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Emergent synthesis in supply network tool management

R. Teti *, D. D'Addona

Department of Materials and Production Engineering, University of Naples Federico II, Piazzale Tecchio 80, I-80125 Naples, Italy

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Abstract

This work fits into a wider research on supply chains concerned with the development and implementation of a Multi-Agent Tool Management System (MATMS) for automatic tool procurement in a supply network. The main purpose of the MATMS is the optimised management of CBN grinding wheels for nickel base alloy turbine blade fabrication while operating in a multiple-supplier network environment made uncertain by external tool manufacturers showing unreliable tool delivery time response.

Emergent synthesis concepts for tool management are analysed and discussed, and the design and functioning of Flexible Tool Management Strategies (FTMS), founded on an emergent synthesis methodology based on neuro-fuzzy paradigms, is illustrated. The FTMS paradigms, integrated in the MATMS as domain specific problem solving functions of the agent responsible tool inventory sizing and control, are proposed as dependable and robust toll delivery time forecasting methods, founded on knowledge evolution, for the solution of this Class II synthesis problem. The evaluation and comparison of the FTMS performance is carried out with reference to real industrial cases of CBN grinding wheel tool management.

Keywords: Tool management; Delivery forecasting; Supply networks; Multi-agents; Neuro-fuzzy systems

1. Introduction

This work is a contribution to a wider scope research concerned with the development and implementation of a Multi-Agent Tool Management System (MATMS) for automatic tool procurement in a supply network.

Recently, a new software architecture for managing supply networks at the tactical and operational levels has emerged. It views the supply network as composed 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 [1].

The MATMS development is realised as the engineering design of an agent-based system operating in the framework of a negotiation based multiple-supplier network where a turbine blade producer (customer) demands from external tool manufacturers (suppliers) new CBN grinding wheels and dressing operations on worn-out CBN grinding wheels for nickel base alloy turbine blade fabrication.

The main scope of the MATMS is the optimum CBN grinding wheel tool inventory sizing and control, including on time delivery and minimisation of tool management cost and stock-out risk.

The MATMS concept was first analysed in [2] where the system model founded on agent technology was presented and a constraint heuristic search technique, the OPL Project, integrated in the MATMS intelligent agent responsible of supplier selection for dressing operation performance, was developed.

In [3–6], the design and functioning of diverse Flexible Tool Management Strategies (FTMS), integrated in the MATMS intelligent agent responsible for optimum tool inventory sizing, were illustrated.

* Corresponding author.
E-mail addresses: roberto.teti@unina.it, tetiro@unina.it (R. Teti).

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In the above papers, it was shown that the tasks of these intelligent agents can be optimised only on the basis of reliable tool delivery forecasting.

In [7,8], a method for reliable dressing cycle time predictions, based on Adaptive Neuro-Fuzzy Inference Systems, was implemented and tested.

2. Emergent synthesis and MATMS

In [9], the problem of synthesis and the concept of emergence as well as their relation to problem solving difficulties in complex manufacturing systems are clarified.

The term synthesis, used in relation to human activities to create 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 [10]:

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

To solve these types 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 [11].

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 behaviour and the global behaviour results in new constraints in the behaviour of the elements" [11]. As for the characteristics of emergent systems, key words such as evolution, adaptation, learning, multi-agents, coordination and interactivity are fitting.

Supply network management represents a typical instance of Class III problems [12]; preliminary results related to supply networks show promising indications that their emergent behaviour can be modelled [13,14].

Thus, the development of the MATMS design involves Class III synthesis problem solving that can be decomposed into Class I, Class II and Class III problems [15], as discussed in Section 5.

The MATMS operational environment is conditioned by external tool manufacturers supplying new tools and worn-out tool dressings. As the number of tool purchases is only 10% of the number of tool dressings and the price of a new tool is only 20% higher than the corresponding tool dressing, CBN grinding wheel dressing operations take up a fundamental role in tool management optimisation. Furthermore, the external suppliers response to customer dressing job orders is not sufficiently dependable in terms of CBN grinding wheel dressing cycle times due to uncertain, though not random, factors (e.g. various human and natural factors, uncertainty due to partial knowledge, etc.), making the MATMS environment of operation undefined and ambiguous.

In the present paper, the implementation and testing of MATMS integrated neuro-fuzzy systems for adaptive, reliable and robust tool delivery forecasting based on knowledge evolution is presented in the framework of an emergent synthesis approach to tool management in a multiple-supplier network.

3. Multi-agent tool management system

In Fig. 1, the block scheme of the MATMS, subdivided into three functional levels, is shown [16]:

- the Supplier Network Level, including the external tool manufacturers in the supply network;
- the Enterprise Level, including the logistics of the turbine blade producer;
- the Plant Level, including the production lines of the turbine blade producer.

The Supplier Network Level is responsible for the dressing jobs on worn-out CBN grinding wheels. It comprises only one type of agents, the Supplier Order Acquisition Agents (SA_i), representing the external tool manufacturers activity of acquiring dressing job orders from the turbine blade producer. The SA_i interact only with two Enterprise Level agents: the Order Distribution Agent (ODA) for dressing job order negotiation, and the Warehouse Timer Agent (WTA) for worn-out/dressed CBN grinding wheel trade.

The Enterprise Level is responsible for coordinating the MATMS activities to achieve the best possible results in terms of its goals, including on-time delivery, cost minimization, and so forth. It comprises different intelligent agents performing the fundamental tool management activities:

- the Resource Agent (RA) that merges the functions of tool inventory management, tool demand estimation and determination of order quantities; the RA domain specific problem solving function is the Flexible Tool Management Strategy (FTMS), see [3–6];
- the Order Distribution Agent (ODA) that selects the supplier for each dressing job order allocation based on negotiations and constraints; the ODA domain specific problem solving function is the OPL Project, developed in ILOG OPL Studio 3.5 [2];