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Job-shop based framework for simultaneous scheduling of machines and automated guided vehicles

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ABSTRACT

This paper deals with the problem of simultaneous scheduling of machines and identical automated guided vehicles (AGVs) which are well known difficult to solve problems. The studied problem can be modelled as a job shop where the jobs have to be transported between machines by AGVs. This article introduces a framework based on a disjunctive graph to modelize the joint scheduling problem and on a memetic algorithm for machines and AGVs scheduling. The objective is to minimize the makespan. Computational results are presented for a benchmark literature instances. New upper bounds are found, showing the effectiveness of the presented approach.

1. Introduction

Automated guided vehicles (AGVs) are among various advanced material handling techniques that are finding increasing applications today. They can be interfaced to various other production and storage equipment and controlled through an intelligent computer control system. Both the scheduling of operations on machines as well as the scheduling of AGVs are essential factors contributing to the efficiency of the overall flexible manufacturing system (FMS) (Blazevicz et al., 1991). Significant improvement of FMS performance is expected as a result of a proper coordination of both AGV and machine scheduling problem.

The considered FMS scheduling problem has the same structure as introduced in 1993 by Ulusoy and Bilge (1993) and successively studied by Bilge and Ulusoy (1995), Ulusoy et al. (1997), Abdelmaguid et al. (2004), Lacomme et al. (2005), Reddy and Rao (2006), Deroussi et al. (2008). It is concerned with the simultaneous scheduling of machines and AGVs in a flexible manufacturing environment where a set of different machines perform different tasks and a set of identical AGVs perform material handling and transportation tasks between machines. The problem addressed in this paper thus falls into the classification of $\mathcal{NP}$-complete combinatorial problems for which efficient optimal solution procedures do not exist unless $\mathcal{P}=\mathcal{NP}$ (Ganesharajah et al., 1998). Scheduling can be achieved in a static mode (off-line scheduling) prior to execution, a dynamic mode (real-time or on-line scheduling) during the execution, or a combination of both. This paper deals with off-line scheduling in FMS. Methods for off-line scheduling are directed at schedule generation over a certain horizon period (from a day to a week), the time during which the schedule is not expected to require any change. This aspect of the scheduling has been studied by several researchers (Raman et al., 1986; Blazevicz et al., 1991; Ulusoy and Bilge, 1993; Bilge and Ulusoy, 1995; Ulusoy et al., 1997; Abdelmaguid et al., 2004; Lacomme et al., 2005; Reddy and Rao, 2006; Deroussi et al., 2008, Caumond et al., 2009).

Exact methods are mainly used for the study of simple or particular FMS, with strict assumptions. Thus, Blazevicz et al. (1991) study an FMS in which identical parallel machines are laid out in loop. Raman et al. (1986) presents a mixed integer programming (MIP) formulation of this problem but with the unrealistic assumption that the vehicles come back to the load/unload (LU) station after each achieved transport. The FMS without this assumption was later formulated in MIP by Bilge and Ulusoy (1995). According to the authors, the resulting model is intractable in practice, because of its nonlinearity and its size. To the best of our knowledge Caumond et al. (2009) is the last publication that deals with linear formulation of the FMS. Their approach differs from previously published publications because it takes into account the maximum number of jobs allowed in the system, limited input/output buffer capacities, empty-vehicle trips and no-move-ahead trips simultaneously. However only one AGV is taken into consideration as special case of the general FMS.

Approximated methods are well adapted to study most of the FMS. Nevertheless, many works are dedicated to simplified forms of this problem. There are essentially two kinds of simplifications.

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The first ones consist in defining dispatching rules for the vehicles and the second ones are the restriction of the material handling system at only one AGV. As illustration, Lacomme et al. (2005) and Soylu et al. (2000) proposed, respectively, branch and bound and neural networks approaches for scheduling of FMS based on single AGV. Finally, few works are undertaken on the FMS scheduling with multiples AGVs. Ulusoy and Bilge (1993) and Bilge and Ulusoy (1995) proposed an iterative method based on the decomposition of the master problem into two subproblems: machine scheduling and vehicle scheduling. A heuristic algorithm generates machines schedules to solve the first subproblem. They introduced a solution heuristic based on the sliding time window (STW) approach to find a feasible solution to the vehicle scheduling problem given the machine schedule. Ulusoy et al. (1997) developed a genetic algorithm (GA) for solving this problem in which GA generates better results compared to the STW heuristic. Abdelmaguid et al. (2004) proposed a hybrid method composed of a genetic algorithm for the scheduling of machines and a greedy search heuristic algorithm for the scheduling of vehicles. This problem has been studied further by Reddy and Rao (2006) for the case of multi objective optimization. They developed a GA approach that can provide a set of non-dominated solutions for the minimization of makespan, mean flow time, and mean tardiness simultaneously. Deroussi et al. (2008) described an efficient neighboring system implemented into three different metaheuristics and a new solution representation based on vehicles rather than machines. Face to the complexity of the joint scheduling of jobs and material handling devices, assumptions are made to simplify the problem. The most common ones are:

- Each job is available at the beginning of the scheduling period.
- The routing of each job types is available before making scheduling decisions.
- All jobs enter and leave the system through the load and unload stations.
- It is assumed that there is sufficient input/output buffer space at each machine and at the load/unload stations, i.e. the limited buffer capacity is not considered.
- Vehicles move along predetermined shortest paths, with the assumption of no delay due to the congestion.
- Machine failures are ignored.
- Limitations on the jobs simultaneously allowed in the shop are ignored.

Under these hypotheses the problem can be without doubt modelled as a job-shop with several transport robots. It is classified as a $JR|t_{kl},t'_{kl}|C_{\max}$ problem according to the $\alpha|\beta|\gamma$-notation introduced by Graham et al. (1979) and extended by Knust (1999) for transportation problems. J indicates a job-shop, R indicates that we have a limited number of identical vehicles (robots) and all jobs can be transported by any of the robots. t_{kl} indicates that we have job-independent, but machine-dependent transportation times. t'_{kl} indicates that we have machine-dependent empty moving time. The objective function to minimize is the makespan $C_{\max}$. The proposed modelling and solving approach problem encompasses job-shop with one single transport robot investigated by Hurink and Knust (2001, 2002, 2005). A very similar problem is the job-shop problem with several identical transport robots which has been investigated by Brucker and Strotmann (2002).

In order to modelize real transportation situation, numerous studies tend to include some additional constraints. Strusevich (1999) included the delay between the end of the processing time on one machine and the earliest due date on the next machine for the same job. This delay is denoted by transportation time. Constraints on the number of robots are stressed for the flow-shop in Hurink and Knust (2001) and for the job-shop in Hurink and Knust (2002,2005). Lastly, Hurink and Knust (2005) introduced a highly efficient disjunctive graph for the job-shop with one single robot and derived some specific properties to a proper definition of neighborhoods in local search procedure.

In this paper we propose a new effective framework based on a disjunctive graph to modelize the joint scheduling problem and on a memetic algorithm for jobs sequence generation on machines, AGVs sequence generation and vehicles assignments to transport operations. The contribution of this paper is twofold. First, an original modelling approach based on disjunctive graph is developed for the studied problem. Second, an efficient memetic algorithm is developed for providing solutions to large instances of the problem in short computational time. The developed framework is not restricted to the case of AGVs as it can be suited easily to any type of trip based material handling systems.

The remainder of the paper is organized as follows. Section 2 defines the framework we promote based on a memetic algorithm search scheme and on a disjunctive graph. This section includes a careful description of the disjunctive graph to modelize transport operation constraints. Section 3 describes the components of the memetic algorithm including population definition, local search, clone detection and restarts. Section 4 deals with computational evaluation of the framework including benchmarks based on a set of instances dedicated to the single robot problem given by Hurink and Knust (2005) and on set of instances dedicated to the several robots given by Bilge and Ulusoy (1995). Section 5 concludes the paper and addresses promising directions for future research.

2. Algorithm based framework

The framework is based on a memetic algorithm for sequence generation on both machines and robots operations in machine and transport selection (*MTS*) and assignment of transport operations assignment (*OA*). This memetic algorithm includes a powerful local search procedure. The problem is modelled first as a non-oriented disjunctive graph. It is possible to obtain an oriented disjunctive graph where a Bellman like longest path algorithm permits to compute the earliest completion time of the last operation: the makespan.

2.1. Job-shop with transportation times and several robots

The job-shop scheduling problem with transportation times and several robots can be classified as a complex combinatorial problem, in which a set of n jobs ($J=\{J_1, \ldots, J_n\}$) required to be processed on a set of m machines ($M=\{M_1, \ldots, M_m\}$). Job transports are achieved by a set of r transport robots $R=\{R_1, \ldots, R_r\}$. An ordered set of n_i operations denoted $O_{i,1},O_{i,2}, \ldots, O_{i,ni}$ fully defines each job J_i since one operation $O_{i,j}$ refers to one machine M_j for duration $p_{i,j}$. Each machine M_j can process only one job J_i during $p_{i,j}$ (without preemption) at one time and each job can be processed by only one machine at the same time. Between two machine operations $O_{i,k}$ and $O_{i,k+1}$ (which refer to machine $\mu_{i,k}$ and $\mu_{i,k+1}$) a transportation operation $t^p_{\mu_{i,k},\mu_{i,k+1}}$ is performed by robot p which can handle at most one job at a time. For convenience, $t^p_{\mu_{i,k},\mu_{i,k+1}}$ is used to denote both a transportation operation and a transportation time. Empty transportation times $v^p_{i,j}$ are also addressed while one robot p moves from machine M_i to M_j without carrying a job. It is possible to assume, for each robot p, that $v^p_{i,i}=0$ and $t^p_{i,j} \geq v^p_{i,j}$. We consider that all transport times are machine dependent and job independent.