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A Dial-a-Ride evaluation for solving the job-shop with routing considerations

Matthieu Gondran [a,*], Marie-José Huguet [b], Philippe Lacomme [a], Alain Quilliot [a], Nikolay Tchernev [a]

[a] Laboratoire d'Informatique (LIMOS, UMR CNRS 6158), Université Clermont Auvergne, Campus des Cézeaux, 63177 Aubière Cedex, France
[b] LAAS-CNRS, Université de Toulouse, CNRS, INSA, Toulouse, France

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ABSTRACT

The Job-Shop scheduling Problem with Transport (JSPT) is a combinatorial optimization problem that combines both scheduling and routing problems. It has received attention for decades, resulting in numerous publications focused on the makespan minimization. The JSPT is commonly modeled by a disjunctive graph that encompasses both machine-operations and transport-operations. The transport-operations define a sub-problem which is close to the DARP where pickup and delivery operations have to be scheduled. The vast majority of the evaluation functions used into disjunctive graphs of JSPT, minimizes the makespan and there is no routing criteria in the objective function. Commonly used evaluation functions lead to left-shifted solutions for both machine-operations and transport-operations.

The present work investigates a new evaluation function for the JSPT which integrates routing problematic to compute non semi-active solutions but which minimize the makespan first and maximize the Quality of Service second thanks to a time-lag max based modeling and an iterative process. The Quality of Service proposed in this paper, is extended from the Quality of Service defined by (Cordeau and Laporte, 2003) for the DARP. The procedure performance is benchmarked with a CPLEX resolution and the numerical experiments proved that the proposed evaluation function is nearly optimal and provides new solutions with a high Quality of Service.

Nomenclature

$J = \{J_1 \dots J_n\}$	Set of jobs
$M = \{M_1 \dots M_m\}$	Set of machines
O	Set of machine-operations
$O_{i,j}$	jth machine-operation of job J_i
$\mu_{i,j}$	Machine on which $O_{i,j}$ must be processed
$pt_{i,j}$	Duration of operation $O_{i,j}$
D	Set of delivery operations
P	Set of pickup operations
$D_{i,j}$	Delivery operation preceding $O_{i,j}$
$P_{i,j}$	Pickup operation succeeding $O_{i,j}$
$R_{(O_{i,j},O_{i,j+1})}$	Transfer request between $O_{i,j}$ and $O_{i,j+1}$ which is an ordered sequence of transport-operations
$T_{(O_{i,j},O_{y,x})}$	Transport-operation from $O_{i,j}$ to $O_{y,x}$
$st_{i,j}$	Starting time of $O_{i,j}$
$c_{i,j}$	Finishing time of $O_{i,j}$
$R = \{R_1 \dots R_r\}$	Fleet of vehicles
C^r	Capacity of vehicle r
$td^{r,c}_{M_1,M_2}$	Transport time of vehicle r between the machines M_1 and M_2 with c loaded jobs
TL_{ji}	Time-lag from operation j to operation i, $i, j \in O \cup D \cup P$
ES_i	Earliest Starting time of the operation i, $i, j \in O \cup D \cup P$
LS_i	Latest Starting time of the operation i, $i, j \in O \cup D \cup P$
$Cmax$	Total completion time of all operations (Makespan)
TRT	Total Riding Time
TWT	Total Waiting Time
TD	Total Duration
QoS	Quality of Service
y	A solution

* Corresponding author.
E-mail addresses: gondran@isima.fr (M. Gondran), huguet@laas.fr (M.-J. Huguet), placomme@isima.fr (P. Lacomme), alain.quilliot@isima.fr (A. Quilliot), tchernev@isima.fr (N. Tchernev).

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$F(y)$	The objective function of solution y
$h_{cmax}(y)$	$Cmax$ of y
$h_{cost}(y)$	$1/QoS$ of y
α, β	Coefficients of F

1. Introduction

This paper focuses on an integrated problem referred to as the Job-Shop Scheduling Problem with Routing (JSPR), which is a generalization of the classical Job-Shop Scheduling Problem (JSP) where a fleet of vehicles transports jobs between machines.

Contrary to the Job-Shop scheduling Problem with Transport (JSPT) which only has to objective the minimization of the makespan, the JSPR takes both the minimization of the makespan and the maximization of the Quality of Service into consideration. A new evaluation function of the disjunctive graph introduces for the JSPT by Lacomme et al. (2013) is designed in this paper. The proposed approach in this paper differs from the JSPT in the literature according to the following points:

- A Definition of the Quality of Service in the JSPR comparable to the Quality of Service definition from Dial-A-Ride Problem.
- A new evaluation function of a disjunctive graph.
- An extension of the benchmarks of the JSPT to encompass the JSPT and JSPR with several non-unitary capacity vehicles.

The paper is organized as follows: Section 1 presents an introduction to the JSPT; a literature review of related works; and the definition of the Quality of Service in the Dial-A-Ride Problem which motivates this study. Section 2 the formulation of the JSPR is introduced. Section 3 is a MILP formulation of the JSPR. Section 4 refers to the new proposed approach for JSPR evaluation, while Section 5 presents experiment results on well-known benchmarks.

1.1. Job-Shop scheduling problem with transport

Routing constraints are involved in numerous scheduling problems including, for example, the Job-Shop with Transport (Knust, 1999; Lacomme et al., 2013); the Flexible Manufacturing Systems (FMS) (Caumond et al., 2009); the Flexible Job-Shop scheduling Problem with Transport (Zhang et al., 2012); the Resource-Constrained Project Scheduling Problem with Transport (Quilliot and Toussaint, 2012) and the Hoist Scheduling Problem (HSP), which can be modeled as a specific case of the JSPT with minimal and maximal time-lags (Honglin et al., 2017; Adnen El and Elhafsi, 2016). These scheduling problems include, but are not limited to AGVs (Automated Guided Vehicles), hoists and robots. Moreover, the coordination between transport and scheduling can be achieved in two possible ways depending on the objective: the first one consists in an explicit modeling of transport-operations; the second one consists in modeling only transport delay.

The Job Shop scheduling Problem (JSP) is characterized by a set of n jobs $J = \{J_1 \dots J_n\}$ and a set of m disjunctive machines $M = \{M_1 \dots M_m\}$. A job i is composed of an ordered set $\{O_{i,1}, O_{i,2} \dots O_{i,n_i}\}$ of n_i operations to be successively performed according to the given sequence. An operation $O_{i,j}$ must be processed on machine $\mu_{i,j} \in M$ for a duration $pt_{i,j}$. Several operations requiring the same machine cannot be processed simultaneously. A classical objective is to minimize the total duration, i.e., the makespan, of the schedule.

The Job-Shop scheduling Problem with Transport (JSPT) is an extension of the Job-Shop scheduling Problem where a fleet of r vehicles $R = \{R_1 \dots R_r\}$ must transport the jobs between the machines. This transport is explicitly modeled and split into two operations: a pickup operation followed by a delivery operation, since non-unitary capacity vehicles are considered. The JSPT is an NP-hard problem because both JSP and transport are simultaneously considered (see Lenstra and Kan, 1979 and Blazewicz et al., 1983). The most common objective is, similarly to the JSP, the minimization of the makespan.

1.2. Literature review

In a survey published by Nouri et al. (2016b), the authors provide a classification scheme that defines seven criteria including: the number of transportation resources; the transportation resource types; the number of operations in each job; the routing flexibility, which is the number of machines able to process each operation; recirculation, which means that jobs visit some machines more than one time; the optimization criteria; and the type of resolution scheme.

Several linear formulations have been introduced for job-shop-like problems with transport, but exact resolution remains difficult due to both a large number of binary variables (modeling disjunctive constraints), and many linear formulations remain intractable for medium-scale instances.

Table A.1 in the Appendix introduces articles concerning the Job-Shop with Transport. Bilge and Ulusoy (1995) studied the simultaneous scheduling of machines and identical AGVs in a job-shop framework, and proposed a heuristic solution. In 2009, Caumond et al. (2009) introduced a modeling for one vehicle only with buffer capacity, the FIFO buffer management rule and limitation on the number of jobs in the system. Ahmadi-Javid and Hooshangi-Tabrizi (2017) introduced a linear formulation into an explicit modeling of a job-shop with transport with a heterogeneous fleet and an employee timetable. The problem remains close to the workforce scheduling problem or to the Skill VRP. Anwar and Nagi (1998) introduced a formulation for the integrated material handling in the context of a job-shop environment with multi-level products. El Khoukhi et al. (2011) focused on a just-in-time job-shop scheduling with Transportation Times and Multirobots with the objective to minimize, on the one hand, tardiness, earliness penalties on delays and advances and, on the other hand, the number of empty moves. The contribution of Morihiro et al. (2006) concerns the Tasks Assignment and Routing Problem (TARP) for Autonomous Transportation Systems (ATSs) and they give TARP results for a specific Pickup and Delivery Problem with Time Windows (PDPTW). Umar et al. (2015) proposed a hybrid multi-objective genetic algorithm taking routing criteria into account: the AGV travel time, job tardiness and conflict avoidance. A vast majority of publications use heuristic-based approaches and focus on unitary vehicle capacity. For example, only three publications address non-unitary capacity: Morihiro et al. (2006), Larabi (2010) and El Khoukhi et al. (2011), they also address the problem with a number of vehicles greater than one.

Addition of routing consideration can consist, as reported by Morihiro et al. (2006), in an explicit modeling of Pickup and Delivery, which are commonly used in the Pickup and Delivery Problem with Time Window (PDPTW) and in the Dial-A-Ride Problem where a Quality of Service is taken into account for the customers who are assumed to be transported between nodes.

1.3. Quality of service in the Dial-A-Ride Problem

The Dial-A-Ride Problem (DARP) was first introduced by Stein (1978). Later, Cordeau and Laporte (2003) defined the DARP as follows: each client (or customer) c has a transportation request between a given pickup node to a delivery node. Each node (pickup or delivery) i is associated with a service duration d_i that corresponds to the time needed to pick up or deliver client c, and to a time window $[e_i; l_i]$ in which the pickup or the delivery operation must be done. A waiting time is allowed before any beginning of service but forbidden after the end of the service. Client transportation is provided by a homogeneous and limited fleet of vehicles of capacity Q. All trips begin and finish at the depot.

According to Chassaing et al. (2016), four variables are required to provide a trip description (Fig. 1):

- A_i is the arrival time of a vehicle on node i,
- st_i is the beginning of the service on node i,