separation, the model design process is much more transparent herewith. On the physical level the static structure of the system and the dynamic sequence of the physical events are represented. The relationships are viewed as a directed graph with two types of nodes, stations and queues. Other important model elements are resources introduced as abstract elements. They can be allocated dynamically and dispose of information about their availability and their behavior. Dynamic elements, moving in the graph, are

introduced as entities, which are characterized and identified individually. In the real world, logistics systems are in general very large and very complex. To perform the modeling task efficiently, a top-down approach is indicated with a stepwise increase in the degree of detail. As a consequence, we get a model in different hierarchical abstraction levels. To support such a proceeding in modeling, the building of subnets is provided.. In a network containing various subnets on different hierarchical levels a strictly logically consistent hierarchical structure is enforced. A subnet is always incorporated in a station in which the subnet substitutes the logic element of the logical level.

The logical level comprises the definition of the processes to be executed on the physical level, the necessary information flow to fulfill this purpose and their logical control. The nodes on this level are logic elements each in charge with the triggering of one specific station. They control the flow process in a decentralized way herewith. The entities arriving at the associated station are handled by the logic element according to a general default proceeding or an individually defined protocol containing activities as to generate, duplicate, split, modify and remove the arriving entities. In addition any algorithmically definable control logic can be implemented. The information is stored partly globally, partly locally in stations and entities. Whereas the global information is globally available, the locally stored information is only available in the local environment. An extension of a local information base is possible by defining explicitly Information flow channels to supplementary information sources.. The local information basis for a logic element can be extended herewith.

The management level is an extension of the logical level and is used to introduce our agent community. For a planning and control process needing more then only static decision rules a multiagent approach is indicated. The agents have to perform the automated part of the management tasks. This extended level provides the basis for developing the coordination process among the agents, which formally regulates competence and responsibility of the individual agents. Agents may interfere on the logical level in the triggering process of a station or directly to the information base of moving entities or resources.

To enable the interaction of human resources into the management process as it will happen in reality we introduced a special type of agents providing the required interface functions, the interface agents. Our multiagent system disposes therefore of two types of agents. The control agents destined for executing the automated control tasks and the interface agents for establishing the necessary interface for the interaction with human resources. Herewith a large field for interesting studies is opened concerning the investigation of the distribution of tasks in logistics management between technical system and human resources.

A graphical representation of reference model for a multiagent system in logistics is shown in figure 1.

5.2 System Control

Discrete event simulation is the most appropriate method for representing a decision oriented dynamic process as we have to deal with in logistics management. Process control is performed by an event list containing events and their due date. The events are sorted after their due dates and executed in the determined time sequence. In a multiagent system this simple procedure is not sufficient. Events

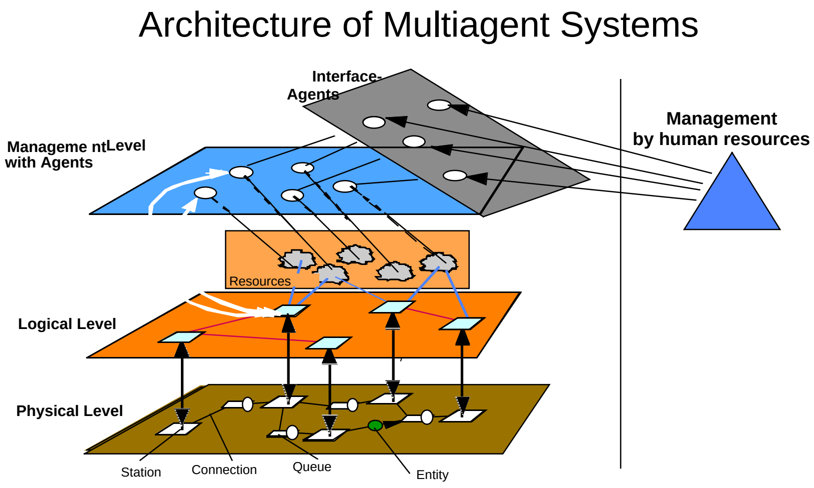

Figure 1: Architecture of multiagent systems

are not only generated as a consequence of other events, agents with there proactive behavior are independent actors in the system generating additional events. System control in a multiagent system is therefore a more demanding task which has to include the synchronization of agent's activities as to simultaneousness and clearing up of contradictions in actions..
We suggest the following approach for system control in a multiagent system which corresponds essentially to an approach Eschenbacher [5]proposes for dealing with simultaneous events in a conventional event list:
As in discrete-event simulation we have a sequential processing of the event list. Each agent enters his next proactive action in the event list. The event list is processed as follows:

- Consolidation of the present system state (updating).
- Cyclic call to all the agents for reaction and release of the responding actions.
- Clearing up of conflicts resulting out of the initiated actions beforehand.
- Consolidation of the new system state (unique definition of the result).
- Proceeding to the next time in the event list and repeating again the same procedure

5.3 The Simulation Platform HIDES

At our institute the simulation platform HIDES (Highly Interactive Discrete Event Simulator, cf. Graber et al. 1993, [6], Ulrich et al. 1994, [7]) was developed for the simulation of logistic systems. HIDES is a general purpose simulation framework which is designed for event-oriented simulation, and implemented in an object-oriented environment. It is based on the above described reference model but comprises until now only the first two levels, the physical and the logical one.

As we have the source code of the simulation platform available for our purposes we intend to realize the above described extension of our simulation platform in a stepwise procedure. For specific applications we add the supplementary management level closely connected to the practical projects. After several specific realizations we will try to identify the best suitable general structure for the management level, in particular we will try to provide a general shell structure for agents in order to facilitate substantially the design process of new systems.

6. Conclusions

To cope with today's requirements in economy and industry an efficient management of logistics on all levels is essential. The use of simulation in the development process for an adequate decision support in logistics management allows to test various solution approaches before their realization. The better a simulation platform corresponds to their application environment the easier the development process will be. As the multiagent approach promises to be successful in logistics management, we propose an architecture for a simulation platform which includes a management level for introducing agents. The design of agents is intended to be supported by a general shell of an agent which has to be completed individually according to their specific purpose and duties. As the multiagent approach up to now is only realized in very simple examples on relatively low levels of intelligence, the benefit of this architecture will be increasing in future with the increasing potential and quality of multiagent solutions.

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