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Comparison of objective criteria for set-up planning in complementary flexible manufacturing systems

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Abstract

A variety of objective criteria are used in optimizing the flexible manufacturing system set-up problem in the academic literature. The literature also provides evidence that the objective criteria used in academic studies are often the least important in practice and that inventory related costs are rarely considered as an objective criterion. This study compares the flexible manufacturing system set-up problem across a set of strategically selected objective criteria including an inventory cost criterion. The comparison is done over varying set-up costs to inventory carrying cost ratios and machine workloads. The study provides guidelines on the merits of using each objective criterion under different conditions. The models used in the study included large mixed integer programming problems and quadratic programming problems with continuous and binary variables present. The binary variables in the quadratic program give the problem a combinatorial nature. In order to circumvent the combinatorial nature of the problem, we have used a combination of generate-and-test and constraint propagation strategies to generate the feasible values of the binary variables at the constraint level and to propagate the feasible binary values into the models. Generate-and-test and constraint propagation strategies used in conjunction with mathematical programming are shown to greatly simplify generating solutions to a family of problems that are otherwise considered intractable.

Keywords: Flexible manufacturing systems; Assembly systems; Mathematical programming optimization; Integer/binary program

1. Introduction

Flexible manufacturing systems (FMS) have provided solutions to a myriad of problems afflicting small to medium job shop type manufacturing firms. There is a substantial and still growing body of literature on a variety of FMS related issues including the complex FMS set-up problem. The set-up problem constitutes a set of sub-problems that include the part mix selection (Choobineh, 1988; Kumar & Shankar, 2000; Kumar, Kusiak, & Vannelli, 1986; Lee, Lim, Lee, Jun, & Kim, 1997; Liang, 1993; Stecke, 1983; Ventura, Chen, & Wu,

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1990; Xiaobo, Wang, & Luo, 2001), the machine grouping (Lee & Lee, 1998; Mohamed, 1998; Yano, 1997), the production ratios (Stecke, 1986), the resource allocation (Azadivar & Lee, 1986; Tuchelmann, 1986; Yao, 1986), and the loading (Guerrero, Lozano, Koltai, & Larraneta, 1999; Kogan, 2001; Kumar, Tiwari, & Shankar, 2003; O'Grady & Menon, 1987; Sarin & Chen, 1987; Stecke & Solberg, 1981; Tiwari & Vidyarthi, 2000; Vidyarthi & Tiwari, 2001) utilized during each production run. Smith, Ramesh, Dudek, and Blair (1986) have ranked the objective criteria used in practice based on a survey of scheduling procedures in FMS installations. Smith et al. (1986) report that the most commonly used criteria in the academic literature are often the least important in practice. One of the objectives of this study is to address the relative merits of a range of objective criteria used in part mix selection and loading sub-problems of the FMS set-up planning. Another objective of this study is to include economy of scale issues as a criterion in the FMS set-up planning. The literature available on FMS commonly assumes ideal FMS conditions where producing unit batch sizes are possible since machine set-ups and economies of scale issues do not exist. However, there is substantial evidence that points to a variety of reasons that can require operating FMS using machine set-ups and hence making economy of scale and inventory costs relevant.

In this study, we optimize the FMS set-up problem using different sets of objective criteria, including an inventory cost criterion, under varying set-up time to holding cost ratios and machine loads. The results generated from each optimization are compared across objective criteria and the merits of using each objective criterion are discussed. The models used to facilitate the study include a quadratic programming (QP) problem with binary and continuous variables and large mixed integer programming (MIP) problems. The QP problem belongs to a class of problems that are very difficult to solve. The MIP problems are relatively easier to solve but can be time consuming. However, both types of problems are amenable to solution techniques that use mathematical programming in conjunction with other quantitative techniques. This study demonstrates that solving such problems can be simplified by using mathematical programming in conjunction with generate-and-test and constraint propagation techniques.

2. Objectives of the study

In the survey of FMS installations by Smith et al. (1986) the most important criteria used in loading or scheduling procedures, in the order of importance, were meeting due dates, maximizing system and machine utilization, minimizing work-in-process, maximizing production rate, minimizing set-ups and tool changes, minimizing flow time, and balancing machine usage. These results are not congruent with the most commonly used criteria in academic research, namely, minimizing flow time, balancing machines, maximizing utilization, and minimizing make-span. Very few studies comprehensively address the merits of the type of objective criterion used for optimizing the FMS set-up problem. Swarnkar and Tiwari (2004) have proposed a model that minimizes system unbalance and maximizes throughput and have solved it using a combination of tabu search and simulated annealing-based heuristic approaches. Kumar and Shankar (2000) have compared various balancing objectives. Grabot (1998) and Min et al. (1998) have discussed neural networks that balance multiple objectives. Yano (1997) has studied the impact of throughput related objectives and machine grouping decisions on make-span performance in the short term. The primary objective of this study is to shed light on the merits of using the different objective criteria prevalent both in academic literature and in practice.

Another objective is to address the economy of scale issues that can be present in FMS set-up planning. A commonly made assumption in the literature is that FMS are complete or ideal systems with the ability to process any part in the system as long as a machine is free. Such assumptions imply unit batch production without the need for set-ups and the accompanying inventory accrual to take advantage of economies of scale. Thomas (1994), however, discusses a number of technological, economic, and operational reasons that can force set-ups and production in batches despite the presence of FMS technology. Smith et al. (1986) report that 47% of FMS installations in their survey produced in batches with 60% of the installations changing batches daily. Primrose and Leonard (1984) has identified a spectrum of FMS use in context with the nature of the plant. At one end of the spectrum is the complementary FMS towards which most manufacturing plants are biased. Machine centers in a complementary FMS have unique processing capabilities that can force machine set-ups when introducing new parts into the system. Falkner (1986) provides three reasons that can dictate the use of frequent set-ups. Batch production in an FMS may also be necessary to achieve potential