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Application of the multi-agent approach in production planning and modelling

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Abstract

The paper describes an experimental multi-agent system developed for and aimed at a computer-supported project-oriented production planning. The system is based on a heterogeneous hierarchy of agents of three types that reflect the managerial structure of the manufacturing enterprise. To improve the system efficiency, a new formalism—called tri-base model—of the multi-agent internal communication/negotiation mechanism has been introduced. The tri-base model that has been tested in an industrial environment is treated in detail in the paper. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The research described here has been focused mainly at *project-oriented production*. Such type of manufacturing is characterised by the majority of labour and costs spent on project-related activities, as product quotation, project configuration and design. Whilst in *manufacturing-oriented production* there are thousands of items being produced once the product has been designed, in *project-oriented production* just a single or very limited number of pieces of one designed product get produced. As each product is unique and the factory administers a number of parallel projects, a certain type of computer assisted production planning and simulation needs to be employed in order to optimise the manufacturing processes.

Tesla TV Comp., Prague, Czech Republic, has been considered as a typical instance of an enterprise the manufacturing activity of which may be classified as project-oriented production. This company manufactures TV and FM transmitters and passive transmitter elements. There is no production line and it is difficult to formalise the production as a traditional continuous process. The production is aimed at customer specific and mutually nearly independent projects of composing unique final products according to a manufacturing documentation designed for the particular business case. The production plan and factory activity schedule must be modified to reflect the large variety and complexity of the particular job order. Consequently, instead of planning and simulation of a flow of semi-products to be assembled, the project-oriented production needs a rather sophisticated information support, which could facilitate simple planning and subsequent optimisation of manufacturing of the unique final products.

Currently, ill suited information flows, lack of communication among particular production units and low utilisation of available information processing solutions is generally what makes the production difficult to understand, model, plan and consequently optimise. Attempts to create global "monolithic" software solutions, no matter how well hierarchically structured, meet usually dead ends. Regardless whether re-use and integration of existing pieces of software is expected or a brand new system is being implemented, there is a strong need for a novel solution in the form of a highly distributed and heterogeneous system. This opinion is advocated by the fact that production is flexible, and frequent changes of production targets, manufacturing facilities, system knowledge and planning strategies are inevitable. Maintenance and updating of single and independent modules is highly desired.

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The process of production planning and simulation in project-oriented production is driven by

- highly specific knowledge of a project-planning engineer who is in charge of the project design and supervision, and
- potential availability of various departments, units, and machines within the enterprise.

The multi-agent systems represent a new and promising solution to problems as complex as those outlined above. We suggest replacing the centralised process of production planning with the process of negotiation among the autonomous cooperating agents. The organisational structure of the respective multi-agent system shall mirror the organisational structure of the production we want to plan. We go further with suggesting an alternative process of negotiation based on agent social models maintenance that minimises inter-agent message exchange.

2. ProPlanT—production planning multi-agent system

Multi-agent systems provide a novel approach to address complex problems, such as project-oriented production, where decisions should be based on processing of information from various sources of diverse nature (Wooldridge and Jennings, 1995). Each of these sources can be viewed as an agent and the whole system as a community of agents—a multi-agent system. Multi-agent systems consist of a set of non-centralised, mutually co-operating elements—agents, each of which acts autonomously. Agents exchange information and knowledge in order to achieve the desired kind of collaboration.

To test the ideas presented here a prototype of a multi-agent system for production planning (ProPlanT) has been implemented (Mařík et al., 1998). The system is composed of a family of agents that are designed to simulate the entire production planning process of TV transmitters manufactured by Tesla TV. The system maintains timetables of departments' activities, statistics on their loads and databases on various shared and individual department responsibilities. It is supposed to reason on possible deadlines of the given project, to simulate the production and to do continuous re-planning activities with respect to dynamically changing conditions and requirements. The system operates in two main functional modes—*planning* and *simulation*. The former prepares possible variants of production and keeps them up-to-date, while the latter finds the best plan among the prepared ones and fixes it. Careful analysis of manufacturing processes in the Tesla TV led to the conclusion that it is necessary to organise the information processing units (=agents) into a structure analogous to administrative organisation of the modelled enterprise. That is why three distinct classes of agents within the ProPlanT system have been introduced. ProPlanT uses the following types of agents:

- PPA—*project planning agent*. Each agent of this type is in charge of the global project planning. It is supposed to construct an exhaustive, partially ordered set of tasks that need to be carried out in order to accomplish the given project (business case). The basic possible interpretation is to have as many PPA agents as is the number of projects running in parallel. Each PPA agent contracts appropriate PMA agents with the aim to manage the job.
- PMA—*project management agent*. PMA agents are responsible for the project management in terms of distributing the work to the best possible executive PA agents (considering operational cost, current manufacturing capacity, available resources, etc.). To fulfil this task, PMA asks for help either PA agents or again PMA. In this way, a multi-level company management structure can be modelled.
- PA—*production agent*. The lowest level agents simulate the manufacturing processes at the shop floor level. They carry out the scheduling of the given tasks thus emulating the behaviour of the workshop supervisors. The agent either reasons about the schedule when in *planning mode* or it updates its internal agendas during the *simulation mode*.

Let's mention that the system typically maintains possible plans for an arbitrary number of projects in parallel. There is no central fixed planning unit and the system's planning agendas are distributed within the community.

3. Communication strategies in multi-agent systems

There is a wide range of possible multi-agent systems' architectures. The mass of identical, conform agents and a highly granular community of deeply specialised agents are the extreme cases in this spectrum. In the case of a large community of identical agents (*collective architecture*) the "social" and "sociological" aspects of behaviour play a dominant role, while in the latter case the community is expected to be strongly internally organised and co-ordinated. The latter architectures (*integration architectures*) are expected to be suitable for (legacy) system integration purposes, for designing and implementing highly distributed modelling, decision making and control algorithms.

The integration architectures usually involve a relatively small number of well-developed agents with clearly defined and highly specialised functionalities. Each agent, in our understanding, consists of a *functional body* (usually a stand-alone, already well

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