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Emergent methodology for solving tool inventory sizing problems in a complex production system

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Abstract

Based on recently established correlations between emergent synthesis classes, a Class III synthesis problem concerning tool inventory management in a complex make-to-order manufacturing environment is addressed. Such environment is shown to be affected by significant non-random uncertainty involving tool delivery time fluctuations and unpredictable tool demand. The trade-off typical of the inventory sizing dilemma is introduced with reference to reusable tools, such as grinding wheels, and a satisfactory solution is achieved by means of a dynamic purpose assignment approach. This leads to a global behavior, expressed by a recurrently oscillating pattern, affecting the inventory level trend in the nearby of a peculiar attraction band: the oscillation amplitude mainly depends on the attractor's bandwidth as well as on the peaks attained by the tool demand rate during the tool management period.

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Keywords: Tool management, Inventory sizing dilemma, Bounded rationality, Supply networks, Multi-agent systems.

1. Introduction

Ueda (1998) clarifies the problem of synthesis and the concept of emergence as well as their connection with problem-solving difficulties in complex manufacturing systems [1].

The term synthesis, used in relation to human activities aimed at creating artificial items, is defined as the "engineering design … of an artifact" where the latter is an "artifactual system having a certain purpose and a certain environment in which the system works". Solving the problem of synthesis is "to determine the system structure in order to realize its purpose under the constraints of the environment".

The difficulties in synthesis problem-solving are categorised into three classes [2]:

- Class I problems with complete description of both purpose and environment;
- Class II problems with complete purpose specification but incomplete environmental description;
- Class III problems with incomplete description of both purpose and environment.

2. Bounded rationality tool inventory management

To solve this kind of problems, traditional analytic and deterministic approaches based on top-down problem decomposition are not enough: emergent methodologies, whereby both bottom-up and top-down features are adopted, are needed to unveil the constraints through repeated interactions between the artifactual system and the environment in order to achieve an efficient and robust solution [3].

The term emergence is defined as "a global order of structure expressing new function" that is "formed through bi-directional dynamic processes where local interactions among elements reveal a global behavior and the global behavior results in new constraints in the behavior of the elements".

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As to the characteristics of emergent systems, key words such as evolution, adaptation, learning, multi-agents, coordination and interactivity are fitting.

With regard to a Class II synthesis problem resolution, emergent synthetic approaches consisting in learning and adaptation based methods, such as reinforcement learning or adaptive behavior based methods in combination with coordination and interactivity, are viable [3].

Figure 1 shows the modified model of Class III problems with the established correlations between the classes.

Dating back to [4], it is well known that most people are only partly rational and are in fact emotional or irrational in the remaining course of their actions.

Introducing the concept of bounded rationality, he argues that "boundedly rational agents experience limits in formulating and solving complex problems and in processing (receiving, storing, retrieving, transmitting) information" [5].

The complex manufacturing environment considered in this paper refers to a real industrial case where a turbine blade producer (client) requires CBN grinding wheel dressing operations from external tool manufacturers (suppliers) in a supply network.

Tool management and control is carried out by the turbine blade producer by operating in an attempt to proactively modify the tool inventory size trend by increasing or reducing the planned inventory level merely on the basis of the experience of its logistic staff.

The result of this policy, founded on expert knowledge of skilled staff, is given by historical inventory trend patterns. The historical pattern, issue of human expert activities, is a suitable ad hoc solution preventing the tool inventory to run out of stock. Being influenced by bounded rationality connected to human behavior, however, it is essentially focused upon stock-out risk prevention, as it seems to assume that a successful management policy is meant to identify a single overriding objective and to make any other consideration bend to that one objective.

Nonetheless, the human expert policy can be used for assessing alternative intelligent computation tool management strategies, independent from expert staff, such as those proposed in the development of the Multi-Agent Tool Management System [6].

3. Multi-agent tool management system

This paper fits into a wider research work concerned with the development and implementation of a Multi-Agent Tool Management System (MATMS) for automatic tool procurement in a supply network [6-8].

Recently, a novel software architecture to manage supply networks at the tactical and operational levels has emerged. The supply network is viewed as a system made of a set of intelligent software agents, each responsible for one or more activities in the supply network and each interacting with other agents in planning and executing their responsibilities [9].

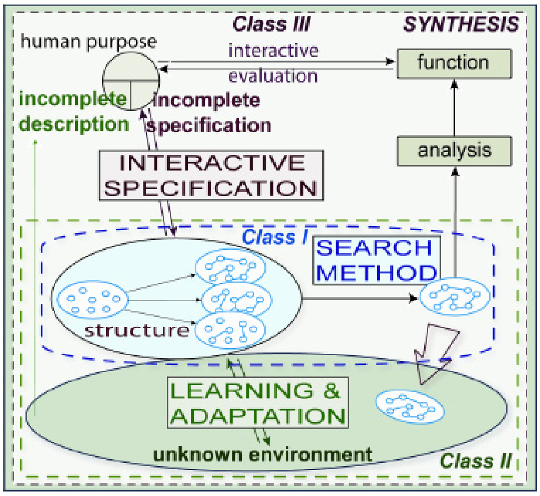

Fig. 1. Modified model of Class III problems showing correlations between classes

The MATMS development involves the engineering design of an agent-based system that operates in the framework of a negotiation based multiple-supplier network where a turbine blade producer (customer) requires from external tool manufacturers (suppliers) the purchase of new CBN grinding wheels and the performance of dressing operations on worn-out CBN grinding wheels for turbine blade fabrication [10, 11]. As the number of tool purchases is only 10% of the number of tool dressings and the cost of a new tool is only about 30% higher than the corresponding tool dressing, wheel dressing operations play a fundamental role in tool management optimisation.

Key purposes of the MATMS comprise:

- dressing job order allocation to external tool manufacturers within the supply network;
- tool inventory sizing and control by the turbine blade producer.

In the MATMS, these activities are the responsibility of two intelligent agents, the Resource Agent (RA) and the Order Distribution Agent (ODA). Both these tasks are optimised on the basis of cost and stock-out risk minimization. This can be accomplished only if reliable tool delivery forecasting is achieved, as emphasized below.

The MATMS performs in a complex make-to-order manufacturing environment. Complexity sources are primarily represented by external suppliers providing for new tools and tool dressings. Indeed, the external supplier's response to dressing job orders is not sufficiently dependable in terms of tool delivery time due to uncertain, though not random, factors (e.g. various human and natural factors, uncertainty due to partial knowledge, etc.), making the MATMS operating environment notably unreliable and ambiguous. Similarly, significant non-random fluctuations in tool demand make the latter unpredictable as well. Thus, the MATMS design and implementation imply the resolution of a Class III synthesis problem, where, beyond incomplete purpose specification (tool management optimization), ambiguous information on the environment (unreliability of