Summary

Dynamic Performance of Hierarchical Planning Systems:
Modeling and Evaluation with Dynamic Planned Lead Times

Within the last few decades, supply chain practitioners have faced major challenges in planning manufacturing and logistics operations that are confronted with a high degree of uncertainty as a result of highly dynamic market conditions. At the same time, there has been a growing awareness on the potential applications of rapid advances in data processing and communication technology. As a result, the attention for new concepts and solution methodologies has increased not only in business management but also in scientific community. Integration of various business units and improved coordination of material and information flows along the supply chain have become essential for the companies to stay competitive in the market. In response to these conceptual requirements, advanced planning systems have been introduced, which are constructed along the principles of hierarchical planning.

Hierarchical planning has been a predominant mode for production planning both in academic research and in industrial practice. It is a management philosophy that is based on the decomposition of a large complex planning problem into small and manageable subproblems. Since the late seventies, the research on hierarchical planning has evolved in various directions mainly concentrating on perfect aggregation and disaggregation issues, and the efficiency of hierarchical decomposition with respect to monolithic models in static (mostly deterministic) settings. There have been recent conceptual advances emphasizing the coordination of different production units and different decision functions both from a material flow and from an information flow perspective. However, the research on the dynamic performance of hierarchical planning systems is quite scarce.

The word dynamic refers to plan-execute-feedback-(re)plan cycle. That is, the planning process is described as a series of decisions taken consecutively in time, and additionally, the planning parameters are subject to changes during
the course of time. Accordingly, the performance evaluation is conducted in a dynamic setting. The performance of the planning decisions given for a single problem instance is not only evaluated based on the status information at the time of decision, but based on their effects on the actual system status changing through time, about which exact information is not available at the time of decision. This aspect becomes essential if there is considerable variability and uncertainty in the demand and production processes. From a practical point of view, rolling horizons are used to keep the system status up-to-date. For an APS that is based on data from an ERP system, all the relevant information e.g. stocks, work-in-process, etc. that is needed to update the plan is continuously available.

There is a positive duration of time between the moment that an order is released to its production unit and that order is available in its stock point, which is referred to as flow time. In planning the release of orders, the flow time is represented by a parameter, which is referred to as planned lead time. In coordinating the flow of materials in a supply chain, planned lead times are indispensable. The traditional approach is to consider the planned lead times as fixed inputs, exogenous to the planning system. However, flow times are generally not fixed, and depend on various factors such as the level of process uncertainty, the workloads in the production units, capacity flexibility, and the sizes of the released orders. It can therefore be argued that status feedback can be used to anticipate the flow times of order releases. It is interesting to consider updating the planned lead times regularly in order to represent the dynamic characteristics of flow times in the planning system.

In this thesis, our objective is to shed some formal light on the dynamic performance of hierarchical planning systems, where our focus is on the coordination of the flow of materials in a supply chain using dynamic planned lead times. The hierarchical planning systems constructed in this thesis are mainly composed of three different decision levels:

- **Tactical Planning**: Planned lead times for each item are determined at this level as integer multiples of a period.

- **Operational Planning**: An MP formulation is provided to decide on periodic order releases, production quantities, and stock levels for each item to satisfy periodic demand forecasts. The objective is to minimize material holding costs given that a target service level (e.g., demand fill rate) is achieved.

- **Operational Scheduling**: Detailed, execution related decisions such as schedule of released orders at each production unit based on the given planned
lead times, and quantities of materials to be loaded to the shop floor at each production unit are given in a decentralized manner.

The performance is measured along two lines:

- **External**: Expressed in terms of the average (periodic) costs such that a predefined customer service level is met.

- **Internal**: Measures the level of consistency between the higher and the lower level planning outcomes.

Related to the use of status feedback and the integration of different decision levels within the planning hierarchy, three different factors that determine the dynamic performance are considered. These are:

- The **frequency** of updating the planned lead times.

- **Anticipation** on the characteristics of the production processes, which are controlled by lower level planning decisions.

- The type of **coupling** between the higher and the lower level decision models in the planning hierarchy.

In the thesis, we first describe the performance consequences of updating the planned lead times. Then, we model dynamic planned lead times such that the relationship between workload levels, throughput quantities, and flow times is considered to realize effectiveness in the flow of materials within a supply chain.

As a first step, using simulation, we show the effects of updating the planned lead times in a multi-stage production-inventory situation. A two-stage serial supply chain is considered, where only the final product planned lead times are updated based on exponentially smoothed averages of the history of actual flow times. Exponential smoothing is considered as a relevant method in estimating the flow times due to a high level of correlation between the flow times of consecutive orders especially when the scheduling discipline is FCFS. Our results indicate that frequently updating the planned lead times leads to erratic order releases with large variation in inventory levels and very long planned lead times. This phenomenon has conceptually been defined as **lead time syndrome** in the literature, and we provide a formal analysis concentrating on the update frequency and the anticipation on production capacity.

We enhance the discussion on the lead time syndrome by providing an analytical evaluation of the phenomenon. A single-stage, single-item produce-to-order situation is considered with the order releases sensitive to the planned
lead time, which is determined according to the number of jobs present in the system. The situation is modeled by a two-dimensional Markov process that is solved by using the matrix-geometric methods. Analytical results on the utilization level and the variability in the system are presented in relation to various design parameters such as the update frequency, and the degree with which the planning system responds to changes in the planned lead time. We have achieved closed form solutions yielding insights that the static utilization level is retained in the dynamic case irrespective of the update frequency when the response function is symmetric, the average backlog size is bigger for higher update frequencies, and on average, jobs spend more time in the system in the dynamic case.

It is shown that updating the planned lead times in planning and coordinating the flow of materials in a supply chain is a challenging task. Naive approaches based on exponential smoothing of realized order flow times, or simple workload dependent rules do not work. In a hierarchical planning system employed in a dynamic setting, the planned lead times that are updated at a higher-level and used to release the orders at a lower-level may cause erratic order releases and increased congestion in the production unit. Thus, there is need for developing more advanced tools to consider the dynamic behavior of production processes in releasing the orders. For this purpose, we use the concept of clearing function to anticipate the flow times of planned order releases, and determine appropriate production quantities at the operational planning level. We first provide a detailed understanding on the relative effects of different clearing functions when the planned lead times are fixed. A single-item produced in a production unit and kept in a stock point facing a stochastic non-stationary demand is considered. Using simulation, clearing functions arising from different modeling approaches are tested based on the internal and the external performance measures. The results indicate that modeling the clearing of WIP should be based on the short-term operational dynamics of the production unit.

Following, we provide insights into the effectiveness of updating the planned lead times of a supply chain in a hierarchical planning context using the clearing function concept. A two-stage serial supply chain is considered, where the capacity loading decisions are separated from the order release decisions, and depend on the hierarchical coupling mechanism. Final product demand is non-stationary, and follows a seasonal pattern. A parameter $\varepsilon$ is introduced in modeling a piecewise-linear approximation of the clearing function. Through $\varepsilon$, various anticipation approaches on the production processes can be implemented. Simulation experiments are performed for dynamic and fixed planned lead times under changing demand uncertainty, clearing structure and hier-
archical coupling. The results indicate that, in conjunction with the concept of clearing, updating the planned lead times provides the flexibility under fluctuating demand conditions, and generates less costly solutions.

The results presented throughout the thesis indicate the need for further research about planning supply chain operations through dynamic and adaptive decision tools. We suggest some ideas for future research topics such as extending the analysis on the lead time syndrome to multi-stage production-inventory situations, enhancing the discussion on realistic clearing functions towards optimal clearing functions by further elaboration of the parameter $\varepsilon$, and developing more efficient updating procedures for planned lead times.