Production planning in reconfigurable enterprises and reconfigurable production systems

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Abstract
Reconfigurable enterprises and reconfigurable production systems represent nowadays one of the key responses towards the organisational and manufacturing needs arising in the new era known as mass customization. The paper proposes an Agent Based approach for the production planning activities in reconfigurable enterprises, characterized by complex, articulated and geographically distributed production capacities contended by many product families and composed by reconfigurable production systems that allow quick adjustment of production capacity and functionality consenting to manufacture different products of the same part family.

Keywords:
Computer aided planning, Distributed manufacturing, Multi-agent system.

1 INTRODUCTION

Mass customization consequences, such as shorter product life cycles and low-cost variety, have brought critical pressures to improve production efficiency, responsiveness to market changes, and substantial cost reduction. Scientific papers, as well as Government and Industry expectations, seem to acknowledge that the challenge keyword is "reconfiguration" [1]. Specifically, two major industrial responses to mass customization can be acknowledged: Reconfigurable Manufacturing and Reconfigurable Enterprise (RE). From a manufacturing perspective, the most agreed response to mass customization is connected to the concepts of modularity and reconfigurability of production systems. Thanks to their modularity Reconfigurable manufacturing systems (RMS) allow to achieve low cost customization [2].
On the other side, from an organizational point of view, Reconfigurable Production Networks or Enterprises are nowadays considered the industrial response to the great challenges conveyed by this new era characterized by the global market and the impressive advances of information and communication technology [3]. Market globalization, indeed, has offered to companies the possibility to split geographically their production capacity; business opportunities lead companies to work together in temporary organizations; in the same firm, business units behave as autonomous profit centres and compete each other for the production capacity allocation. In other words, REs represent production networks made of different and geographically dispersed plants which can be reconfigured in order to gather a specific production process or product family. However, the RE members need to be properly coordinated to achieve reduction in lead times and costs, alignment of interdependent decision-making processes, and improvement in the overall performance of each member, as well as of the RE. In this context, operations management and coordination of RE and RMS are challenging issues involving distributed problem solving tasks. Specifically, in production planning and control activities, the concern on internal production planning is replaced by the complexity of external supply chain. Indeed, as soon as a manufacturing unit tries to achieve coordination with its partners, it quickly faces difficulties associated with different operational conventions, locally specific constraints, software legacy and properties, conflicting objectives and misaligned incentives. This task becomes even more difficult when each RE member or plant consist of reconfigurable production system; indeed, the reconfiguration capability makes planning and scheduling processes even more complex.

Multi Agent Systems (MAS) techniques have been largely used for their suitability in modelling complex systems involving multiple autonomous agents with internal knowledge and reasoning engines which communicate and negotiate with each other by exchanging messages according to specific negotiation protocols [4]. The aim of this paper is to give an overview on the new problems associated with production planning and control in RE and RMS and to present how distributed decision making, MAS technology and negotiation mechanisms can be utilized for solving these kinds of problems.

2 PRODUCTION PLANNING IN RE AND RMS

Reconfigurable enterprises are multinational enterprises with a distributed and worldwide networked organizational and production plants. Such kind of organizational model is very common to the automotive or semiconductor Industries which by integrating their modular horizontal supply chain achieve huge dimensions while maintaining a good level of reactiveness. Such reactiveness, though, strongly depends on capability of the enterprise in reconfigure its organizational structure and its distributed production plants and systems in order to respond to markets dynamics. The reconfiguration ability makes the production planning (PP) process, starting from the long-term capacity planning until the short-term shop-floor scheduling, a very complex one.

As an example, in a worldwide electronic component company, which is world leader in developing and delivering semiconductor solutions, every year, a corporate level assigns to the company groups (responsible for product families such as electronic memories) a certain level of the total production capacity (called capacity ownership) basing on long-term demand forecasting and products strategic positioning. Every three months the groups, after having collected backlog and forecast orders coming from the regional divisions, according to the ownership they hold and to the demand they have to supply, make their capacity allocation plan. If the group capacity ownership is not enough to supply the demand orders, then the group can negotiate portion of capacity with the other groups whose assigned ownership exceeds their actual demand [5]. In practice, such negotiation and, the consequent possible capacity exchange, turns out into a re-assignment of some production plants to a new group. Plants assigned at the beginning of the year to the production of components belonging to a specific product family, could be reconfigured throughout the year for producing different type of components, i.e. different product families. Also, within the annual quarter in which the assignment of plants to group remain fixed,

orders of products belonging to a product family (group) must be allocated to the different plants temporary assigned to the group. Plants represent reconfigurable production systems able to be reconfigured in the short period (within the three months) in order to manufacture different product types of the same part family. Such a brief description demonstrates how complex, multi-period, multi-decision and multi-issue is the PP process in distributed organization when a somewhat reconfigurable capability is considered. Table 1 reports a hierarchical view of the PP process in a RE.

3 NEGOTIATION MODELS FOR PP IN RE

Given the complex and decentralized nature of the production planning process as described in the previous section, MAS decision making and negotiation mechanisms become a powerful solution. Indeed, each involved entity keeps its autonomy, in term of planning process decisions, and global decisions are made by a coordination and negotiation of autonomous decision makers. This can be obtained by developing tools based on the concept of autonomous agents and by designing proper coordination and negotiation strategies. Negotiation differs from other coordination mechanisms because each actor can exercise influence power and mainly because it can deal with uncertain transactions and asymmetric knowledge typical of a negotiation process [6]. Designing a negotiation model as coordination mechanism for such kind of distributed decision making processes involves, for each level of production planning, the definition of the actors involved in the negotiation process and the definition of the negotiation mechanisms, i.e. the negotiation static (issues, roles, sub-negotiations, etc.) and dynamic (strategies and tactics) variables, besides the negotiation protocol. Figure 1 gives an overview on some negotiation variables for the five planning levels reported in table 1. For each level of the PP process, Figure 1 shows the different families of actor involved in the negotiation (separated by a dashed line) and the bilateral communication channels among agents (bidirectional arrows).

The specific focus of the research presented in this paper concerns the design of a negotiation mechanism for solving the medium level production planning process. Indeed, this negotiation level presents some peculiar characteristics which make the mechanism more complex respect to the others, specifically when referring to the multiple communication channels which need to be activated and managed simultaneously throughout the negotiation. In this case, in fact, the negotiation occurs concurrently among all different plants and all different groups. As already mentioned, every three months and after having negotiated the capacity ownerships, the groups' agents negotiate with the plants' agents for awarding the production plants where to accomplish the real production of the own product family. This is a bilateral, parallel, multi-actor and multi-roles negotiation. In the next section a negotiation model for such a medium level PP process is presented.

3.1 The medium level negotiation model

The scenario

The company produces I product families, each associated to a group. Such products are produced in J plants, each geographically dispersed and reconfigurable in order to produce all of the different product families. The reconfiguration is allowed once every three months and every three months the J plants are assigned to the I groups for accomplishing the annual quarter production of the associated product family. At this planning level, if A is the production capacity of each plant and c_i is the annual quarter capacity ownership, it results:

$$C_{tot} = \sum_{i=1,2,\ldots I} c_i = J \cdot A \qquad (1)$$

The association group-plant is accomplished by negotiation. Indeed, such association can be interpreted as an internal transaction among a given group and a given plant. The group is requested to pay a certain amount of money to the plant in order to receive the needed service. Such amount of money is the sum $p_{ij} \cdot V_{ij}$ that the group i pays to the plant j at the end of the quarter. V_{ij} is the volume of family i that will be produced by the plants j while p_{ij} is the negotiated transaction price.

The negotiation model

Given the annual quarter capacity ownership (c_i), assigned to each group as outcome of the high planning level, the Group Agents (GAs) negotiate with the Plant Agents (PAs) in order to gain a sufficient number of plants for supplying the required c_i. The negotiation is bilateral and simultaneous: all of the GAs, every three months, concurrently submit their own offer to the PAs. During the negotiation the GAs make offers, based on their *generative functions*, to the PAs and these, based on their *reactive functions*, evaluate such offers and decide whether they want to sign the contract with a given group or to ask for a new proposal.

Planning Level	Planning Horizon	Planning Issue	Planning Makers	Planning Mechanisms
Top	1 year	Assign capacity ownership to groups	Corporate agent and groups' agents	long-term demand forecasting and products strategic positioning
High	3 months	Re-modulate ownership among groups	Groups' agents	Unbalancing level among medium term forecasting plus backorder and assigned ownership
Medium	3 months	Assign plants to group	Groups' agents and plants' agents	Plant skills in producing a given part family, geographical position of the plants
Low	Real-time	Allocate orders to plants	Order agent and plants' agents	Plants skills in processing the order and geographical position of the plants
Shop-floor	Real-time	Allocate jobs to production resources	Job agent and resources' agents	Resource skill in processing the job, reconfiguration time required to process the job

Table 1: Production planning levels