M2 - IA and decision -
1st Case Study
Optimizing the acquisition plan
of a earth optical observation satellite

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1 Introduction

The SPOT satellites constitute a family of earth optical observation satellites, which are developed by the CNES(French Centre National d'´Etudes Spatiales) and exploited by the SPOT Image company. The first (SPOT1) was launched in 1986. The last generation (SPOT7) have been launched in 2014. All of them use a circular, near-polar, sun-synchronous orbit, with about 14 revolutions per day and has a cycle of 26 days. They are equipped with HRV (High Resolution Visible) imaging instruments, with adjustable oblique viewing capability.

SPOT5, which is the target of the proposed case study, was equipped with three instruments (front, middle, and rear). Mono-images need one of the three instruments. Stereo-images need the front and the rear instruments. If it is possible, image data are directly down-linked to a ground receiving station. If not, they are stored using the on-board recorders and down-linked when the satellite is within range of a receiving station. The SPOT Image company receives imaging orders coming from clients all over the world and is in charge of satisfying them as well as possible. Long-term and short-term management systems are used with this aim. The problem we present is the shortest term management problem, which consists in deciding each day which images will be taken the next day and how to take them.

1.1 Orbit of the satellite

The orbit of the satellite has the following characteristics :

1. it is circular, hence a constant altitude (here about 700 km) ;
2. it is near polar, hence a low angle between the orbital plan and the polar axis ;
3. it is sun-synchronous, hence a constant angle between the orbital plan and the sun-earth axis ;

As a consequence :

1. Each revolution has a duration of about 100 minutes ;
2. Each revolution involve a lightly (day) period (from north pole to south pole) and a dark period (from south pole to north pole) ;

3. The daily and nightly equatorial visits are performed at constant local time
4. The shift between two ground tracks is about 2500 km on the equator ;
5. The satellite performs about 14 revolutions per day and has a cycle of 26 days.

1.2 Instruments

The satellite is equipped with 3 (identical) optical instruments : *instrument 2* points the ground vertically ; *instrument 3* is a rear instrument (the angle with the orbital plan is about 25 degrees) and *instrument 1* points the ground forwards (with the same angle)

Because the technology is optical, the images cannot be acquired nightly nor in presence of clouds

Each instrument is equipped with a mirror that allows lateral acquisition, within a corridor of 800 km (400 km on each side of the ground track). The mirrors of the different instruments are independent of each other.

1.3 Imaging orders

The images correspond to 60 km squares (this globally corresponds to the swath of the instruments). A *mono* image can be realized by any of the 3 instruments. Stereo images are realized by *instrument 1* (forwards) and *instrument 3* (backwards) - two image are actually acquire for the stereo ; they do not involve *instrument 2*.

Because of meteorological conditions (clouds) some images can be of bad quality. Cloudy images will no be sold.

The probability of failure of each instrument must also be taken into account. It is very low in the nominal case and can rise up to 1 when the instrument seems to be down.

1.4 Technological and physical constraints

The duration of an acquisition by an instrument is constant (= time required by the satellite for a ground track of 60km)

The start date of an acquisition only depends on the date at which the satellite will cross the target zone, modulo the angle of the instrument considered. Hence 3 possible dates for each mono image.

If the starting time of two images imply an overlap (including the time required by the rotation of the mirror), both cannot be taken by the same instrument during the same day .

Once acquired, the image must be stored in the memory of the satellite, which is limited.

2 The problem

The problem is the problem of scheduling the acquisition of some image by the satellite : which imaging order will be acquired, and by which instrument.

Most of the time, it is not possible to realize all the imaging orders, because of feasibility constraints :

1. The satellite cannot memorize more images that permitted by its memory
2. When two images are scheduled on the same instrument, a sufficient delay must be observed between the end of the first one and the beginning on the second one ; it corresponds to the time necessary to rotate the mirror in order to target the good zone
3. Stereo images must be realized on instruments 1 and 3 ; mono images can be realized by any instrument
4. An instrument cannot realize to images simultaneously.

A payoff (a monetary value) is associated to each image, and the general objective, in absence of any uncertainty, is to maximize the sum of the payoff realized.

Because of meteorological conditions (clouds) some images can be of bad quality. Cloudy images will no be sold. The forecast provides an interval limiting the probability of clouds for each image (for instance, $p \in [1, 1]$ when the zone targetted is certainly cloudy, $p \in [0, 0]$ when the zone is certainly without any cloud, $p \in [0.7, 0.9]$ when the probability of clouds in "about 0.8" - not less than 0.7 nor more than 0.9).

The probability of failure of each instrument must also be taken into account. It is very low in the nominal case and can rise up to 1 when the instrument is down.

3 Data

The present case study is a simplified version of the SPOT 5 problem ; For each revolution, the data are :

1. a number `NbImages` of imaging orders (called "images" in the following) ;
2. an array `TY` of size `NbImages` indicating, for each image the type of the image : 1 for the mono image, 2 for the stereo images ;
3. an array `PM` of size `NbImages`, specifying the quantity of memory required by each image (already doubled for the stereo images) ;
4. an array `PA` of size `NbImages`, specifying the payoff for each image (the price at which the image will be sold if selected) ;
5. the number `NbInstruments` of instruments (it is equal to 3) ;
6. A bi dimensional array `DD` of size `NbImages`×`NbInstruments`, specifying for each image and each instrument the date at which the image will be acquired if acquired by this instrument (in seconds, from the beginning of the revolution) ;
7. A bidimensional array `AN` of size `NbImages`×`NbInstruments`, specifying for each image and each instrument the depointing angle (in degrees) required for targeting the image (it depends on the instrument used) ;
8. a duration of acquisition `DU` common to all the images ;

9. a angular speed `VI` of rotation of the mirror (in degrees per second) ;
10. the maximum memory capacity `PMmax`.
11. an array `Failure` of size `NbInstruments` specifying the probability of failure of each instrument
12. two arrays `ProbaInf` and `ProbaSup`, both of size `NbImages`, specifying for each image targeted the probability that the targeted zone will be cloudy

4 Data Sets

Several data set are provided on moodle These data sets have been artificially created for this exercise, but are inspired by a real case study.

You can use the 3 first ones to test and debug your model. Each contains a small problem with only 3 images (2 *mono* and one *stereo*) . In the second one, the memory capacity has been lowered, while the duration is increased in the third one. When the uncertainty in not taken into account the payoff for the first one (respectively the second one, respectively the third one) is 70 (respectively 60, respectively 60). Variants pervaded with uncertainty are included as comments in the first file.

5 Aim of the case study

The objective is to determine the best acquisition plans for the problems described in files `spotproba4.dat` and `spotproba5.dat`, that involve respectively 20 and 40 images. In `spotproba4.dat` the instruments are supposed to be totally reliable (the probability of failure is equal to 0), while in `spotproba5.dat` there are non negligible probabilities of failure, especially for instrument 3.

To this extend, you will build a model of the problem based on Mixed Linear Programming and/or Constraint Programming. An example of such a program is provided on mooddle that implements the second constraints. It is realized thanks to the "OPL IDE" environment and script language that call the CPLEX linear solver (if the problem is linear) or the ILOG CP libraries (for CP models). You shall use this environment and simply complete the partial model.

Your report (pdf) + OPL code (.mod) is due for the 11th of November. Please explain and defend you model, and discuss your results before concluding (the code shall also be added as an annex).