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Cooperative Multi-Agent Scheduling to Improve Resource Utilisation in Large-Scale Manufacturing

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ABSTRACT

Scheduling production in large-scale manufacturing is a complex challenge that requires dynamically allocating tasks to machines while balancing throughput and resource utilization. Game-theoretic approaches have been widely applied, with traditional models treating either all machines as players competing for tasks or all tasks competing for access to machines. Such formulations overlook the joint perspective of machines and tasks, often leading to schedule fragmentation, i.e. small, unusable gaps that severely reduce machine utilisation. This paper introduces a novel cooperative framework in which both machines and tasks act as players, negotiating directly to determine feasible start times when tasks are assigned to machines. Manufacturing systems are modelled as multi-agent networks, with a classifier selecting scheduling strategies based on the relative importance of machines and tasks. Machine importance is dynamically assessed using PageRank centrality, while task importance is determined by urgency and complexity. The negotiation process is formulated as a cooperative game that maximizes a collective utility function incorporating processing costs, penalties for early or late completion, importance of machines and tasks, and a new measure of opportunity loss caused by fragmented schedules. This cooperative game model can result a schedule with minimised gaps, thereby improving machine utilisation without compromising production speed. A discrete-event simulation was conducted to evaluate performance against a traditional multi-objective optimization approach. The findings indicated that 76% of machines identified as bottleneck resources demonstrated an average enhancement in utilisation of 1.5%, thus providing an effective solution for efficient and sustainable production management.