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A multitasking continuous time formulation for short-term scheduling of operations in multipurpose plants

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ABSTRACT

Short-term scheduling in multipurpose batch plants has received significant attention in the past two decades. Both discrete-time and continuous time formulations have been proposed to model the problem; however, multipurpose plants that have machines with the ability to process multiple tasks at the same time, i.e. multitasking, have been overlooked by the available continuous time formulations in the literature. This paper presents a novel MILP formulation that is capable of accommodating the multitasking feature in the machines of a facility. The performance of the presented formulation is studied in comparison with a single-tasking formulation. The results show that, while the multitasking formulation is not more costly in terms of solution time, it is capable of producing significantly better solutions. The presented formulation takes into account several other operational constraints of multipurpose facilities and can be readily applied to facilities that have machines capable of multitasking, including plants in the analytical services sector.

1. Introduction

The problem of scheduling operations can be generally described as a set of tasks that need to be performed on a set of machines, under capacity and demand constraints. In this work, we address scheduling of operations in multipurpose facilities with the following operational constraints: Each task, with a specific quantity of materials, needs to visit a specific *sequence* of processing units, where some processing units may appear more than once in the sequence of a task. Different tasks may have different processing sequences. Each processing unit consists of a set of machines in parallel that are not necessarily identical in terms of capacity and processing time; however, materials in the tasks need to be processed only at one of the machines in each processing unit before they can proceed to the next processing unit in the sequence of the task. Machines are assumed to run continuously, i.e., without disruptions, and accordingly, materials processed in the machines cannot be removed from the machines while in operation. This scheduling problem can be represented as a network of interconnected processing units, where each machine has the ability to *multitask*, i.e., they can process materials from multiple tasks simultaneously, provided the materials in the tasks are available and the machine has enough capacity to process them. Therefore, flow conservation of materials in each task through the network is necessary, meaning that it is essential at each time point, to keep track of the amount of materials in each task that are available to be processed at each processing unit in the task sequence. Furthermore, it is necessary to make sure that the same amount of materials in a task that starts being processed in a machine, leaves the machine, after completing its processing. Another point to notice is the fact that the amount of materials from each task that will be processed at each processing unit, at each point in time, is determined from the optimization, making it a simultaneous batching and scheduling problem (Harjunkoski et al., 2014).

An additional operational condition is that some machines or materials may only become available sometime in the near future. In other words, there are release dates for both the machines and the tasks. This is because, in some cases, processing subsets of materials at a machine may not be completed within the scheduling horizon and therefore, their processing must be completed in a later scheduling horizon.

Fig. 1 presents an illustration of the layout of a plant with characteristics that are similar to what was discussed above. The processing units are depicted through rectangles, while different possible sequences for different tasks are shown through arrows.

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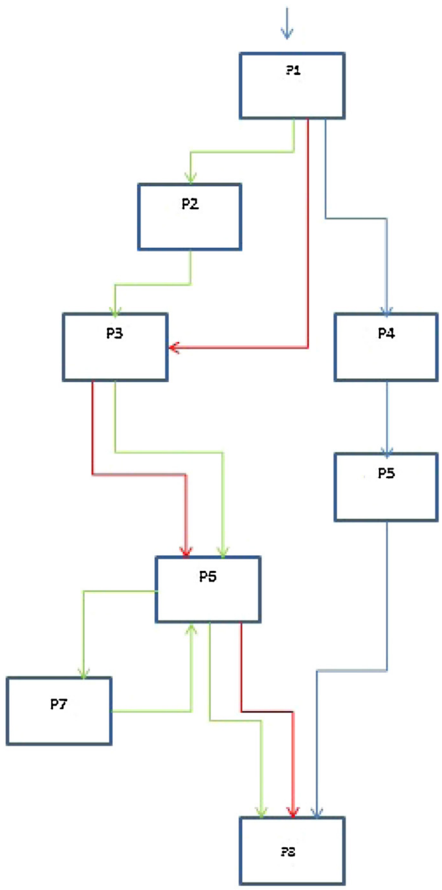

Fig. 1. Illustration of a possible plant layout.

As it is apparent, different tasks may have different sequences, while some processing units might appear more than once in the sequence of a task. Fig. 2 shows a more detailed look at a portion of the facility in Fig. 1 showing in addition two tasks: task 1, with 130 units of material in it, presented in red, and task 2, with 110 units of material in it, depicted in green. The machines in each processing unit are depicted through circles. The maximum capacity of the machines is shown inside the circles. The machines are assumed to have no minimum working capacity and all the tasks and the machines in the facility are assumed to be available from the beginning of the scheduling horizon. As it is evident from the figure, each task has its own specific sequence, where the sequence of task 1 is ($P1$, $P3$, $P6$, $P8$) and the sequence of task 2 is ($P1$, $P2$, $P3$, $P6$, $P7$, $P6$, $P8$). Note that $P6$ appears twice in the sequence of task 2. The machines can process multiple tasks at the same time, provided that their capacity is not violated. To illustrate a possible sequence of operations, consider machine M1 in processing unit P1. The machine has a capacity of 140, therefore, it can start processing 120 units of material from task 1 and 20 from task 2. After such processing is done and the corresponding materials have proceeded to the next processing unit in their sequence, still 10 units of materials from task 1 and 90 units of material in task 2 will be left, which can be loaded into machine M1 when it starts operating for the second time.

The key motivation to consider this type of scheduling problem is that it incorporates several operational details present at analytical services facilities. The analytical services industry forms a major sector in which various types of analysis are carried out on a set of samples in order to determine its properties and chemical composition, which can be used by end-customers in the decision making-process, e.g., Mining, Health, Petroleum and Food industries. Such facilities receive samples in the order of thousands to be processed on a daily basis. Therefore, devising an efficient scheduling algorithm for such facilities is both challenging and economically important. Furthermore, scheduling of operations for such facilities has not been widely studied. Indeed, although the scheduling of operations for such facilities could be categorized as a simultaneous batching and scheduling problem, the existing works on simultaneous batching and scheduling problems (Sundaramoorthy and Maravelias, 2008) have not considered facilities that have machines with multitasking capabilities. To the best of the authors' knowledge, Patil et al. (2015) is the only work reported that has presented an optimal scheduling framework for this type of facilities.

In that study, time is represented as a series of discrete events, i.e. the scheduling horizon is partitioned into several time intervals with predetermined lengths. Hence, the length of the time intervals is determined prior to solving the scheduling algorithm; accordingly, the quality of the solution is highly dependent on the predetermined length of the time intervals, which may lead to large-sized formulations depending on the accuracy desired (Sundaramoorthy and Maravelias, 2011).

To overcome this difficulty, continuous time formulations have been proposed to address several scheduling problems. Furthermore, continuous time formulations are capable of modeling some operational features, e.g., variable machine processing times, that are challenging for discrete time formulations, with relative ease. However, these types of formulations have not been used to address multipurpose plants with multitasking. The existing continuous time formulations for multipurpose plants have only considered the case where each machine is capable of processing one task at a time and therefore, they cannot be readily used for the present problem. Nonetheless, since several characteristics of the present

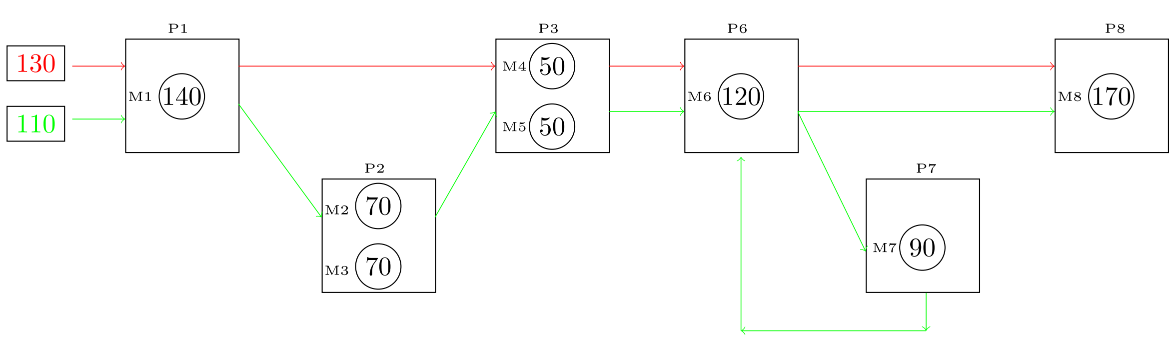

Fig. 2. Operations figure.