BIASED RANDOM KEY GENETIC ALGORITHM FOR MULTIPLE PRIORITIES TASK SCHEDULING APPLIED TO EARTH OBSERVING SATELLITE MISSION

Panwadee Tangpattanakul and Supatcha Chaimatanan
Geo-Informatics and Space Technology Development Agency (Public Organization)
120, The Government Complex (Building B), Chaeng Wattana Road, Laksi, Bangkok 10210, Thailand
Email: panwadee@gistda.or.th, supatcha@gistda.or.th

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ABSTRACT: This work proposes a biased random key genetic algorithm (BRKGA) for solving a multiple priorities task scheduling problem. Generally, some chromosomes are initially generated by encoding as key vectors of real value between [0, 1] in BRKGA process. To obtain the solution, the chromosome has to be decoded. The multiple priorities task scheduling problem, which needs to schedule strips of Earth observation before sending the sequence to the satellite, is considered in this work. Strips are required from customers with different priorities and each strip has its own priority. The objective of this scheduling problem is to minimize the finishing date for taking all strips. For encoding, each gene in the chromosome represents each strip. The gene value of each strip is a real number in different intervals depending on the priority of related strip. Let s_i be a strip with priority $P[i]$, where $i \in \{1, 2,\ldots, n\}$ and $P[i] \in \{1, 2,\ldots, np\}$, n is number of strips and np is number of different priorities. Thus, gene values of strip s_i with priority $P[i]$ is a real value in the interval $[(P[i]-1)/np, P[i]/ np)$. For decoding, the sequence of strip acquisition can be obtained from the represented gene values. The strip with the lowest gene value is considered firstly. It is assigned in the sequence of strip acquisition as early as possible and it must also satisfy the constraints. Then, the strip with the next higher gene value is considered and it can be inserted to the available spaces of the sequence that satisfy the constraints. Moreover, the considered strip is assigned in the sequence as early as possible. Experiments are conducted on a realistic instance, which concerns strips with two different priorities. All strips are assigned in the sequence and then, this sequence will be sent to the Earth observing satellite.

1. INTRODUCTION

A biased random key genetic algorithm (BRKGA) is an efficient method for solving combinatorial optimization problems. It was first proposed in (Gonçalves, 2002) and it was developed from random key genetic algorithm (RKGA), which was proposed in (Bean, 1994). BRKGA combines the random key concept and the genetic algorithm principle. In BRKGA, there are two important steps, which depend on the considered problem. They are encoding and decoding steps. Moreover, BRKGA uses the three main operators of genetic algorithm, which are selection, crossover, and mutation, to manage individuals in the population. BRKGA was applied to solve combinatorial optimization problems in various domains, for example, communication, transportation, scheduling, as presented in (Gonçalves, 2011). In this paper, we propose to use BRKGA to schedule the multiple priorities tasks and apply to the Earth observation planning for the Earth observing satellite.

The Earth observing satellite has the mission to obtain photographs of the Earth surface for satisfying customers' requirements as in Figure 1. The ground station center receives many requests with different priorities from the customers. Therefore, all requests must be scheduled before sending to the satellite. Many researchers proposed different algorithms to manage the acquisition of satellites, for both non-agile satellite and agile satellite. An example of the non-agile satellite is SPOT 5, which is a French Earth observing satellite. SPOT 5 is equipped with three imaging instruments, which are fixed on-board on the satellite (Bensana, 1999). The satellite can turn around only roll axis during the transition. Thus, the starting time for taking each photograph cannot be changed. The feasible acquisitions can be pre-computed and each photograph will be assigned to the cameras (Lemaître, 2002). In (Vasquez, 2001), the SPOT 5 observation scheduling problem was presented as the formulation of knapsack problem and a tabu search was used to solve this problem. An example of the agile satellite is PLEIADS, which is also a French Earth observing satellite. A fixed on-board camera is equipped on this satellite, but the satellite can turn around three axes: roll, pitch, and yaw. Therefore the starting time for taking each photograph is not fixed, however taking in the given time interval called time window. Thus, the scheduling problem of the agile satellite is more complicate to be solved than the non-agile satellite (Lemaître, 2002). The objective of the observation scheduling problem is to maximize the total profit from the selected photograph acquisitions in the limited time. A simulated annealing and a tabu search were proposed to solve this problem (Kuipers, 2003 and Cordeau, 2005). Moreover, the second objective was included to ensure the fairness between customers. The problem was considered as the multi-objective optimization problem and an algorithm based on a local search was proposed to solve this problem (Tangpattanakul, 2015). However, the objective of this work is to minimize finishing date or makespan (C_{max}) with priority consideration. We consider the requests of Thaichote satellite, which is an Earth observing satellite of Thailand. This satellite can move in two axes: roll and pitch. The request has to be taken in the given period of time, which is given by the customers. Most requests are polygon and they cannot be taken at once by the camera. Thus, all polygonal requests must be managed from the ground station center by transforming into several rectangular shapes along the satellite direction called strips. All strips have fixed width but variable length. The possible orbits and dates for taking the photograph of each strip can be pre-computed and they are the input for the scheduling problem. The outputs of this problem are a sequence of strip acquisition, a set of acquiring date, and a finishing date for acquiring all strips. Then, the sequence of strip acquisition will be transmitted to the satellite.

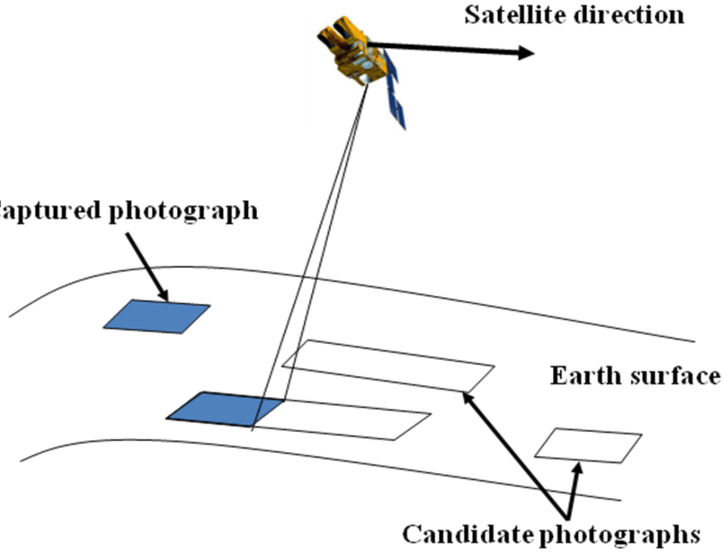

Figure 1: The satellite captures photographs (Tangpattanakul, 2013).

The article is organized as follows. Section 2 explains the problem description about the multiple priorities task scheduling problem applied to the Earth observations scheduling before transmitting to the satellite. The BRKGA, which is used to solve our considered problem, is presented in Section 3. The computational results are reported in Section 4. Finally, conclusions are discussed in Section 5.

2. MULTIPLE PRIORITIES EARTH OBSERVATIONS SCHEDULING PROBLEM

As presented in the introduction, the requests ordered from customers, especially the polygonal area, have to be decomposed into several strips as Figure 2, since the mission and physical constraints of the Earth observing satellite. Then, the ground station center must schedule all strips before transmitting to the satellite. This work considers the strip scheduling problem of Thaichote satellite, which is an Earth observing satellite of Thailand. Therefore, we generate an instance for the experiments from the real conditions and search for the optimal solution, which obtains the best objective function value and also satisfies the constraints of this satellite.

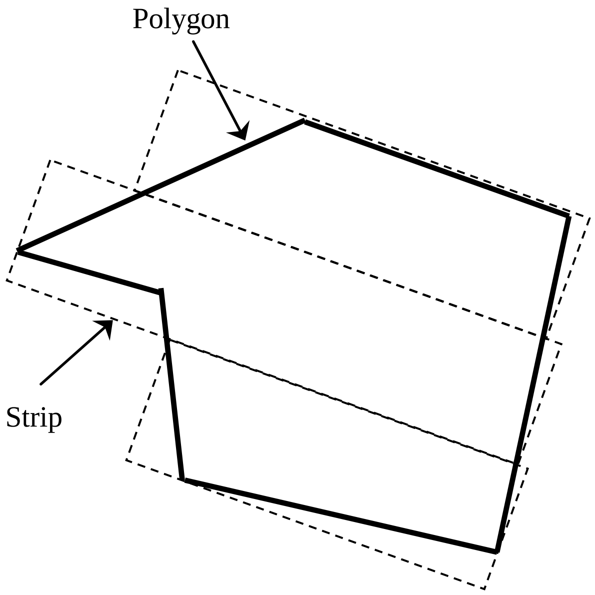

Figure 2: A polygon is decomposed into several strips.

Each instance has data details as follows:

- Set of strips *Strip* = $\{s_1, s_2, \ldots, s_i, \ldots, s_n\}$

For each strip s_i, $1 \leq i \leq n$:

- $P[i]$ is the priority of strip s_i,
  where $P[i] \in \{1, 2, \ldots, np\}$ and np is the number of different priorities
- $O[i]$ is the number of possible orbit to take strip s_i
- The positions in the setting coordinates of the two ends of strip s_i are:
  - $X1[i]$ and $Y1[i]$ for the coordinate values of the beginning position
  - $X2[i]$ and $Y2[i]$ for the coordinate values of the ending position
- $L[i]$ is the length of strip s_i
- $D[i]$ is the set of possible orbit date for acquiring strip s_i,
  where $D[i] \in \{d_{i1}, d_{i2}, \ldots, d_{ij}, \ldots, d_{iq}\}$ and q is the size of $D[i]$.

Thaichote satellite turns around the Earth and returns on the same orbit every 26 days. Thus, the set of all possible orbit date for acquiring strip s_i can be computed by using the repetition of the 26 days. Two adjacent strips can be acquired in the same day, if they satisfy the constraint concerning the sufficient transition time, which is converted to the limited distance, between these adjacent strips. The transition constraint has 2 cases as follows:

- *Case1*: Y coordinate value of the starting position of the next strip must be less than or equal to the ending position of the previous strip

$$Y1[\text{next}] \leq Y2[\text{prev}]$$

or

- *Case2*: If Y coordinate value of the starting position of the next strip is more than the ending position of the previous strip, the distance between the ending position of the previous strip and the starting position of the next strip must be less than 150 kilometers.

$$\text{If} \quad Y1[\text{next}] > Y2[\text{prev}], \text{ then}$$
$$((X1[\text{next}] - X2[\text{prev}])^2 + (Y1[\text{next}] - Y2[\text{prev}])^2)^{1/2} < 150{,}000$$

One of these two cases must be satisfied as in Figure 3. We need to obtain the optimal sequence of strip acquisition for transmitting to the satellite. The objective function of this optimization problem is to minimize the finishing date to acquire all strips, which are required from customers.

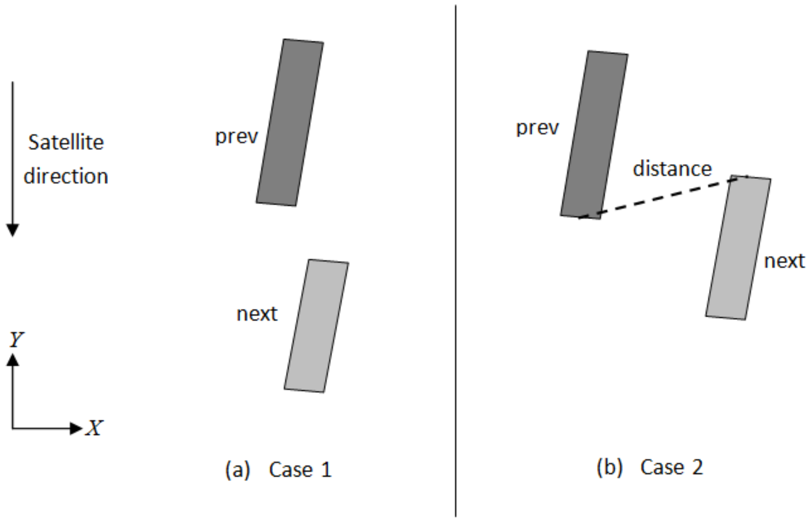

Figure 3: Two cases of sufficient transition constraint

3. BIASED RANDOM KEY GENETIC ALGORITHM FOR THE MULTIPLE PRIORITIES TASKS SCHEDULINHG

A genetic algorithm is a metaheuristic method that mimics natural evolution process. It operates on several individuals in a population. Individuals should spread through the search space. The genetic algorithm uses the concept of survival of the fittest to find the optimal solution. Each individual consists of a chromosome, which represents a solution. The process of genetic algorithm is started by generating an initial population, which its size equals to p. For generating the next generations, selection, crossover, and mutation operators are applied. The iterations are repeated until a stopping criterion is satisfied.

For BRKGA, the random key chromosome consists of several genes, which are encoded by real values in the interval [0, 1]. Then, the chromosome is decoded in order to obtain the solution. The decoding strategy depends on the problem and the fitness value of solution is computed in this decoding step. The current population is divided into two groups by using the selection mechanism. Selections are applied to choose p_e preferred chromosomes from the current population to become the elite set. The remaining chromosomes will be stored in the other group of non-elite chromosomes. Then, the population in the next generation is generated from three parts, as in Figure 4. The first part is copied from the elite set of the current generation. The second part is called mutant set. It contains p_m chromosomes, which are generated by random generation as the initial population generation. The target of the mutant set generation is to avoid the entrapment in a local optimum. The last part is the crossover offspring set. The set is filled by generating offspring from the crossover operation of two parents, which are a chromosome from elite set and a chromosome from non-elite set. Each element of the offspring is copied from the element of elite parent with probability ρ_e. Otherwise, the element of the offspring is copied from the non-elite parent. Thus, the size of the crossover offspring set equals to $p - p_e - p_m$.

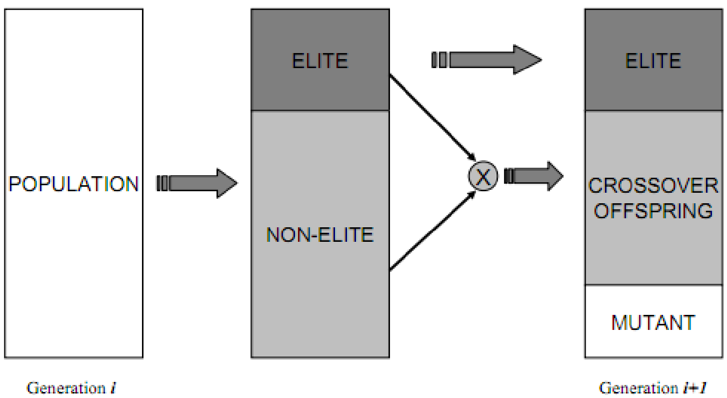

Figure 4: the population of the new generation by using BRKGA (Tangpattanakul, 2013)

For the encoding step of this strip scheduling problem, each gene in the chromosome represents each strip. In this work, we propose the chromosome encoding that the gene value of each strip should be a real number in different intervals depending on its priority. As in Section 2, s_i is a strip with priority $P[i]$, where $i \in \{1, 2,\dots, n\}$ and $P[i] \in \{1, 2,\dots, np\}$, n is number of strips and np is number of different priorities. The strips can be classified according to their priority. Therefore, gene values of strip s_i with priority $P[i]$ is a real value in the interval $[(P[i]-1)/np, P[i]/ np)$.

For instance, if number of different priorities equals to 2 ($np = 2$),

- the gene value of strip s_i with the first priority ($P[i] = 1$) can be the real value in the interval [0, 0.5) and
- the gene value of strip s_i with the second priority ($P[i] = 2$) can be the real in the interval [0.5,1).

We obtain the solutions from the chromosomes in the decoding step. A strip, which is represented by a gene in the chromosome, must be assigned in the sequence. According to the encoding step, the strip with higher priority will have lower gene value. Hence, the strip will be assigned to the sequence by using the order of gene values from low to high. The strip with the lowest gene value will be assigned firstly and it must be taken from the satellite as early as possible but satisfying the imperative constraints. Then, the next strip with higher gene value will be assigned to the sequence. It must be taken from the satellite as early as possible without moving the assigned strip. However, it is possible that this strip can be taken earlier than the assigned strip. The decoding step will be complete, when all strips are assigned to the sequence. The flowchart of decoding step is shown in Figure 5. The fitness value, which is the finishing date to acquire all strips, is also obtained from the sequence.

4. COMPUTATIONAL RESULTS

For the proposed biased random key genetic algorithm (BRKGA), parameter values of the algorithm were experimentally tuned for our work. The population size (p) of BRKGA is set equal to ten times of number of strips. Three parts, which are the elite set, the mutant set, and the crossover offspring set, are generated to become the population in the next generation. The sizes of the elite set (p_e) and the mutant set (p_m) are equal to $0.3p$. The probability of elite element inheritance for crossover operation (ρ_e) is set to 0.6. The number of iteration since the last improvement of the best solution is used to be a stopping criterion. We opt for 30 iterations. The algorithm is implemented in C++ and tests on a realistic instance, which concerns strips with two different priorities.
For the instance, the size of strip set is equal to 17. It consists of

- 5 strips for the first priority
  Strip1 = {*901, 902, 903, 904, 905*} and
- 12 strips for the second priority
  Strip2 = {*101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 201, 202*}.

The results of this test are the optimal sequence of strip acquisition, the optimal set of acquiring date, which is related to the optimal sequence of strip acquisition, and the optimal finishing date for acquiring all strips, which is the fitness value. According to the instance, we obtain the results as follows:

- The optimal sequence of strip acquisition is
  Sequence = {*107, 905, 104, 901, 902, 103, 109, 903, 904, 108, 201, 106, 202, 105, 102, 101, 110*}
- The optimal set of acquiring date is
  Date = {*41947, 41948, 41952, 41953, 41954, 41957, 41958, 41958, 41959, 41963, 41964, 41968, 41969, 41973, 41978, 41983, 41984*}
- The optimal finishing date for acquiring all strips is
  Fitness = 41984.

The results show that the biased random key genetic algorithm with the proposed encoding and decoding methods is efficient to solve the multiple priorities task scheduling problem. Moreover, it is proper to tackle the strip scheduling problem of the Earth observing satellite.

5. CONCLUSIONS

A biased random key genetic algorithm (BRKGA) is used to solve the multiple priorities task scheduling problem. The BRKGA operates on some chromosomes in the population. Each chromosome consists of several genes, which are random keys. They are real values in the different interval, depending on the priorities of related strips. To obtain the solution, the chromosome has to be decoded by using the proposed decoding strategy. Each strip is assigned to the sequence in the order of gene values from low to high. Moreover, the imperative constraints of the satellite must be satisfied. Three operations, which are selection, crossover, and mutation, are used in the genetic algorithm process in order to generate new population for the next generation.

The experiments are conducted on a realistic instance of Thaichote satellite. The required strips have different priorities to be scheduled in the sequence. The objective of this problem is to minimize the finishing date to acquire all strips. In this work, we propose the encoding strategy to obtain the chromosome and the decoding strategy for obtaining the solution in the BRKGA process. The outputs of this experiment are the optimal sequence of strip acquisition, the optimal set of acquiring date, and the optimal finishing date for acquiring all strips. The optimal sequence of strip acquisition will be transmitted to the satellite as the satellite planning. The optimal finishing date for acquiring all strips is the fitness value of this work. The obtained results show that the proposed BRKGA is efficient to solve the multiple priorities task scheduling problem, which is applied to the Earth observing satellite mission.

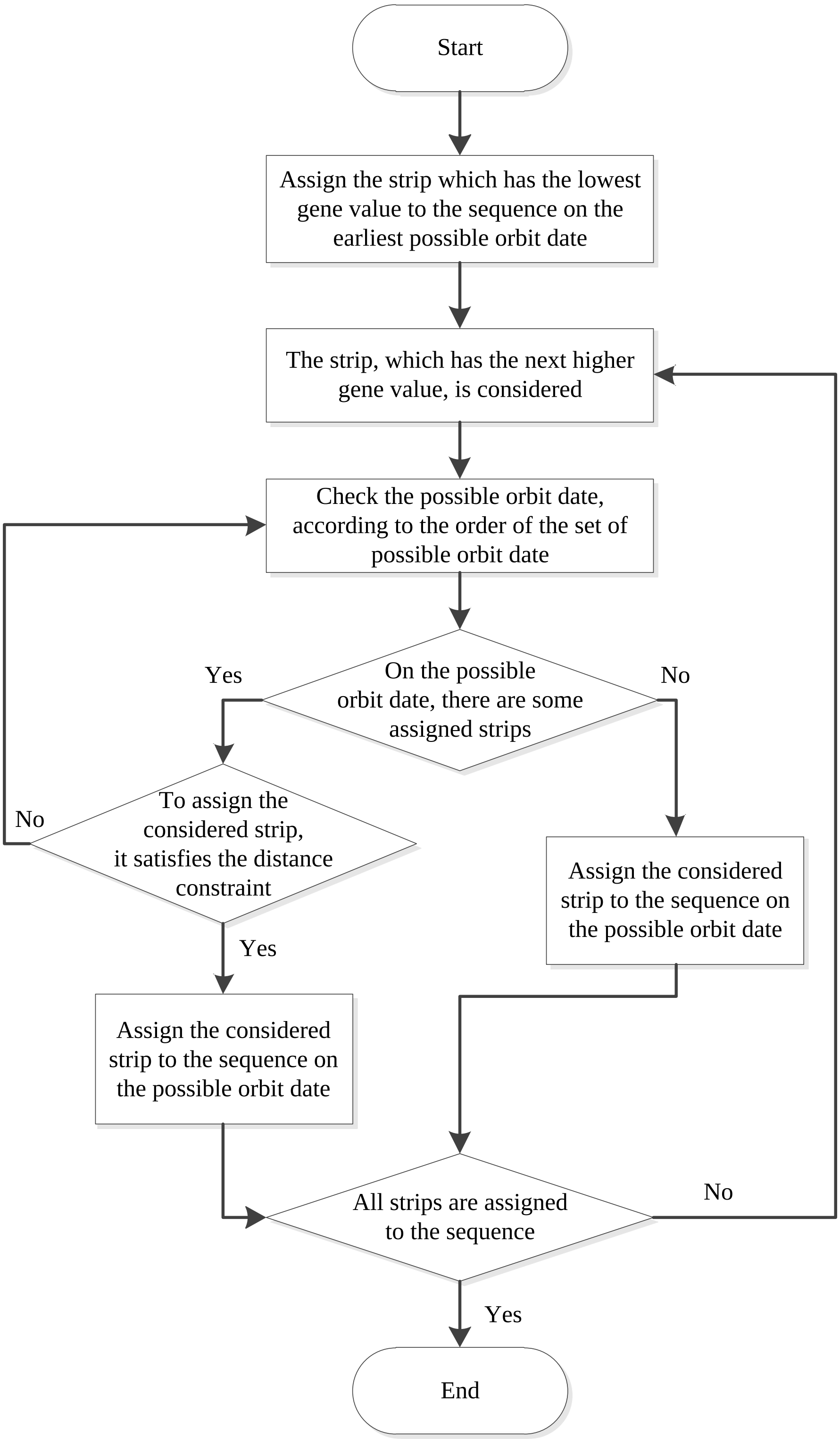

Figure 5: Flowchart of decoding step

REFERENCES

Bean, J. C., 1994. Genetic algorithms and random keys for sequencing and optimization. ORSA Journal on Computing, 6(2), pp. 154-160.

Bensana, E., Lemaître, M., Verfaillie, G., 1999. Earth observation satellite management. Constraints, 4, pp. 293-299.

Cordeau, J. F., Laporte, G., 2005. Maximizing the value of an earth observation satellite orbit. Journal of the Operational Research Society, 56, pp. 962-968.

Gonçalves, J. F., Almeida, J. R., 2002. A hybrid genetic algorithm for assembly line balancing. Journal of Heuristics, 8, pp. 629-642.

Gonçalves, J. F., Resende, M. G. C., 2011. Biased random-key genetic algorithms for combinatorial optimization. Journal of Heuristics, 17(5), pp. 487-525.

Kuipers, E. J., 2003. An algorithm for selecting and timetabling requests for an earth observation satellite. Bulletin de la Société Française de Recherche Opérationnelle et d'Aide à la Décision, Editor Automme-Hiver, 11, pp. 7-10.

Lemaître, M., Verfaillie, G., Jouhaud, F., Lachiver, J. M., Bataille, N., 2002. Selecting and scheduling observations of agile satellites. Aerospace Science and Technology, 6(5), pp. 367-381.

Tangpattanakul, P., 2013. Multi-objective optimization of Earth observing satellite missions. PhD thesis, INSA Toulouse, France.

Tangpattanakul, P, Jozefowiez, N., Lopez, P., 2015. A multi-objective local search heuristic for scheduling Earth observations taken by an agile satellite. European Journal of Operational Research, 245(2) pp. 542-554.

Vasquez, M., Hao, J. K., 2001. A "logic-constrained" knapsack formulation and a tabu algorithm for the daily photograph scheduling of an earth observation satellite. Computational Optimization and Applications, 20(2), pp. 137-157.