Minimizing the total travel time in the flexible job-shop scheduling problem with transportation resources

Lucas Berterottière[1], Stéphane Dauzère-Pérès[1,2], Claude Yugma[1]

[1] Mines Saint-Etienne, CNRS, UMR 6158 LIMOS,
Gardanne, France

[2] Department of Accounting and Operations Management, BI Norwegian Business School, Oslo, Norway

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1 Introduction and motivations

The Flexible Job Shop scheduling Problem (FJSP) involves optimizing job assignment and sequencing to minimize makespan. A recent attention has been given to the management of transportation resources, as several works include the transportation of jobs between machines in the model (see for instance the survey of [5]). The aim of this study is to address the FJSP with Transportation resources (FJSPT) by optimizing both the makespan and the total travel time.

Minimizing the total travel time of vehicles offers significant benefits such as reduced energy consumption and decreased wear and tear on the vehicles. Energy-aware scheduling has become increasingly relevant due to factors like rising energy costs, limited resources, and the imperative to cut down greenhouse gas emissions, as discussed in [2]. Additionally, reducing travel times can help to avoid unnecessary trips that could lead to congestion in the network, particularly in the case of on-rail vehicles, which is the case in modern semiconductor manufacturing facilities. The optimization of energy consumption in manufacturing facilities is a rising topic as more and more papers are interested in incorporating sustainability in production planning [4]. [6] consider an energy-efficient schedule in the FJSP with a time-changing price of energy. The schedule must respect a threshold on the makespan and the time of energy use is optimized to minimize the cost. The authors propose and combine several methods, including MILP modeling, dynamic programming, and a Tabu search method.

		TTT			
Instance	C_{max}	first	best	worst	gap ($\frac{w-b}{b}$)
fjsp1	134	200	192	202	**+5%**
fjsp2	114	138	138	156	**+13%**
fjsp3	120	170	122	182	**+49%**
fjsp4	114	194	188	198	**+5%**
fjsp5	94	120	94	122	**+30%**
fjsp6	134	138	138	154	**+12%**
fjsp7	112	182	182	182	**+0%**
fjsp8	178	194	188	198	**+5%**
fjsp9	144	178	152	216	**+42%**
fjsp10	174	202	194	222	**+14%**

TAB. 1: First, best and worst total travel times of schedule with the same makespan on the instances from [3]

Based on our recent study on the FJSPT [1], we noted that schedules with identical makespan could exhibit substantially different total travel times. Table 1 presents the total travel time of schedules with the best found makespan. Among the solutions with the best makespan, the total travel time of the first solution encountered, which is often retained as the optimal solution, as well as the minimum and maximum total travel times, are reported. The gap between the best and worst total travel time, computed as $\frac{TTT_{worst}-TTT_{best}}{TTT_{best}}$, is reported as well.

2 Problem definition and optimization approaches

A set of jobs must be processed on a set of machines. Each jobs requires a route of production operations to be completed. Before being processed, jobs must be transported to the machines by a fleet of homogeneous vehicles of unitary capacity. The processing times of production operations are machine-dependent. Travel times depend on the assignment of production operations, are not vehicle-dependent and does not depend on whether the vehicle is loaded or not. The travel times from machine k_1 to machine k_2 is denoted $\tau_{k_2}^{k_1}$ and must respect the triangular inequality, i.e. for any three machines k_1, k_2 and $k_3 \in \mathcal{M}$, we have $\tau_{k_2}^{k_1} \leq \tau_{k_3}^{k_1} + \tau_{k_2}^{k_3}$. The goal is to efficiently allocate transportation operations to vehicles, assign each production operation to an eligible machine and sequence the operations on both vehicles and machines to minimize both the total time needed to complete all jobs, known as the makespan (C_{max}), and the Total Travel Time (TTT) of the vehicles.

Several optimization approaches have been studied, all extending the tabu search proposed in [1]. When the objective is to minimize the makespan, the focus is typically on critical operations on a longest path since moving these operations have the potential to reduce the makespan. However, when optimizing the total travel time, moving many other operations can contribute to a decrease of the total travel time. With the increasing number of potential operations to move, the size of the neighborhood structure becomes an important parameter for the efficiency of the search. Thus, new neighborhood structures of different sizes have been studied. During the conference, we will present the main results obtained, both theoretical and experimental.

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