

# ROADEF 2009 Challenge: Disruption Management for Commercial Aviation

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## 1 Introduction

Commercial airlines operate flights according to a published flight schedule that is optimized from a revenue standpoint. However, external events such as mechanical failures, personnel strikes, or inclement weather frequently occur, disrupting planned airline operations. In such cases, it is necessary to find efficient solutions that minimize the duration of the disruption, thus minimizing its impact.

Traditionally, resources are re-allocated sequentially, according to a natural hierarchy: aircraft, crew, passengers. Nonetheless, this method is seriously flawed. Namely, decision making at the local level, concerning one resource, can lead to global repercussions, affecting all resources. For example, a change in the flight schedule, potentially impacting aircraft resources, may also lead to a missed connection for crew or for passengers. Thus, an increasing effort is being made to integrate different levels of decision making. The topic proposed for this challenge follows this trend, since it aims at re-assigning aircraft and passengers simultaneously in case of disruptions.

## 2 Flight Schedule

A flight schedule contains the set of all flights operated by an airline over a given time period. Each flight is defined by:

- a *flight number*;
- an origin airport and a destination airport, thus defining the *length* of the flight, as well as its *type* (domestic, continental, or intercontinental). For this challenge, we will express the length of a flight in terms of *duration*;
- *departure time and date*, and *arrival time and date*.

The sequence of flights assigned to an aircraft is called a *rotation*. Obviously a rotation satisfies the *continuity* of operations: the origin airport of a given flight is the same as the destination airport of the previous flight; moreover, its departure time is later than the arrival time of the previous flight plus the *turn-round time* of the aircraft (i.e., the minimum time to prepare the aircraft for the subsequent flight: deplaning/boarding of passengers, cleaning of the cabin, possible crew change). Figure 1 shows an example of a rotation.



Fig. 1. A rotation

This example features two flights with the same flight number (261). This corresponds to a multi-leg flight that must be operated by the same aircraft, except in the case of a mechanical failure at the intermediate airport (BBB in this example). The advantage of this configuration is that it allows for a reduction in the time necessary to prepare the aircraft for the second leg (BBB to CCC in this example); this time is called *transit time*.

In order to clarify the formulation, each flight will be assigned a unique flight number. In the case of a multi-leg flight, each leg will also receive a unique flight number; however, additional information will indicate a link between the flight legs. For example, flight 261 (as denoted in figure 1) will be made up of two distinct flights (e.g., 2611 and 2612), and additional information will indicate that flight 2612 is preceded by flight 2611, thus composing a multi-leg flight.

In order to account for the complexity of the real-life problem, surface public transportation trips (with type *proximity*) will be added to the regular flight schedule (examples of these trips include buses connecting different airports within the same city, e.g., in Paris or London). These additional “flights” will be operated by specific vehicles (bus, train, etc). Modifying them is not allowed.

### 3 Key Players in the Problem

#### 3.1 Airports

The *network* of an airline is the set of legs (i.e., non-stop flights from an origin airport to a destination airport) offered by the airline. Airports are characterized by given restrictions, such as the maximum departure and arrival rates, as well as a maximum number of aircraft on the airport surface (*airport capacities*). For simplicity, the airport surface capacity will not be taken into account. For each airport, hourly arrival and hourly departure capacities are given. The number of departures (or arrivals) is counted only for 60-minute periods beginning on the hour (referred to as *one-hour intervals*), not for rolling periods. For example, they are counted for periods such as 7:00–7:59, 8:00–8:59 but not for periods such as 7:01–8:00, 7:02–8:01, 7:03–8:02, etc. The one-hour intervals are open on the right-hand side, i.e., they are of the form  $[H, H + 1[$  (with units of hours), where  $H$  is the beginning of an hour (e.g., 7:00). Figure 2 illustrates this concept for an airport with a departure capacity of three.

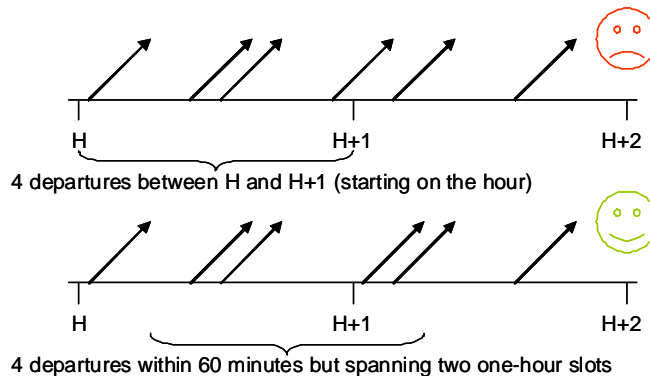


Fig. 2. Examples of situations violating (above) and satisfying (below) a departure capacity of three

#### 3.2 Aircraft Fleet

A fleet is composed of the set of aircraft operated by an airline. Each aircraft is defined by:

- a unique *identification number*;
- a *model* (e.g., Boeing 747, A320, etc);
- a *cabin configuration*, i.e., a breakdown of all seats within each *cabin class* (first, business, economy). The configuration may be modified in some instances; however, it is considered fixed for a given aircraft for this challenge.

Operational characteristics are common to all aircraft of a given model: turn-round time, transit time, *range*, and set of possible configurations.

Subsets of aircraft with common characteristics are grouped within *families* (e.g., A318, A319, A320, and A321 in the “AirbusSmall” family). Crews can switch between all models within a given family, since the cockpits and flight operations are very similar.

An aircraft may be unavailable for an extended period of time when *maintenance* is performed on it. Maintenance actions require a large amount of resources (workforce and equipment). Moreover, an aircraft can fly a given maximum number of hours between two consecutive maintenance actions. At a given time, the number of flight hours remaining until the following maintenance action must be performed is called *remaining flight hours*.

### 3.3 Airports within the Same Urban Region

Surface public transportation is offered between airports within the same urban region. The service is modeled using “flights” operated by a special fleet of vehicles (“TranspCom”). These vehicles are assumed to have infinite capacity in all cabin classes and an operating cost of zero.

### 3.4 Crews

Crew personnel is divided into two categories: cockpit crew (pilot and copilot) and cabin crew (flight attendants). For a commercial flight, a given number of crew personnel of both categories must be assigned to an aircraft. The size of the crew depends upon the model and configuration of the aircraft.

Crew scheduling during the management of the disruption is an important task. However, it is not considered for this challenge, in order to limit the scope of the problem.

### 3.5 Passengers

Passengers make reservations on flights offered by airlines. A reservation is defined by:

- a unique *reservation number*;
- the *number of passengers* (also referred to as *passenger count*) for which the reservation is made;
- the *average price* paid per passenger;
- the description of the itinerary, which is composed of one or several flight legs, with one cabin class specified for each leg;
- the *nature* of the itinerary (*outbound* or *inbound*). For this challenge, “outbound” corresponds to a one-way trip or the outbound portion of a round trip whose inbound portion will be travelled beyond the planning horizon; “inbound” corresponds to the inbound portion of a round trip whose outbound portion was performed before the beginning of the planning horizon.

## 4 Problem Formulation

The goal of this challenge is to develop methods to resume normal operations as quickly as possible, in case of disruptions to the planned flight schedule. It is very important that the flight schedule that was originally planned be applied without modification after a given period of time called *recovery period*. A flight schedule must be determined for the recovery period. Therefore, the rotation for each aircraft must be determined. The solution must minimize the resulting costs and the potential impacts to passengers.

The nature of incidents depends upon the disturbance. The following cases must be taken into account:

- Flight delays. The causes may be longer than usual boarding, a ground personnel strike, a longer than usual turn-round time, or waiting for connecting crew or passengers.
- Flight cancellations.
- Unavailability of an aircraft for a given period. No flight may be assigned to that aircraft for the period during which it is unavailable.
- Limited number of operations for a given period. This may be caused by inclement weather conditions (reducing the airport departure and arrival capacities) or by a strike.

The updated flight schedule is the result of decisions regarding flights planned for the original schedule: intentional *cancellations* and *delays, aircraft changes* within a given family, and the possible *additions* of flights. The primary objective is the minimization of costs for the airline; therefore, changes to the flight schedule may be detrimental to passengers. To account for this, an objective of minimization of the *disutility* to passengers is also included.

There are potential disturbances for the passengers of *impacted* flights (flights that have been modified as compared to the original schedule). These disturbances may lead to the *re-accommodation* of those passengers on a new itinerary or the *cancellation* of their trip. These modifications are evaluated, not only in terms of delay or cancellation costs, but also in terms of comfort. The flight schedule may in turn be modified in order to minimize the inconvenience caused to the passengers.

The problem proposed for this challenge is therefore a bi-objective optimization problem, in which a *trade-off* between costs and level of service must be found.

## 5 Objectives

The objective function includes parameters related to additional costs or gains due to the modification of the flight plan (operating costs of added flights, deduction of operating costs for cancelled flights, costs associated with delays and cancellations of flights included in the original schedule), as well as a measure of the disutility to passengers. The objective is to minimize a weighted sum of those factors.

### 5.1 Operating Costs

Operating costs include all costs associated with the operation of a flight:

- direct aircraft operating costs (fuel, maintenance, crew), which depend upon the aircraft model and the flight time (given as gate-to-gate time in this problem)
- costs of services (ground service, fees associated with the use of runways, parking stands, and gates)

For this challenge, these costs will only be a function of the aircraft model and will be expressed per hour of flight time. In particular, the costs will be independent of the number of passengers on board and of the possible delay. If a flight planned in the initial flight schedule is cancelled, the operating costs described above must be subtracted from the objective function.

The proposed scheme for delay and cancellation costs is inspired from European Union regulations:

- The airline must provide drinks and a meal in case of a delay longer than: two hours on a trip with an initially planned duration strictly less than two hours; three hours on a trip with a duration greater than or equal to two hours and strictly less than four and a half hours; four hours on a trip with a duration greater than or equal to four and a half hours. For this challenge, the cost associated with this item is assumed to be 15 euros per passenger.
- In addition to the previous item, the airline must provide lodging (if necessary) in the case of a delay longer than five hours. The cost of a hotel night is assumed to be 60 euros per passenger for this problem.
- In the case of a cancellation, the airline must reimburse the ticket price regardless of the length of the trip, as well as provide financial compensation. The financial compensation per passenger is: 250 euros for a trip with an initially planned duration strictly less than two hours; 400 euros for a trip with a duration greater than or equal to two hours and strictly less than four and a half hours; 600 euros for a trip with a duration greater than or equal to four and a half hours.

If the trip consists of one leg, the initially planned duration of the trip is the duration of that flight leg, as provided by the initial flight schedule. If the trip consists of several legs, the duration of the trip is defined as the sum of the durations of those flight legs, as provided by the initial flight schedule (thus excluding connection times).

### 5.2 Modeling of Passenger Inconvenience

The disutility to a passenger measures the disturbance perceived by the passenger, regardless of the compensations mentioned above. The disutility is expressed in monetary units (euros), as a

function of the total delay as compared to the original itinerary (or the cancellation of the trip, if applicable). It also includes a penalty in the case of *downgrading* (change to a lower cabin class on all or part of the trip).

If an itinerary is composed of several legs, the itinerary's *reference cabin class* is assumed to be the highest of the booking cabin classes on those legs. All costs will be calculated based on this cabin class. The itinerary type is defined as the type of its longest leg (intercontinental > continental > domestic).

The delay cost is linear in the total delay at the destination, with a slope depending upon the itinerary type and the itinerary's reference cabin class. The cost associated with cancellation is a constant, depending only on those two factors as well. The cancellation cost of a trip is obviously much larger than the maximum delay cost for that trip; the cancellation cost is much larger in case of a return (inbound) portion of a trip.

Costs associated with downgrading are applied only in the case of re-accommodation of a passenger. They are calculated on an individual leg basis, for all legs of the updated itinerary. For each leg, these costs depend upon the type of the leg and the level of downgrading (difference between the itinerary's reference cabin class and the cabin in which the passenger actually travels on that leg).

Let us consider the example of a passenger booked on Nice-Paris (domestic) in economy class followed by Paris-Bangkok (intercontinental) in business class. The reference cabin class is business and the trip is intercontinental. The following situations may occur:

- The trip is cancelled. The passenger is compensated with respect to cancellation on an intercontinental trip in business class.
- The passenger is re-accommodated on a later flight from Nice to Paris in economy class, but can make the original connection in Paris. Costs associated with downgrading from business to economy class on a domestic flight are applied (even though the passenger was originally travelling in economy class between Nice and Paris).
- The passenger is upgraded to first class on Paris-Bangkok the following day. The delay costs are calculated with respect to an intercontinental trip in business class (itinerary's reference cabin class). Costs associated with downgrading from business to economy class are applied on the leg between Nice and Paris (see previous item), even though the passenger was upgraded on the second leg.
- The passenger is re-accommodated on Nice-London (continental) and London-Bangkok flights. Costs associated with a potential downgrading on the Nice-London leg are calculated with respect to continental flights.

Let us consider the example of a passenger booked on Nice-Paris (domestic) in economy class and Paris-Bangkok (intercontinental) in first class. Consider the extreme situation where the passenger is re-accommodated on three flights: Nice-London (continental) in economy class, London-Frankfurt (continental) in business class, and Frankfurt-Bangkok in first class. The possible delay cost is calculated based on an intercontinental flight in first class. The total cost associated with downgrading is the sum of the costs associated with downgrading on the first two legs of the trip: downgrading from first to economy class, and downgrading from first to business class on continental flights.

### 5.3 Return to Normal Operations

The objective function also includes a penalty in the case of *non-compliant location of aircraft* at the end of the recovery period. Constraints are added to the problem in order to enforce the requirement that operations match the original flight schedule by the end of the recovery period. The goal of these constraints is to enforce the number of aircraft of each model and configuration at each airport at the end of the recovery period. Only those aircraft that actually landed at the considered airport are taken into account; in other words, aircraft in flight or landing after the end of the recovery period are excluded.

The violation of this constraint prevents operations from taking place according to the original flight schedule and leads to a penalty in the objective function. The value of the penalty depends upon the severity of the violation:

- zero for each aircraft required at a given airport, which can be matched with a similar aircraft (same model and configuration) actually present at that airport by the end of the recovery period

- $C\_config$  for each required aircraft that can be matched with an (actually present) aircraft of the same model but with a different configuration
- $C\_model$  for each required aircraft that can be matched with an (actually present) aircraft of the same family but of a different model
- $C\_family$  for each required aircraft that cannot be matched with an (actually present) aircraft of the same family.

Each aircraft that is actually present at an airport by the end of the recovery period can be matched with only one aircraft required at that airport.

#### 5.4 Mathematical Formulation

To summarize, the objective function can be expressed as follows:

$$\begin{aligned}
\min \alpha & \left( \sum_{f \in Created} C_{op}^f - \sum_{f \in Cancelled\_F} C_{op}^f + \sum_{p \in Delayed} C_{delay\_legal}^p + \sum_{p \in Cancelled\_P} C_{cancel\_legal}^p \right) \\
& + \beta \left( \sum_{p \in Delayed} C_{delay\_pax}^p + \sum_{p \in Cancelled\_P} C_{cancel\_pax}^p + \sum_{p \in Downgraded} C_{down}^p \right) \\
& + \gamma \sum_{a \in Airports} (NbFamily^a \times C_{family} + NbModel^a \times C_{model} + NbConfig^a \times C_{config})
\end{aligned}$$

where:

- $Created$  is the set of added flights (i.e., flights that were not scheduled originally),  $Cancelled\_F$  is the set of cancelled flights.
- $Delayed$  is the set of delayed passengers,  $Cancelled\_P$  is the set of passengers whose trip has been cancelled,  $Downgraded$  is the set of downgraded passengers. Although the input data are given as flows (passengers with the same itinerary are aggregated within a single reservation), the re-accommodations may be on an individual basis.
- With respect to the constraints of location of aircraft at the end of the recovery period,  $NbFamily^a$  is the number of required aircraft that cannot be matched with aircraft of the same family at airport  $a$ ,  $NbModel^a$  is the number of aircraft that cannot be matched with aircraft of the same model at airport  $a$ , and  $NbConfig^a$  is the number of aircraft that cannot be matched with similar aircraft at airport  $a$ .
- $C_{op}^f$  is the total operating cost associated with flight  $f$  (as a function of the aircraft),  $C_{delay\_legal}^p$  is the cost associated with the delay caused to passenger  $p$  (as a function of the duration of the trip and the length of the delay),  $C_{cancel\_legal}^p$  is the airline cost associated with the cancellation of the trip of passenger  $p$  (ticket price plus financial compensation as a function of the duration of the trip).
- $C_{delay\_pax}^p$  and  $C_{cancel\_pax}^p$  are the costs associated with delay and cancellation for passenger  $p$ , respectively. They depend upon the itinerary type, and of the incurred delay and the nature of the itinerary (inbound or outbound), respectively.
- $C_{down}^p$  is the total cost associated with downgrading for passenger  $p$ , i.e., the sum of the costs associated with downgrading on each leg of the itinerary of passenger  $p$ . On each leg, this cost depends upon the type of the leg and the level of downgrading (difference between the itinerary's reference cabin class and the cabin in which the passengers actually travelled on that leg).
- As explained previously,  $C_{family}$ ,  $C_{model}$ , and  $C_{config}$  are the penalties for non-compliant location of aircraft at the end of the recovery period, relating to the family, the model, and the configuration, respectively.
- $\alpha$ ,  $\beta$  et  $\gamma$  are the weights associated with different cost factors in the objective function: operating costs, costs modelling passenger inconvenience, and penalties for non-compliant location of aircraft, respectively.

## 6 Constraints

### 6.1 Operational Constraints

Since the problem considered for this challenge is a simplified version of a real-life problem, all constraints associated with crews are ignored. However, an aircraft change can only be done within the same family of aircraft.

Constraints associated with aircraft, airports, itineraries, and turn-round times must be verified: *seating capacities, maintenance, airport capacities, minimum connection time, minimum turn-round time* (or *transit time* for multi-leg flights), respectively.

The seating capacity constraint enforces the number of seats on each aircraft and in each cabin. For each flight, the number of passengers travelling in each cabin must not exceed the seating capacity of that cabin. The seating capacity is given by the configuration of the aircraft assigned to that flight.

The maintenance constraint enforces the given number of flight hours between the beginning of the recovery period and for each aircraft, the beginning of required maintenance. Moreover, each aircraft to be maintained must be located at a given specific airport by the time of required maintenance. The aircraft will be unavailable during the maintenance period.

The airport capacity constraints enforce an upper bound on the number of departures and arrivals for each one-hour interval at each airport (not counting the “flights” corresponding to surface public transportation). Since these upper bounds account for several operational constraints (availability of gates, parking stands, ground personnel, etc), they are a simplified version of the actual situation.

The minimum connection time constraint must be satisfied for all connecting passengers: two consecutive flights on the itinerary of a passenger must be separated by at least 30 minutes at the connection airport. This constraint also applies for connections to or from surface transportation.

Similarly, the constraints on minimum turn-round time (or transit time, when applicable) must be satisfied within all rotations, including those assigned to surface transportation vehicles: two consecutive flights of a rotation must be separated by at least the minimum turn-round (or transit) time corresponding to the aircraft operating the flights.

Neither the surface public transportation “flights” nor the vehicles that operate them may be modified. These “flights” are not counted towards the airport capacity constraints.

### 6.2 Functional Constraints

The following rules apply to passenger re-accommodations (i.e., the modification of their itineraries):

- The modified itinerary must have the same final destination as the original itinerary. If this is infeasible, the trip must be cancelled.
- The modified itinerary must not start before the time of the first flight of the original itinerary.
- Priority in re-accommodation is given to passengers who have upcoming connecting flights and have already started their trip at a given time or passengers with an itinerary corresponding to the return portion of their trip. Namely, these passengers must reach their destination, and very large penalties are used if this is not the case.
- The maximum total delay at the destination (as compared to the original itinerary) must not exceed 18 hours for domestic and continental flights, and 36 hours for an intercontinental flight. If this constraint cannot be satisfied, the trip must be cancelled. Passengers mentioned in the previous item are excluded from this rule (e.g., a passenger may be delayed for 40 hours if he or she is on the return portion of an intercontinental trip).

Flights that have arrived or have already left at the beginning of the period (i.e., whose departure time from the initial flight schedule is strictly earlier than the beginning of the recovery period) cannot be modified. However, these flights are taken into account in the calculation of the airport capacity constraints and the costs in the objective function. If a passenger has arrived or has already left at the beginning of the recovery period, the part of his/her itinerary that is before the beginning of the recovery period cannot be modified. Costs that potentially apply to this passenger must be included in the objective function.

The length of the recovery period may be different for different instances. It may be one or several days.

## 7 Challenge Formalities and Conventions

The web site for this challenge (<http://challenge.roadef.org>) contains all the modalities described in the present document. Candidates are encouraged to visit the web site frequently: data delivery, FAQ, etc.

### 7.1 Types of Instances

Amadeus will provide several sets of instances of the problem to the candidates throughout the challenge. The data were partially derived from publicly available information about flight timetables. These data will be provided to candidates according to the following schedule:

- The first set of instances (set A) is provided to the candidates at the beginning of the challenge, and until the end of the enrollment period, at the latest. This sample will be used to select candidates for the final round.
- The second set of instances (set B) will be available after the qualifying phase. It will consist of harder problems than the previous set and will allow the selected candidates to fine-tune their methods.
- The third and last set of instances (set X) will be used to determine the ranking of all finalists before the beginning of the 2009 ROADEF conference. this set will be released to the candidates after the announcement of the final results.

### 7.2 File Formats

Each instance will be provided as a folder `instance_XXX` containing the following files:

- *config.csv*: configuration file specifying the parameters of the problem (recovery period, operating costs, cancellation costs, penalties, etc)
- *airports.csv*: airport capacities
- *dist.csv*: nominal flight time and type between each airport pair
- *flights.csv*: characteristics of the flights
- *aircraft.csv*: data about the aircraft
- *rotations.csv*: description of the rotation for each aircraft
- *itineraries.csv*: description of itinerary for each passenger
- *positions.csv*: desired location of each aircraft by the end of the recovery period *alt\_flights.csv*, *alt\_aircraft.csv*, and *alt\_airports.csv*: disruptions to flights, aircraft, and airports, respectively

For each file, comment lines start with the `%` character. The end of each file is denoted by a line starting with the `#` character.

Data types frequently used in the input files include the following:

- type “airport”: three-character string corresponding to the IATA three-letter code of an airport (e.g., CDG for Paris-Charles de Gaulle, NCE for Nice)
- type “itin\_char”: character specifying whether the itinerary corresponds to the outbound portion of a trip (A for *aller* in French) and to the inbound or return portion of a trip (R)
- type “itin\_type”: character specifying the flight type or the itinerary type (D for domestic, C for continental, I for Intercontinental, P for proximity)
- type “cabin”: character specifying the cabin class (F for first, B for business, E for economy)
- type “duration”: strictly positive integer specifying a duration in minutes
- type “price”: float specifying a price in euros

Complex data types used in the input files are as follows:

- type “date”: **dd/mm/yy** string specifying a date, where **dd**, **mm**, and **yy** are integers with a leading zero when applicable (e.g., 10/01/08, 24/12/09)
- type “time”: **hh:mm**(**[+-]**[1])? string specifying a GMT time, where **hh** and **mm** are integers with a leading zero when applicable (e.g., 12:00, 05:00-1 , which indicates 5:00 on the preceding day)
- type “aircraft”: **model#n** string specifying the aircraft ID of an aircraft, where **model** is a string specifying the aircraft model and **n** is a positive integer representing an identification number (e.g., A320#1, B747#12)



- type “config”: **f/b/e** string, where **f**, **b**, and **e** are nonnegative integers (or equal to -1 in the case of an infinite value) specifying the seating capacity in each cabin class
- type “maint” : **aaa-sd-st-ed-et-d** specifying the characteristics of maintenance (airport, start date and time, end date and time, remaining flight hours), where the type of **aaa** is “airport”, the type of **sd** and **ed** is “date”, the type of **st** and **et** is “time”, and the type of **d** is “duration”

**Configuration File.** This file provides the parameters of the considered instance, including:

- the recovery period: start and end dates (type “date”), start and end times (type “time”)
- the costs per minute (type “price”) associated with delay, given as a function of the cabin class (type “cabin”) and the itinerary type (type “itin\_type”)
- the costs (type “price”) associated with cancellation for passengers on the outbound portion of their trip, given as a function of the cabin class (type “cabin”) and the itinerary type (type “itin\_type”)
- the costs (type “price”) associated with cancellation for connecting passengers having already started their trip or passengers on the inbound portion of their trip, given as a function of the cabin class (type “cabin”) and the itinerary type (type “itin\_type”)
- the costs (type “price”) associated with downgrading, given as a function of the severity of the downgrading (reference cabin class and actual cabin class, both of type “cabin”) and the itinerary type (type “itin\_type”)
- the penalty costs (type “price”) associated with the violation of the constraints of location of aircraft at the end of the recovery period, given in a decreasing order of severity of violation (missing aircraft of the required family, missing aircraft of the required model, missing aircraft of the required configuration)
- the weights  $\alpha$ ,  $\beta$ , and  $\gamma$  of the different cost factors in the objective function, given as floats

Costs mentioned in this file are *unit costs* (per passenger or per aircraft). Moreover, only the costs associated with the disutility to passengers and with penalties due to non-compliant location of aircraft are included in the file. The other costs (i.e., operating costs) are given in the file *aircraft.csv*.

Format of the file *config.csv*:

```
StartDate StartTime EndDate EndTime
(Cabin Type Cost/min )+
(Cabin Type Cost )+
(Cabin Type Cost )+
(Cabin Cabin Type Cost )+
P1 P2 P3
 $\alpha$   $\beta$   $\gamma$ 
```

Example file:

```
10/01/08 06:00 10/01/08 23:30
F D 0.75 F C 1.08 F I 1.5 B D 0.5 B C 0.75 B I 1 E D 0.33 E C 0.5 E I 0.66
F D 1000.0 F C 2000.0 F I 3000.0 B D 650.0 B C 1300.0 B I 2000.0 E D 350.0 E C 650.0
E I 1000.0
F D 3000.0 F C 6000.0 F I 9000.0 B D 2000.0 B C 4000.0 B I 6000.0 E D 1000.0 E C 2000.0
E I 3000.0
F B D 150.0 F B C 300.0 F B I 450.0 F E D 250.0 F E C 500.0 F E I 750.0 B E D 100.0
B E C 200.0 B E I 300.0
20000.0 5000.0 1000.0
1.0 1.0 1.0
#
```

In the above example, the recovery period spans from 10/01/08 from 06:00 to 23:30. Lines 2 to 5 provide the costs associated with the disturbance perceived by passengers, namely the costs associated with delay, cancellation, and downgrading. The costs associated with delay are on line 2, e.g., 0.75 euro per minute of delay for a first-class passenger on a domestic flight, 1.08 euros

per minute for a first-class passenger on a continental flight, 1.50 euros per minute for a first-class passenger on an intercontinental flight, 0.50 euro per minute for a business-class passenger on a domestic flight. The costs associated with cancellation for passengers on the outbound portion of a trip are on line 3, e.g., 1,000 euros for a first-class passenger on a domestic flight, 2,000 euros for a first-class passenger on a continental flight, 3,000 euros for a first-class passenger on an intercontinental flight, 650 euros, 1,300 euros, and 2,000 euros for a business-class passenger on a domestic flight, continental flight, intercontinental flight, respectively, etc. The costs associated with cancellation for passengers on the inbound portion of a trip or connecting passengers who have already started their trip are given on line 4. The costs associated with downgrading are on line 5, e.g., 150 euros for a change from first class to business class on a domestic flight, 300 euros for a change from first class to business class on a continental flight, 450 euros for a change from first class to business class on an intercontinental flight, 250 euros, 500 euros, and 750 euros for a change from first class to economy class on a domestic flight, a continental flight, and an intercontinental flight, respectively. The sixth line of this file provides the decreasing penalty costs associated with non-compliant location of an aircraft: 20,000 euros per missing aircraft of a given family, 5,000 euros per missing aircraft of a given model, and 1,000 euros per missing aircraft of a given configuration. The last line indicates that the weights  $\alpha$ ,  $\beta$ , and  $\gamma$  are equal to 1.0.

**Airport Capacity File.** This file provides the departure and arrival airport capacities, which correspond to a maximum number of operations allowed per one-hour interval, for a typical day. These thresholds depend upon the time of day (peak time, normal time, night time, possible curfew). Each line of the file contains the three-letter code of the airport (type “airport”) followed by a series of quadruples specifying the capacities associated with each time period. Capacities are nonnegative integers and the time periods are characterized by two entries of type “time” corresponding to the start time and end time of the period.

Format of the file *airports.csv*:

```
Airport (Dep/h Arr/h StartTime EndTime )+
```

Example file:

```
NCE 0 0 00:00 03:00 5 0 03:00 07:00 20 20 07:00 19:00 5 10 19:00 21:00 0 0 21:00 00:00
#
```

The above example describes a typical day (in GMT) for Nice airport:

- neither departures nor arrivals between 21:00 and 3:00
- maximum five departures per one-hour interval  $[H, H + 1[$  between 3:00 and 7:00 (and no arrivals)
- maximum 20 departures and 20 arrivals per one-hour interval  $[H, H + 1[$  between 7:00 and 19:00
- maximum five departures and 10 arrivals per one-hour interval  $[H, H + 1[$  between 19:00 and 21:00

**Distance File.** This file provides the typical flight times between each airport pair, as well as the flight type. Note that, for a given airport pair, the flight times may depend on the direction of the flight. Each line of the file contains the three-letter codes of the origin and destination airports (type “airport”), the flight time (type “duration”) and the flight type (type “itin\_type”).

Format of the file *dist.csv*:

```
Origin Destination Dist Type
```

Example file:

```
CDG NCE 95 D
NCE CDG 95 D
#
```

The above example provides the flight times between Nice airport and Paris-Charles de Gaulle (95 minutes in both directions) and specifies that the flight is domestic.

**Flight File.** This file provides information regarding the flights operated by the airline on a typical day of the recovery period. For each flight, the following data are provided: unique identification number (strictly positive integer), origin and destination airports (type “airport”), departure and arrival times (type “time”), and the flight number of the preceding leg (strictly positive in the case of multi-leg flights, 0 otherwise).

Format of the file *flights.csv*:

```
Flight Orig Dest DepTime ArrTime PrevFlight
```

Example file:

```
1 NCE CDG 14:00 15:35 0
2 SIN LHR 15:20 05:30+1 0
3 LHR CDG 06:30 07:45 2
4 ORY CDG 08:30 09:00 0
#
```

The above example describes flight number 1 (domestic, see file *dist.csv*), leaving from Nice at 14:00 GMT and arriving at Paris-Charles de Gaulle at 15:35 GMT. It also describes the multi-leg flight from Singapore to Paris-Charles de Gaulle via London Heathrow, composed of flights numbered 2 and 3. The first leg (intercontinental) leaves from Singapore at 15:20 GMT and arrives at London-Heathrow at 5:30 GMT the following day; the second flight (continental) departs London-Heathrow at 6:30 GMT and arrives in Paris at 7:45 GMT. The last line describes flight number 4 (proximity) from Paris-Orly to Paris-Charles de Gaulle, corresponding to a surface transportation “flight”.

**Aircraft File.** This file provides the aircraft characteristics. For each aircraft, the following data are provided: aircraft ID (type “aircraft”), model, family, configuration (type “config”), range in flight hours (type “duration”), hourly operating cost (type “price”), turn-round and transit times (type “duration”), origin airport (type “airport”), i.e., the airport where the aircraft is located at the beginning of the recovery period or where it is parked in the case of an aircraft with no planned rotation, maintenance when applicable (type “maint”). The model and the family are given as strings.

Format of the file *aircraft.csv*:

```
Aircraft Model Family Config Dist Cost/h TurnRound Transit Orig Maint
```

Example file (including presence and absence of maintenance, surface public transportation):

```
A320#1 A320 AirbusSmall 0/20/150 480 1500.0 30 30 CDG CDG-10/01/08-14:00-10/01/08-20:00-900
A320#2 A320 AirbusSmall 10/30/110 480 1500.0 30 30 NCE NULL
TranspCom#1 TranspCom TranspCom -1/-1/-1 60 0.0 5 5 CDG NULL
TranspCom#2 TranspCom TranspCom -1/-1/-1 60 0.0 10 10 ORY NULL
#
```

The above example provides the characteristics of the first two Airbus A320s in the fleet. Note that they have several common characteristics, but their configurations are different. The first one is located in Paris-Charles de Gaulle at the beginning of the recovery period, and must undergo maintenance there on 10/01/08 between 14:00 and 20:00 (it cannot fly more than 15 hours between two consecutive maintenance actions). The second one is located in Nice and has no planned maintenance until the end of the recovery period. The characteristics of surface transportation vehicles 1 and 2 are also provided. Both of them belong to the family TranspCom, have infinite seating capacities, and operating costs of zero. Vehicle 1 is located in Nice at the beginning of the period, whereas vehicle 2 is in Paris-Orly.

**Rotation File.** This file describes rotations for all aircraft throughout the recovery period. Each flight is uniquely defined by a flight number (strictly positive integer) and a departure date (type “date”). The aircraft operating the flight is also provided (type “aircraft”). The lines are grouped by aircraft and sorted chronologically for each aircraft.

Format of the file *rotations.csv*:

Flight DepDate Aircraft

Example file:

```
2 20/01/08 B747#5
3 21/01/08 B747#5
2 21/01/08 A340#2
3 22/01/08 A340#2
4 21/01/08 TranspCom#2
#
```

The above example describes the rotations of the Boeing 747 number 5, the Airbus A340 number 2, and the surface vehicle number 2 throughout the recovery period, which is from 20/01/08 to 21/01/08. These rotations consist of flights number 2 and 3 (multi-leg flights from Singapore to Paris-Charles de Gaulle, see file “flights.csv”) on 20/01 and 21/01, and of the surface trip from Paris-Orly to Paris-Charles de Gaulle on 21/01, respectively. Note that flight number 3 on 22/01 is not within the recovery period; however, since this flight is linked to a flight within the recovery period (flight number 2 on 21/01), it is included in the problem.

**Itinerary File.** This file provides information about passenger itineraries. The following data are included for each itinerary: unique identification number (strictly positive integer), nature of the itinerary (inbound or outbound, type “itin\_char”), unit price in euros (type “price”), number of passengers booked on this itinerary, series of flights, dates, and cabin classes constituting the itinerary. The number of passengers is a strictly positive integer.

Format of the file *itineraries.csv*:

Ident Type Price Count (Flight DepDate Cabin )+

Example file:

```
1 A 784.21 320 2 20/01/08 E
2 R 1752.5 27 2 20/01/08 B 3 21/01/08 B
#
```

The above example describes the following itineraries: 320 passengers booked on flight number 2 (Singapore-London Heathrow, see file *flights.csv*) on 20/01/08, on the outbound portion of their trip, travelling in economy class, and having paid 784.21 euros on average; 27 passengers booked from Singapore to Paris-Charles de Gaulle via London, on the inbound portion of their trip, travelling in business class on both flights, and having paid 1,752.5 euros on average.

**Aircraft Positioning File.** This file provides the number of aircraft of each kind (model and configuration) required to be at any given airport by the end of the recovery period. Each line provides the list of the number of aircraft of each model (string) and each configuration (type “config”) required at one airport (type “airport”). The number of aircraft is a strictly positive integer.

Format of the file *positions.csv*:

Airport (Model Config Count )+ #

Example file:

```
NCE A320 0/20/150 5 A320 10/30/110 2 B737 0/0/115 7 #
#
```

The above example describes the number of aircraft required at Nice airport by the end of the recovery period: five Airbus A320s having 20 seats in business class and 150 seats in economy class; two Airbus A320s having 10 seats in first class, 30 seats in business class, and 110 seats in economy class; and seven Boeing 737s having 115 seats in economy class.

**Flight Disruption File.** This file provides the disruptions happening to flights operated by the considered airline, namely delays and cancellations. Each impacted flight is uniquely identified by a flight number (strictly positive integer) and a departure date (type “date”). Information about the disruption is also provided: the length of the delay (type “duration”) in case of delay, and -1 in case of cancellation. Flights mentioned in this file, as well as passengers travelling on them, must be taken into account for the calculation of costs in the objective function.

Format of the file *alt\_flights.csv*:

Flight DepDate Delay

Example file:

```
2 20/01/08 45
1 21/01/08 -1
#
```

The above example specifies a delay of 45 minutes on flight number 2 (Singapore-London Heathrow, see file *flights.csv*) on 20/01/08 and the cancellation of flight number 1 (Nice to Paris-Charles de Gaulle) on 21/01/08.

**Aircraft Disruption File.** This file provides the periods of unavailability of aircraft. Each line contains the aircraft ID of the unavailable aircraft (type “aircraft”), the date (type “date”) and time (type “time”) of the beginning of the period of unavailability, and the date and time of the end of the period of unavailability.

Format of the file *alt\_aircraft.csv*:

Aircraft StartDate StartTime EndDate EndTime

Example file:

```
A320#1 20/01/08 04:00 20/01/08 20:00
#
```

The above example mentions that the Airbus A320 number 1 will not be available between 4:00 and 20:00 on 20/01/08.

**Airport Disruption File.** This file provides the periods of temporary reductions in airport capacities. Each line contains the three-letter code of the airport where the reduction occurs (type “airport”), the date and time of the start of the period of reduction (types “date” and “time”), the date and time of the end of the period of reduction, and the applicable departure and arrival capacities during the period of reduction. The capacities are nonnegative integers.

Format of the file *alt\_airports.csv*:

Airport StartDate StartTime EndDate EndTime Dep/h Arr/h

Example file:

```
LHR 20/01/08 04:00 20/01/08 10:00 0 2
#
```

The above example corresponds to dense fog in London: no departures and only two arrivals are allowed per one-hour interval  $[H, H + 1[$  from 4:00 to 10:00.

### 7.3 Deliverables

The candidates must provide the following documents:

- A form specifying the names, occupations (student or researcher), and affiliations of the team members.
- An extended abstract (about five pages) describing the proposed solution method.
- A table summarizing the results obtained for each instance.
- Solution files corresponding to each instance, namely two files containing the description of the updated set of rotations (*sol\_rotations.csv*) and of the updated set of passenger itineraries (*sol\_itineraries.csv*), respectively. The file names must be prefixed with the name of the considered instance (e.g., *A01\_sol\_rotations.csv* for the file describing the rotations for instance *A01*). The required format of these files is detailed below.

The candidates must be able and willing to supply the programmes that provided these solutions, either as an executable file or as a source code including instructions on how to compile and, when applicable, the makefile.

**Rotation Solution File.** This file provides information for all entries of the original flight and rotation files, including modifications (i.e., the results of the optimisation). All flights from the initial flight schedule are therefore included, with changes when applicable (updated departure and arrival times, updated aircraft assignment, cancellation). Added flights are also included, which must have a unique identification number that is also different from all identification numbers in the original flight schedule.

Format of the file *XXX\_sol\_rotations.csv* :

```
Flight Orig Dest NewDepTime NewArrTime PrevFlight Date Aircraft
```

Let us consider the input file *flights.csv*:

```
1 NCE CDG 14:00 15:35 0
10 SIN LHR 15:20 05:30+1 0
11 LHR CDG 06:30 07:45 10
43 CDG SXB 16:30 17:35 0
100 CDG ORY 16:40 17:10 0
#
```

and the input file *rotations.csv*:

```
1 20/01/08 A320#1
1 21/01/08 A320#2
10 19/01/08 A340#2
11 20/01/08 A340#2
10 20/01/08 B747#5
11 21/01/08 B747#5
10 21/01/08 A340#2
11 22/01/08 A340#2
43 20/01/08 Fokk100#1
43 21/01/08 Fokk100#1
100 20/01/08 TranspCom#15
100 21/01/08 TranspCom#8
#
```

For this instance (Test01), the Boeing 747 number 5 has mechanical problems, and a strike of ground personnel in Paris-Charles de Gaulle leads to a severe reduction in arrival capacity throughout the recovery period, which is on January 20 and 21, 2008.

Solution file *Test01\_sol\_rotations.csv*:

```
1 NCE CDG 14:00 15:35 0 20/01/08 A320#1
1 NCE CDG 14:30:16:05 0 21/01/08 A320#2
10 SIN LHR 15:20 05:30+1 0 19/01/08 A340#2
10 SIN LHR 15:20 05:30+1 0 20/01/08 cancelled
```

```

10 SIN LHR 15:20 05:30+1 0 21/01/08 A340#2
11 LHR CDG 06:30 07:45 10 20/01/08 A340#2
11 LHR CDG 06:30 07:45 10 21/01/08 B747#16
11 LHR CDG 06:30 07:45 10 22/01/08 A340#2
43 CDG SXB 16:30 17:35 0 20/01/08 cancelled
43 CDG SXB 16:30 17:35 0 21/01/08 cancelled
100 CDG ORY 16:40 17:10 0 20/01/08 TranspCom#15
100 CDG ORY 16:40 17:10 0 21/01/08 TranspCom#8
2 ORY SXB 17:40 18:40 0 20/01/08 BAE300#7
#

```

The recovery period starts on 20/01/08 at 15:00 and ends on 21/01/08 at 23:59. Since flight number 1 on 20/01/08 has already left at the beginning of the period, it remains unchanged. Similarly, flight numbers 10 and 11 on 19/01/08 and 20/01/08 remain unchanged, as they arrived before the beginning of the recovery period. Surface transportation “flights” 100 also remain unchanged (they are not affected by the restrictions on airport capacity). We decide to cancel flight number 10 on 20/01/08 and to assign a spare aircraft (Boeing 747 number 16) to flight number 11 on 21/01/08. Flight number 1 on 21/01/08 is delayed by 30 minutes at departure (and thus arrives with a 30-minute delay) because no arrival is allowed at Paris-Charles de Gaulle before 16:00 on 21/01/08. Flight number 43 is cancelled on both days due to the reduction in airport capacity. We decide to add flight number 2 from Paris-Orly to Strasbourg on 20/01/08, leaving from Orly at 17:15 and operated by a BAE300 available at Orly.

**Itinerary Solution File.** The format of this file is exactly the same as that of the itinerary input file. The original identification number of the reservation is kept for each passenger. Therefore, there may be several lines with the same reservation number, if passengers from the same original reservation are re-accommodated in different ways.

Let us consider the file *itineraries.csv*:

```

1 A 784.21 320 10 20/01/08 E
2 R 1752.5 27 10 20/01/08 B 11 21/01/08 B
3 A 150.7 12 43 20/01/08 E
4 R 150.7 70 43 20/01/08 E
#

```

For this instance (Test01), flight number 10 on 20/01/08 is cancelled. The 27 passengers on the return portion of their trip must be re-accommodated (due to prohibitive penalties if this is not the case); they are re-accommodated on the flight the following day, where some passengers are upgraded and some passengers are downgraded. On the contrary, only some of the 320 remaining passengers can be re-accommodated on the following flight, due to the lack of seating capacity on the aircraft. The trips of some passengers are therefore cancelled. Since flight number 43 on 20/01/08 is cancelled, passengers that were booked on that flight are re-accommodated on another itinerary.

Solution file *Test01\_sol\_itineraries.csv*:

```

1 A 784.21 50 10 21/01/08 E
1 A 1752.5 270 cancelled
2 R 1752.5 2 10 21/01/08 F 11 22/01/08 B
2 R 1752.5 8 10 21/01/08 B 11 22/01/08 B
2 R 1752.5 17 10 21/01/08 E 11 22/01/08 B
3 A 150.7 12 100 20/01/08 E 2 20/01/08 E
4 R 150.7 70 100 20/01/08 E 2 20/01/08 E
#

```

Fifty passengers of reservation number 1 were re-accommodated on the flight the following day, whereas the trips for the remaining 270 passengers were cancelled. All passengers of reservation number 2 were re-accommodated on the following day: two passengers in first class then business class (upgrade), eight passengers in their original cabin class, whereas the remaining 17 passengers

were downgraded on the Singapore-Heathrow leg (leading to a penalty cost). All 82 passengers of reservations number 3 and 4 were re-accommodated on the itinerary composed of surface transportation “flight” number 100 followed by flight number 2.

## 7.4 Evaluation

The programmes provided by the candidates will be evaluated on a test computer provided by Amadeus, namely a PC with an AMD Turion64x2 processor and 2 GB of RAM. Supported operating systems are Windows XP Professional SP2 (32 bits) and Fedora 9 (64 bits).

Artelys and Dash Optimization agreed to provide:

- one Academic Research with CP licence and one Kalis C++ license per team;
- technical support by email (one contact person per team).

Moreover, the use of the following Ilog products is allowed: CPLEX 10.2 and CP Optimizer 1.0.

The programmes supplied by the candidates must run on the test computer mentioned above and return results for all instances of the problem. The programmes must be run from the command line, using the following format:

```
programme_name -t cpu_time -i instance_name
```

where `cpu_time` specifies the maximum running time allowed and `instance_name` is the name of the considered instance. Failure to comply with these requirements will lead to disqualification.

By default, the maximum running time allowed is 10 minutes. Programmes that do not return a result within this time will be disqualified.

The programmes meeting all the above requirements will be evaluated using the average scores normalized over all instances. The score obtained for an instance is given by the value of the objective function, normalized with respect to the best solution over all programmes for this instance.

In the case where two or more candidates are tied, they will be ranked through successive rounds. A round will consist of running each programme with a shorter running time and recalculating the scores. Rounds will be performed with decreasing running times until all ties have been resolved.

## 7.5 Schedule of the Challenge

The challenge will consist of two distinct periods: a qualifying phase and a final phase. Initial data sets will be provided at the beginning of the challenge, followed by additional sets, which will be provided until the end of the enrollment period, at the latest. A programme that verifies the validity of the solutions will also be supplied to the candidates during this phase. A selection will be performed at the end of the qualifying phase, as described above. Those candidates allowed to continue will receive a second set of instances that will be used for the final evaluation. At the end of the final phase, all finalists’ programmes will be evaluated on a new set of unknown instances, leading to the final ranking. The ranking will be disclosed at the 2009 ROADEF conference.

The initial schedule is as follows:

- 2008 ROADEF conference: official launch of the challenge and beginning of the enrollment period. The subject of the challenge and the first instances are provided to the participants.
- 16/05/08: end of the enrollment period.
- 13/06/08: deadline to submit the deliverables (list of documents in section 7.3).
- 01/09/08: notification of the results of the qualifying phase and beginning of the final phase. The set B of instances is provided.
- 05/01/09: end of the final phase.
- 2009 ROADEF conference: announcement of results and ranking. The set X of instances is provided.



## 8 Appendix: Scenario \*

### 8.1 Set \*

#### Configuration File

```
%Recovery window
%StartDate StartTime EndDate EndTime
10/01/08 06:00 10/01/08 23:30

%Delay costs (given by cabin and itinerary type)
%(Cabin Type Cost/min )+
F D 0.75 F C 1.08 F I 1.5 B D 0.5 B C 0.75 B I 1 E D 0.33 E C 0.5 E I 0.66

%Cancellation costs for outbound itineraries (given by cabin and itinerary type)
%(Cabin Type Cost )+
F D 1000.0 F C 2000.0 F I 3000.0 B D 650.0 B C 1300.0 B I 2000.0 E D 350.0 E C 650.0
E I 1000.0

%Cancellation costs for inbound or already begun itineraries (given by cabin and itinerary type)
%(Cabin Type Cost )+
F D 3000.0 F C 6000.0 F I 9000.0 B D 2000.0 B C 4000.0 B I 6000.0 E D 1000.0 E C 2000.0
E I 3000.0

%Downgrading costs (given by flight type and downgrading level)
%(Cabin Cabin Type Cost )+
F B D 150.0 F B C 300.0 F B I 450.0 F E D 250.0 F E C 500.0 F E I 750.0 B E D 100.0
B E C 200.0 B E I 300.0

%Penalties associated with incorrect location of aircraft (w/r to family, model, config)
%P1 P2 P3
20000.0 5000.0 1000.0

%Weights for different cost factors in the objective function
% $\alpha$   $\beta$   $\gamma$ 
1.0 1.0 1.0
#
```

#### Airport Capacity File

```
%Airport (Dep/h Arr/h StartTime EndTime )+
BKK 1 1 00:00 03:00 2 2 03:00 05:00 4 4 05:00 00:00
CDG 1 2 00:00 05:00 4 4 05:00 21:00 2 2 21:00 00:00
JFK 1 2 00:00 04:00 3 3 04:00 00:00
LHR 3 4 00:00 05:00 6 6 05:00 23:00 3 4 23:00 00:00
NCE 0 0 00:00 04:00 1 2 04:00 06:00 4 4 06:00 22:00 2 2 22:00 00:00
SYD 0 0 00:00 05:00 3 3 05:00 22:00 1 2 22:00 00:00
#
```

#### Distance File

```
%Origin Destination Dist Type
BKK CDG 739 I
BKK JFK 1077 I
BKK LHR 749 I
BKK NCE 742 I
BKK SYD 594 I
BKK ORY 741 I
CDG BKK 739 I
CDG JFK 468 I
CDG LHR 55 C
CDG NCE 77 D
CDG SYD 1302 I
CDG ORY 34 P
```

```

JFK BKK 1077 I
JFK CDG 468 I
JFK LHR 446 I
JFK NCE 495 I
JFK SYD 1232 I
JFK ORY 468 I
LHR BKK 749 I
LHR CDG 55 C
LHR JFK 446 I
LHR NCE 100 C
LHR SYD 1308 I
LHR ORY 57 C
NCE BKK 742 I
NCE CDG 77 D
NCE JFK 495 I
NCE LHR 100 C
NCE SYD 1305 I
NCE ORY 74 D
SYD BKK 594 I
SYD CDG 1302 I
SYD JFK 1232 I
SYD LHR 1308 I
SYD NCE 1305 I
SYD ORY 1304 I
ORY BKK 741 I
ORY CDG 34 P
ORY JFK 468 I
ORY LHR 57 C
ORY NCE 74 D
ORY SYD 1304 I
#

```

### Flight File

```

%Flight Orig Dest DepTime ArrTime PrevFlight
1 BKK CDG 18:00 06:15+1 0
2 NCE CDG 08:00 09:30 0
3 CDG LHR 10:20 11:20 0
4 CDG LHR 08:30 09:30 0
5 LHR JFK 12:00 19:30 0
6 NCE LHR 09:30 11:15 0
7 CDG BKK 11:30 21:45 0
8 LHR CDG 12:30,13:30 0
9 CDG NCE 14:35 16:05 0
10 LHR NCE 13:10 14:55 0
11 JFK LHR 22:30 06:00+1 0
12 LHR CDG,07:15 08:15 0
#

```

This file describes the characteristics of each flight, as shown in figure 3.

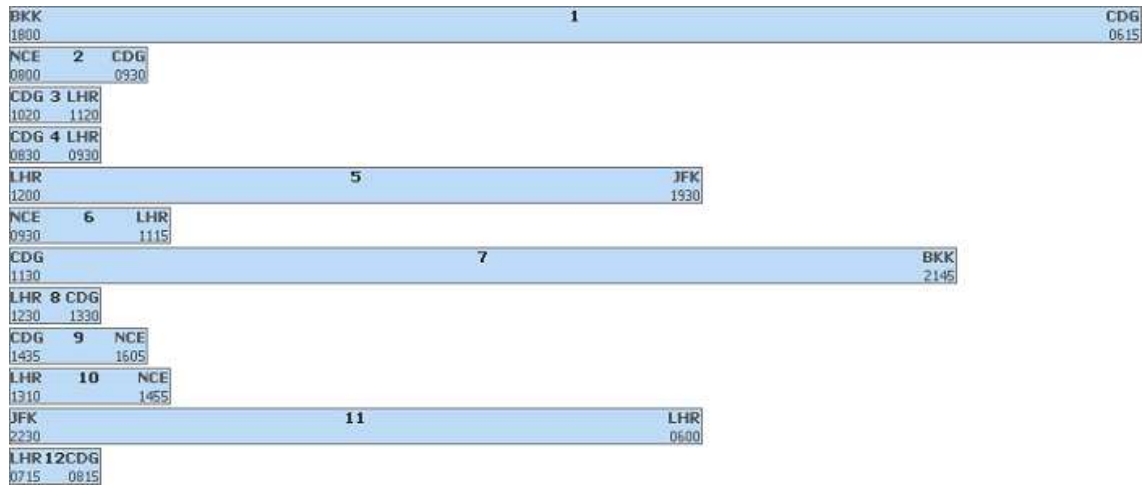


Fig. 3. Characteristics of the flights considered in the problem.

### Aircraft File

```
%Aircraft Model Family Config Dist Cost/h TurnRound Transit Orig Maint
B767#1 B767 Boeing 10/20/160 12250 3000.0 75 50 CDG
CDG-10/01/08-06:00-10/01/08-10:00-20

B767#3 B767 Boeing 10/20/160 12250 3000.0 75 50 BKK NULL

A320#1 A320 Airbus 0/20/160 5700 2000.0 40 40 NCE
NCE-10/01/08-17:00-11/01/08-12:00-10

A320#2 A320 Airbus 0/20/160 5700 2000.0 40 40 NCE NULL

B777#1 B777 Boeing 20/45/310 14000 4000.0 90 60 CDG NULL

B777#4 B777 Boeing 20/45/310 14000 4000.0 90 60 LHR
CDG-10/01/08-12:00-10/01/08-22:00-80

#
```

### Rotation File

```
%Flight DepDate Aircraft
1 10/01/08 B767#3
7 10/01/08 B767#1
2 10/01/08 A320#1
3 10/01/08 A320#1
8 10/01/08 A320#1
9 10/01/08 A320#1
4 10/01/08 B777#1
5 10/01/08 B777#1
11 10/01/08 B777#1
12 10/01/08 B777#4
6 10/01/08 A320#2
10 10/01/08 A320#2

#
```

This file provides the aircraft assignments of each flight. Figure 4 shows the resulting flight schedule, represented on three 12-hour intervals placed in chronological order from top to bottom. The red vertical line indicates the beginning of the recovery period. Aircraft shown on the left-hand side are associated, on the right-hand side, with the flights assigned to them.

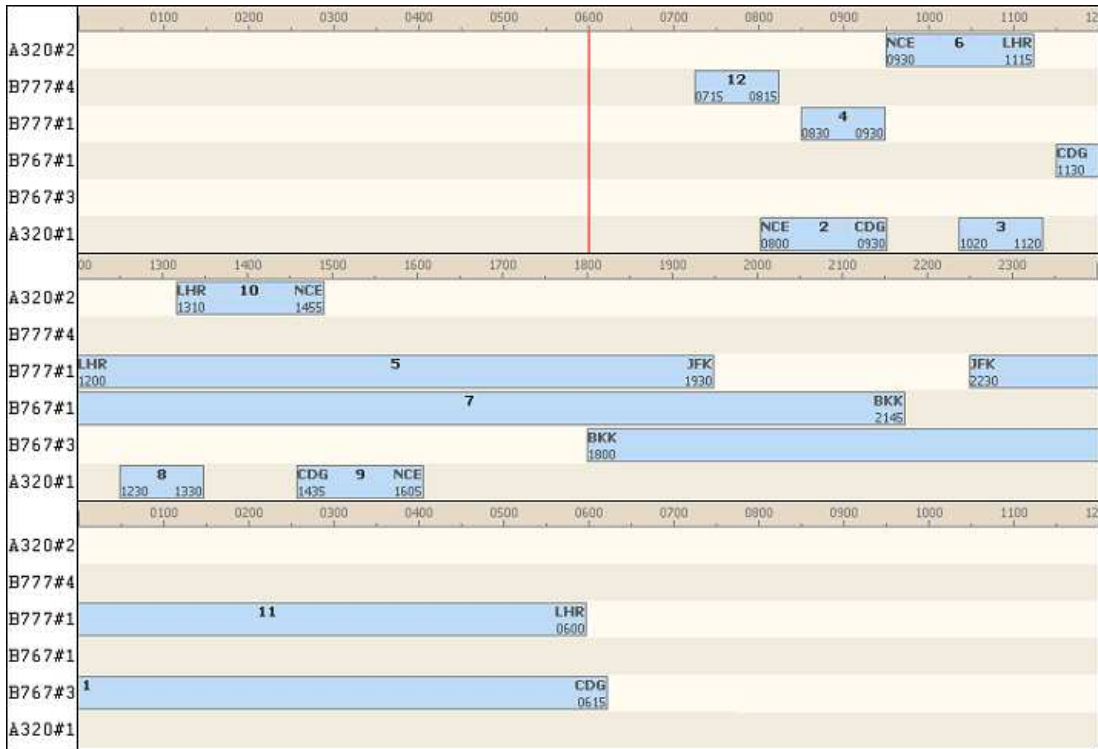


Fig. 4. The rotations considered in the problem.

### Itinerary File

```
%Ident Type Price Count (Flight DepDate Cabin )+
1 A 2800.0 5 1 10/01/08 F
2 A 2200.5 7 1 10/01/08 B
3 A 1000.2 75 1 10/01/08 E
4 R 2200.5 9 1 10/01/08 B
5 R 1000.2 60 1 10/01/08 E
6 A 400.25 30 2 10/01/08 E
7 R 400.25 20 2 10/01/08 E
8 A 350.0 30 3 10/01/08 E
9 R 1200.17 1 3 10/01/08 B
10 R 350.4 30 3 10/01/08 E
11 A 1700.0 3 2 10/01/08 B 3 10/01/08 B
12 A 900.18 20 2 10/01/08 E 3 10/01/08 E
13 R 1700.0 1 2 10/01/08 B 3 10/01/08 B
14 R 900.18 10 2 10/01/08 E 3 10/01/08 E
15 A 1100.15 13 4 10/01/08 B
16 A 600.7 60 4 10/01/08 E
17 R 1100.15 9 4 10/01/08 B
18 R 600.7 40 4 10/01/08 E
19 A 2200.75 5 5 10/01/08 B
20 A 2900.1 1 5 10/01/08 F
21 R 2900.1 1 5 10/01/08 F
22 A 950.0 45 5 10/01/08 E
23 R 950.0 55 5 10/01/08 E
24 A 3400.61 4 4 10/01/08 F 5 10/01/08 F
25 A 2800.8 8 4 10/01/08 B 5 10/01/08 B
26 A 1100.0 80 4 10/01/08 E 5 10/01/08 E
27 R 3400.61 4 4 10/01/08 F 5 10/01/08 F
28 R 2800.8 4 4 10/01/08 B 5 10/01/08 B
```

29 R 1100.0 45 4 10/01/08 E 5 10/01/08 E  
30 A 1600.09 3 6 10/01/08 B  
31 A 450.64 32 6 10/01/08 E  
32 R 1600.09 1 6 10/01/08 B  
33 R 450.64 25 6 10/01/08 E  
34 A 2500.25 0 7 10/01/08 F  
35 A 1800.0 3 7 10/01/08 B  
36 A 900.3 55 7 10/01/08 E  
37 R 2500.25 2 7 10/01/08 F  
38 R 1800.0 2 7 10/01/08 B  
39 R 900.3 40 7 10/01/08 E  
40 A 1100.05 4 8 10/01/08 B  
41 A 400.8 55 8 10/01/08 E  
42 R 1100.05 4 8 10/01/08 B  
43 R 400.8 30 8 10/01/08 E  
44 A 1200.0 3 9 10/01/08 B  
45 A 350.42 40 9 10/01/08 E  
46 R 1200.0 2 9 10/01/08 B  
47 R 350.42 20 9 10/01/08 E  
48 A 1700.76 6 8 10/01/08 B 9 10/01/08 B  
49 A 900.0 25 8 10/01/08 E 9 10/01/08 E  
50 R 900.0 15 8 10/01/08 E 9 10/01/08 E  
51 A 1600.98 12 10 10/01/08 B  
52 A 500.25 78 10 10/01/08 E  
53 R 500.25 65 10 10/01/08 E  
54 A 1400.34 7 11 10/01/08 F  
55 A 1100.87 13 11 10/01/08 B  
56 A 600.0 85 11 10/01/08 E  
57 R 1100.13 19 11 10/01/08 B  
58 R 600.0 148 11 10/01/08 E  
59 A 2000.71 18 12 10/01/08 B  
60 A 950.15 45 12 10/01/08 E  
61 R 950.15 95 12 10/01/08 E  
62 A 2200.03 4 12 10/01/08 F  
63 R 1400.69 8 11 10/01/08 F  
64 R 2200.03 8 12 10/01/08 F  
65 R 2800.75 4 12 10/01/08 B  
66 A 2500.5 2 4 10/01/08 F  
67 R 2500.5 2 4 10/01/08 F  
68 A 1600.38 7 6 10/01/08 B 5 10/01/08 F  
69 A 450.0 50 6 10/01/08 E 5 10/01/08 E  
70 R 1600.38 5 6 10/01/08 B 5 10/01/08 B  
71 R 450.0 25 6 10/01/08 E 5 10/01/08 E  
72 A 2350.91 4 2 10/01/08 B 7 10/01/08 F  
73 A 900.14 20 2 10/01/08 E 7 10/01/08 E  
74 A 1700.72 1 2 10/01/08 B 7 10/01/08 B  
75 R 900.14 3 2 10/01/08 B 7 10/01/08 F  
76 R 900.14 10 2 10/01/08 B 7 10/01/08 B  
77 R 900.14 10 2 10/01/08 E 7 10/01/08 E  
78 A 1700.3 5 2 10/01/08 B 9 10/01/08 B  
79 A 900.75 32 2 10/01/08 E 9 10/01/08 E  
80 A 1200.0 7 12 10/01/08 B 3 10/01/08 B  
81 A 350.41 60 12 10/01/08 E 3 10/01/08 E  
82 A 3500.0 2 3 10/01/08 B 5 10/01/08 F  
83 A 2800.6 3 3 10/01/08 B 5 10/01/08 B  
84 R 1500.24 10 3 10/01/08 E 5 10/01/08 E  
#

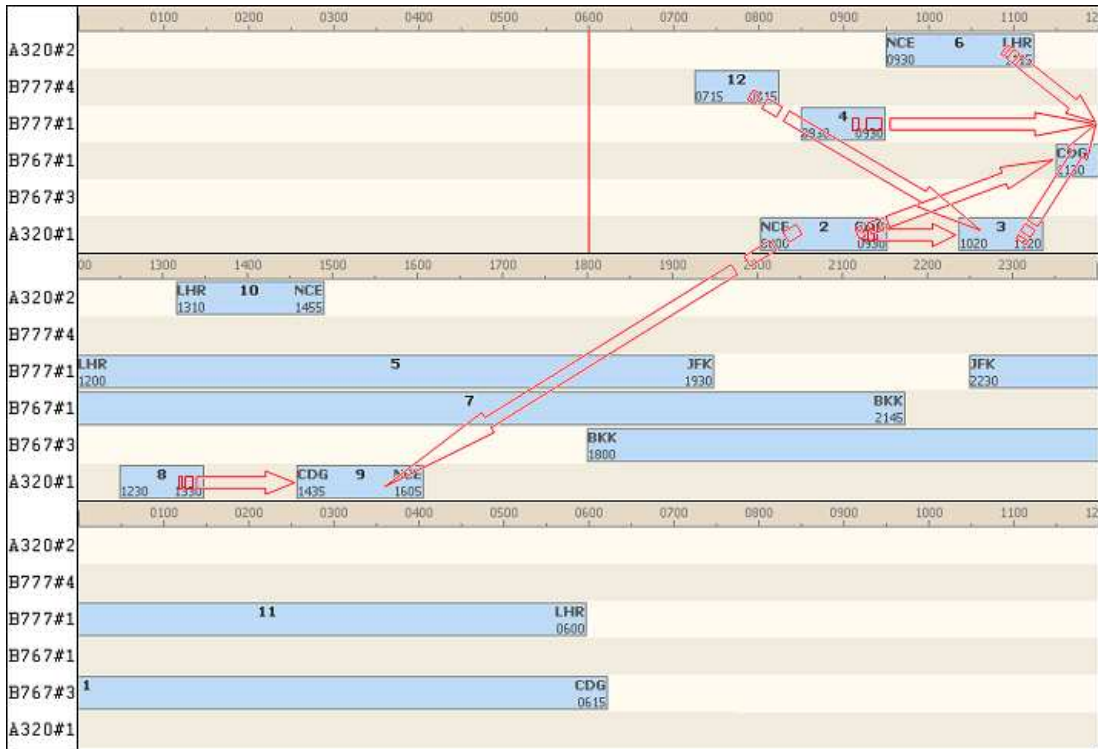


Fig. 5. Diagramme of the connections.

This file describes the itinerary of each passenger. Figure 5 shows passenger connections with red arrows. As already mentioned for the previous figure, three 12-hour intervals are placed in chronological order from top to bottom. The red vertical line indicates the beginning of the recovery period.

#### Aircraft Positioning File

```
%Airport (Model Config Count )+ #
CDG B777 20/45/310 1 B767 10/20/160 1 #
LHR B777 20/45/310 1 #
NCE A320 0/20/160 2 #
BKK B767 10/20/160 1 #
#
```

#### Flight Disruption File

```
%Flight DepDate Delay
3 10/01/08 60
#
```

#### Aircraft Disruption File

```
%Aircraft StartDate StartTime EndDate EndTime
#
```

#### Airport Disruption File

```
%Airport StartDate StartTime EndDate EndTime Dep/h Arr/h
#
```

#### Impact of Disruptions

The disruption consists of one delayed flight (flight number 3). If the disruption is not managed

properly, this delay propagates through the system, leading to delays of two later flights (due to the constraints of turn-round time) and missed connections for passengers from flight number 3. Figure 6 summarizes the consequences of the disruption on the resources considered in the problem.

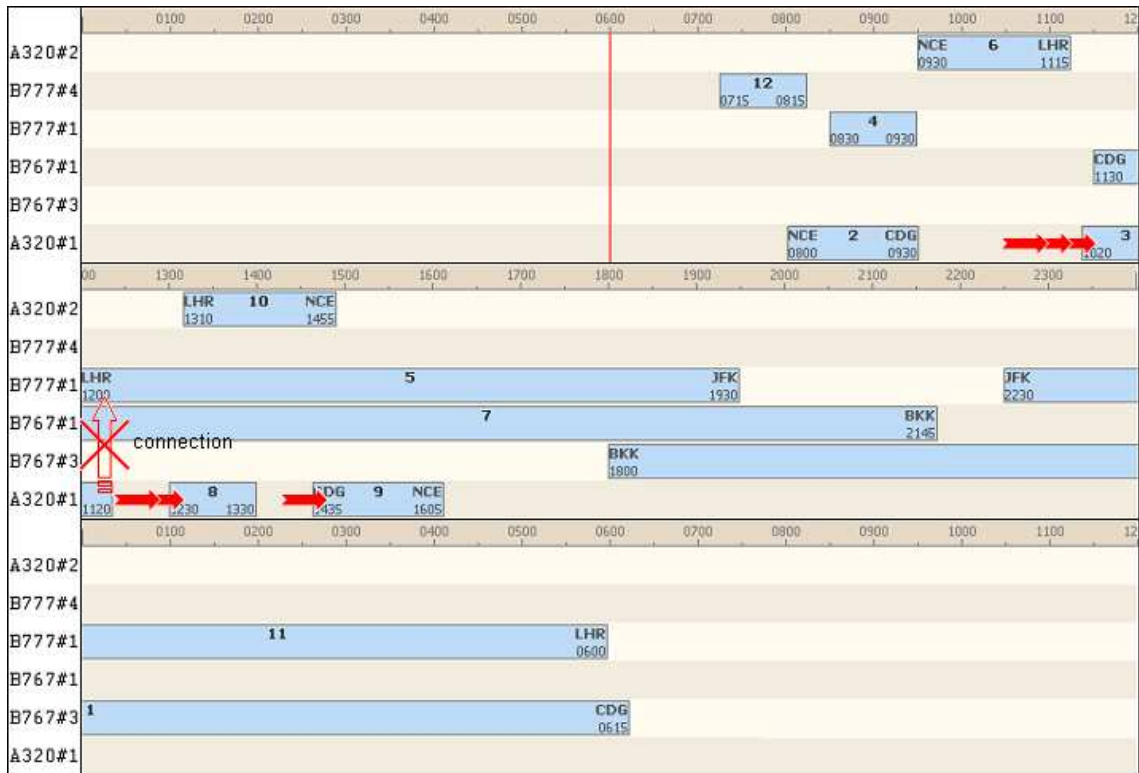


Fig. 6. Consequences of the delay of flight number 3.

### Solutions for Disruption Recovery

In order to alleviate the propagation of the delay of flight number 3 to flights 8 and 9, parts of the rotations assigned to the A320 number 1 and number 2 are swapped, as shown in figure 7. Thus, flights 8 and 9, which are re-assigned to the A320 number 2, can leave on time. Flight number 10 is re-assigned to the A320 number 1 and can also leave on time. This leads to substantial savings in delay costs.

A slight (intentional) delay to flight number 5 can also be suggested, in order to allow for the connection of passengers coming from flight number 3. This delay has no further impact on the rotation of the B777 number 1, as shown in figure 8. Passengers whose trip would have been cancelled otherwise can reach their destination. This leads to substantial savings in cancellation costs, which are most likely greater than the costs associated with the delay imposed on passengers of flight number 5.

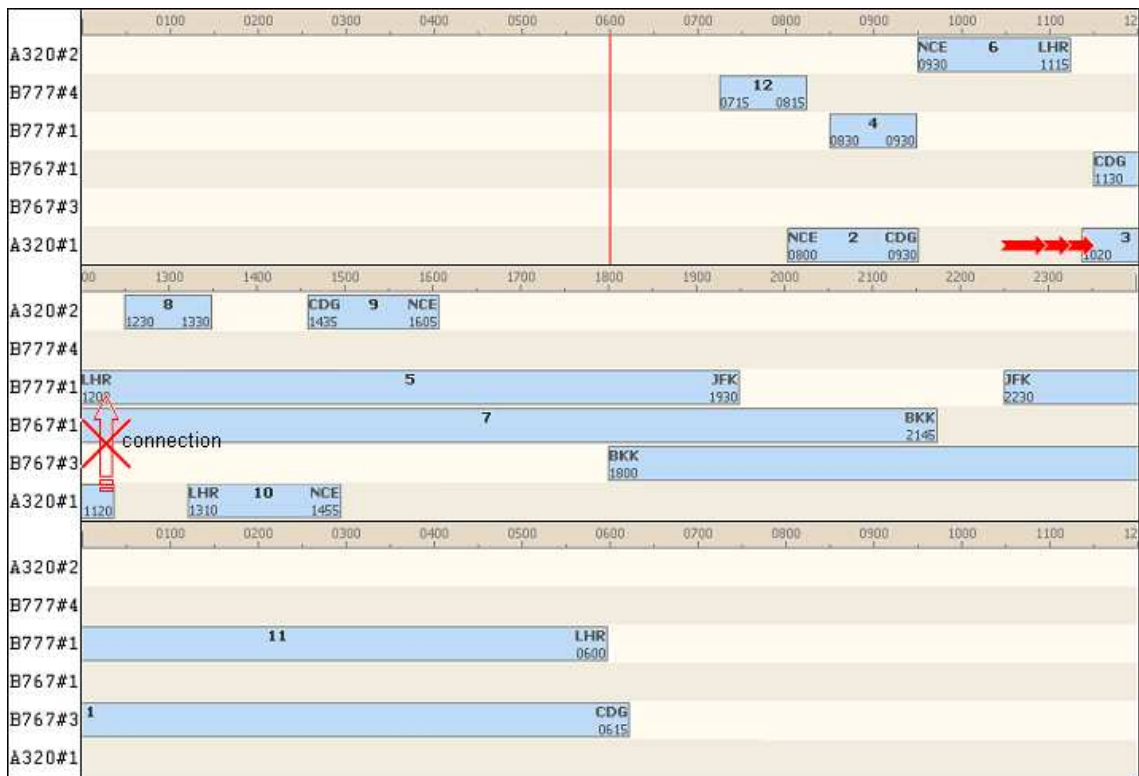


Fig. 7. Impact of aircraft changes for flights number 8, 9, and 10.

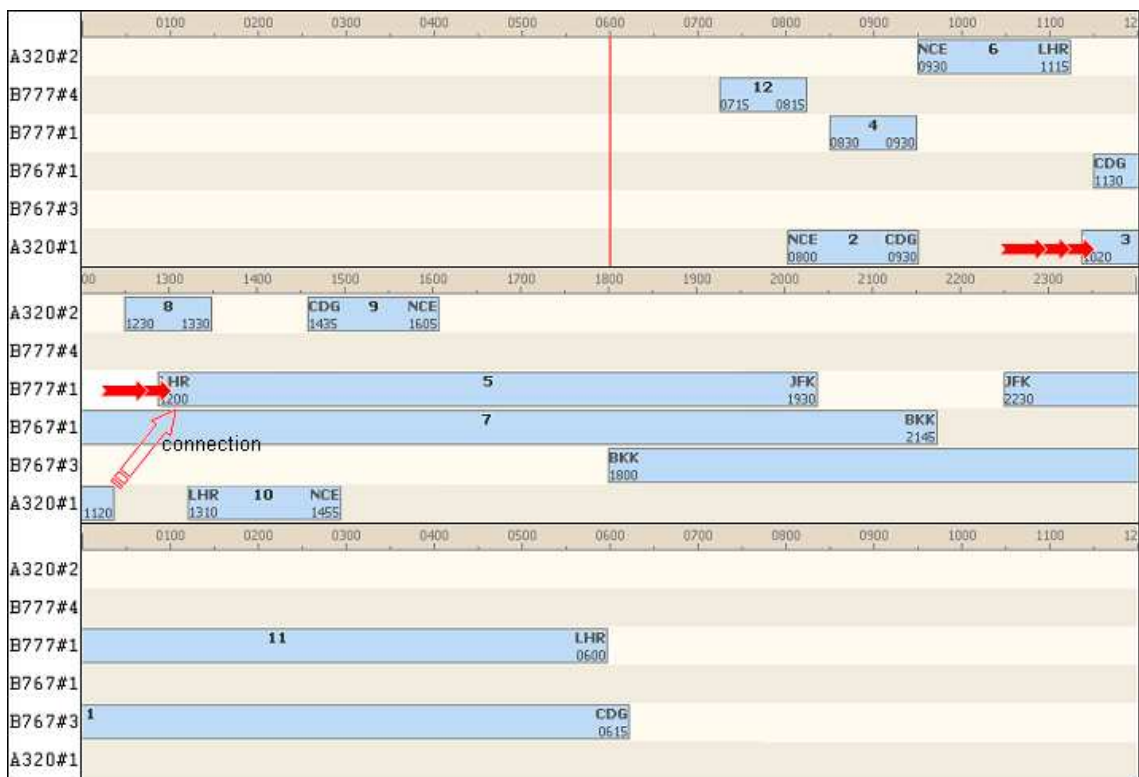


Fig. 8. Impact of intentional delay to flight number 5.