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Logistics models in flexible manufacturing

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Abstract

An integrated modeling approach that considers the overall production schedule is needed in order to effectively manage different material flows in a flexible manufacturing system (FMS), where large amounts of data intervene in the dynamic control and decision making process. This study focuses on the development of an integrated FMS control model that includes essential features, such as routing of simultaneously processed work orders and batch dispatching, as well as dynamic vehicle path determination and conflict-free routing. A logistics-oriented modeling methodology for FMS distributed control design is proposed that provides the capability for rapid development and evaluation of the control policy. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

A high degree of flexibility and quick response times have become essential features of modern manufacturing systems. Flexible manufacturing systems (FMS) allow for more efficient use of resources in terms of increased machine utilization, reduced work-in-progress inventory, increased productivity, a reduced number of machine tools, lower labor costs, shorter lead times and less floor space [1,3]. This is obtained, however, at the expense of more complex control of these systems. Some of the most recurring and important control tasks are those related to scheduling and dispatching, because it is commonplace in an FMS environment — where many different types of work orders, in varying batch or lot sizes, are produced simultaneously — to find jobs competing simultaneously for the same resource [14], be it an intersection in an automated guided vehicle system (AGVS), machine tool time or access to an automated materials handling system.

In order to maximize total productivity (considered as a mixture of various measures, such as net profit, time delay, and inventory level at local input buffer) of the pre-fixed work orders and their lot sizes, the following issues have to be taken into account.

- Selection of the best configuration at the design stage.
- Selection of an optimal route and workload balancing at the production planning stage.
- Identification of the most efficient scheduling and/or dispatching strategies at the operation stage.
- Handling the information interchange between the components of the distributed manufacturing environment, and the material and information flows.

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Considering the complex nature of the above problems and their domain-dependent solutions, it is virtually impossible to satisfy the requirements, such as manufacturing cycle time, delivery time and batch size limitations, of several simultaneously processed work orders and, at the same time, to decide on the optimal routings, workload balancing, scheduling rules and control strategy. Consequently, a research approach that has been recently followed is to develop a framework for considering all this issues in a unified manner. Examples of such a unified approach include scheduling for a materials handling system [13], as well as work-order routing and workload balancing [6]. This approach offers a broader perspective for evaluating system performance and for describing possible schemes for managing the workflows within the system [10].

In order to characterize production processes from a logistic point of view, close attention has to be paid to the problem of synchronized manufacturing [12]. The concept of synchronized manufacturing is built around the postulate that the shortest throughput time gives the maximum profit rather than following a more traditional view where resources must be kept busy all the time. Its main idea derives from the optimized production technology (OPT) method that predicts where bottlenecks will appear and uses them to control output [11,15]. In other words, instead of balancing capacity, which is inefficient, the FMS should be a balancing flow. Flow balancing, in turn, guarantees that all resources are produced at the same relative rate while no resource is overloaded, resulting in minimum inventory.

In this study we propose some generalizations of previous contributions to the concept of synchronized manufacturing [4,5,8,16]. We emphasize, in particular, the role of a logistics approach to process control (i.e. the role auxiliary processes such as transportation, materials handling and diagnostics repair processes play in flexible manufacturing) from the point of view of distributed bottleneck (i.e. critical resource) control. The main objective of the study is the development of conditions sufficient for a cyclic steady-state operation of a system composed of a set of sequential cyclic processes, and not only of the regular mesh-like structures [9]. The discussion focuses on the conditions guaranteeing the cyclic steady-state behavior of an FMS, which provide a formal basis for the distributed control strategy. The problem of distributed system control is seen as a problem of defining a set of rules (laws) that locally constrain the way the distributed processes (e.g. workflows, AGVS, repair processes) interact with each other so as to guarantee the desired performance of a whole system. The resulting system may be considered as a self-synchronized system, by which we mean a system capable of returning to a unique steady state from any state it was forced into as a result of an accidental disturbance. The self-synchronization paradigm allows us to construct an FMS that has the required functional properties, and opens up the possibility of building distributed systems that can be dynamically rescheduled.

2. Repetitive manufacturing

2.1. Logistics of materials flow

Let us consider an FMS composed of workstations linked by an AGVS as shown in Fig. 1. Four kinds of products are processed along with the following production routes.

$$P_1 = B_1, M_1, B_3, M_2, B_4,$$
$$P_2 = B_6, M_3, M_1, B_5, M_4, \qquad P_3 = B_2, M_4, B_3,$$
$$P_4 = B_2, M_5, B_3$$

Each machine and buffer is served by a dedicated set of AGVS. Each particular workflow follows a unique path in the AGVS network. The routes RP_i, $i = \overline{1,4}$ of AGVS dedicated to particular workflows are as follows.

$$RP_1 = A, B, \qquad RP_2 = D, C, B,$$
$$RP_3 = E, F, B, D, \qquad RP_4 = E, G, B, D$$

Since the workflows share common resources (Fig. 2a), the dispatching rules have to be applied locally so as to avoid process starvation. This means that instead of smooth automatic-line-like workflows, one may observe repetitive flow interruptions. The same applies to the AGVS. Processes are defined here as sequentially executed operations following a given production route or a given transportation path. The workflows take into account different batch sizes and job flow control, such as pipeline-like control.