# A STATE VARIABLE APPROACH FOR THE MODELING AND CONTROL OF FLEXIBLE MANUFACTURING SYSTEMS

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In this paper we present a new approach for the modeling and control of flexible manufacturing systems (FMS) characterized by unreliable machines, buffers of finite capacity, arbitrary service time distributions and deterministic sequencing and routing policies. Our main goal is the design of the FMS configuration embedded with its optimum control policy. The problem is addressed using first and second order fluid approximation obtained by splitting the process in two hierarchical layers and defining what we call micro and macro events. With an original approach this fluid approximation lends itself to a discrete time linear stochastic state variable model which offers average values and variances of both performance measures and of their gradients with respect to the most significant FMS parameters. Finally we investigate problems concerning the non-differentiability of the performance indices with respect to certain design parameters, specifically the control parameters as they appear as structural elements of the model.

## 1 Introduction

An FMS is a queueing network system where different classes of products are processed contemporaneously. Each product has to perform its own orderly sequence of operations, different for each class, in order to be completed. The same machine can perform operations on different product classes, eventually with different service times. The same operation can be performed on alternative machines. Flexibility is the capability of the FMS to cope in time with changing product class blend and production inconveniences such as buffer blockages and machine breakdowns, maintaining optimum production target, machine load balance and, if required, an assigned production mix.

The evolution in time of the FMS will be discussed within a framework that distinguishes two levels of aggregation. The lower layer represents the microscopic behavior of arrivals and departures of parts to/from each machine (*micro events*). It will be modeled in an aggregate view by using first and second order fluid approximation. At the higher layer a discrete event model will represent the transitions of the FMS through a sequence of operational states, that we call *macro states*, at the occurrence of the *macro events*. The degrees of freedom of an FMS are exploited by its control system by dynamically changing routing and priority of parts according to their class as a function of the current operational state of the shop-floor. The control is composed of two parts: a dispatcher and a monitoring system. During the permanence into each macro state, the dispatcher will perform myopically with heuristic rules based on the current state configuration, by sequencing parts waiting in the buffers and by routing them at the exit of the machines according to their class. Similar ideas have been already adopted in their developments by Chen and Yao [2]. At the same time the monitoring system will detect macro events and will dictate the transition into a new macro state. The overall control behavior along with its heuristics will be accounted for in an aggregate view by assuming that at the occurrence of any macro event new reference values of all average flow rates will be computed for each product class as the solution of a linear programming (LP) problem. Then these reference values will be guaranteed by the control during the macro state.

The main contribution of our work is to represent both layers of the process by a discrete time linear stochastic state variable model that can be used to evaluate average values and variances of both performance measures and of their gradients with respect to the design parameters. A further result of this modeling approach consists in a neat presentation of the non-differentiability of performances with respect to certain parameters of the model, as already observed by other authors [10]. Finally this model avoids any other non-differentiability problem related to the perturbations made on structural parameters [5], such as routing coefficients and priority sequencing, as they are embedded along with the control law directly in the model, hence they are no more independent parameters.

### 1.1 Previous Results

A substantial body of literature about DEDS is concerning the analysis of production lines. Even so analytic results for the more general settings discussed here are available only for lines composed of 2 and 3 machines, while the analysis of longer lines involves the use of approximate