

Intelligent Agent-Oriented Systems for Integrated, Online Planning, Scheduling and Control of Manufacturing and Distribution Systems

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Over the past five years, Intelligent Automation Inc. (IAI) and its partners have been developing a unique, agent-based approach to online optimization that is intended for use in complex, large-scale systems operating in uncertain, dynamic environments. This approach involves a fundamental shift in paradigms, away from horizontally decomposed and logically distinct planning, scheduling and execution modules, towards communities of medium-grained agents, in which each agent is responsible for a portion of the overall planning, scheduling and execution in the system. A major advantage of this shift towards vertically integrated intelligent agents is the increase in reactivity that can result from localizing the problems of planning, scheduling, and execution control. We also believe that this “bottom-up” philosophy has tremendous software engineering advantages when compared to centralized, top-down approaches to the construction of extremely large and complex systems. In addition, the ease with which such agent-based software systems can be distributed across networks of computers implies that large problems can be managed at relatively low cost.

The main challenge to our approach centers upon the problem of obtaining high quality global performance in a system founded upon locally optimizing agents. Inspired by the apparent advantages that free-market economies exhibit, when compared to centrally planned economies, we have adopted a series of market-based solutions to this problem. Our basic philosophy is to allow agents to quickly find local solutions to partial problems, and then to apply market-based optimization techniques to improve the global quality of solution as time allows. A major advantage of this economic focus is the way that it supports the modeling of complex objective functions, taking into account factors such as inventory holding, storage, and setup costs, power consumption, and tardiness. Compared to conventional metrics, such as makespan, these objective functions are much more indicative the overall effectiveness of the manufacturing facility.

In addition to the optimization issues, the shift towards an agent-oriented paradigm raises a number of issues in software engineering. We have developed *Cybele*, an agent infrastructure for deploying high-performance multi-agent systems on computer networks. In addition to communication services, *Cybele* supports the intelligent

use of network computational capacity by providing agent migration and market-based load-balancing services. To facilitate the implementation of large, diverse communities of intelligent agents, we have also developed a software design approach to building multi-agent systems, that allows us to reuse and extend substantial amounts of code. The associated tools we have developed, which extend UML, the *de facto* standard object-oriented design language, significantly improve the quality and maintainability of the software, while simultaneously reducing design and implementation time.

We have applied this basic framework to a number of diverse application domains, including manufacturing and vehicle routing. Our manufacturing system, which was designed in cooperation with Rock Island Arsenal, deals with unexpected incoming jobs, machine break-downs, and delayed operations in a time-sensitive manner, while maintaining an accurate model of cost that is without precedence in an online optimization system. Our agent-based system for routing pickup and delivery vehicles employs a novel stochastic improvement heuristic that permits high-quality solutions in an online system that outperform the most commonly used offline heuristics for the problem.