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Quality assurance laboratory planning system to maximize worker preference subject to certification and preference balance constraints

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ABSTRACT

This research addresses the assignment of technicians to quality control tests in a pharmaceutical manufacturing environment. The problem is complex as it includes constraints related to the capabilities of the quality assurance technicians, as well as various criteria related to efficiency, customer service, and worker satisfaction. We consider several factors that are particular to labor scheduling in the pharmaceutical industry: preference to certain types of work and certification related to training in specific tests. We propose and utilize a technician satisfaction metric and develop a heuristic to maximize this measure. Experiments are performed in order to evaluate the performance of the proposed heuristic, and gain insights regarding the relationship among key experimental factors. The results demonstrate that, in general, the proposed heuristic quickly generates scheduling assignments that provide a very good approximation of the optimal solution.

1. Introduction

The increased attention on economic considerations and operational efficiency has resulted in an extensive focus on personnel scheduling problems in the past few decades. The assignment of workers to tasks is a challenging problem encountered in both the manufacturing and service industries. For example, in manufacturing operations the problem may be assigning workers to particular machines, while in hospitals the problem may be the assignment of nurses to particular tasks or work shifts. Such problems are challenging, as each task requires specific skills that individual workers may not possess. Also, there are only a limited number of workers and tasks that need to be matched in a manner so as to optimize an objective function.

The classic assignment problem involves matching the elements of two sets on a one-to-one basis (i.e., tasks or jobs to agents or labor). Depending on the objective function, different types of problems are encountered ranging from linear assignment problems to quadratic and higher dimensional assignment problems. There is a large body of literature dealing with such problems and there are numerous applications in diverse areas such as production planning, telecommunications, and semiconductor design. The personnel scheduling problem encountered in today's workplace is different from the one addressed in most earlier studies, as the relative importance of satisfying employee needs in scheduling decisions has increased; many organizations consider employee preferences and offer flexible work schedules.

This research addresses the assignment of technicians to quality control tests (called test tasks) in a pharmaceutical manufacturing environment. In this environment test tasks are assigned to technicians by considering several factors, including worker certification and their task type preferences. Each technician is certified through internal training and examination to perform a certain set of task types. To maintain this certification a technician must perform a task of this type with certain regularity (or lose certification). Thus, at the start of each plan there is a set of task types that should be assigned to technicians in order to maintain their certifications. Furthermore, technicians have different preferences regarding performing each of the test tasks. In general, these preferences relate to two factors: the self-perceived skill of the technicians (typically, technicians prefer to perform tests they are good at), and the complexity of the tests (generally, technicians prefer the simpler tests or tests that have low probability of failure). The primary reason for such technician preferences is that they are incentivized to perform tests correctly. When a test fails it must be repeated, taking additional labor time and delaying the production / release processes. Clearly, these are outcomes

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management would like to avoid and therefore incentivizing technicians to execute tests correctly.

Each plan has a specified time window, and not all the pending tasks must be scheduled within the time window (test tasks not completed in the current plan are left for the next plan). Tasks are either priority tasks or non-priority tasks. Priority tasks are typically related to the quality tests required of production lots that are due within the time window of the plan, and to stability tests, which are tests performed for production lots already in the market that are being re-evaluated to ensure that they meet all specifications. In general, priority tasks consist of about half of the available workload. The scheduling process should use resources as fully as possible to maintain a high utilization level.

The production planning and scheduling literature has primarily focused on environments with either machine or labor type resources (e.g., Parsa et al., 2010; Wang and Chou, 2010). This research is different from the previous literature as it considers several factors that are particular to labor scheduling: preference to certain types of work and certification related to training in specific test types. It also has the uncommon consideration that not all the tasks must be scheduled within the specified time window. We propose and use technician satisfaction metrics and develop a heuristic to maximize them. We also conduct experiments to gain insights about the relationship among key variables, and compare the performance of the proposed heuristic with the optimal solution.

The rest of the paper is organized as follows. A review of the relevant literature is presented in Section 2. Section 3 provides a detailed problem description. Section 4 presents an example to further describe the problem and discuss the tradeoffs involved. Section 5 provides the proposed heuristic procedure, while Section 6 presents the results of the computational experiments. Finally, Section 7 provides conclusions and presents directions for future work.

2. Literature review

There is a large body of research dealing with the assignment problem. Votaw and Orden (1952), and Kuhn (1955) are regarded as pioneers in this area. Their work inspired others to study several variations of the classic assignment problem to solve a variety of practical problems in the past several decades. Pentico (2007) provides a comprehensive survey of the different variations of the assignment problem, as well as several examples of the problems.

Bergh et al. (2013) and Ernst et al. (2004) provide comprehensive reviews of the personnel scheduling literature and offer useful classifications. They also discuss the different application areas and solution methods, identify trends, and propose areas for future research. Bergh et al. (2013) concluded that many real-life characteristics of the personnel-scheduling problem are often neglected, limiting the applicability of solution methods. They suggest including as many real-life characteristics as possible, such as different worker skills, flexible worker contracts, and employee preferences. In fact, it is widely recognized that the current gap between theory and practice in short-term scheduling needs to be bridged (Ruiz et al., 2008; Mendez et al., 2006).

Involving employees in the scheduling decision could result in great benefits, as suggested by recent studies (e.g., Tang et al., 2008). Shetrone (2011) suggests that happy employees are loyal and productive employees. She claims that happiness is affected by the employees' sense of control over their lives and urges employers to look for ways to give employees more control over their schedules and environments. Furthermore, 86% of the Millennial generation (those born roughly between 1980 and 2000) surveyed said that they expect flexible work arrangements from employers (Reynolds, 2010). Several models of preference scheduling have been proposed, including employee tour scheduling (e.g., Alfaras, 2004), nurse scheduling (e.g., Shahnazari-Shahrezaei et al., 2012), field workforce scheduling (e.g., Alsheddy and Tsang, 2011), and part-time workers scheduling (e.g., Mohan, 2008). Note that in previous work, preference is associated with time assignments (shift preferences), and not the type of work to be performed, thus the research proposed in this article is dealing with a significantly different problem.

The current environment in the process industry is characterized by rapid market changes, uncertainty in demand, intense competition, more stringent environmental and safety polices, and the entrance of new competitors. This has resulted in dwindling margins and a challenging economic climate (Klatt and Marquardt, 2009). In particular, the pharmaceutical industry is facing additional economic challenges compared with other sectors of the chemical process industry due to high cost and low success rate in product discovery; high cost and extended time to conduct clinical trials; long total manufacturing cycle times; and generic competition at the end of product patent life (Lainez et al., 2012). As a result, flexible, multi-product production processes have become common as they help pharmaceutical companies respond to changing customer demand and increase plant utilization. However, the greater complexity of these processes has made the traditional scheduling techniques inadequate.

Several papers investigate scheduling in the pharmaceutical environment. Mathematical programming, in particular mixed integer linear programming, is the most widely reported method for addressing scheduling problems in the pharmaceutical industry. For example, Colvin and Maravelias (2010) proposed a multi-stage stochastic programming formulation for the resource-constrained scheduling of clinical trials in the pharmaceutical research and development pipeline. Their algorithm which was optimized over multiple parameters is applicable to a wide range of multi-stage stochastic programming models with endogenous uncertainty observation.

While most of the studies in the pharmaceutical environment focus on the research and development pipeline, research addressing production planning and scheduling of the quality assurance laboratories is rare. We know of only one such study. Ruiz-Torres et al. (2012) investigated the complex scheduling problem dealing with assigning tasks to technicians in the quality assurance laboratories to minimize the total flow time and the number of jobs not meeting the required time window. They considered test batching, overlapping tests and resource assignments constrained by test specific capability requirements. Five different heuristics were developed for the dynamic creation of the test task schedules. The results indicated that there was not a dominant heuristic and the performance of the heuristics were sensitive to factors such as problem size, the length of the planning horizon, the number of product types, the demand distribution, the number of technicians, and the flexibility of technicians. However, this study did not consider additional constraints such as resource assignment based on the preferences and abilities of available technicians.

This paper considers several factors that are particular to labor scheduling: preference to certain types of work and certification related to training in specific test types. We also consider that not all the tasks must be scheduled within the specified time window. We propose and use measures of performance based on technician satisfaction and develop a heuristic to maximize these measures. We also conduct computational experiments to compare the performance of the proposed heuristic with the optimal solution. The problem is complex as it includes constraints related to the capabilities of the quality assurance technicians, as well as various criteria related to efficiency, customer service, and worker satisfaction. The problem is highly relevant to the pharmaceutical industry and has not been previously addressed in the literature.