Multi-Item Inventory Systems with Selective Use of Imperfect AdvanceDemand Information

Engin Topan, Geert-Jan van Houtum, Tarkan Tan

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We consider a multi-item inventory system where it is possible to collect information about the quantity and timing of future demand of items in advance. A typical example is original equipment manufacturers (OEM) providing after sales services for advanced capital goods that have critical functions in production of goods and services such as trains, ships, airplanes, trucks, baggage handling systems, MRI-scanners, wind turbines, construction machines, etc. Inherently, breakdowns of these systems may lead to high down-time costs for the users, therefore, a high system availability is needed. To ensure uninterrupted system availability, the supplier stores multiple types of spare parts for critical components, whose failure may cause system failure. Nevertheless, spare parts of these complex systems, especially the critical ones, are often very expensive, thus, storing even one part can be very costly. Therefore, it is desirable to keep low stock, zero if possible, while maintaining the availability of parts. This can be achieved to some extent by implementing a condition monitoring (CM) system which can provide advance demand information (ADI) for parts being monitored.

Motivated by a real-life application at ASML, a world-leading original equipment manufacturer (OEM) producing lithography systems for the semiconductor industry, we consider a setting where it is possible to monitor critical components at a certain per-component condition monitoring cost (CM). We focus on the use of CM for the optimal control of spare parts supply for its multiple type of critical components. The ADI available via monitoring can be used to predict the failures and also to issue a demand signal for spare parts in advance. This can then be used to optimize the spare parts supply decisions. Nevertheless, the use of these demand signals raises two main issues: First, demand signals that are produced by condition monitoring can be imperfect in three ways: (i) the prediction model sometimes produces false demand signals or so called *false positives*, in which the model predicts a failure but actually no failure occurs; (ii) there are also sudden, unpredicted demand occurrences that cannot be detected by CM, e.g., a failure as an outcome of an unexpected incidence such as an operator error, material impurity, etc; (iii) exact timing of the demand realization or literally the demand lead time -time between when a signal first appears and when it turns into an actual demand- is not known. Second, when monitoring is employed, a certain monitoring cost is incurred for each component being monitored. This may include investment and operating costs of sensors, data storing and processing costs, personnel costs for analysis and inspection. These two issues indicate that the benefit of using ADI may depend on the reliability of information, ratio of predicted demand over total demand, average demand lead time and cost of monitoring per component and therefore, ADI may not be worthwhile for some components.

We propose a multi-item, single-location, continuous review inventory system with a general representation of imperfect ADI. subject to high availability requirements, formulated by a maximum system-wide target for the total down-time. To achieve that target, there are two alternative policies, namely, demand-driven supply (without ADI) and proactive supply (with ADI). In the demand-driven supply policy, the inventory system operates with a given inventory policy for each part. If a part is available on stock, demand is immediately satisfied from stock whereas unmet demand is satisfied by an emergency shipment within a negligible lead time at a certain emergency cost. In the proactive supply policy, just like the demand-driven supply policy, the system operates with a given inventory policy and when a part is out of stock unmet demand is satisfied by an emergency shipment. The proactive supply policy policy differs in three sense: In the proactive supply policy information, (i) the ADI provided via monitoring is used to predict the future demand for spare parts, which is then proactively used to optimize the spare parts stock and this leads to a more sophisticated state-dependent policy. (ii) This comes with a certain monitoring cost. (iii) The proactive orders given for demand signals which turns out to be false later leads to accumulation of excess inventory. There we allow excess inventory on stock and on order to be returned to the central depot or external supplier at a certain return cost. For both proactive and demand driven policies, demand for each spare part follows a Poisson process, lead times have an exponential distribution. For proactive supply policy, demand signals follows a Poisson process.

Under this problem setting, our objectives are (1) to determine the parts for which ADI should be collected (or CM is employed), (2) to determine the optimal inventory policy for parts with or without ADI, and (3) to find the optimal values of the policy parameters associated with each selected optimal policy such the total CM, inventory holding, emergency, and return costs is minimized subject to the total down-time (system availability) constraint. We formulate a Markov Decision process to determine the optimal policy (objective 2). Using this model, we characterize the optimal ordering and return policy for the proactive supply policy and the optimal ordering policy for the demand-driven supply policy. After defining the optimal policies for each with ADI and without ADI cases and taking them as given, we propose a solution procedure to determine the items for which ADI should be collected (objective 1) and to find the optimal values of the policy parameters for each part (objective 3). Our solution procedure is based on the Lagrangian decomposition of the multi-item inventory model to obtain a dual solution or equivalently a lower bound for the optimal total cost and then applying a greedy algorithm to generate an integer feasible solution starting from that lower bound. The method is known for its high performance in multi-item inventory models with a total down-time target. It also allows decomposing the problem into single-item problems, which brings a computational efficiency. In this paper, we use this method for a multi-item inventory model with imperfect ADI.

Our paper contributes to the literature in three ways: First, we provide a recipe for a typical supplier who wants to use CM information in planning the supply of spare parts for its critical component by proposing an efficient and effective solution procedure that can solve practical size problems. Second, in a computational study, we show that (i) the value of imperfect information under the system availability constraint is high, (ii) the system availability constraint is quite influential on decisions about optimal selection of CM and optimal values of the policy parameters and also total cost, (iii) imperfectness of the information as well as some system parameters are found to be quite influential on the optimal decisions. Third, based on the numerical results, we develop several interesting results about the consequences of using ADI in our setting, which can be very useful in design and improvement of such systems. Our observations are important for capital goods manufacturers who consider selective use of condition monitoring for multiple components. We numerically show that it performs quite well also for our case. We also show that the lower bound obtained by Lagrangian decomposition is asymptotically tight and the heuristic is asymptotically optimal in the number of items.