Adaptive Control of Supply Chains: Building blocks and tools of an agent-based simulation framework

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Abstract
An adaptive control concept for supply chains is presented. Its background is a complex supply chain scenario originating from the machine building domain with a focus primarily on the development of an agent-based method concerning the adaptive coordination of customer orders along the supply chain. It aims at flexibly handling disturbances in relation to the re-allocation of alternative suppliers to ensure a timely and accurate fulfilment of customer orders. The researched and described building blocks and tools originate from artificial intelligence, decision theory and operations management, which have been implemented in an agent-based simulation framework.

Keywords:
Adaptive control, Agent, Coordination

1 INTRODUCTION

Companies are forced by competition to develop new optimization potentials. After nearly all internal possibilities of companies to improve have been exhausted, the off-site concepts to generate competitive advantages seem to be very promising. In view of this situation, the supply chain management concept appears to be an appropriate solution. Therefore, the main goal is to organise the overall process of the supply chain, especially the top-level order processes, to achieve an optimum in cost and time. This can be achieved, for example, by improving key figures, such as increasing capacity utilization, decreasing inventories, decreasing lead times and so on. The supply chain represents a very dynamic and complex multi-level system with multiple input and output relations [1]. In this kind of tight networked system, stability frequently rises to a certain degree, before it declines again due to the greater complexity. In this context, supply chain management can be regarded as a management or control concept for complex, dynamic systems, which imperatively needs to be reflected in the development of modern planning and control concepts [1, 2]. Today's conventional control of a supply chain mainly pursuits sequential, top-down planning approaches supported by different MRP (Material Requirements Planning) or ERP (Enterprise Resource Planning) concepts and information technologies. They coordinate the supply flows between the different companies, which very often cause time lags [3]. Sudden disturbances in the supply chain basically ripple all the way through and can easily make the complex and inherently distributed planning processes invalid. Expensive re-planning sessions about the quantity delivered, the delivery times and search for new suppliers are the most likely consequences. Taking these aspects into account, a concise supply chain management concept for tomorrows near future must clearly address the following, very challenging key issues:

- Acceleration and especially direct transmission of information flows related to customer orders starting at the point of sale
- A deeper understanding of the relation between the product structure and the structure (customer order oriented) configuration of the supply chain respectively
- More efficient methods to support a coordinated, decentralised and pull-oriented scheduling
- Enriched and extended decision [4] and planning methods for an efficient and effective handling of disturbances along the supply chain
- Intelligent support concerning the re-allocation of alternative suppliers [5] on all levels of the supply chain in order to be able to fulfil the customer orders at any time

The following sections present some of the most promising basic building blocks for an adaptive supply chain management against the background of a conducted research project and on the basis of an underlying industrial scenario from the machine building industry.

2 THE RESEARCH APPROACH

The research project **agent-based reactive control of supply chains** basically followed a hierarchical four layer model (Figure 1) as a fundamental research approach. The aim was to develop an agent-based supply chain control module by deploying on the one hand a commercial simulation framework (layer 1 and 2) in order to model, simulate and analyse the supply chain of a realistic industrial scenario, and on the other hand to develop a specific multi-agent system according to the planning and control tasks along the supply chain, especially in relation to troubleshooting and re-allocation of suppliers concerning order processing issues (layer 4). These four layers did not directly match the carried out work packages, for example in the sense of a sequential work plan, but they describe the overall concept of the research project and its results. First of all it was an important issue to research a realistic industrial scenario, to be able to describe and model all the different aspects and properties, like business units, products, production facilities and boundary conditions (e.g. goals, key figures, delivery policies) as well as the suppliers, on the sub-model layer (layer 1). In this context the aim was to not simplify the supply chain model too much. The simulation model of the supply chain was finalized on the model layer (layer 2) to be able to run this model first of all as a stand-alone version, depending on the basic functionalities of the deployed simulation framework and the options to enhance these functionalities. Furthermore, an important issue and some work packages were related to the connection via a communication layer (layer 3) between the model of the supply chain inside the simulation framework on the one hand, as well as the agent-platform containing the developed multi-agent system, on the other hand. The connection was established via TCP/IP-interfaces on both sides.

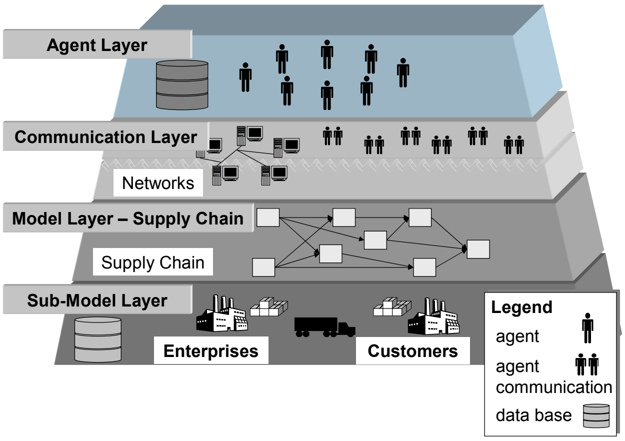

Figure 1: A hierarchical 4-layer-model as research approach.

On the top level agent layer (layer 4), the specified and modelled multi-agent systems were implemented, with the JIAC IV (Java Intelligent Agent Component Ware) [6] agent-platform.

3 THE UNDERLYING INDUSTRIAL SCENARIO

The presented project deployed an industrial scenario originating from the machine building industry. It was acquired during an industrial research project, which was carried out partly simultaneous to the introduced research project. The scenario is related to the European market and business area of a global operating group producing industrial pump sets, for example, for the chemical and food industries. These pump sets are mainly integrated into large scale continuous production processes for the purpose of conveying a broad range of liquids. Figure 2 shows the main in-house (pump type A, B) and outbound parts, especially related to the 1st-tier suppliers. In the viewed context a pump set comprises a type of pump (A or B), an electric motor, a baseplate, a coupling or clutch between pump and motor, a device cover plate to cover the coupling or clutch and finally some integrated ball bearings. The overall supply chain scenario consists of the two business units on the OEM-level (original equipment manufacturer) and encompasses eleven suppliers on the 1st-tier level (3 motor, 4 baseplate, 1 device cover plate, 1 ball bearings, 2 different suppliers of couplings/clutches) as well as twenty suppliers on the 2nd-tier level. As a result, the supply chain scenario includes twelve possible, alternative pump set configurations for each pump type depending on the customer orders. The pump sets are made to order at two different business units (type A in Germany, type B in France). This includes on the one hand the design and made to order production of the pump itself and the final assembly of the pump set according to the customer order. Electric motors are purchased from a 1st-tier supplier according to customer order, as well as the baseplate, friction coupling or magnetic clutch and so on. The suppliers on 2nd-tier level are directly related to the 1st-tier suppliers, which means, for example, that a German electric motor always comes with a German metal housing, German ball bearings and a German fan stage as its outbound components, without substitutes. These relations are very important and have to be considered very carefully in order to model them as boundary conditions or constraints. These relations will subsequently have enormous effects on the ability to trouble shoot along the supply chain in relation with the re-allocation of suitable suppliers, in order to still fulfil the customer order or at least to offer acceptable alternative pump sets to the customer.

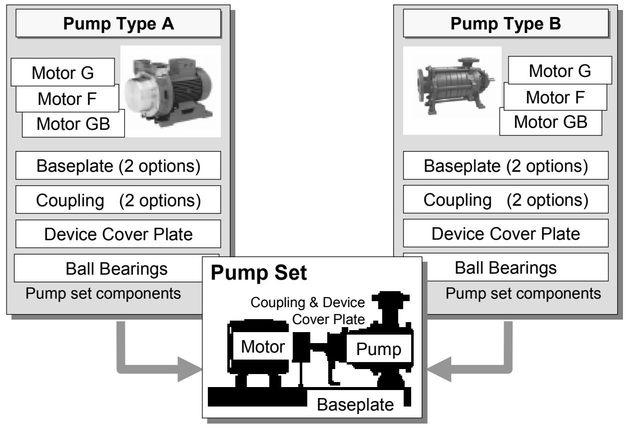

Figure 2: The viewed products and their components.

The available and deployed data are related to type and amount of customer orders including customer preferences, production, assembly and transportation times related to the business units and freight forwarders, average inventory level and initial inventory level, available capacities and prices. The prices have been reasonably changed in the considered scenario.

4 BUILDING BLOCKS OF THE RESEARCH PROJECT

4.1 Supply chain management and production planning and control

The SCOR (supply chain operations reference) model as well as the Aachener Production Planning and Control model were central theories and thus used as starting basis. The SCOR model appeared to be very useful in achieving a common understanding of the application domain supply chain management from the software agent point of view. It pursues a four layer modelling approach of some of the most important core business processes (e.g. plan, source) and their underlying process types (e.g. planning, executing, enable), but turned out to be a more or less unfinished, empty framework, which is still lacking a lot of the needed modelling details (e.g. specific planning tasks) in order to identify the starting points for the software agents. Nevertheless it appeared to be very useful for the conceptional, frame base modelling (e.g. Protégé-2000) [7] of the knowledge base (e.g. concepts like products or business units) for the deployed software agents [7]. Further research was on how a set of suitable software agents could be aligned to the underlying process types (e.g. mediator agent → execution) [8]. The Aachen Production Planning and Control model [9] offered a very structured and detailed approach to the important planning and control aspects from various perspectives (e.g. processes, data, objects). The most important aspects in the project were related to order processing, which appear to be one of the most important aspects of the Aachen Production Planning and Control model as well. Concerning the project, the best analogies were found in relation to the (global) coordination of orders along the supply chain. This process has been identified as a weak point not only in distributed supply chains, but also locally in an enterprise. The coordination of orders comprises all activities (e.g. quotation processing, clarification, rough-cut scheduling) to adjust and synchronise the distributed sub-processes in order to fulfil customer orders. The research project focussed on a more adaptive approach concerning the coordination of customer orders along the supply chain by developing and deploying agent technology.