Timed Route Approaches for Production Planning with Time Constraints

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1 Context, problem statement and motivation

Semiconductor manufacturing processes are probably the most complex manufacturing processes in the world. They are characterized by long cycle times, a very large number of operations (more than 1,000 for some product routes) that require hundreds of different machines to process a large volume of wafers constantly circulating in the manufacturing facility, called fabs. The notion of time constraints increases the complexity of the management of semiconductor fabs. These time constraints are defined between two processing steps (consecutive or not), where a lot must respect a maximum time between these two processing steps to ensure the quality of the wafers in the lot. A time constraint might "cover" more than 20 operations.

Our problem is a multi-product, multi-step, multi-machine production planning problem. Each product has a route, i.e. needs to perform a certain sequence of processing steps, and each step has a processing duration and can be performed by multiple machines. In addition, time constraints overlapping two or more steps need to be respected. The goal is to minimize the work in process (WIP), inventory and backlog costs.

Mathematical programming methods can be used to solve production planning problems with limited capacity and fixed lead times [5]. As modeling with fixed lead times has limitations, in particular in correctly using production capacity, workload dependent lead times using clearing functions and simulations [2] have been proposed. Robust optimization [1] and flexible lead times [4] have also been proposed.

This work focuses on the integration of time constraints and practical considerations in tactical production planning using the notion of timed routes and the column generation approach introduced in [3]. Moreover, industrial instances are used to validate the proposed approach. Timed routes are product routes with a time period assigned to each processing step. We extend the column generation approach of [3] to take industrial constraints, including time constraints, into account.

2 Solution approach

As the duration of critical time constraints is usually smaller than one day, the time period in the planning horizon should be at most one day. For similar reasons, when considering time constraints, detailed machines should be taken into account and not only workshops (set of machines) as in [3]. In addition, as a wafer fab is never empty, the initial Work-In-Process (i.e. products already started and waiting in front of machines or being processed) should be considered. Three mathematical models were proposed.

First, we extended the fixed lead time model introduced in [3]. This model ensures, by definition of the fixed lead times, that the time constraints are respected. However, the lack of flexibility of fixed lead times makes the model not relevant. Modeling flexible lead times instead makes the model too large, and thus too slow to solve with a standard solver.

To face this problem, [3] introduces the concept of timed routes. As already explained, a Timed Route (TR) is a route in which every processing step is assigned to a period. We extend this concept to Machine Timed Route (MTR), where the machine on which to process each step is also specified. Thus two different models have been proposed: **(i)** a TR model where TR patterns are used to solve a linear programming model, where the quantity to process on each TR and the machines assigned to each step of the TR are optimized and **(ii)** a MTR model where MTR patterns are used to solve a linear programming model where “only” the quantity to be processed on each MTR is optimized.

To solve these two models, the column generation approach of [3] is extended. An initial set of TR and MTR is generated using historical data, and new TR and MTR are generated by solving the pricing problem and using similar dominance properties as in [3]. In addition, time constraints are implemented as constraints to be respected when generating new timed routes and machine time routes.

The three models have been compared using industrial instances. The numerical results, that will be presented in the conference, show that the MTR model outperforms the fixed lead time model and the TR model in terms of computational time, but also of solution quality. As expected, time constraints have a negative impact on the quality of the optimized production plans as they reduce the capacity to fulfill the demand.

3 Conclusions and perspectives

The timed route model and the column generation approach proposed in [3] have been extended at the machine level considering periods of one day and to consider additional industrial constraints, including time constraints. Computational experiments on industrial instances show that the MTR model performs very well.

This work has multiple perspectives. The initialization of the TR model and the MTR model could be improved by proposing a better set of initial patterns. In addition, considering periods of different lengths should be relevant to optimize production plans on longer horizons. This is particularly relevant in semiconductor manufacturing where products have very long cycle times.

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