Available online at www.sciencedirect.com
SCIENCE DIRECT®
PERGAMON
Engineering Applications of Artificial Intelligence 16 (2003) 335–348
Engineering Applications of
ARTIFICIAL
INTELLIGENCE
www.elsevier.com/locate/engappai

Agent-based optimisation of logistics and production planning

Anthony Karageorgos[a,*], Nikolay Mehandjiev[a], Georg Weichhart[b], Alexander Hämmerle[b]

[a] Department of Computation, UMIST PO Box 88, Manchester M60 1QD, UK
[b] PROFACTOR Produktionsforschungs GmbH, Wehrgrabengasse 1-5, A-4400 Steyr, Austria

Abstract

Manufacturing and logistics service provision enterprises are currently moving towards open virtual enterprise collaboration networks to meet the needs of the Global Economy. In such networks, manufacturing and logistics planning and scheduling is challenging due to the difficulties in integrating information from different partners and in exploring a large and dynamically changing number of planning and scheduling alternatives. Agent-based technology is considered suitable to support planning and scheduling in such enterprises because agents can dynamically adapt their behaviour to changing requirements and they can reduce the number of planning and scheduling alternatives via negotiation.

This paper presents an agent-based approach for supporting logistics and production planning, taking into account not only production schedules but also availability and cost of logistic service providers. This is achieved through efficient negotiation mechanisms based on an extended contracting protocol. The agent infrastructure is being developed within the context of Agentcities, a successful EU-funded initiative to build a world-wide distributed and open platform which provides agent-based services.

The proposed approach is illustrated in a case study concerning optimisation of production planning of a virtual manufacturing enterprise in relation to sub-contracted logistic services used to transport materials between the enterprise units.

Keywords: Agents; Agent-based systems; Enterprise integration; Manufacturing systems; Interaction protocols; Holonic systems

1. Motivation

Manufacturing and logistic service provision enterprises are trying to organise and optimise the efficiency of their cooperation, using software that supports negotiations at different levels of automation. E-marketplaces are examples of such software. In contrast to these centrally organised software solutions, systems using the agent paradigm are built to reflect the distributed and autonomous nature of virtual enterprises and thus provide a natural way to design and implement such environments. When, for example, a non-trivial reasoning and negotiation has to be performed in order to optimise the execution of the system, agent capabilities can be used to illustrate advantages as compared to a solution based on centralised optimisation techniques and conventional inter-enterprise business process infrastructures.

Calculating the optimum of a scheduling problem is a non-trivial task. For example, scheduling of product-orders on a number of machines is a non-deterministic polynomial (NP) hard problem (Bongaerts, 1998; Jain and Meeran, 1998). It is not possible for such problems to calculate the best solution in a straightforward manner. Therefore all possible solutions have to be calculated, to be able to then choose the best solution. But with this set of problems, the number of solutions literally explodes when increasing the values of input variables (numbers of machines and product-orders in this case). The following "mathematically" simple example shall illustrate the statements above (Jain and Meeran, 1998).

Given a finite set O of n (product-)orders $\{O_i\}_{i=1}^{n}$ to be processed on a finite set $\grave{I}$ of m machines $\{M_k\}_{k=1}^{m}$ and assuming that each order $O_i \in O$ has one operation on each machine m, a machine can work on one order at a time (machine capacity = 1). We further assume that one order can be processed on one machine at a time, and a

*Corresponding author. Tel.: +44-161-200-3306; fax: +44-161-200-3324.
E-mail addresses: karageorgos@acm.org (A. Karageorgos), mehandjiev@acm.org (N. Mehandjiev), georg.weichhart@profactor.at (G. Weichhart), alexander.haemmerle@profactor.at (A. Hämmerle).

0952-1976/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/S0952-1976(03)00076-9

started operation cannot be interrupted. Given this set of assumptions there are $(n!)^m$ possible solutions for the allocation of orders to machines (Jain and Meeran, 1998). Fig. 1 illustrates this combinatorial explosion by displaying the logarithm of the number of possible (but not necessarily feasible) solutions $(\log_{10}((n!)^m))$ for different numbers of orders and machines. This indicates that even for small problems the number of solutions is greater than 10^{100} (the enormous size can be realised better if compared to 8.64×10^{10} ms = 24 h).

Given the combinatorial explosion of "brute force" optimal scheduling, a number of approaches have been developed to prune down the search tree. We can divide those into centralised scheduling approaches, such as SYSPRO (2020 Software 2003), and decentralised agent-based solutions as proposed in this paper. Centralised approaches have many advantages but suffer from a number of serious weaknesses which make them unsuitable for virtual enterprises. One of these weaknesses is the "closed system" assumptions inherent in the software, which does not allow for dynamic change of enterprise configuration and provide poor interoperability mechanisms. The second weakness is the centralised mode of planning and scheduling, which does not favour localised re-planning and use of negotiation to prune down the search tree.

In this paper, an alternative agent-based approach to planning and scheduling of manufacturing and logistics services in virtual enterprises is proposed. Agents can use negotiation to reduce the search tree and agree on viable optimised schedules. Within the holonic modelling paradigm, local optimal solutions can be found at lower levels of the holonic organisation, and combined at the higher level into aggregated solutions using negotiation.

The holonic paradigm is an emerging approach for modelling of manufacturing enterprises (Vancza and Markus, 1998; Leitão and Restivo, 2002). The idea of holonic business is based on the collaboration of

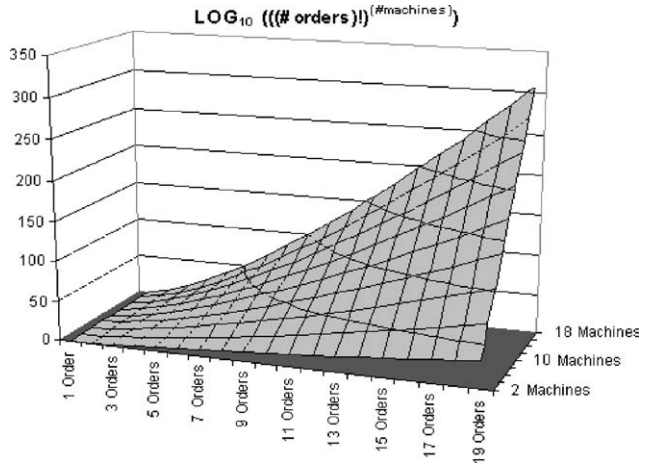

Fig. 1. Solution space of a simple scheduling problem.

autonomous and cooperative business units (*holons*). A holon is composed of sub-holons acting as a whole. A (dynamic) business network can be seen as a temporarily existing holon where the sub-holons are the necessary service providers (business partners) within the network. The holonic relationships can be extended to many levels inside an enterprise, creating organisational structures known as *holarchies* (Koestler, 1976, p. 12). In contrast to hierarchies, the decision power in holarchies lies on the lower organisational levels. The holonic view captures the dynamism of virtual enterprises since holons can be created dynamically according to the requirements as is the case in open business environments (Ulieru et al., 2001). Due to their flexibility and adaptivity, software agents are particularly suitable to support holonic business organisations (Ulieru et al., 2001; Leitão and Restivo, 2002). The terms holonic agent and holonic agent system are used to refer to agents and agent systems organised according to the holonic metaphor.

Providing an agent-based infrastructure where holonic agents will be able to interoperate is currently an open issue (Gou et al., 1998). Major obstacles towards this goal are the lack of standardised technologies that would enable (possibly heterogeneous) agents corresponding to different enterprises advertise their services, locate each other and interact in a dynamic manner using commonly shared domain knowledge.

A successful agent-based systems interoperation initiative is *Agentcities* (Willmott et al., 2001). The Agentcities initiative works towards the vision of an ambient proactive environment where heterogeneous, autonomous and increasingly intelligent systems, which represent businesses, services and individuals, are able to interact with each other and enable flexible and dynamic composition of services. In the first year of its operation, the Agentcities initiative has resulted in an experimental open infrastructure providing "white" and "yellow pages" information concerning available agent platform locations and agent service types.

The project described in this paper is based on the holonic agent framework as a modelling and design paradigm. The holonic design is implemented using open agent technologies compatible with the Agentcities platform. The main goal is to build such a system which can deliver co-optimisation of production and logistics planning within a virtual enterprise. The approach proposed in this paper is based on dynamic interaction of holonic business agents, including an appropriate ontology and an extension of the standard *Contract Net Protocol (CNP)*.

The objectives of the project are to develop an agent-based planning and scheduling approach, a demonstrator to show the feasibility of this approach, and to evaluate the proposed approach using a number of scenarios drawn from a case study. The case study used