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Heuristic algorithms for assigning and scheduling flight missions in a military aviation unit ☆

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ABSTRACT

We consider an operations planning problem in a military aviation unit that performs a number of flight missions with multiple identical aircrafts. The problem is to assign the flight missions to the aircrafts and to schedule these assigned missions on each aircraft. Sequence-dependent setup times are required between the missions, and multiple aircrafts may be needed for a mission, but the aircrafts assigned to the same mission should start the mission simultaneously. We develop heuristic algorithms for the problem with the objective of minimizing makespan, i.e., the time by which all the missions have been completed. For evaluation of the performance of the algorithms, a series of computational tests was performed on a number of problem instances, and results show that the proposed algorithms give good or near optimal solutions in a reasonable amount of time.

1. Introduction

In this paper, we consider an operations planning problem in the army aviation units of Korea. There are two types of aviation units in the army, assault units and mobility units. An assault unit performs missions of attacking enemy's aircrafts, armors, and combat forces and protecting friendly units including mobility aviation units, while a mobility aviation unit conducts transportation missions such as moving infantry forces, ammunitions, and/or equipments to a place where they are needed. In this study, we focus on a scheduling problem in mobility aviation units. The problem considered is to assign transportation missions to each aircraft and to schedule these assigned missions on each aircraft for the objective of completing a given set of missions as early as possible. (Most, if not all, aircrafts in the aviation units are helicopters.)

An aircraft has a limited capacity in terms of volume and weight that can be loaded on it. A mission is defined as a task to move combat forces or freights from one point to another point for further operations. If the capacity of an aircraft is not large enough to handle a mission, multiple aircrafts are needed to perform the mission. In this case, it is assumed that the aircrafts should start the mission simultaneously. This is because aircrafts may be easily attacked by the enemy after taking off from the starting point of the mission. Note that if multiple aircrafts perform the mission simultaneously they can mutually protect each other from attacks of the enemy.

To perform a mission, an aircraft should move from the base to the starting point (origin) of the mission and then to the end point (destination) of the mission, and finally back to the base. The flight time from the base to the starting point of the mission can be considered as *setup time* and that from the end point of the mission to the base as *set-down time*. An aircraft may perform multiple missions consecutively before returning to the base. In this case, there should be setup time between two missions, i.e., flight time from the end point of the preceding mission to the starting point of the succeeding mission. Note that such setup times depend on the sequence of the missions. In this study, we regard the time to move from the end point of a mission to the starting point of the next mission as the setup time for the latter mission and we do not consider set-down time of the former mission or assume the set-down time is zero.

This study focuses on the mission scheduling problem with the objective of minimizing makespan i.e., the time by which all the missions have been completed. This problem may be considered as a parallel-processor scheduling problem. However, while it is assumed that a task can be scheduled on only one machine in most research articles on parallel-machine scheduling problems, a task (mission) may have to be performed by multiple machines (aircrafts) in our problem if resource required for the task exceeds the capacity of the machine.

The mission scheduling problem is similar to the split delivery vehicle routing problem (SDVRP) presented by Archetti and Speranza (2006) and Kang and Lee (2007), in which the demand

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of a customer exceeds the capacity of a vehicle and multiple vehicles are used for the delivery of the demand. Note that aircrafts and missions in our problem may be regarded as vehicles and deliveries for the customers, respectively, in the SDVRP. The mission scheduling problem is also similar to the multi-processor task scheduling problem (MTSP), in which each task needs to be processed on a number of parallel processors simultaneously. However, in our problem, sequence-dependent setup times are required between tasks, and hence our problem can be considered as a generalized version of the SDVRP and MTSP. Since the SDVRP and MTSP are proven to be NP-hard by Archetti and Speranza (2006) and Błażewicz, Drabowski, and Węglarz (1986), respectively, the mission scheduling problem considered in this paper is also NP-hard.

There have been many studies on the problem of scheduling jobs on identical parallel machines with the objective of minimizing makespan, which is shown to be NP-complete even in the two-machine case (Garey & Johnson, 1979). Various heuristic algorithms have been developed for the problem including those of Blackstone and Phillips (1981), Lee and Massey (1988), França, Gendreau, Laporte, and Müller (1994), Hübscher and Glover (1994), Ho and Wong (1995), Gupta and Ruiz-Torres (2001), Mokotoff, Jimeno, and Gutiérrez (2001), Hwang and Kim (2003), Akyol and Bayhan (2006) and Kashan and Karimi (2009), while the worst-case performance is analyzed for simple heuristic algorithms in Graham (1969), and Coffman, Garey, and Johnson (1978). On the other hand, Dell'Amico and Martello (1995) propose a branch and bound algorithm, and Mokotoff (2004) presents a cutting plane method for optimal solutions.

There are a number of research articles on multiple-machine scheduling problems for jobs with sequence-dependent setup times. Guinet (1993), França, Gendreau, Laporte, and Müller (1996), Gendreau, Laporte, and Guimarães (2001), Mendes, Müller, França, and Moscato (2002), and Behnamian, Zandieh, and Fatemi Ghomi (2009) develop heuristic algorithms for identical parallel machine problems with the objective of minimizing makespan, while Kurz and Askin (2001) present heuristics considering release dates of jobs. In addition, Helal, Rabadi, and Al-Salem (2006) and Rabadi, Moraga, and Al-salem (2006) present heuristic algorithms for unrelated parallel machine problems with the makespan criterion, and Das, Gupta, and Khumawala (1995), Ríos-Mercado and Bard (1998, 1999), Norman (1999), Ruiz, Maroto, and Alcaraz (2005), and Ruiz and Stützle (2008) develop heuristics for flowshop scheduling problems with the makespan criterion. See Allahverdi, Ng, Cheng, and Kovalyov (2008) for a survey on studies on multi-machine scheduling problems with setups.

There also have been various studies on the multi-processor task scheduling problem (MTSP), especially on the following two cases: the one in which a job (task) should be processed by a fixed (and pre-specified) number of machines that can be arbitrarily selected, and the one in which a set of machines is pre-specified for each job. For the first case, Błażewicz et al. (1986) show that there exists a polynomial-time algorithm for the problem with the objective of minimizing makespan when the processing times for all jobs are equal. Later, Błażewicz, Drozdowski, Schmidt, and Werra (1990) extend the study for a preemptive scheduling case in which each job can be processed on one of parallel processor groups, each with one or two processors. In addition, Chen and Lai (1991), Zhu and Ahuja (1993), Lin and Chen (1994), Oğuz and Ercan (1997), Li, Cai, and Lee (1998), and Sung and Park (1998) consider the first case and give heuristic algorithms for the makespan criterion. The second case is dealt with in Bozoki and Richard (1970), Bianco, Dell'Olmo, and Speranza (1994), Krämer (1997), Bianco, Dell'Olmo, Giordani, and Speranza (1999), Chen and Lee (1999), and Caramia and Giordani (2010). See Drozdowski (1996) and Lee, Lei, and Pinedo (1997) for reviews on research papers on MTSPs.

In this study, we focus on the problem of assigning given missions to aircrafts and scheduling the assigned missions on the aircrafts while considering sequence-dependent setup times between the missions and the constraint that individual tasks for the same mission should be started simultaneously if the mission needs to be performed by more than one aircraft. We develop heuristic algorithms for the mission assignment/scheduling problem with the objective of minimizing makespan.

This paper is organized as follows. In the next section, we describe the problem in more detail and present an integer programming formulation for the problem. Heuristic algorithms developed for the problem are presented in Section 3. To evaluate performance of the proposed heuristics, computational experiments are performed on randomly generated problem instances and results are reported in Section 4. Finally, Section 5 concludes the paper with a short summary and recommendations for further research.

2. Problem description

There are n missions to be performed by m ($\leqslant n$) identical aircrafts. Each mission requires a given number of aircrafts and *processing time*, i.e., flight time for moving from the starting point (origin) to the end point (destination) of the mission, as well as setup time, i.e., flight time for moving from the base or the current location of the aircraft to the starting point of the mission, and set-down time, i.e., flight time for moving from the end point of the mission to the base. The flight time for moving from the end point of a mission to the starting point of another mission is regarded as the setup time of the latter mission. Note that the setup times depend on the sequence of the missions.

A mission may require one or more aircrafts according to work required for the mission. A mission requiring one aircraft for its task is called a *one-aircraft mission*, and a mission that needs multiple aircrafts is called a *multiple-aircraft mission*. Each mission may be regarded as a job in typical terms of operations scheduling problems. In this study, a task to be performed by each aircraft for a multiple-aircraft mission is called a *unit-job*. An aircraft can perform at most one unit-job at a time, and at most one unit-job from the same job can be assigned to an aircraft. Hence, the number of unit-jobs of a job is equal to the number of aircrafts required for the job. In the mission scheduling problem considered in this study, unit-jobs of the jobs should be assigned to the aircrafts and the unit-jobs should be scheduled on each aircraft. In addition, unit-jobs of the same job should be started at the same time (because of the reason stated in Section 1). Note that setup times for a multiple-aircraft mission may be different on different aircrafts since the current locations of the aircrafts may be different.

The following assumptions are made in this study.

(1) The information of the missions, i.e., the number of aircrafts required for the mission, the starting and end points, and flight time between the two points, is given. Note that although the number of aircrafts required for a mission is given, aircrafts to perform unit-jobs of the mission are not specified and this should be determined by the assignment decision.
(2) Setup time, the time required for moving from the end point of a mission or the base to the starting point of another mission, and set-down time, the time required for moving from the end point of a mission to the base, are known. Those times may differ depending on the pairs of origins and destinations of the missions, that is, setup (and set-down) times are sequence-dependent.
(3) The number of aircrafts required for a mission is not greater than the number of aircrafts in the aviation unit.