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Dissertation Title: Energy-efficient Scheduling for Sustainable Production and Transportation in Flexible Manufacturing Systems

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Abstract or Public Summary: The steady growth in energy demand and environmental awareness has placed increasing pressure on manufacturing industries to improve energy efficiency and reduce emissions while coping with volatile electricity costs and stricter environmental regulations. In this context, energy-efficient scheduling has emerged as a cost-effective strategy to achieve sustainability goals without requiring significant investment in new equipment or product design. This has propelled a surge in research on sustainable manufacturing, with a growing number of works focusing on energy-efficient operation scheduling. This thesis addresses the Energy-Efficient Job Shop Scheduling Problem (EEJSP) and its extensions, focusing on decisions that minimize makespan and energy consumption in bi-objective problems. This research explores multiple energy-saving strategies – namely variable machine and vehicle speed settings – as well as transportation scheduling with limited resources. Two main goals are pursued. First, the thesis seeks to comprehensively analyze and systematize EEJSP literature, clarifying modelling assumptions, performance measures, and energy-saving strategies and additionally identifying gaps related to the integration of transport. Second, it aims to develop appropriate models and algorithms for relevant EEJSP extensions, namely the EEJSP with limited transportation resources (EEJSPT), which better reflects real-world production settings where optimized scheduling can reduce emissions and energy costs. Throughout the development of this work, two peer-reviewed journal articles were published, each presented as an individual chapter in this thesis. The first provides a systematic literature review of EEJSP articles, identifying research gaps and highlighting the limited integration of transport and speed-related decisions. The second article introduces both an exact and a heuristic approach to jointly optimize production and transport operations in EEJSPT. The exact approach employs a bi-objective mixed-integer linear programming (MILP) model that, in combination with a lexicographic and ϵ-contraint method approximates the true Pareto front. The heuristic approach presents a novel multi-population biased random-key genetic algorithm to approximate Pareto-optimal solutions. Computational

experiments across multiple test instances demonstrate that coordinated speed control across machines and vehicles can significantly reduce energy consumption with limited impact on makespan, with the test instances having been made publicly available for future research. Overall, the thesis advances the study of energy-efficient scheduling by providing tools and insights to support sustainable manufacturing decisions through a comprehensive review of EEJSP state of the art, proposing a new and more realistic extension to this problem, and providing a novel MILP problem formulation, a new multi-population genetic algorithm, and benchmark instances.
Keywords: Job shop scheduling, Energy efficiency, Sustainable manufacturing, Optimization, Multi-objective scheduling, MILP, NSGA-II, BRKGA.

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Scientific Domain: [Computer Science and Engineering]; [Power and Energy Systems]; [Systems Engineering and Management]

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