Periodic Capacity Management under a Lead-time Performance Constraint

N. Cagdas Buyukkaramikli, J. Will Bertrand, Henny P.G. van Ooijen
Technical University of Eindhoven,
Industrial Engineering and Innovation Sciences Department

In order to have a manageable planning model for supply chains, assumptions are frequently made about the throughput time of a job order in a production system. One such assumption is to take the throughput time as fixed. This assumingly fixed time is often referred to as the *lead time*, and it can either be dictated externally or resulted from contractual agreements made between the production system management and its customers in the supply chain.

In reality, job order throughput times are stochastic due to the inherent uncertainties of the system (*e.g.* uncertainty in demand or in production times). These uncertainties create a risk that the agreed lead time of a job order is not met. It is a common knowledge that on-time delivery is one of the most important determining metrics for success in supply chains. Therefore, supply chain parties often operate with long enough lead times in order to avoid late deliveries as much as possible. On the other hand, the fierce competition in the business environment puts pressure on supply chain parties to respond quickly to demands, which results in short lead times.

Accordingly, the supply chain managers are inclined to set targets for short and reliable lead times. These targets are then communicated to the shop floor managers in the form of service level agreements (SLA's). There are different forms of SLA's, but we are interested in the SLA that guarantees the completion of a job order within a pre-determined lead time (*e.g.* 1 week) with a certain (*e.g.* 95%) probability. After a SLA requirement is communicated, it is expected from shop floor manager to attain this lead time performance constraint at the lowest possible operating costs. As these targets get more ambitious (*i.e.* a more ambitious SLA either dictates a shorter lead time or a better on-time delivery performance), more capacity may be needed, which would lead to higher operating costs.

Under these circumstances, capacity flexibility can play a soothing role for the operational level that is stuck between the conflicting objectives of attaining ambitious lead time performance targets and to reduce the operating costs. Actually, in the presence of demand uncertainty, capacity flexibility can be of high value to avoid under-utilization of the capacity. Empirical studies show that capacity flexible policies (*e.g.* flexible staffing, under/over working hours, outsourcing) are commonly used in the manufacturing as well as service industries.

For various reasons, flexible capacity practices in real life are often periodic. Firstly, a company's reach to the external capacity pool may be restricted to certain specific times like the start of a day or a week. Secondly, decisions about working times (e.g. working over/under time) are often taken on a periodic basis, in order to abide to labour regulations and to accomplish the timely communication of these working time decisions to the relevant employees. In addition, periodic flexible capacity policies are compatible with the modus operandi of resource planning software systems, most of which also operates on a periodic basis due to decision-information synchronization issues. For instance, a ground-handling company in Turkey uses a software system that creates weekly work schedules for its employees. Within the software, weekly workforce size (in terms of total working hours) can be adjusted based on the flight traffic. Similarly, a German car manufacturer and a lighting equipment manufacturer in the Netherlands, make use of capacity control techniques such as hiring of temporary workers, implementing variable working hours, employing multifunctional employees and shifting work internally in order to deliver the customer orders on time. These capacity control actions are taken periodically, in the most ambitious case, on a daily basis.[1]

Motivated by these observations, in this paper, we analyze the periodic flexible capacity control problem for production systems which operate under a fixed lead time and a delivery performance target. Orders arrive according to a stationary Poisson process and each job order requires a random processing time. We primarily focus on the cost reductions that can be achieved by using flexible capacity policies. For the sake of convenience and practicality, we assume two levels of capacity: permanent and contingent capacity.

At the start of each period, the production manager decides whether or not to deploy the contingent capacity for that period. This decision is based on the workload in the system at the decision instant. The contingent capacity must be available and ready to be deployed at the start of each period before the production system's decision. Contingent capacity is a shared resource that can be used by other systems, therefore the uncertainty on the use of the contingent capacity creates an opportunity cost, since it could be deployed somewhere else if it was not reserved for the production system. This opportunity cost makes per time unit cost for contingent capacity larger than the permanent capacity cost, particularly for shorter period lengths.

---

[1] Some of the company names are not mentioned for confidentiality.

For a given permanent/contingent capacity cost structure, production manager tries to minimize capacity related operational costs while satisfying the lead time performance constraint. Decision variables are the frequency of making capacity decisions, the size of permanent capacity, the size of contingent capacity and the workloads at which the contingent capacity is deployed.

In order to analyze this problem, we develop a queuing model of the production system where the service rate is updated periodically. The transient behaviour of this queuing system is needed in order to derive the necessary performance characteristics. We use a computational approach to assess the performance of two-level, threshold type, periodic capacity policies under different decision frequencies (period lengths) and permanent/contingent capacity cost structures and lead time performance constraints. Due to the cost structure of the permanent and contingent capacity, the behavior of the operational costs changes drastically under different period lengths. In our computational study, we observe that the periodic capacity management reduces the operational costs significantly. The percentage savings are higher for more ambitious lead time performance constraints.