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An integrated approach to the design and operation for spare parts logistic systems

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A R T I C L E I N F O

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A B S T R A C T

This paper attempts to solve a comprehensive design problem for a spare part logistic system. The design factors encompass *logistic network design, part vendor selection,* and *transportation modes selection.* Two approaches to solve the problem were proposed. In Approach 1, we simultaneously considered all the design factors and proposed two algorithms (SGA-1 and TGA-1). In Approach 2, the design problem was solved in two stages. Firstly, we aimed to find a near-optimal logistic network. Secondly, with the obtained *logistic network,* we proposed three algorithms (SGA-2, TGA-2, and NN-GA-Tabu) to find optimal combinations for part vendor and transportation modes selection. Numerical experiments indicate that Approach 2 outperforms Approach 1, and the NN-GA-Tabu outperforms all the other four algorithms. The proposed NN-GA-Tabu might also be a good solution architecture for solving other comprehensive space search problems.

1. Introduction

Spare part management is a very important issue for capitally-intensive industries (e.g., semiconductor manufacturing, aerospace, defense, and high-speed train). Building a leading-edge semiconductor wafer fab may cost up to 2 billion dollars; and the associated spare parts inventory may need 10–15% of the total expenditure. Other capitally-intensive industries also reveal the same characteristics. Thus, the design and operation of a spare part logistic system is very important for these industries.

A spare part logistic system (also called a *logistic network*) typically involves a group of stations that are hierarchically structured as shown in Fig. 1. In the hierarchy, terminal stations, essentially designed to repair machines in the service field, are equipped with machine-repairing staffs and spare parts inventory. Other higher-layer stations are designed to store and repair spare parts in order to supply spare parts to terminal stations. Parts delivery between any two stations needs a transportation time. In literature, such a logistic network is characterized as a *multi-echelon system* (Sherbrooke, 1968)

As shown in Fig. 2, a machine typically comprises a hierarchical assembly of parts – called *bill of materials* (BOM). In literature, a spare part logistic system that considers only one kind of part is called a *single-indenture* system. In contrast, a *multi-indenture* system is a spare part logistic system that considers a BOM hierarchy involving many kinds of parts. This research is concerned with a *multi-indenture, multi-echelon* (simply called MIME) spare part supply chain system.

Several survey papers on spare part logistics in a MIME system have been published (Guide & Srivastava, 1997; Kennedy, Patterson, & Fredendall, 2002). Prior studies could be essentially grouped in two categories.

One category aimed to find optimal *operation policies* for a given spare part logistic system; that is, how to determine optimal inventory level and repair-staff level for each station in order to reduce the total operational cost. Some assumed that each station is equipped with an *infinite staffing capacity for repairing parts*; and paid attention to the decision of *stocking levels*. The pioneer one is the METRIC model developed by Sherbrooke (1968); many of its extensions have been developed (e.g., Graves, 1985; Muckstadt, 1973; Sherbrooke, 1986). Given a *finite staffing capacity for repairing parts*, some others investigated the decision for optimum *stocking levels* (e.g., Diaz & Fu, 1997; Kim, Shin, & Park, 2000; Perlman, Mehrez, & Kaspi, 2001). Extending the frontier, Sleptchenko, van der Heijden, and van Harten (2003) aimed to solve a more complex problem – finding an optimum combination for both repair-staff capacities and stocking levels.

The other category attempted to find an optimal design for a spare part logistic system. Some aimed to design an optimal logistic network (Candas & Kutanoglu, 2007; Jeet, Kutanoglu, & Partani, 2009; Rappold & van Roo, 2009); some focused on optimal selection of part vendors (Wu & Hsu, 2008); and some others examined optimal selection of transportation modes (Kutanoglu & Lohiya, 2008). Such design factors were only *partially* addressed in prior studies. Their obtained solutions might leave a space for further improvement if more design factors are simultaneously addressed.

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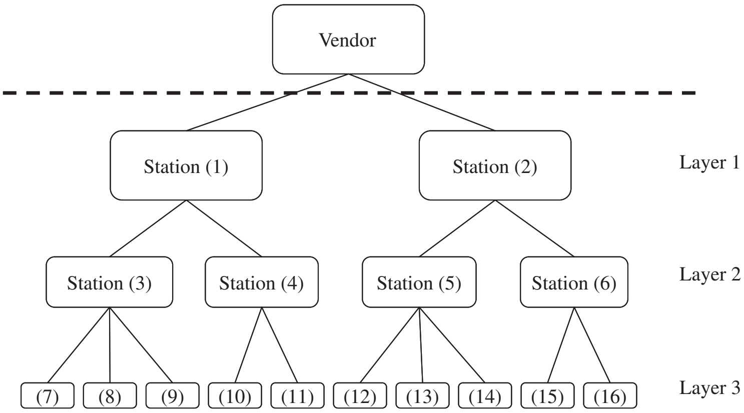

Fig. 1. The hierarchical structure of a logistic network.

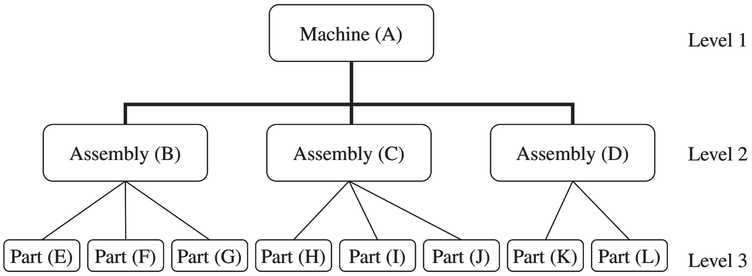

Fig. 2. The BOM hierarchy of each machine.

Yet, such a comprehensive inclusion of design factors may require formidable computational efforts.

In this paper, we attempt to solve a comprehensive design problem for a spare part logistic system. The design factors encompass *logistic network design*, *part vendor selection*, and *transportation modes selection*. Two approaches to solve the problem were proposed.

In Approach 1, all the design factors are *simultaneously* considered. That is, a new solution could be generated by varying the selection for any of the design factors. Based on such a solution representation, two meta-heuristic algorithms were proposed to solve the design problem. The two algorithms, adapted from literature (Goldberg, 1989; Tsai, Liu, & Chou, 2004), are respectively called SGA-1 (simple genetic algorithm in Approach 1) and TGA-1 (Taguchi genetic algorithm in Approach 1).

Approach 2 decomposes the design problems into two subproblems. That is, we solve the design problem in two stages. In stage 1, we focus on finding a near-optimal logistic network, by the application of a technically sound heuristic rule. In stage 2, with the obtained *logistic network*, we proposed three meta-heuristic algorithms to find optimal combinations for part vendor and transportation modes selection. The three algorithms are called SGA-2 (simple genetic algorithm in Approach 2), TGA-2 (Taguchi genetic algorithm in Approach 2), and NN-GA-Tabu (neural network-genetic algorithm-tabu-search).

Numerical experiments indicate that Approach 2 outperforms Approach 1. This advocates the use of a problem-decomposition approach in solving a large-scale problem, if a technically sound heuristic rule can be found. Of the three algorithms in Approach 2, the NN-GA-Tabu outperforms the other two both in solution quality and computation time. We developed the NN-GA-Tabu based on two ideas. First, we develop an *efficient* yet *rough* performance evaluator to quickly justify a solution. Second, we use GA to find a quality solution and then use a tabu-search (a local tuning process) to obtain an improved one.

The remainder of this paper is organized as follows: Section 2 describes the problem in more detail. Section 3 formulates the comprehensive design problem and analyzes possible ways to solve the problem. Section 4 describes the two algorithms in Approach 1. Section 5 describes the solution architecture of Approach 2 and the proposed NN-GA-Tabu algorithm. Experiment results of all the five algorithms are compared in Section 6. Concluding remarks are in the last section.

2. Problem statement

In this research, machines are capitally-intensive and their *availabilities* are very important. Machine availabilities are determined by the installing levels of two resources: (1) spare part inventory and (2) repair-staffs. Having a higher installing level for any of the two resources would lead to higher machine availabilities, yet at a price of incurring higher costs. How to make such a trade-off decision is critical to capitally-intensive industries.

As shown in Fig. 2, the BOM of a machine is a hierarchy comprising many assembly/parts. An assembly/part hereafter is called an *item*. The failure of each item follows a Poisson process. With long-lead times for acquisition, all items if failure need to be repaired. Repair time is an exponential distribution and first-come-first-serve policy is adopted.

The failure of any item in the BOM would lead to machine-down and reduce its availability. Quick replacement of the failure item can alleviate the effect of machine unavailability. This is achievable by installing a high stocking level, yet would incur higher inventory costs. By installing a higher level of repair-staffs, we would shorten the failure duration of items and consequently