A timed route reformulation for detailed production planning in semiconductor manufacturing

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1 Introduction

Semiconductor manufacturing is probably the most complex industrial environment. Wafer manufacturing aims at producing chips on wafers in front-end facilities. Wafers are later cut, sorted and packaged in back-end facilities to make Integrated Circuits. European semiconductor manufacturing facilities have to deal with orders of limited size for hundreds of products (low volume/high mix). Furthermore, each product has to go through a sequence (route) of hundreds of process operations on hundreds of heterogeneous machines. In its route, a product may be processed on the same workshop more than forty times. Cycle times range from 6 weeks to 3 months. In this capital-intensive context, quickly determining relevant optimal production plans that take machine congestion into account is an important and complex task. In production planning, quantities of products to be started at each period of the planning horizon must be determined to meet demands at the lowest cost or maximum profit while satisfying capacity constraints on resources. A detailed production plan aims at allocating capacities to products on their production routes. A large part of the research literature in semiconductor manufacturing has focused on modeling congestion effects. A first approach is to use fixed Lead Times (LT), i.e. a fixed delay in number of periods between the arrival of products at a given operation and their completion time. However, fixed lead times do not take into account that the actual lead times depend on the production quantities of the different products. In 1996, [3] tackles this circularity issue by proposing an approach that iterates between an optimization model and a simulation model. The optimization model optimizes the production plan given fixed lead times, and the simulation model updates the lead times given a production plan. Another and more recent way to model congestion is the use of Clearing functions, which are non-linear functions that determine the output according to the resource workload (see e.g. [1]).

2 Concept of timed routes

In this work, we present a reformulation of the classical production planning model presented in [2] by using the concept of timed routes. Compared to a production route, which corresponds to a sequence of operations for a product, a timed route adds the information on the period in which each operation will be performed. As shown in Figure 1, a timed route can be considered as an allocation of operations to time periods.

When solving a mathematical model relying on timed routes and from a production planning point of view, the flows of product quantities are fully determined, together with how the production capacity is used.

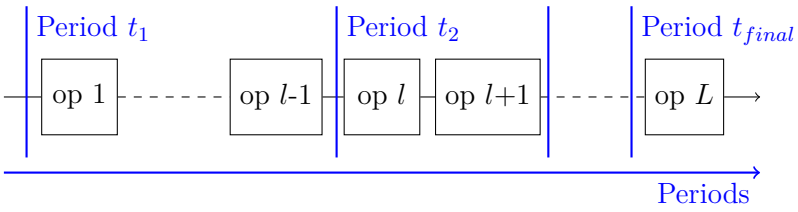

FIG. 1 – A timed route

3 A column generation approach

If the set of all possible timed routes is available, solving the production planning problem is equivalent to determining which product quantities are assigned to each timed route, subject to the demand and capacity constraints. The timed route mathematical model is compared with classical models by solving them using a commercial solver, and with an objective function that minimizes backlog, inventory and work-in-process costs.

To solve the time routed model, the entire set of possible timed routes must be determined. When considering fixed lead times, it can be done with a polynomial time algorithm. However, when using flexible lead times (which may be longer than a minimal lead time), the number of timed routes becomes exponential. To deal with this issue, a column generation approach is proposed, which is shown to be effective. In particular, the CPU time needed to generate timed routes can be highly reduced using a dynamic program with a dominance rule.

4 Conclusions and perspectives

In this work, a new mathematical formulation for a production planning problem in semiconductor manufacturing is proposed. This formulation is solved using a column generation approach when the number of timed routes is exponential. Numerical experiments on industrial data sets are being conduct to validate the approach. Furthermore, the new formulation and the column generation approach allow new industrially relevant constraints on timed routes (e.g. maximal and minimal cycle times) or alternative pricing of timed routes to be considered.

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