PERGAMON

Computers & Industrial Engineering 43 (2002) 529–552

computers & industrial engineering

www.elsevier.com/locate/dsw

Evaluation of agent-based manufacturing systems based on a parallel simulator

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Abstract

Recent research in artificial autonomous agents has paved a way to fulfill the requirements of autonomous operations in manufacturing systems in terms of planning, scheduling, control, and processing. Those manufacturing systems are also coined agent-based manufacturing systems (ABMS). However, it still lacks an evaluation tool to judge the performance of a designed ABMS. Hence, an ABMS is difficult to be accepted by users and managers, and is difficult to be realized in the real world.

Based on a developed ABMS model, this research develops a simulator on a parallel computer system. The simulator is designed to imitate the changes of the environment by the changes of incoming tasks, and to imitate the internal changes by the resource breakdowns. Besides, the autonomous, communicative, and cooperative behaviors of agents are also developed in the simulators.

Cases and scenarios for ABMS are developed to apply in the simulator. The analytical results show that through the simulators, decision-makers can clearly observe the viability of each agent as well as the whole ABMS. Thus, adjustments on the ABMS design can be made accordingly and the final ABMS can successfully survive in the real world.

Keywords: Autonomy; Message passing interface; Task administration protocol; Teamwork integration evaluation; Viability

1. Introduction

The research work by Huang and Nof (1999, 2000) has provided an organization for the development of agent-based manufacturing systems (ABMS). Based on their research, an agent has four internal functions: *reflexivity mechanism* (RM), *goal-adjustment mechanism* (GAM), *collaboration management* (CM), and *internal resource management* (IRM) (Fig. 1). An agent collaborates with other agents to fulfill the requirements of incoming tasks. Meanwhile, the collaborative planning and execution are developed by the four functions.

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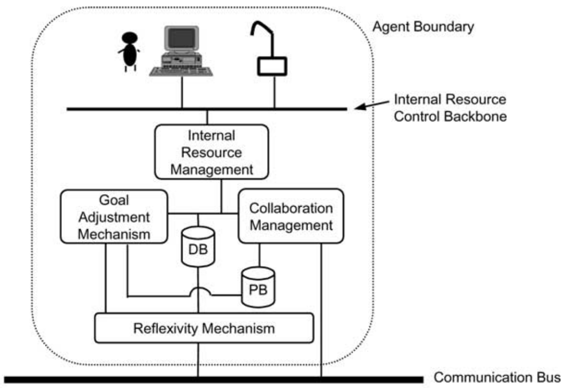
0360-8352/02/$ - see front matter
PII: S0360-8352(02)00124-9



DB: Database
PB: Protocol Base

Fig. 1. A generic model of agent: resources, four agent functions, a database, and a protocol base are within an agent model.

However, the origin of agent research largely relies on a paradigm shift-from Turing machines to interactive machines (Wegner, 1997). Hence many tools, including most analytical and simulation methods, are unable to be applied to ABMS. Especially, because of the characteristics of autonomy, the performances of an individual agent and an ABMS, which consists a group of agents, are difficult to be estimated; hence, impeding the applications of ABMS models to the real world.

In order to resolve such a problem, Teamwork Integration Evaluation/Agent (TIE/Agent) project is designated. TIE (Khanna & Nof, 1994) was a simulation project that intends to simulate the collaborative behaviors of distributed decision-makers. By advancing the similar concept of TIE to a parallel computer, TIE/Agent is developed to simulate the rational, autonomous, and collaborative behaviors of agents. Fujimoto (2000) identifies four benefits to execute a simulation across multiple computers (in parallel or distributed): (1) reducing execution time, (2) geographically distribution, (3) integrating simulators that execute on machines from different manufacturer, and (4) fault tolerance. The parallel simulator in this research however can only receive the first and second benefits, since the simulator was applied in a given environment-Paragon supercomputer. The other advantage of applying parallel simulator can be to catch the fact of message transmission delays among processors. The principal drawback of applying parallel simulator is that the synchronization among processors has to be considered, which however increases the difficulty of developing the simulator.

This article reports the design of TIE/Agent and how it can be applied to investigate the performances of an individual agent and an ABMS, so the associated design and implementation recommendations can be made. The remainder of the article is organized as follows. In Section 2, the background of ABMS and the hardware and software specifications of TIE/Agent are introduced. In Section 3, the architecture and logic of TIE/Agent is presented. The applications of TIE/Agent to the designated cases are presented and analyzed based on the theory of experimental design are given in Section 4. The extension of using TIE/Agent to outsourcing policy in supply chain management is also illustrated. Finally, the discussion and concluding remarks are made in Section 5. Future research directions are also recommended there.

2. Research background

2.1. Agent-based manufacturing systems

2.1.1. Definition of agent

Numerous definitions have been given to characterized agent since 1994 (Franklin & Graesser, 1997; Maes, 1994; Moulin & Cloutier, 1994; Oliveira, Fischer, & Stepankova, 1999; Russell & Norvig, 1995; Wooldridge & Jennings, 1995). According to Huang and Nof (2000) summary, an agent in production planning perspective can be defined as follows:

> An agent is a computing system that can autonomously react and reflexively respond to the impacts from the environment in accordance with its given goal(s). The reactivity is performed by executing some pre-loaded programs, while the reflexivity is performed by autonomously adjusting the protective threshold(s) of an agent. An agent may seek collaboration through communicating with other agents. The communication is regulated by protocols, structures of dialogues, to enhance the effectiveness and efficiency of communication.

This research takes the above definition and the structure in Fig. 1 as a foundation to develop an ABMS simulator, TIE/Agent. Additionally, since an agent is an autonomous entity, internally it must adjust its own behaviors based on a measure or belief. For this research, the measure is viability (Huang & Nof, 1999, 2000).

2.1.2. Definition of viability

The viability of an autonomous agent is characterized by Eq. (1). s_i represents a static viability that is given when an agent is designed; it is unchangeable over time. The definition of s_i is shown in Eq. (2). On the other hand, $d_i(t)$ is a dynamic viability at time t. $d_i(t)$ changes over time in accordance with the accumulated rewards in agent i (Eq. (3)).

$$v_i = \langle s_i, d_i(t) \rangle \tag{1}$$

where v_i represents the viability of agent i.

$$s_i = \left(\tau_i / \sum_{j=1}^{N} \tau_j \right) \times \left(\sum_{j=1}^{N} w_j / w_i \right) \tag{2}$$

where s_i is the static viability of agent i; τ_i the number of resource types in agent i; w_i the minimal required cost to keep agent i active and N is the number of agents in an ABMS.

$$d_i(t) = \frac{W_i(t)/w_i}{\max_{j=1}^{N} \{W_j(t)/w_j\}} \tag{3}$$

where $d_i(t)$ is the dynamic viability of agent i at time t and $W_i(t)$ is the accumulated rewards in agent i at time t.

To lead the above definitions to the viability of ABMS, however, needs a further investigation on ABMS. Normally, in an ABMS, say G, there are two kinds of agents. One kind of them is very