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Agent-based hierarchical production planning and scheduling in make-to-order manufacturing system

N. He [a,1], D.Z. Zhang [a,b,*], Q. Li [b,2]

[a] College of Engineering, Mathematics and Physical Sciences, University of Exeter, Harrison Building, North Park Road, Exeter EX4 4QF, UK
[b] State Key Laboratory on Mechanical Transmission, Chongqing University, Chongqing 400044, China

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ABSTRACT

Nowadays, manufacturing organisations face increasing pressures from the frequent change in product type, continuous demand fluctuation and unexpected change in customer requirements. In order to survive in the turbulent environment, manufacturing organisations must become flexible and responsive to these dynamic changes in the business environment. This paper presents a hierarchical agent bidding mechanism that is particularly designed for Make-to-Order manufacturing system and attempts to enhance the operational flexibility of manufacturing system in dealing with dynamic changes in the business environment. The novelty of this mechanism is that it enables manufacturing resources to be self-organised cost-efficiently within structural constraints of manufacturing system for fulfilling customer orders. However, when orders cannot be fulfilled within the structural constraints of manufacturing systems, the mechanism can enable manufacturing resources to be regrouped flexibly across system boundaries but with minimum disturbances to existing system structure. Based on an example application to a manufacturing company, this paper demonstrates that the operational flexibility provided by this mechanism is able to help manufacturing system to respond demand fluctuation through balancing the capacity across the entire system. Meanwhile, this mechanism potentially enables manufacturing systems to deal with unexpected changes in product type. As long as the manufacturing system has the technicality required by a new product, this mechanism enables resources across the manufacturing system to be cost-efficiently and flexibly self-organised to fulfil the new product.

1. Introduction

Nowadays, due to the shift of production modes from mass production to mass customisation, increase of customer knowledge, and rapid development of communication technology, manufacturing organisations face more and more pressures from the dynamic changes in the business environment e.g. frequent change in product type and unexpected change in demand pattern. Over the past decades, several approaches have been developed to assist manufacturing organisations in dealing with changes in the business environment. For example, manufacturing system concepts exist, which are designed to aid manufacturing organisations in responding to change in product type. These include Flexible Manufacturing System (FMS) (Stecke, 1983; Buzacott and Yao, 1986) and Reconfigurable Manufacturing System (RMS) (Koren et al., 1999). Both concepts stem from the introduction of advanced machines (i.e., flexible machines and reconfigurable machines) and aim to cope with change in product type through machine flexibility. However, they are not applicable to manufacturing systems with existing available resources due to a large amount of initial capital investment on resource replacement. Further, these concepts, particularly FMS, may create waste of investment because of inaccurate forecasting of future product types and customer requirements. Moreover, other changes in the business environment like change in demand pattern cannot be handled simultaneously by the use of these two concepts. In terms of changes in demand pattern, two approaches related to layout design have been developed, including the dynamic layout (Rosenblatt and Hau, 1987; Balakrishnan et al., 1992; Balakrishnan and Cheng, 1998; Kochhar and Heragu, 1999) and robust layout (Rosenblatt and Kropp, 1992; Benjaafar et al., 2002). These approaches aim to add built-in flexibility or robustness to system layout in response to forecasted changes in demand pattern. However, since either the layout flexibility or layout robustness is pre-determined based on demand pattern forecasting at the beginning of a long-term planning period, both approaches are

* Corresponding author. Tel.: +44 1392723363.
E-mail addresses: N.He@exeter.ac.uk (N. He), D.Z.Zhang@exeter.ac.uk (D.Z. Zhang), cuq.qiangli@gmail.com (Q. Li).
[1] Tel.: +44 1392723613.
[2] Tel.: +86 13668006620.

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unable to deal with unexpected changes incurred within the planning period. Also, as these two approaches only consider machine arrangement at the bottom manufacturing system level (e.g., manufacturing cells), they cannot be applied to manufacturing system with complex hierarchy and therefore do not necessarily enhance the overall system flexibility.

Consequently, current approaches to how manufacturing systems respond to changes in the business environment only focus on machine flexibility and system layout flexibility. However, these approaches lack the applicability to manufacturing systems with existing resources and also each approach is merely able to deal with one kind of change in the business environment. In the manufacturing industry, every change in the business environment can be directly or indirectly detected from customer demand. Hence, the most effective approach to helping manufacturing systems with existing resources deal with changes in the business environment is through operational flexibility, regardless of the need for new machine functionalities. This requires an effective production planning and scheduling method by which a manufacturing system is able to cost-effectively fulfil customer demand in order to sustain their business competitiveness. More importantly, the planning and scheduling method must also be able to flexibly organise and utilise available resources to satisfy customer demand related to changes in the business environment. A manufacturing system is always hierarchical, wherein resources are grouped into sub-systems in line with given product design and process design through considering cost and time efficiency in production. Therefore, to satisfy the aforementioned cost-efficient planning and scheduling requirement, this method must enable customer demand to be fulfilled within existing system structure as far as possible. Nevertheless, if that is not possible due to dynamic changes in the business environment, this method must then enable resources to be flexibly regrouped across boundaries between different sub-systems for satisfying customer demand and dealing with the changes. Ultimately, a prerequisite for the proposed production planning and scheduling method is that there must be a manufacturing system control model that is able to represent the hierarchy of manufacturing system.

Control models for manufacturing systems are usually based on implementation of three typical architectures: centralised architecture (Dilts et al., 1991), hierarchical architecture (Jones and McLean, 1986; Jackson and Jones, 1987) and heterarchical architecture (Lin and James, 1992; Gu et al., 1997; Macchiaroli and Riemma, 2002; Wong et al., 2006a). In centralised and hierarchical architecture there is a singular centralised controller, or a hierarchy of many, that is/are rigidly designed based on static system status and global objectives of the manufacturing system. These two architectures are able to represent the physical hierarchy of a manufacturing system and also offer advantages such as global optimisation, predictability, and robustness in production planning and scheduling (Dilts et al., 1991; Chiu and Yih, 1995). Despite this, they lack operational flexibility due to centralised control. Conversely, the heterarchical architecture contains a collection of local controllers for individual resources within a manufacturing system without the existence of a hierarchy. Local controllers are given full autonomy to make local decisions based on their local status and objectives, whereas global decisions are made through the interactions amongst local controllers (Heragu et al., 2002). Due to the distributed nature of the architecture, heterarchical control models are very flexible and fault-tolerant. Also, resources within a manufacturing system can be self-organised together without centralised control, which produces real operational flexibility in decision-making. However, because of lack of hierarchy, applications of heterarchical architecture merely concern resource allocation in shop floor or single layer systems, and are unable to address the production planning and scheduling within manufacturing system having a complex hierarchy. In addition, since each local controller attempts to achieve its local objectives without considering global objectives, global control decisions based on heterarchical architecture are not always optimised. Therefore, none of the aforementioned typical architectures are able to simultaneously satisfy the prerequisite of a control model defined previously and at the same time provide production planning and scheduling methods with both features of cost-efficiency and flexibility. A new modelling and control architecture with the following three generalised features is therefore needed:

- This architecture must be able to represent the complex physical hierarchy of manufacturing system.
- This architecture must avoid centralised control so as to achieve operational flexibility of manufacturing systems.
- This architecture must have a planning and scheduling method that is able to cost-efficiently fulfil customer demand within the structural constraints of the manufacturing system and also have the ability to flexibly regroup resources across system boundaries when needed. At the same time, because resource regroupings across system boundaries will create disturbances to manufacturing system, this method must be able to find the resource regrouping with the lowest disturbances.

In 2007, Zhang et al. (2007) proposed a manufacturing system methodology that is termed as Dynamically Integrated Manufacturing System (DIMS). This methodology encompasses a multi-agent modelling architecture — Hierarchical Autonomous Agent Network (HAAN) and an agent-based control method — Hierarchical Agent Bidding Mechanism that is particularly designed for production planning and scheduling in Make-to-Order (MTO) manufacturing system. This control method enables the hierarchy of resources in a MTO manufacturing system to not only be automatically controlled but also to be cost-efficient and flexibly self-organised within structural constraints and across system boundaries when needed. DIMS perfectly addresses the three features mentioned above. However, in this work, Zhang et al. (2007) did not demonstrate the effect of the bidding mechanism on the operational flexibility of a manufacturing system, nor its ability to deal with changes in the business environment. As a following work, this paper aims to fulfil the demonstration work that was not covered in Zhang et al. (2007). As a reminder, this paper is organised into six sections. Following the introduction section, Section 2 provides a literature review of the emerging modelling architectures aside from the three typical architectures. Section 3 introduces the modelling architecture in DIMS. Section 4 presents the hierarchical agent bidding mechanism in DIMS and illustrates the hierarchical planning and scheduling process based on this mechanism. Section 5 demonstrate the positive effect of the agent bidding mechanism on operational flexibility of manufacturing system and its ability to help manufacturing system deal with changes in the business environment, especially change in demand quantity, on the basis of an industrial example. Section 6 is a conclusion section.

2. Modelling and control architectures of manufacturing system

As mentioned in the previous section, centralised and hierarchical architectures offer the ability to model system hierarchy and globally optimise control decisions, but do not support the flexible operational decision-making. On the contrary, heterarchical architecture facilitates manufacturing systems to make operational decisions flexibly, but cannot represent system hierarchy and achieve global optimisation in decision-making. With a view

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