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Mathematical optimization for earliness/tardiness minimization in a multiple automated guided vehicle manufacturing system via integrated heuristic algorithms

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HIGHLIGHTS

- Scheduling problem for multiple automated guided vehicles (AGVs) in a manufacturing system is proposed and formulated.
- Propose a mathematical program to minimize the penalized earliness and tardiness.
- Optimization method in two stages, namely searching the solution space and finding optimal solutions are proposed.
- The performance of the proposed mathematical model is tested in a numerical example and compared with several methods in the current literature.

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ABSTRACT

In this paper, a scheduling problem for multiple automated guided vehicles (AGVs) in a manufacturing system is proposed and formulated. Considering the due date of AGVs requiring for material handling among shops in a jobshop layout, their earliness and tardiness are significant in satisfying the expected cycle time and from an economic view point. Earliness results in AGVs waiting and tardiness causes temporary part storages in the shop floor. Therefore, we propose a mathematical program to minimize the penalized earliness and tardiness. Since the mathematical program is difficult to solve with a conventional method, an optimization method in two stages, namely searching the solution space and finding optimal solutions are proposed. The performance of the proposed mathematical model is tested in a numerical example and compared with several methods in the current literature.

1. Introduction

Flexible manufacturing systems (FMSs), container terminals, warehousing systems, and service industries including hospital transportation are employing automated guided vehicle systems (AGVs) for the material handling to maintain flexibility and efficiency of production and distribution. For efficient operation, synchronized operations for the simultaneous scheduling of production systems and transportation systems is necessary. The main issue treated in this paper is the simultaneous optimization of penalized earliness and tardiness for the AGVs in the manufacturing system. The production scheduling problems require an optimal production sequence and starting time of operations for jobs at machines for multi-stages with respect to a specified technical precedence relation. The vehicle management problems are classified into:

(1) dispatching, which is to assign tasks to vehicles;
(2) routing, which is to select specific paths taken by vehicles;
(3) scheduling, which is to determine the arrival and departure times.

Unlike the classical vehicle routing problem (VRP) formulation, conflict-free constraints should be considered for the routing of AGVs for automated manufacturing systems. The interaction between production and transportation control is discussed by Mantel and Landeweerd [1]. In the flowshop production systems, the production and transportation schedules are usually controlled by a pull type of policy in case of fork lifts or conveyor systems. However, for FMSs environment with AGV systems, the optimal machine schedules highly depend on the selection of dispatching

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and routing because it is extremely difficult to predict the transportation time when the conflicts and interferences between vehicles cannot be neglected.

Automated guided vehicle (AGV) is a material handling equipment traveling on a network of guide paths. The FMS is a configuration of various work cells, also called work stations, each with a specific function such as milling, washing, or assembly. Each shop is connected to the guide path network by a pick-up/delivery (P/D) station where pallets are transferred from/to the AGVs. Pallets of products are moved between the shops by the AGVs. The guide path is composed of aisle segments on which the vehicles are assumed to travel at a constant speed. The vehicles can travel forward or backward. As many vehicles travel on the guide path simultaneously, collisions must be avoided. AGV systems are implemented in various industrial contexts: container terminals, part transportation in heavy industry, and flexible manufacturing systems. For a general review on AGV problems, the reader is referred to [2–4]. For a recent review on AGVs scheduling and routing problems and issues, the reader is referred to the survey of [5]. These authors identified three types of algorithms for AGVs problems:

(1) general path topology,
(2) path optimization,
(3) specific path topologies.

Methods of the first type can be divided in three categories:

(1a) static methods, where an entire path remains occupied until a vehicle completes its route;
(1b) time-window based methods, where a path segment may be used by different vehicles during different time-windows;
(1c) dynamic methods, where the utilization of any segment of path is dynamically determined during routing rather than before as with categories (1a) and (1b).

This paper addresses a penalized earliness and tardiness scheduling problem for AGVs in a manufacturing system.

2. Literature review

Scheduling problems arise in areas as diverse as production planning, personnel planning, product configuration, and transportation. An overview of the wide range of constraints in scheduling, together with the most powerful propagation algorithms for these constraints are given [6,7].

Production scheduling, dispatching, routing and scheduling decisions for AGVs can be made simultaneously or separately. Most of the literature treats one or two of the problems at the same time. An extensive review has been addressed by Vis [8] for operational control of AGVs. A widely used technique for dispatching is simulation. The heuristic rules are used in on-line control systems. For routing and scheduling of AGVs, several techniques have been used to maximize the total system performance taking in to account deadlocks or conflicts for AGVs. Kim and Tanchoco [9] studied the problem of finding conflict-free routes in a bi-directional network. The algorithm is based on the shortest path methods through the concept of time-window graph. Petri net is also used to analyze deadlock and conflict-free conditions [10,11]. Singh and Tiwari [12] presented an intelligent agent framework to find a conflict-free shortest-time path. Nishi et al. [13] provided a mathematical model for routing problem. Lagrangian decomposition technique was used to solve the problem. Ghasemzadeh et al. [14] presented a conflict-free scheduling and routing in mesh topologies. It can generate the shortest path for scheduling predicting conflicts and select another path in the case of failure.

The literature discussed above on scheduling of AGVs hardly considers the capacity constraints of the machines where transportation jobs become available, and sequencing of operations at the machines. The simultaneous production scheduling and transportation routing problem is a difficult joint problem. The problems for AGVs have been studied mostly in operations research and/or FMS literature. A common approach for FMS scheduling is based on discrete event simulation with dispatching rules [15].

Lacomme et al. [16] introduced a branch and bound algorithm coupled with discrete event simulation. Blazewicz et al. [17] addressed the two steps algorithm for integrating machine scheduling and the conflict-free routing problems. In their approach, the production scheduling and routing problems are solved separately. Bilge and Ulusoy [18] developed a time-window approach to solve the simultaneous scheduling of machines and material handling in FMSs. They formulated the problem as a mixed integer programming problem. Ulusoy et al. [19] and Jerald et al. [20] dealt with the application of the genetic algorithm on the problem. Khayat et al. [21] studied an integrated method with mixed integer linear programming (MILP) and constrained programming. Nevertheless in their model, vehicles can always select a shortest path from a machine station to another without the consideration of conflict and collision on the detailed routing for vehicles. Corréa et al. [22] proposed an integrated scheduling of dispatching and vehicle routing with the consideration of conflict-free path selection, but it does not take into account the scheduling of machines and vehicles simultaneously.

In the above literature, it is extremely difficult to consider production scheduling and conflict-free routing because the number of decision variables increases significantly. Therefore, the conventional decomposition algorithm is not sufficient to solve the problem efficiently. The integration of cut generation with various decomposition methods was widely studied recently [23]. The logic-based Benders decomposition method was introduced by [24]. The advantage of the logic-based Benders is that it permits to combine MILP and the constraint programming approaches. A similar idea was applied to solve the simultaneous planning and scheduling problem [25].

A number of authors have addressed the conflict free routing problem with a static transportation requests set, i.e., with all requests known a priori. Lee et al. [26] present a two-staged traffic control scheme to solve a conflict free routing problem. Their heuristic method consists of generating off-line *k*-shortest paths in the first stage before the on-line traffic controller picks a conflict free shortest path whenever a dispatch command for an AGV is issued (second stage). Rajotia et al. [27] proposed a semi-dynamic time window constrained routing strategy. They use the notions of reserved and free time windows to manage the motion of vehicles. Krishnamurthy et al. [28] proposed an optimization approach. Their objective is to minimize the makespan. They assume that the assignment of tasks to AGVs is given and they solve the routing problem by column generation. Their method generates very good solutions in spite of the fact that it is not optimal (column generation is performed at the root node of the search tree only).

Oboth et al. [29] presented a heuristic method to solve the dispatching and routing problems but not simultaneously. Scheduling is performed first and a sequential path generation heuristic (SPG) is used to generate conflict free routes. The SPG is inspired by the [28] static version of the AGV routing problem and is applied to a dynamic environment while relaxing some of the limiting assumptions like equal and constant speeds of AGVs. When conflict is encountered, no feedback is sent to the scheduling module. The AGV being routed has to be delayed if an alternate route cannot be generated. The authors use rules for positioning idle AGVs instead of letting the system manage them.

Langevin et al. [30] proposed a dynamic programming based method to solve exactly instances with two vehicles. They solve the combined problem of dispatching and conflict free routing. Desaulniers et al. [31] proposed an exact method that enables to