Robust Spare Parts Inventory Management with Emergency Shipments

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We study the spare parts inventory control problem under high demand uncertainty, particularly during the new product introduction (NPI) stage when historical demand data is scarce. To mitigate stockouts and achieve a low target waiting time, we satisfy unfulfilled demand through emergency shipments. Most state-of-the-art stochastic models rely on demand distribution assumptions that may not hold in the NPI stage, limiting their effectiveness in addressing the challenges of high demand uncertainty.

We formulate a multi-item spare parts inventory control problem as an adaptive robust optimization (ARO) model. To ensure computational tractability, we reformulate the ARO model as a deterministic counterpart and prove that it can be decomposed into two mixed-integer optimization problems. We then develop an efficient algorithm to obtain near-optimal solutions for large-scale problems with thousands of items. When limited demand data is available, we propose an approach that incorporates initial failure rate estimates from engineers into the uncertainty set construction, which enhances the model's performance in the NPI stage. We demonstrate the practical value of our model through a comprehensive case study at ASML, a leading semiconductor equipment supplier.

The case study shows that our model achieves a simulated mean waiting time up to 3.5 hours shorter than the state-of-the-art stochastic model employed at ASML at the same simulated total cost, potentially saving over €250,000 in lost production per breakdown of an expensive lithography system.