Modeling FMS Scheduling Problems As Hybrid Flowshop Scheduling Problems

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Abstract: Scheduling problems in Flexible Manufacturing Systems (FMS) appear as a specific field in the scheduling literature. Hybrid Flowshop Scheduling Problems (HFSP) also appear as another typical field of investigation. The FMS studied in this paper concern an Automated Guided Vehicle system (AGVs) organised in single loop. We propose to link these two classes of problems by underlining how to model this type of FMS scheduling problem as an HFSP. Our final goal is to identify the algorithm classes of one field that can be applied in the other context and vice versa.

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1. Introduction

Modern production systems must keep pace with the increasing demand on both product diversity and rapid answers to client orders. With this aim, firms tend to organise their production systems into Mass-Workshop system [Le Moal et al, 1979]. So the goal is to anticipate the production of semi-finished products in the Mass part, and to ensure an accurate production in the Workshop part of the system to deal with the client demand. The workshop part is then often organised in a Flexible Manufacturing System (FMS) that can realise various kinds of products according to several routings.

In this paper we focus on the workshop system and we consider a particular class of FMS. Indeed, the flexibility of the system is mainly sustained by the material handling system which interconnects different machines in the system. An Automated Guided Vehicle system (AGVs) links the machines in the FMS.

The design of an AGV system consists of several stages [Tanchoco et al, 1992][Lin et al, 1994][Wang et al, 1994]. The first is the design of the guide path and the location of the pick-up/delivery stations. The guide path can be either conventional, tandem or single loop and the flow can be unidirectional, bidirectional or mixed. The second design stage is the determination of the total number of AGV in the system.

The next stage of the designing phase is the definition of AGV system traffic management where two options are possible:

- the first management option is independent of the production to be achieved. That means that each AGV routing is determined in order to ensure a non conflict traffic but without considering any product completion time. Indeed, the co-ordination of different AGV is mainly aimed at in this approach;

- the second option for traffic management is a classical scheduling approach. In FMS scheduling literature, either part and machine scheduling or AGV routing are largely dealt with.

The FMS we consider here is a single closed loop AGV system composed of several AGV that follow a unique virtual flow path through all the workshop machines (Figure 1), and transport only one product at a time. This AGV system corresponds to the real FMS we study in our research laboratory in the EOWYN project [Proust et al, 1989][EOWYN, 1996]. It is also supported by ANVAR Association.

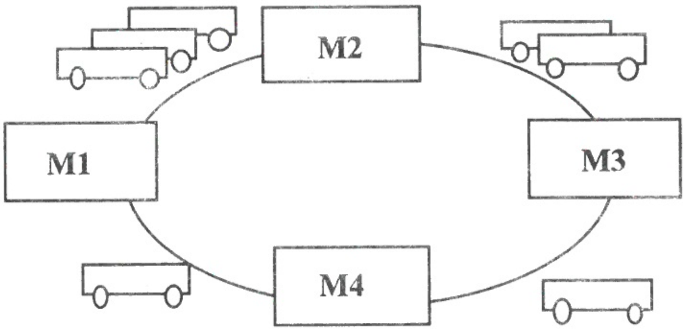

Figure 1. Single Closed Loop AGV System

Considering this kind of a lay-out, we are interested in simultaneous part scheduling and AGV routing (as in [Blazewicz et al, 94]). This paper shows that an attractive way of modeling exists in terms of hybrid flowshop scheduling problems.

The studied workshop is composed of two types of resources: transformation resources (i.e. machines), and transport resources (i.e. AGV). These resources are disjunctive, that means they can perform only one operation at a time, and they are gathered into resource pools. A pool contains identical resources in terms of functionalities, but not in terms of performances.

We consider that we have to schedule a set of jobs, where each job is characterized by a routing, a quantity, and possibly a due date. The job routing represents all the operations required to obtain the final product. Each operation of a job is characterized by a resource or a set of resources, and a processing time.

Classical scheduling approaches operate in two phases (see Blazewicz et al, 1994). First, the scheduling problem is applied on transformation resources in order to obtain the best production schedule. Next, a new scheduling problem appears: how to schedule the AGV, given this production schedule.

The main idea underlying our scheduling approach is to consider an AGV as a resource of the workshop, which is only used to transport one operation to its next processing place. This paper describes how the problem of sequencing and scheduling jobs in this type of FMS, can ,under some conditions, be formulated as a hybrid flowshop scheduling problem. Section 2 first presents several modeling characteristics which are usually considered in general scheduling problems. Then we restrict those characteristics in order to formulate a "basic scheduling problem" which is modelled as a hybrid flowshop scheduling problem. Section 3 emphasizes how hybrid flowshop modeling techniques can be applied on more complex FMS problems. Two particular characteristics are then considered : jobshop production and AGV exclusion areas.

2. Description of the Basic Problem

The modeling of FMS industrial scheduling problems leads to considering such characteristics as the flexibility of the production to realize (relative products or machines), the limited capacities associated with the resources (machines and AGV), the AGV guide path, the AGV dimension and their mutual exclusion in front of a machine.

Before starting consider more general FMS problems, we consider a basic problem, subject to five conditions:

- C 1: the job routing is the same for each job, i.e. in terms of scheduling problems, it is a flowshop. The products will use the machines in the same order.

- C 2: there is no exclusion area for the AGV in front of the machines. That means several AGV may be available for loading or unloading at the same time. In practice, this condition is seldom verified.

- C 3: each AGV brings a job from one machine to the next one, and comes back empty (it is not a real looped system). For each transfer between two successive machines, there are one or more AGV.

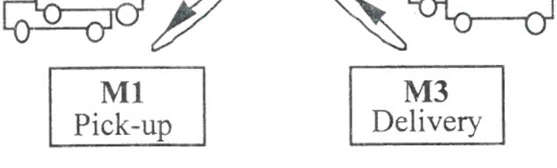

Figure 2. Bidirectional Path Between Machines

- C 4: the buffer capacity is unlimited before and after each machine. An AGV will always be able to deliver a part, and a machine will always be able to put a processed part in the buffer capacity.

- C 5: a pool contains identical resources in terms of performances.

To illustrate this basic problem, we assume that the previous conditions are satisfied. For example, let us consider a workshop composed of three machines M1, M2 and M3 and four AGV. Two identical AGV move between M1 and M2 (P(M1,M2) pool) and two identical AGV move between M2 and M3 (P(M2,M3) pool) (conditions C3 and C5, and see Figure 2).

Three jobs J1, J2 and J3 have to be scheduled on these resources. We consider that the routing of each job is:

M1 - P(M1,M2) - M2 - P(M2,M3) - M3 (condition C1).

After processing a job on machine M1, an AGV has to be chosen in pool P(M1,M2) to take it to the next machine M2: it is an assignment problem. The duration of a job on a machine is equal to its processing time on this machine, and the duration of a job on an AGV is equal to the transport time t between the two considered machines. We model the return of the AGV to the previous machine, as a removal time, no sequence dependent. This time is equal to the time t' required by the AGV to go back to the starting point. It prevents the AGV from being used when it comes back. According to the notation defined in [Vignier et al, 1995], this problem is noted: FH5, (1,P2,1,P2,1)/R_{nsd}/C_{max}, if the criterion of the scheduling problem is the minimization of the maximum completion time. Figure 3 illustrates this model with the sequence of jobs (J1, J2, J3).

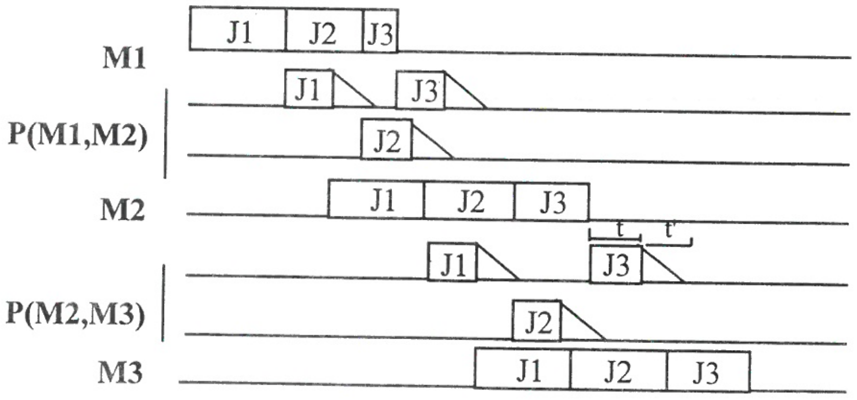

Figure 3. Gantt Representation of This Basic Problem

This basic problem is not realistic at all, but it presents a first step towards a more general FMS problem. We would like to emphasize that when we release each condition separately, a model in terms of HFSP still exists [Collectif, 1996].

3. Description of More General Problems

To consider more and more difficult problems, a step by step modeling approach is now presented. The next sections develop different condition releases.

3.1 Jobshop Model

The FMS flexibility can be associated with the product routings. We now consider a jobshop scheduling problem. Thus, we release condition C1, that means that not all jobs have the same part routing. In the literature, static or dynamic jobshops are solved with polynomial time algorithms or with exact methods based on branch and bound [Conway et al, 1967], [Carlier et al, 1989].

We want to consider a jobshop as a particular flowshop, so we consider a reference part routing, and we can say that any part routing can be modelled as a sequence of several reference routings (including dummy operations, noted 0) subject to precedence constraints (noted →).

Example: We consider the single loop AGV system described in Figure 1, where M1 is considered as the loading and unloading resource of the whole FMS. We consider for example three jobs with the following part routings:

- J1: M1-M2-M3-M4
- J2: M1-M3-M4-M2
- J3: M1-M3-M2-M4

We set the reference routing equal to M1-M2-M3-M4, and we can establish that:

- J1: (M1-M2-M3-M4)
- J2 becomes J2a → J2b with
  - J2a: (M1-0-M3-M4)
  - J2b: (0-M2-0-0)
- J3 becomes J3a → J3b with
  - J3a: (M1-0-M3-0)
  - J3b: (0-M2-0-M4)

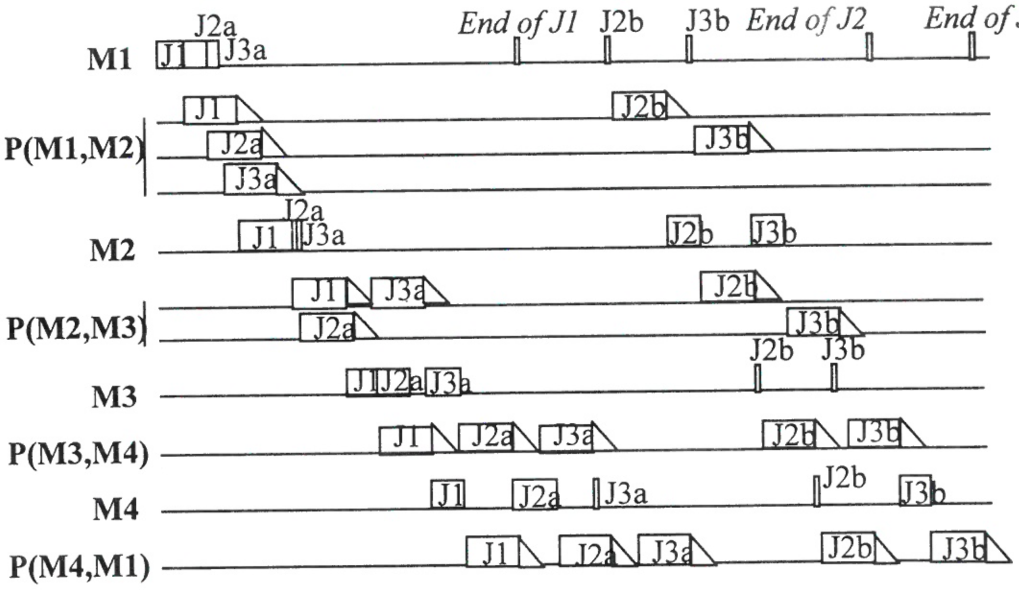

Figure 4. Gantt Representation of A Jobshop Problem in our Studied System

This problem can now be considered as a classical flowshop problem with the following part routings:

- J1: (M1-P(M1,M2)-M2-P(M2,M3)-M3-P(M3,M4)-M4-P(M4,M1))
- J2a: (M1-P(M1,M2)-0-P(M2,M3)-M3-P(M3,M4)-M4-P(M4,M1))
- J2b: (0-P(M1,M2)-M2-P(M2,M3)-0-P(M3,M4)-0-P(M4,M1))
- J3a: (M1-P(M1,M2)-0-P(M2,M3)-M3-P(M3,M4)-0-P(M4,M1))
- J3b: (0-P(M1,M2)-M2-P(M2,M3)-0-P(M3,M4)-M4-P(M4,M1))

and with the following precedence constraints: J2a → J2b and J3a → J3b.

Figure 4 illustrates this jobshop problem if the sequence is (J1, J2, J3).

3.2 AGV Exclusion Area in Front of the Machines

In order to consider this exclusion problem, we release condition C2. In real workshops, generally it is impossible for several AGV to be simultaneously in front of the same machine. To model this constraint, we consider that a pick-up area and a deliver area are both associated with each machine (see Figure 5). Those areas are considered as mutual exclusion areas.

We model these two areas by two dummy resources. The access to those areas is considered as a disjunctive constraint. The first resource is

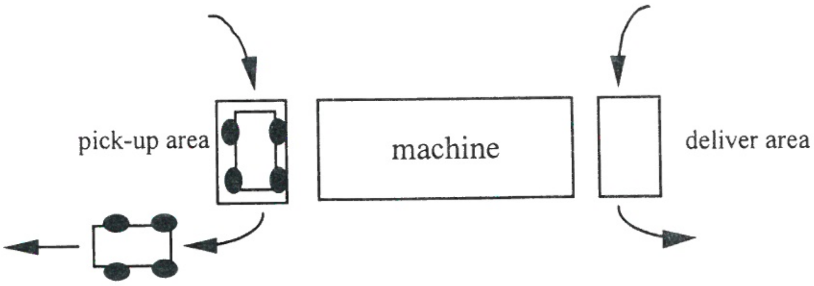

Figure 5. Pick-up and Deliver Areas

called delivery-resource and the second one is called pick-up-resource. A transport operation is modelled with an operation simultaneously involving several resources:

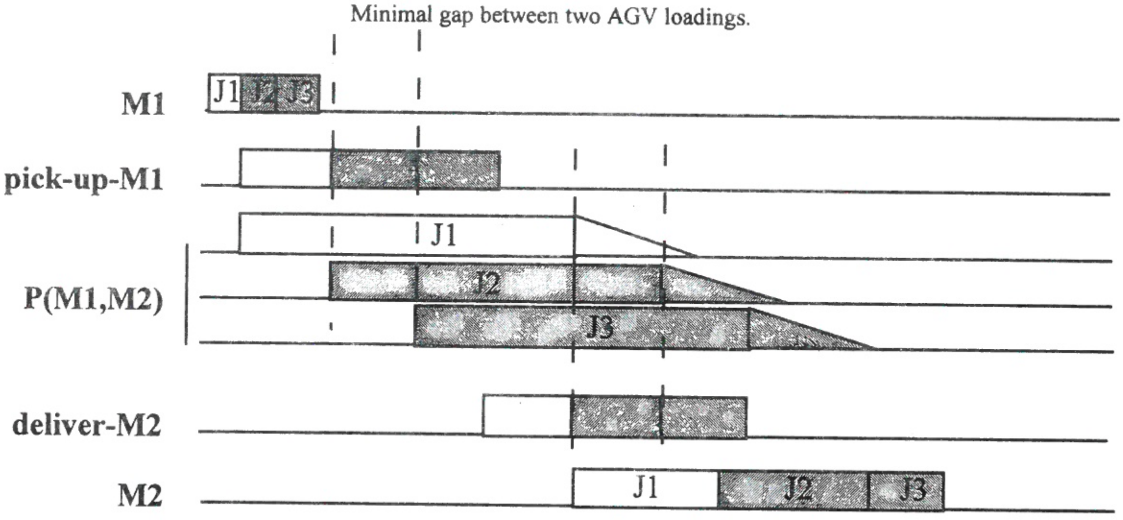

Figure 6. Gantt Representation of Pick-up and Deliver Areas

- the transport operation begins simultaneously on the pick-up-resource and on the AGV resource. Its processing time on the pick-up resource is equal to a constant Tpick-up
- the transport operation ends simultaneously on the AGV resource and on the delivery-resource. Its processing time on the delivery-resource is equal to a constant Tdelivery
- the processing time of the transport operation is equal to the full AGV utilization
- as in the basic model, a removal time not sequence dependent on the AGV resource, corresponds to the time necessary for the AGV to come back to the previous machine.

We set T(pick-up or delivery) = t1 + t2 + t3, where:

- t1 stands for the part loading duration,
- t2 is the time necessary for the AGV to leave the area,
- t3 is the time for the following AGV to be ready for a next load.

Example: We consider only two transformation resources M1 and M2, and the sequence of three jobs on these resources. The pick-up-resource of M2 and the delivery-resource of M1 ensure respectively the AGV exclusion associated with M1 and M2.

4. Conclusion

We have already developed all the steps towards the whole FMS modeling [Collectif, 1996]. An extended review of the resolution methods of hybrid flowshop problems to apply on our FMS problem can be found in [Vignier et al, 1995]. A framework for resolution methods of this class of problems can be found in [Vignier et al, 1996].

In this paper, we emphasize that simultaneous part scheduling and AGV routing problems in FMS can be considered as particular k-stage hybrid flowshop scheduling problems. Under these considerations, we can say that these two kinds of problems are similar, and we propose now to cross the resolution methods associated with HFSP and FMS scheduling problems, with the aim at enriching the literature in these two distant research areas.

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