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INTEGRATED MODELING AND OPTIMIZATION OF SPARE PART LOGISTIC OPERATIONS AND CONDITION-BASED MAINTENANCE POLICIES IN A SYSTEM OF GEOGRAPHICALLY DISTRIBUTED ASSETS

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ABSTRACT

This study presents joint optimization of Spare Parts Logistics (SPL) operations with condition-based maintenance (CBM) policies in a system of geographically distributed assets, each consisting of multiple degrading parts. The model considers facility location selection, network connectivity design, inventory levels for replenishment triggering, and CBM policies that minimize overall system operating costs. The solution is implemented as a sequential model consisting of two stages: the initial stage utilizes mathematical programming for facility location selection and network design. It is followed by a simulation-based method using Continuous Time Markov Chain to model degradation of spare parts and link it with inventory managements. Additionally, the maintenance operations model includes opportunistic maintenance, which enables further reduction of operating costs. Overall, the newly proposed approach addresses scale limitations and overly restrictive simplifications of previously published models, which enables a more comprehensive operational decision-making.

1 BACKGROUND

Studies on logistic network optimization and preventative maintenance (PM) have been conducted separately for years (Jeet and Kutanoglu 2018; Celen and Djurdjanovic 2020). Recently, there has been a growing interest in explorations of the interactions between PM and inventory management (Wang and Djurdjanovic 2018; Karatas and Kutanoglu 2020). However, existing joint optimization studies often oversimplify system configurations for analytical tractability, or limit system size to enable simulation-based approaches. Our research aims to alleviate aforementioned drawbacks in joint considerations of logistic operations and PM policies in systems of multiple geographically distributed assets, each consisting of multiple degrading components.

2 SEQUENTIAL OPTIMIZATION MODEL

We propose a novel sequential optimization model illustrated in Figure 1. It breaks down the decision-making process into two stages. In the first stage, we adopt the logistic network design model introduced by Jeet and Kutanoglu (2018). It employs a mixed-integer nonlinear programming (MINLP) approach to design a network of SPL centers, each storing multiple parts. In the second stage, we employ Discrete-events Simulation (DES) with a meta-heuristic-based optimization to obtain PM policies and inventory levels at which SPL centers replenish spare parts. The benefits of adopting this modeling and optimization structure are as follows: (1) The first stage efficiently provides a foundation for the optimal network design on a large scale; (2) Given the defined network structure and a more plausible range of inventory, we are computationally capable of developing a joint decision-making of maintenance and inventory management throughout the network system by simulation approach.

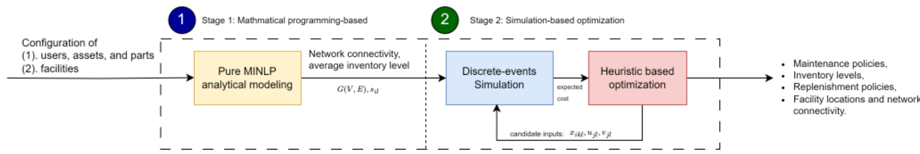

Figure 1: Sequential optimization model framework.

3 RESULTS

Figure 2 illustrates the interaction of SPL logistic and maintenance policies for a single part degrading according to a Markov degradation model. Shorter spare part lead time results in less impacting unscheduled downtimes, allowing a riskier PM policies with part replacements allowing more pronounced degradation. Conversely, longer spare part lead times lead to more severe consequences of part failures and tend to execute earlier PM replacements. Such interdependencies between PM decisions and logistics operations can be observed in multi-asset, multi-part systems as well.

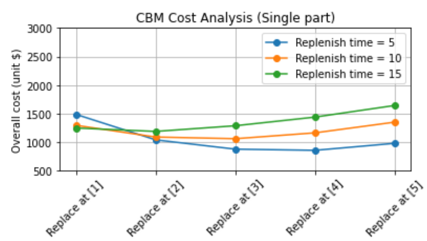

Figure 2: Operation costs for different PM replacement conditions and lead times in a single-part system.

Figure 3 presents a comparison between the PM policies with and without opportunistic maintenance option, demonstrating cost improvements for different spare part lead time situations. It illustrates that benefits of opportunistic maintenance grow with spare part lead times, leading to reduced overall SPL network and maintenance costs.

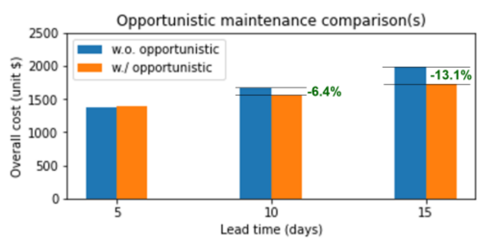

Figure 3: Costs comparison between the maintenance with and without opportunistic maintenance.

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