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Selecting machines and buffers in unreliable assembly/disassembly manufacturing networks

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ABSTRACT

This paper formulates an optimal design model for assembly/disassembly manufacturing networks. The objective is to maximize production rate subject to a total cost constraint. Machines are chosen from a list of products available on the market, and sizes of the buffers are chosen within a predetermined range. Each machine type is characterized by its total cost of ownership, failure rate, repair rate and processing time. The buffers are also characterized by their total cost of ownership coefficients associated with the buffer size. To estimate assembly/disassembly network performance, a decomposition-type approximation is used. The optimal design model is formulated as a combinatorial optimization one in which the decision variables are buffers and types of machines. A genetic algorithm is proposed as an optimization technique. Numerical examples are used to highlight the benefit of selecting simultaneously the buffers and the machines.

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1. Introduction

1.1. Problem description

A manufacturing system can be defined as a set of machines, storage buffers, conveyers, transportation components, computers, and other elements that are used together for manufacturing (Gershwin, 1994). In manufacturing systems, assembly operations consist of bringing two or more parts together to create a single product, while disassembly operations consist of separating a product into two or more parts. A large number of manufacturing systems can be modeled as high-volume, assembly/disassembly (*A*/*D*) networks of unreliable machines separated by finite buffers. Such *A*/*D* networks are widely encountered in industry (Burman, 1995). Assembly operations are frequently encountered for example in automotive, electronics, window and door industries. Even if assembly seems to be more important in manufacturing, disassembly operations also occur widely, for example in cloth cutting, sheet metal cutting, recycling, and waste handling (Kouikoglou, 2002). Furthermore, assembly and disassembly operations can be used to model transfer mechanisms in which parts are loaded on pallets where they undergo a set of operations and, upon completion of these operations, the parts are unloaded and the pallets are liberated (Di Mascolo et al., 1991).

Fig. 1 illustrates an acyclic *A*/*D* network. Squares represent machines or stations while circles represent buffers. A square can also represent a sequence of machines without buffers, since in the following we treat a sequence of machines without buffers as a single machine. At each station, machines are denoted by M_1, M_2, etc. An intermediate buffer connecting one upstream machine M_k and one downstream machine M_i is denoted by $B_{k,\,i}$. As shown in Fig. 1, material flows in the direction of the arrows. Machines M_3 and M_4 are fed by infinite sources of raw parts and machines M_1 and M_2 release items into infinite output buffers. Machine M_3 disassembles a part into two sub-products that are sent to machines M_2 and M_1 for further processing, whereas M_2 assembles two parts into a composite product. It takes one part in each of M_2 upstream buffers $B_{4,2}$ and $B_{3,2}$ to perform an assembly operation. At the disassembly machine M_3, one part is needed from its upstream buffer to perform the disassembly operation.

It is advantageous to find ways to optimize machine selection and buffer space allocation to make factories more efficient and more profitable. Tools for rapid design of manufacturing systems are especially important for products with short life cycles. Usually, designers of such systems want to optimize the production rate of the system. However, material flow may be disrupted by machine failures. Both the selection of more efficient machine

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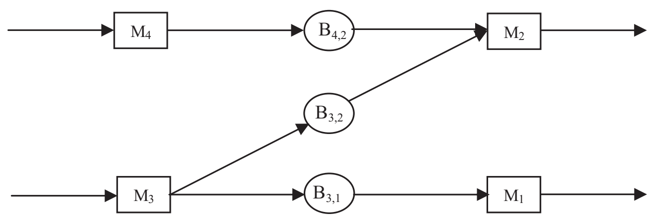

Fig. 1. Example of an *A*/*D* network.

technologies and the inclusion of larger buffers increase the average production rate of the system, but at the cost of additional capital investment.

In this paper, we consider an acyclic *A*/*D* network for which the manufacturing process has already been chosen. The decision variables are buffer sizes and machine technologies. It is assumed that the incurred cost comes mainly from buffer space cost and machine cost. We consider the practical problem for which several machine choices are available. Each machine has its own distinct parameters and cost, and different machine combinations lead to diverse *A*/*D* network performance. Buffers are characterized by their maximum capacity and associated cost. In order to find the optimal design structure, the appropriate versions should be selected from the list of available versions for each machine, and the appropriate size of buffers should be chosen within a fixed range. Aiming to maximize the average production rate of the *A*/*D* network under budget and space constraints, we present an efficient genetic algorithm for selecting both machines and buffers. Such investment decisions are costly and thus very important from a strategic design viewpoint.

In our study, each machine cost is calculated by its total cost of ownership (TCO). TCO modeling is a tool that systematically accounts for all costs related to an investment decision. TCO includes all costs, direct and indirect, incurred throughout the life cycle of an asset, including acquisition and procurement, operations and maintenance, and end-of-life management. Heilala et al. (2006) presented a methodology to calculate the TCO in the context of assembly systems. TCO concepts are widely used in the automobile industry and in that context, the TCO denotes the cost of owning a vehicle from the purchase, through its maintenance, and finally its sale as a used car. In our context, many types or technologies may exist for each machine in the *A*/*D* network. We assume that the TCO is known for each machine type.

We do not consider the average inventory holding cost in our study. As for the machines, we assume the use of Total Cost of Ownership (TCO) modeling to determine each cost coefficient associated with the buffer size. This means that each cost associated to one unit of buffer space is calculated considering all unitary costs, direct and indirect, incurred throughout the life cycle of the buffer, including acquisition and procurement, operation and maintenance, and end-of-life management. The average inventory holding cost should then be considered in the estimation of the operation costs. Also, the design problem studied is related to the strategic planning level (long-term), while the inventory holding cost is rather related to the tactical level (medium-term) and the operational level (short-term). The time horizons may vary for each planning level depending on the industry. Typical values are one week (or less) for operational planning, one month (or more) for tactical planning, and one year (or more) for strategic planning. Strategic, tactical and operational decisions are usually made separately. In our context, the TCO of machines and buffers are estimated at the strategic level, with the operation and maintenance costs corresponding to anticipated estimations from tactical and/or operational levels.

1.2. Literature review

There is a substantial literature on the optimization of buffer allocation in serial production lines (Gershwin and Schor, 2000). Papers on buffer design algorithms for serial lines were reviewed in Shi and Gershwin (2009). More recent papers dealing with buffer allocation problems (BAP) include Demir et al. (2012a, 2012b), Staley and Kim (2012), Demir et al. (2013) and Traina and Gershwin (2013). In Demir et al. (2012a), a comprehensive survey on BAP in production systems was presented. Demir et al. (2012b) developed an extensive study dealing with BAP to maximize throughput of unreliable non-homogeneous production lines. Staley and Kim (2012) shown that for closed systems buffer allocation decisions are less important than open systems. Demir et al. (2013) proposed an integrated approach to solve the BAP using tabu search and binary search. Traina and Gershwin (2013) developed an efficient algorithm for machine and buffer selection for transfer lines. There are many studies that focus on serial lines but few studies concentrate on the evaluation and the optimization of *A*/*D* networks.

The production rate evaluation of *A*/*D* networks has been treated by extending the results of serial production lines. Decomposition techniques were proposed by Gershwin (1991), Gershwin and Burman (2000), and Di Mascolo et al. (1991) to analyze the tree-structured *A*/*D* networks. Aggregation methods were developed by Kuo et al. (1997) and Chiang et al. (2000) to analyze the assembly systems with Bernoulli models and Markovian models. Smith and Daskalaki (1988) proposed a heuristic for buffer space allocation for the assembly systems. The assembly lines are modeled as finite open queuing networks. Fuxman (1998) developed an efficient heuristic to solve a problem of optimal buffer allocation in asynchronous cyclic mixed-model assembly lines with deterministic processing times. Bukchin and Meller (2005) proposed a model for calculating the fill-rate of assembly lines. This model was incorporated into a design algorithm that determines the space allocation. Bulgak (2006) presented an approach for optimal inter-stage buffer allocation problem of split-and-merge un-paced open assembly systems. A simulation model based on artificial neural networks was developed in conjunction with genetic algorithms, to find optimal inter-stage buffer configurations yielding a maximum production rate.

1.3. Paper contribution

In the relatively small body of literature on the optimization of *A*/*D* networks, it is always assumed that the number of machines is specified, and the only parameters to find are buffer sizes. To our knowledge, for manufacturing systems with unreliable machines, the only existing papers dealing with selecting both machines and buffers are Nahas et al. (2009) and Traina and Gershwin (2013), but they are restricted to series–parallel and series production lines, respectively. In the present contribution, the proposed approach to optimal design aims to select both buffers and machines for *A*/*D* networks. The objective is to maximize the system production rate subject to a budget constraint. There is a benefit in selecting simultaneously the buffers and the machines. Such a benefit results from the possibility of reaching a higher production rate for the network without requiring any additional budget. Machines and buffers can both contribute to the improvement of the system production rate, since the use of larger buffer sizes and/or more efficient machines may lead to a better production rate. At each station of the network, there is a correlation between machine efficiency and buffer size. When simultaneously selecting the buffers and the machines, we take advantage of considering the correlation and therefore we can reach a better design. It is important to capture this benefit, because such investment and strategic decisions are

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