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A sequence dependent single machine scheduling problem with fuzzy axiomatic design for the penalty costs

Sena Kır *, Harun Reşit Yazgan

Sakarya University, Engineering Faculty, Department of Industrial Engineering, Sakarya, Turkey

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ABSTRACT

In this paper, a scheduling problem on a single machine producing dairy products subject to variable due dates, earliness and tardiness penalty costs and sequence dependent setup times was studied. The main purpose was to meet demands of customers just in time whilst total penalty costs of earliness and tardiness were minimized. In addition, applicability of the schedules was appraised using Fuzzy Axiomatic Design (FAD) to determine earliness and tardiness penalty costs. A hierarchical approach consisting of meta-heuristic algorithms such as a tabu search and a genetic algorithm was proposed to generate proper schedules. In the first stage, an initial solution was found by the tabu search algorithm. The solution was improved using the genetic algorithm to find an optimum or a near optimum solution in the second stage. The proposed approach was employed on a cheese production process in the food industry. An instance of the algorithm was demonstrated to illustrate the applicability of the proposed approach and the results obtained were highly favourable.

1. Introduction

The effectiveness of a just in time production strategy requires that sequencing and scheduling of resources are correctly and successfully performed to minimize earliness and tardiness under machine setup constraints. Determining a sequencing and scheduling strategy is an important decision in the just in time production philosophy. In the literature sequence dependent scheduling problems have been studied for more than half a century with numerous studies being made.

We studied minimization of the earliness and tardiness penalty costs of the problem in order to meet variable due dates of jobs just in time. The problem can be classified as $1|S_{ij}|\sum(\alpha_i E_i + \beta_i T_i)$. As can be seen, there are different earliness (E) and tardiness (T) penalty costs and due dates for each job (α_i and β_i).

A single machine scheduling problem can be seen as the simplest structure amongst scheduling problems. But there are other reasons which make this problem important other than its simplicity such as, it being a special form of other problems. It generally has similar characteristics to parallel and sequential machines. Therefore, the problem is not only crucial because it consists of a single machine structure, but it also inspires the investigation of heuristics for more complex machine structures. In most practical scheduling problems a complex machine structure problem is an adaptation of a set of single machine structures. For example, a complex machine structure which has a single bottleneck can possibly be formed as a single machine model (Pinedo, 1995).

Baker (1974) first studied the problem and proposed a mathematical model. Coleman (1992) studied the same problem and proposed a mathematical model similar to Baker's model. The proposed mathematical model can only be applied in the case of the S_{ij} (setup time) matrix having a triangular form because the problem was modelled on the travelling salesman problem. It is not possible to reach a solution by employing the proposed mathematical model even in the case of a small sized problem in which S_{ij} is not in a triangular form. In this study we propose a hierarchical approach which consists of a tabu search and a genetic algorithm to solve the problem. Coleman's mathematical model is not appropriate for our approach because the setup matrix employed in our problem is not triangular.

In this paper the penalty costs or weights (α_i and β_i) in our problem were determined using the FAD. Due to the limited detailed understanding of the most appropriate way of pre-determining costs or weights, we chose not to place too great an importance on determining the weights. The weights of each job are used to indicate the importance of the earliness and tardiness of each job generally. But the authors mostly chose or assumed any values for the weights. We think that the determination of weights should depend on the real constraints. For instance, a shelf life is an

* Corresponding author. Tel.: +90 2642955965.
E-mail addresses: senas@sakarya.edu.tr (S. Kır), yazgan@sakarya.edu.tr (H.R. Yazgan).

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important constraint in dairy production. Assuming that two products will be scheduled and one of them has a longer shelf life than other, then in this case, we should consider a shelf life constraint when determining the earliness weights of the products. Namely, the product which has a longer shelf life should be produced earlier and its earliness weight should be less than for the other. There are many similar constraints in other industries. We propose using the FAD to determine the weights. Thus, the weights reflect more the real life constraints whilst the schedules, which are obtained considering these weights, can be made actual smoothly.

The FAD and the proposed hierarchical approach are mentioned briefly in Section 3. Parameters were determined to generate a schedule for a real life application in this section. Fresh cheese production in a factory that has the largest food production capacity in Turkey was chosen. The production scheduling problem using the proposed approach to illustrate the effectiveness of the approach is examined in Section 4.

2. Literature survey

Scheduling problems have been studied for a long time. Numerous studies in terms of different models and their solution methodologies are found in the literature. In this article we restrict our survey on the scheduling problem to only the studies which are related to a sequence dependent setup time on a single machine. It is observed that most of the studies examined are related to either the minimization of total positive tardiness or the weighted total positive tardiness. In addition, in terms of solution methodology these studies have mainly chosen heuristics, meta-heuristics and hybrid algorithms.

The objective function of the scheduling problem is defined either as total positive tardiness or weighted total positive tardiness in the literature. Chang, Chou, and Lee (2004) examined and modelled the same problem through mathematical programming and also proposed a different heuristic technique. Gupta and Smith (2006) developed a local search technique based on a space and a greedy random adaptable local search procedure. Valente and Alves (2008) proposed a beam search technique consisting of classical beam procedures. Mandahawi, Al-Shihabi, and Altarazi (2011) investigated apparent tardiness cost with setup procedures in order to achieve a best movement. Kirlik and Oguz (2012) established a mathematical form and proposed a general neighbourhood search method that assumed a heuristic result as an initial solution. Liao, Tsou, and Huang (2012) proposed a neighbourhood search procedure to improve the time complexity of searching the interchange, insertion and the twist neighbourhoods. Tanaka and Araki (2013) proposed an exact algorithm which starts with Lagrangian relaxation. Recently, Xu, Lü, and Cheng (2014) presented an iterated local search heuristic algorithm including a new neighbourhood structure called blockmove to evaluate neighbour solutions quickly and Subramanian, Battarra, and Potts (2014) developed an iterated local search randomised variable neighbourhood descent algorithm.

Meta-heuristic algorithms have also been widely applied to investigate the minimization of total positive tardiness or weighted total positive tardiness. Tan, Narasimhan, Rubin, and Ragatz (2000) studied the problem by employing and comparing different techniques such as a branch and bound algorithm, a genetic algorithm, a simulated annealing algorithm and a random start pairwise interchange algorithm, concluding that each technique was superior to others under different circumstances. Gagné, Price, and Gravel (2002) applied an ant colony algorithm to solve the same problem. Lee and Asllani (2004) formulated the problem through mathematical programming and solved it using a genetic algorithm. Chao and Liao (2012) developed a method called discrete electromagnetism which consisted of push–pull, crossover and mutation operators.

In addition to the above studies, hybrid methods have also been applied to solve the scheduling problem. França, Mendes, and Moscato (2001) developed a memetic algorithm which was an integration of a local search and a hierarchical population approach. Lin and Ying (2007) developed a random swap and an insertion search for a simulated annealing technique, a mutation operator with a greedy search technique for a genetic algorithm and a swap and insertion of an adapted tabu list for a tabu search algorithm. A comparison of the techniques was given in their study. Liao and Juan (2007) developed an ant colony optimization algorithm which had several features including a new parameter for the initial pheromone trail and adjusting the timing of application of a local search amongst others. Tasgetiren, Pan, and Liang (2009) discussed a hybrid discrete differential evaluation algorithm in their study. Sioud, Gravel, and Gagné (2012) developed a genetic algorithm which consisted of a hybrid crossover structure integrated with a constraint programming concept. Akrout, Jarboui, Siarry, and Rebai (2012) also proposed a hybrid algorithm consisting of a greedy randomized adaptive search and a differential evaluation. Xu, Lü, Yin, Shen, and Buscher (2014) presented six hybrid evolutionary algorithms with block order, linear order and position based crossover operators.

Apart from the above studies there are some studies that not only considered tardiness but also earliness and flow time. Shin, Kim, and Kim (2002) proposed a two phase algorithm. In the first phase, a solution was found by a minimization of the modified apparent tardiness cost with a setup rule. In the second phase the initial solution was improved by a tabu search algorithm. Cheng, Ng, and Yuan (2003) proved that the problem, which was aimed at removing total positive tardiness, was NP-Hard with a non-polynomial solution time. Rabadi, Mollaghasemi, and Anagnostopoulos (2004) studied minimization of tardiness and earliness by applying the lower and upper branch and bound strategy. Sourd (2005) proposed a mixed integer formulation from which lower bounds were derived and used in a branch and bound procedure and a heuristic algorithm for minimizing the sum of the setup, earliness and tardiness costs. Bigras, Gamache, and Savard (2008) modelled their problem through mathematical programming for a minimization of flow time and total positive tardiness and advised a branch and bound algorithm under LP relaxation. Chen, Chen, and Liou (2014) developed new artificial chromosomes with a genetic algorithm in which some heuristics and a local search algorithm and a variable neighbourhood search algorithm are employed.

Penalty costs were assumed to be either equal or different without any specific reasons given in these studies. Penalty costs are important factors in terms of total cost, therefore these costs should be determined by any meaningful method. Based on this importance, we have chosen the FAD to determine penalty costs. This technique allows us to include not only properties of a product but also to factor in the experiences of an expert. The following is a brief survey of the literature on the FAD.

The FAD was developed by Kulak and Kahraman (2005a) and is one of the new set of methodologies used for decision making problems within a fuzzy environment. In the literature there are a few applications of the FAD. Kulak and Kahraman (2005b) studied selection of the best company subject to pre-determined criteria using a fuzzy multi-attribute Axiomatic Design (AD) and compared it to one of the fuzzy AHP methods in the literature. Kahraman, Kaya, and Çebi (2009) attempted to determine the most appropriate renewable energy alternative for Turkey by using the FAD. Çelik, Kahraman, Çebi, and Er (2009) used a multiple criteria FAD to investigate a systematic evaluation model on docking