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Scheduling a single vehicle in the just-in-time part supply for a mixed-model assembly line

Yun-Qing Rao [a,b], Meng-Chang Wang [a,b,*], Kun-Peng Wang [a,b], Tou-Ming Wu [c]

[a] The State Key Laboratory of Digital Manufacturing Equipment and Technology, Wuhan 430074, China
[b] The School of Mechanical Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, China
[c] Shenzhen Entry-Exit Inspection and Quarantine Bureau, Shenzhen 518045, China

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ABSTRACT

This paper focuses on the scheduling of a single vehicle, which delivers parts from a storage centre to workstations in a mixed-model assembly line. In order to avoid part shortage and to cut down total inventory holding and travelling costs, the destination workstation, the part quantity and the departure time of each delivery have to be specified properly according to predetermined assembly sequences. In this paper, an optimisation model is established for the configuration that only one destination workstation is involved within each delivery. Four specific properties of the problem are deduced, then a backward-backtracking approach and a hybrid GASA (genetic algorithm and simulated annealing) approach are developed based on these properties. Both two approaches are applied to several groups of instances with real-world data, and results show that the GASA approach is efficient even in large instances. Furthermore, the existence of feasible solutions (EOFS) is analysed via instances with different problem settings, which are obtained by an orthodox experimental design (ODE). An analysis of variance (ANOVA) shows that the buffer capacity is the most significant factor influencing the EOFS. Besides this, both the assembly sequence length and distances to workstations also have noticeable impacts.

1. Introduction

The increasing product varieties have posed greater challenges to manufacturers on efficient just-in-time (JIT) part supply for production lines, especially when billions of different models are assembled through a single mixed-model line in the automotive industry [4].

This research is motivated by the real-world part supply processes involved in the engine production of an automobile manufacturer in China, where a mixed-model engine assembly line is served by a material handler and a vehicle. To be more specific, the material handler collects a number of parts for a workstation from the storage centre, then the vehicle loads them at the storage centre, delivers them to the workstation and it returns to the storage centre after parts being unloaded into the part buffer at the workstation (see Fig. 1).

The problem is that the start time, the destination workstation, and the quantity of parts to be loaded within each delivery, i.e., the vehicle schedule, are to be determined so that the line will not stop due to part shortage.

When many different models are assembled in the same shift, a subsequent engine that is assembled after the current one may be of a quite different model, and the part needed may also be of a quite different type. So it may cause wrong parts assembled or the part buffer re-shuffled when storing a lot of parts for one model in a part buffer at a time. Scarce spaces at the workstations or part buffers' capacities also restrict the part quantity within each delivery. This is not a common situation that is often met in traditional single-product large-batch production environments.

In addition, the inventory in the storage centre is managed by vendors, and the payment for each part is done electronically at the time when the part is pulled out from the storage centre. So it is also required to make the time between the payment and the assembly of each part as short as possible to cut down the manufacturer's total part inventory holding cost in the phase of part supply.

The present paper develops an optimisation model for this problem and proposes solving approaches, considering a real-world requirement that no part is allowed to arrive at the workstation after the expected start time of its respective assembly operation.

The remainder of the paper is organised as follows. Section 2 reviews related literature. Section 3 describes the problem in

* Corresponding author at: The School of Mechanical Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, China. Tel.: +86 13871053724.
E-mail addresses: wangmc@hust.edu.cn, wangmengchang@gmail.com (M.-C. Wang).

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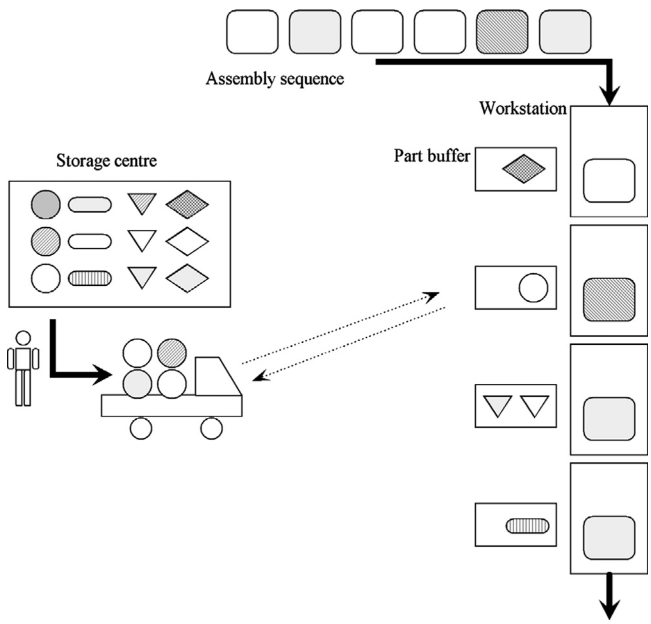

Fig. 1. A representation of the part supply.

detail and develops the optimisation model. Four properties of the model are deduced in Section 4. Then a backwards–backtracking approach is proposed in Section 5 and a hybrid GASA approach is proposed in Section 6. Both two approaches are applied to several groups of instances with real-world data in Section 7, where the performance of the two approaches is investigated. The factors of the problem settings influencing the EOFS are analysed in Section 8. In the end, Section 9 presents a conclusion of this work.

2. Literature review

Scheduling problems within mixed-model lines have been studied for decades, most of which fall into one of these two categories: (1) the level-scheduling problems to keep the usage rate of all parts fed into the final assembly as constant as possible and (2) the car-sequencing problem to keep the line's workstation loads as constant as possible [8]. Extensive models and procedures are developed and an excellent review of these works is given by Boysen et al. [5].

As pointed out by Khayat et al. [11], material handling vehicles are becoming more valuable resources in JIT production environments so as vehicles should be considered as constraint resources as well as production machines.

Jerald et al. [10] propose an adaptive genetic algorithm (GA) to simultaneously schedule machines and AGVs (automated guided vehicles) in an FMS (flexible manufacturing system) environment, in which the inter-cell movements between flexible machining cells (FMCs) are performed by two identical vehicles. The algorithm adopts an adaptive scheme to enable the crossover and mutation rates to be changed during the course of genetic search process. Similarly, a simultaneous production scheduling and conflict-free AGV routing problem in flexible flowshop systems are studied by Nishi et al. [13], where jobs are delivered by AGVs between consecutive production stages. A bilevel formulation is adopted, incorporating a Lagrangian relaxation and two types of cutting schemes. The approach can effectively solve the problems up to 3 stages, 4 vehicles and 100 jobs.

Anwar and Nagi [2] consider simultaneous scheduling of manufacturing equipments and material handling transporters in a job-shop environment with the goal minimising the total makespan. They extend the integrated operation network proposed in [1] by inserting transportation operations between operations performed by different workstations.

Caumond et al. [6] present a mixed integer linear programming (MILP) model for a scheduling problem of an FMS with one vehicle, considering buffer capacities, job numbers and machine blockages. The MILP provides optimal solutions to the problem for small and medium instances.

These works show insights into vehicle scheduling in manufacturing environments. However, only transportation operations between workstations/stages are involved in these works and those of materials needed by assembly are not considered.

Singh and Tiwari [18] propose a framework for AGV dispatching systems assigning vehicles to transport demands based on an object oriented approaching using the unified modelling language (UML), and develop a dispatching algorithm to minimize lateness, travelling time and distance of empty vehicles, which is tested in a simulated job-shop scenario. Capacities of input buffers at workstations are considered in the algorithm, but the situation that several parts can be assigned together into one delivery (combinable delivery demand) is not considered.

Choi and Lee [7] study part-feeding for mixed-model assembly lines, where different models of products consume a different number of same non-sequential (equivalent or interchangeable) parts at the same workstation and parts are transported by feeders from warehouse to workstations. They propose a dynamic part-feeding system, which hourly determines the parts quantities assigned to each feeder and their feeding routes, according to the estimation of part consumptions of the assembly line. The problem is formulated as a vehicle routing problem (VRP). While limits on capacities of part buffers beside workstations and sequential or non-interchangeable parts are not considered.

Boysen and Bock [3] propose a hoist scheduling problem (HSP), in which a batch of boxes with parts in them are to be delivered to a mixed-model assembly line, and the goal is to find an order of boxes to be loaded by a single forklift. They also consider the scenario that only one destination workstation is involved within each delivery. In addition, a fixed cycle time and no idle time between two deliveries are taken into account. The HSP is proven to be NP-hard in the strong sense. Also a bounded dynamic programming approach and a simulated annealing algorithm (SA) are developed. The major difference between the HSP and the problem under consideration is that the quantities of parts loaded within deliveries are not predetermined in this paper, which results in that the total number of deliveries is an unknown value and to be specified. Moreover, the assembly operation time variances caused by different models are permitted here, as well as idle times between any two successive deliveries.

As far as our best knowledge, few attempts have been made to schedule a vehicle considering all of the sequential parts, the combinable delivery demands and buffer capacities at workstations within mixed-model assembly production environments. In the present work, an attempt is made to deal with such an issue. Assumptions and more details of the problem are described in the following section.

3. Detailed problem description

3.1. Situations and assumptions

In our problem settings, part needs are derived from the prespecified assembly sequence, and the due time of a part delivery is the start time of the earliest respective assembly operation determined by the sequence. One or more parts are picked up at the storage centre and then delivered to the part buffer at a