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A multi-agent system for sharing distributed manufacturing resources

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ABSTRACT

This paper considers a shared scheduling environment for distributed manufacturing resources. In this paper, we proposed a multi-agent system based approach to promote competition and cooperation among multi-agents and to achieve global optimal scheduling. We first build two multi-agent system (MAS) architectures. One is enterprise multi-agent subsystem (Sub-EMAS) architecture comprises job agents, resource agents and manager agents; the other one is enterprise alliance multi-agent system (EA-MAS) architecture involves the addition of a mediator agent and a scheduling agent. Then we design a Shared Contract Net Protocol (SCNP) to support both the Sub-EMAS and EA-MAS. We propose two heuristic algorithms to solve the scheduling model. The computational experiments show that the EA-MAS, with the integration of shared resource information, is able to provide shared scheduling scheme for distributed manufacturing with a good performance.

1. Introduction

With the increasing of market demand, under the condition of limited resources, the manufacturing enterprises which are geographically distributed at different locations are difficult to supply products or services for meeting the needs of the market only relying on their own manufacturing resources. Traditional scheduling methods are assumed that a local environment where all resources are on the same site, which leads to low utilization efficiency in the rapidly changing market environment. In order to adapt the current situation, optimize the use of resources, respond to market demand rapidly, and improve the competitiveness, manufacturing enterprises have to seek to collaborate with other enterprises to achieve the sharing of manufacturing resources (Adhau, Mittal, & Mittal, 2013). The sharing of manufacturing resources refer to the different enterprises, according to their own resource capacities, use advanced Information and Communication Technologies (ICT) to share idle manufacturing resources to the resource pool, thereby meeting the demand for the use of manufacturing resources for others (Xu, Archimède, & Letouzey, 2012).

The manufacturing resources belonging to the enterprises are also scattered in different space when the enterprises are geographically dispersed, which are called distributed manufacturing resources. For the sake of completing the given task efficiently, the purpose of this paper is to propose a shared scheduling scheme for distributed manufacturing resources, and to improve collaboration among different enterprises and inner-enterprise. Manufacturing resources scheduling is to arrange the best time to operate each order or task and the best match for manufacturing resources and order, taking into account the constraints on the completion time of the task, the capacity of the resource, and the priority of the operation, minimizing manufacturing costs, maximum lateness, makespan and maximizing resource utilization (Kempenaers, Pinte, Detand, & Kruth, 1996; Lee, Kang, & Park, 1996).

The shared scheduling for distributed manufacturing is based on manufacturing resources scheduling which means that each enterprise will realize the sharing of idle manufacturing resources information via the internet on a larger space and obtain the global information effectively. It ensures consistency of the information acquisition, avoids the incomplete of local decision-making, and improves the coordination of distributed scheduling for enterprises and the flexibility and robustness of the manufacturing resource sharing system. Therefore, in recent years, the shared scheduling for distributed manufacturing resources has been applied to Industry Sector. For example, the well-known manufacturing resources sharing platform MFG.com founded in 2012 connects the demand side and the supply side of manufacturing resources around the world. Customers can ask for service requirements on the site. The MFG system will instantly match customers' requirements with suppliers around the world. The supplier will match and quote the customer based on its own manufacturing capacity. As a result, the MFG.com helps manufacturers implement shared scheduling of

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resources. Some of industrial practices in China have a greater impact on resource allocation. An example is the Internet platform molds.cn for the mold manufacturing. It integrates the purchase and supply of mold information. This shared model enables the matching of customer orders with manufacturing resources. The shared scheduling of distributed manufacturing resources belongs to the category of distributed scheduling problem. There are two major types of methodologies to solve distributed scheduling problems, one is a distributed problem solving (DPS), one is the agent-based approach (Hsu, Kao, Ho, & Lai, 2016).

Agents technology is one of the main information technology in industry. It is a branch of distributed artificial intelligence (DAI). The other two branches are distributed problem solving (DPS) and parallel artificial intelligence (PAI) (Andreadis, Klazoglou, Niotaki, & Bouzakis, 2014; Cantamessa, 1997; Guo & Zhang, 2009). The term “agent” means an intelligent entity with autonomy, learning ability, environmental perception and responding in a timely manner (Jana, Bairagi, Paul, Sarkar, & Saha, 2013; Kaplanoğlu, 2014; Kitano, 2007; Parkes & Wellman, 2015). Physical entities or abstract entities can be used as intelligent entities. Parts, equipments, orders, manufacturing units and human can be assumed as intelligent entities (Cantamessa, 1997). Agents can communicate, coordinate, collaborate, negotiate and auction with each other. The collaboration among agents can be performed through negotiation protocols, such as the well-known Contract Net Protocol (CNP), Game Theory (Renna, 2011). Multi-agent system (MAS) is a distributed intelligent system combines multiple agents that interact and compete with each other. A single agent in a multi-agent system can play the role of a manager, a facilitator, a mediator, a broker and a supervisor (Andreadis et al., 2014; Cantamessa, 1997; Wong, Leung, Mak, & Fung, 2006). Each agent takes the initiative to make decisions, considering its own goals and the global goals of the system (Adhau et al., 2013). This system has the characteristics of flexibility, modularity, distribution, openness, reconfigurability and expansibility, and can solve the complex, dynamic, and decentralized scheduling problem which is difficult to handle for a single agent (Kaplanoğlu, 2014; Kitano, 2007). Agents share resources through the network, achieve the global goal by negotiating and cooperating. Therefore, multi-agent system can provide a good solution for the shared scheduling of distributed manufacturing resources. The key to shared scheduling of distributed manufacturing resources based on multi-agent system is to design effective negotiation protocols to promote competition and cooperation among multi-agents and to achieve global optimal scheduling.

In consideration of the problem of shared scheduling for distributed manufacturing resources. Two MAS architectures are built in this paper. One is internal architecture of a enterprise comprises job agents, resource agents and manager agents; the other one is alliance architecture of multiple enterprises involves the addition of a mediator agent and a scheduling agent. A negotiation protocol is designed in this paper to support both types of MAS architectures. Two optimization algorithms are proposed to solve the scheduling model. Simulation runs are conducted to demonstrate the effectiveness of the proposed method. Results show that the multi-agent-based optimization algorithm performed significantly good.

The remainder of this paper is organized provided as follows: Section 2 summarizes existing related work on distributed manufacturing resources scheduling problems and MAS. Section 3 formally presents the detailed description of the problem and describes the shared architecture of multi-agent based system. Section 4 presents the proposed algorithms, computational experimentation and analysis of results. Finally, conclusions are drawn and the future research direction is put forth in Section 5.

2. State of the art

2.1. Manufacturing resource sharing

Currently, manufacturing resource sharing problem has become a hot topic for many researchers. Advanced information and communication technology, such as Internet of Things, Cloud Computing, Big Data, make it easier for manufacturing resources in different places to share fully (Du, Guo, Li, & Guo, 2013). Therefore, combining the emerging advanced technologies with advanced manufacturing modes, some new manufacturing paradigms are proposed (Tao, Zhang, Venkatesh, Luo, & Cheng, 2011). Cloud manufacturing (CM) is considered to be one of the more rapid development of advanced manufacturing paradigm. It is a service-oriented manufacturing resource sharing model. Cloud computing technology is used to integrate and optimize manufacturing capabilities and resources in CM. A collaborative manufacturing resource sharing platform in CM is constructed to achieve manufacturing resource sharing and cooperative between manufacturing enterprises (Ahn, Park, & Hur, 2017; Ding, Yu, & Sun, 2012; Wang & Xu, 2013). Wang and Xu (2013) proposed a service-oriented, interoperable cloud manufacturing system. Zhang et al. (2014) discussed the concept of CM and built three core components for a CM system, i.e. cloud manufacturing resources, manufacturing cloud service and manufacturing cloud. Tao et al. (2011) studied four typical CM service platforms, i.e. public, private, community, and hybrid CM service platforms, as well as key technologies for implementing CM. Ahn et al. (2017) developed a framework for estimating the collaboration level among enterprises in CM by adopting a probabilistic graphical model (PGM). The collaboration level among enterprises in CM refers to the ability to produce a manufacturing service that satisfies a customer by means of collaborative production amongst enterprises. Through the cooperation among enterprises, the total cost of the enterprise is reduced and the enterprise's resource utilization or quality is improved. Jiang, Wang, Zheng, and Sun (2014) proposed a distributed manufacturing resource sharing system model according to peer-to-peer and the Chord protocol. The above literature on the manufacturing resource sharing are discussed basically from the concept or architecture of manufacturing. The manufacturing service is supported from a theoretical point of view, but the manufacturing intelligence is not fully reflected. The practical application methods of manufacturing resource sharing still need to be further explored.

2.2. Shared scheduling of distributed manufacturing resources

Manufacturing resource scheduling problem has attracted the attention of many scholars. The classic scheduling problem assumes that manufacturing resources are in the same geographic location. And the scheduling optimization model and algorithm will alter due to the change of scheduling objective or constraint condition. The solutions to this problem become more and more complex. It will be more sophisticated to solve the problem of shared scheduling of distributed manufacturing resources.

According to the different attribution of manufacturing resources, the existing research on shared scheduling for distributed manufacturing resources can be divided into three categories: (1) Manufacturing resources belong to the same enterprise but at different sites. To solve the resource sharing problem in multi-site companies, Aissani (2009) construct a adaptive scheduling model by adopting a multi-agent approach. (2) Manufacturing resources belong to different enterprises located in different geographical locations. To meet the resource requirements of multiple projects geographically distributed in different locations, considering the transfer time of global resource sharing for decentralized resource constrained multi-project scheduling problem (DRCMPSP),