
2018.08.21
Presented by Haneol Choi
Contents

1. Literature review

2. Problem description – Model(1), (2), (3)

3. Solution approach

4. Computational results

5. Conclusion
### Literature review

- **Airline integrated recovery problem – Aircraft, Crew**

<table>
<thead>
<tr>
<th>Year</th>
<th>The author</th>
<th>Objective</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Abdelghany</td>
<td>Minimizing total cost</td>
<td>The simulation based rolling horizon</td>
</tr>
<tr>
<td>2015</td>
<td>Maher</td>
<td>Minimizing total cost</td>
<td>Column-and-row generation</td>
</tr>
<tr>
<td>2015</td>
<td>D Zhang</td>
<td>Minimizing total cost</td>
<td>Heuristic Algorithm</td>
</tr>
</tbody>
</table>

- **Airline integrated recovery problem – Aircraft, Passenger**

<table>
<thead>
<tr>
<th>Year</th>
<th>The author</th>
<th>Objective</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>Sinclair</td>
<td>Minimizing total cost</td>
<td>A large neighborhood search heuristic</td>
</tr>
<tr>
<td>2014</td>
<td>M sama</td>
<td>Minimizing total cost</td>
<td>Heuristic algorithm</td>
</tr>
<tr>
<td>2015</td>
<td>D Zhang</td>
<td>Minimizing total cost</td>
<td>Heuristic Algorithm</td>
</tr>
<tr>
<td>2016</td>
<td>ZHANG, Dong, et al</td>
<td>Maximizing total airline profit</td>
<td>A three stage heuristic</td>
</tr>
</tbody>
</table>

- **Airline integrated recovery problem – Aircraft, Crew, Passenger**

<table>
<thead>
<tr>
<th>Year</th>
<th>The author</th>
<th>Objective</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>Letтовsky</td>
<td>Maximizing total airline profit</td>
<td>Decomposition scheme</td>
</tr>
<tr>
<td>2012</td>
<td>Petersen et al.</td>
<td>Maximizing total airline profit</td>
<td>Bender’s decomposition-based algorithm</td>
</tr>
</tbody>
</table>

The main drawback: a feasible solution cannot be obtained within a reasonable timeframe.
Problem description – Model(1)

Decision variables
- A binary decision variable which indicates whether flight arc $fc$ is chosen or not
- A binary decision variable which indicates whether flight $f$ is cancelled or not
- An integer decision variable which indicates flow values on ground arc $ga$

Constraints
- Flow balance constraint
- Airport slot capacity constraint
- Maintenance constraint

Assumptions
- Each airport has a specific hourly departure and arrival capacity.
- Scheduled aircraft maintenance is given.
- The minimum connection time is set as thirty minutes for all itineraries and aircraft types

Objective function
- Minimizing the total cost related to flight delays and cancellations
### Notation – Model(1)

#### Sets
- \( F \): Set of original flight legs, indexed by \( f \)
- \( E \): Set of configuration types, indexed by \( e \)
- \( FC \): Set of flight arcs, indexed by \( fc \)
- \( F_{c} \): Set of flight arcs involved in the network corresponding to \( e \)\( \in E \)
- \( F_{c_m} \): Set of maintenance arcs
- \( Slot \): Set of airport resources slots, indexed by \( s \)
- \( Node \): Set of all activity nodes (with the exception of aircraft output nodes), indexed by \( n \)
- \( Node_e \): Set of all activity nodes (with the exception of aircraft output nodes) in the network corresponding to \( e \)\( \in E \)
- \( F^{n}_{fc, in} \): Set of flight arcs arriving at node \( n \) for configuration type \( e \)
- \( G^{n}_{a, in} \): Set of ground arcs ending at node \( n \) for configuration type \( e \)
- \( F^{n}_{c, out} \): Set of flight arcs departing from node \( n \) for configuration type \( e \)
- \( G^{n}_{a, out} \): Set of ground arcs starting from node \( n \) for configuration type \( e \)
- \( GA \): Set of all ground arcs, indexed by \( ga \)
- \( FC_{f} \): Set of flight arcs corresponding to flight leg \( f \)
- \( FC_{s} \): Set of flight arcs using the airport slot \( s \)

#### Parameters
- \( Input_n \): Aircraft input value at node \( n \)
- \( c_{bc} \): Cost of choosing flight arc \( fc \)
- \( cancel_f \): Cancellation cost of flight leg \( f \)
- \( cap_s \): Capacity of airport slot \( s \)

#### Decision variables
- \( x_{fc} \): A binary decision variable which indicates whether flight arc \( fc \) is chosen or not
- \( y_{f} \): A binary decision variable which indicates whether flight \( f \) is cancelled or not
- \( Z_{ga} \): An integer decision variable which indicates flow values on ground arc \( ga \)
Mathematical formulation – Model (1)

Model 1:

\[
\begin{align*}
\text{min} & \sum_{fc \in FC_m} c_{fc} x_{fc} + \sum_{f \in F} \text{cancel}_f y_f \\
\text{s.t.} & \sum_{fc \in FC_m} n_{i_{\text{input}}} + \sum_{g \in GA_{\text{in}}^{e}} z_{ga} = \sum_{fc \in FC_{e_{\text{out}}}^{e}} x_{fc} + \sum_{g \in GA_{e_{\text{out}}}^{e}} z_{ga}, \quad \forall e \in E \forall n \in \text{Node}_e \\
\sum_{fc \in FC_f} x_{fc} + y_f = 1, \quad \forall f \in F \\
\sum_{fc \in FC_i} x_{fc} \leq \text{Cap}_s, \quad s \in \text{Slot} \\
x_{fc} = 1, \quad \forall fc \in FC_m
\end{align*}
\]

(1a) Flow balance constraint

(1b) Covering of Cancellation constraint

(1c) Airport slot capacity constraint

(1d) Maintenance request constraint

Integrated model for aircraft/passenger rotation
Problem description – Model(2)

Decision variables

- A binary decision variable indicates whether flight delay arc $f_c$ is selected or not
- A binary decision variable indicates whether a passenger connection $\tau$ is disrupted or not

Constraints

- Airport slot capacity constraint
- Aircraft connection constraint
- Passenger connection constraint

Assumptions

- Each airport has a specific hourly departure and arrival capacity.
- Scheduled aircraft maintenance is given.
- The minimum connection time is set as thirty minutes for all itineraries and aircraft types

Objective function

- Minimizing the total flight delay cost and passenger itinerary disruption cost
Notation – Model(2)

- **Sets**
  - $F$: Set of flights selected from the first stage
  - $T$: Set of passenger connections, indexed as $\tau$
  - $W$: Set of aircraft connections
  - $FC'$: Set of flight arcs in the second stage
  - $FC_f$: Set of flight arcs generated from a flight $f \in F$
  - $FC_s$: Set flight delay arcs using the airport slot $s$

- **Parameters**
  - $c_f$: Cost of a flight copy $f_c$
  - $c_{\tau}$: Disruption cost of a passenger connection $\tau$
  - $cap_s$: Capacity of airport slot $s$
  - $arr_{fc}$: Arrival time of flight delay arc $fc$
  - $dep_{fc}$: Departure time of flight delay arc $fc$
  - $conn_{wo}$: Minimum connection time between two consecutive flights for an aircraft connection $weW$
  - $conn_{\tau}$: Minimum connection time between two consecutive flights in a passenger connection $\tau$

- **Decision variables**
  - $x_{fc}$: A binary decision variable indicates whether flight delay arc $fc$ is selected or not
  - $z_{\tau}$: A binary decision variable indicates whether a passenger connection $\tau$ is disrupted or not
Mathematical formulation – Model(2)

Model 2

Minimize \( \sum_{f \in F} \sum_{f_{fc} \in F_{fc}} p_{fc} c_{fc} x_{fc} + \sum_{\tau_{c} \in C_{c}} z_{\tau_{c}} \)

s.t.

\( \sum_{f_{fc} \in F_{fc}} x_{fc} = 1 \quad \forall f \in F' \)  
(2a)

\( \sum_{f_{fc} \in F_{fc}} x_{fc} \leq \text{cap}_{s} \quad \forall s \in S \)  
(2b)

\( \sum_{f_{fc} \in F_{fc}} \text{arr}_{fc} + \text{conn}_{\omega} \leq \sum_{f_{fc} \in F_{fc}} \text{dep}_{fc} \quad \forall \omega = (f_1, f_2) \in W \)  
(2c)  
Airport slot capacity constraint

\( \sum_{f_{fc} \in F_{fc}} \text{arr}_{fc} + \text{conn}_{\tau} \leq \sum_{f_{fc} \in F_{fc}} \text{dep}_{fc} + M z_{\tau} \quad \forall \tau = (f_1, f_2) \in T \)  
(2d)  
Aircraft rotation feasibility

\( \sum_{f_{fc} \in F_{fc}} \text{arr}_{fc} + \text{conn}_{\tau} \leq \sum_{f_{fc} \in F_{fc}} \text{dep}_{fc} + M z_{\tau} \quad \forall \tau = (f_1, f_2) \in T \)  
(2e)  
Passenger itinerary feasibility

\( f_{11} f_{12} \)  
Fig. 4. Illustration of crew connection.
Problem description – Model(3)

- Decision variables
  - An integer decision variable indicates the flow along itinerary arc $i_a$ in $i_d$'s network
  - An integer decision variable indicates the flow along ground arc $g_a$ in $i_d$'s network
  - An integer decision variable indicates the number of cancelled passengers in itinerary $i_d$
  - An integer decision variable indicates the number of the passenger included in $i_f$
  - An integer decision variable indicates the number of the passenger cancelled from $i_f$

- Constraints
  - Flow balance constraint
  - The number of passenger constraint in infeasible itineraries
  - The number of passenger constraint in feasible itineraries
  - Passenger capacity constraint

- Assumptions
  - The passenger itineraries (the number of passengers, the origin and destination of itinerary, the scheduled departure and arrival time and maximum and allowable delay) and passenger capacity of each flight are given.

- Objective function
  - Minimizing the total passenger re-accommodation cost and the passenger cancellation cost
Notation – Model(3)

- **Sets**
  - $F$ Set of all flight legs, indexed by $f$
  - $\Phi$ Set of disrupted itineraries selected in this iteration, indexed by $i_d$
  - $I_f$ Set of feasible itineraries, indexed by $i_f$
  - $IA$ Set of all itinerary legs, indexed by $ia$
  - $IA_f$ Set of itinerary legs generated from flight $f$
  - $i_a$ Set of itinerary legs in $i_d$’s network
  - $GA$ Set of ground arcs in $i_d$’s network, indexed by $ga$
  - $N_{i_d}$ Set of activity nodes in $i_d$’s network, indexed by $n$
  - $i_{in}a$ Set of input itinerary legs to node $n$
  - $i_{out}a$ Set of output itinerary legs to node $n$
  - $i_{out}g$ Set of output ground arcs to node $n$

- **Parameters**
  - $V_i$ Number of passengers in either itinerary $i_d$ or $i_f$
  - $c_{i_d,i_a}$ Cancellation cost of either itinerary $i_d$ or $i_f$
  - $cap_{i_d,i_a}$ Passenger capacity of itinerary leg $i_a$ in $i_d$’s network
  - $i_a$ Cycle arc in $i_d$’s network

- **Decision variables**
  - $x_{i_d,i_a}$ An integer decision variable indicates the flow of along itinerary arc $i_a$ in $i_d$’s network
  - $z_{i_d,ga}$ An integer decision variable indicates the flow along ground arc $ga$ in $i_d$’s network
  - $r_{i_d}$ An integer decision variable indicates the number of cancelled passengers in itinerary $i_d$
  - $e_{i_f}$ An integer decision variable indicates the number of the passenger included in $i_f$
  - $y_{i_f}$ An integer decision variable indicates the number of passenger cancelled from $i_f$
Mathematical formulation – Model(3)

\[\text{Minimize } \sum_{i_k \in \Phi \cup \Phi_{\text{input}}} \sum_{i_{k,a} \in \Phi_{\text{input}}} c_{i_k,a} \cdot x_{i_k,a} + \sum_{i_k \in \Phi} \sum_{i_{k,a} \in \Phi_{\text{input}}} \text{cancel}_{i_k} \cdot \tau_{i_k} + \sum_{i_k \in \Phi} \text{cancel}_{i_k} \cdot y_{i_k} \]

s.t.

\[\sum_{i_k \in \Phi_{\text{input}}} \sum_{i_{k,a} \in \Phi_{\text{input}}} c_{i_k,a} \cdot x_{i_k,a} + \sum_{i_k \in \Phi} \sum_{i_{k,a} \in \Phi_{\text{input}}} \text{cancel}_{i_k} \cdot \tau_{i_k} + \sum_{i_k \in \Phi} \text{cancel}_{i_k} \cdot y_{i_k} \]

\[\text{For the disrupted itineraries} \quad \text{For the feasible itineraries}\]

\[\sum_{i_{k,a} \in \Phi_{\text{input}}} z_{i_{k,a}} + \sum_{i_{k,a} \in \Phi_{\text{input}}} x_{i_{k,a}} = \sum_{i_{k,a} \in \Phi_{\text{input}}} z_{i_{k,a}} + \sum_{i_{k,a} \in \Phi_{\text{input}}} x_{i_{k,a}} \quad \forall i_{k,a} \in \Phi, \forall a \in N_{i_k}\]

\[\sum_{i_{k,a} \in \Phi_{\text{input}}} \sum_{i_{k,a} \in \Phi_{\text{input}}} x_{i_{k,a}} \quad \forall i_{k,a} \in \Phi, \forall a \in N_{i_k}\]

\[\sum_{i_{k,a} \in \Phi_{\text{input}}} \sum_{i_{k,a} \in \Phi_{\text{input}}} x_{i_{k,a}} \quad \forall i_{k,a} \in \Phi, \forall a \in N_{i_k}\]

\[\sum_{i_k \in \Phi_{\text{input}}} \sum_{i_{k,a} \in \Phi_{\text{input}}} c_{i_k,a} \cdot x_{i_k,a} + \sum_{i_k \in \Phi} \sum_{i_{k,a} \in \Phi_{\text{input}}} \text{cancel}_{i_k} \cdot \tau_{i_k} + \sum_{i_k \in \Phi} \text{cancel}_{i_k} \cdot y_{i_k} \]

\[\text{Set of disrupted itineraries selected in this iteration, Set of ground arc}\]

\[\text{Set of feasible itineraries}\]

\[\sum_{i_k \in \Phi_{\text{input}}} \sum_{i_{k,a} \in \Phi_{\text{input}}} c_{i_k,a} \cdot x_{i_k,a} + \sum_{i_k \in \Phi} \sum_{i_{k,a} \in \Phi_{\text{input}}} \text{cancel}_{i_k} \cdot \tau_{i_k} + \sum_{i_k \in \Phi} \text{cancel}_{i_k} \cdot y_{i_k} \]

\[\text{Set of all itinerary legs}\]

Flow balance constraints

The number of passenger (in infeasible itineraries) constraint

The number of passenger (in feasible itineraries) constraint

Passenger capacity constraint

Decision variables

\[x_{i_k,a} \quad \text{An integer decision variable indicates the flow of itinerary arc} \ i_k \ a \ \text{in} \ i_k \ \text{’s network}\]

\[z_{i_{k,a}} \quad \text{An integer decision variable indicates the flow along} \ a \ \text{arc} \ i_{k,a} \ \text{in} \ i_k \ \text{’s network}\]

\[\tau_{i_k} \quad \text{An integer decision variable indicates the number of} \ \text{cancelled passengers in itinerary} \ i_k\]

\[y_{i_k} \quad \text{An integer decision variable indicates the number of passengers included in} \ i_k\]

\[\epsilon_{i_k} \quad \text{An integer decision variable indicates the number of passengers cancelled from} \ i_k\]
Solution algorithm: A three-stage math-heuristic framework

Stage (1). Aircraft schedule recovery

- Step 1: A Multi-commodity network flow model

\[
\begin{align*}
\text{Model 1:} & \\
\min & \sum_{f \in F} \left( c_e x_{f_c} + \sum_{f \in F} \text{cancel}_{e} y_{f} \right) \\
\text{s.t.} & \\
& \sum_{f \in F_{\text{input}}} n_{\text{input}} + \sum_{f \in F_{\text{output}}} x_{f} + \sum_{g \in G} z_{g} = \sum_{f \in F_{\text{output}}} x_{f} + \sum_{g \in G} z_{g} \quad \forall e \in E \forall n \in \text{Node}_{e} \\
& \sum_{f \in F_{e}} x_{f} + y_{f} = 1 \quad \forall f \in F \\
& \sum_{f \in F_{s}} x_{f} \leq \text{Cap}_{s} \quad \forall s \in \text{Slot} \\
& x_{f_c} = 1 \quad \forall f \in F_{c} \\
\end{align*}
\]

- Step 2: Flight insertion algorithm

- Two-Cycle detection
- Two-Cycle insertion
- Single flight insertion
- Flight insertion cost estimation

Output of this stage: New feasible flight schedule + Aircraft rotation solution

ILOG CPLEX 12.1.0

2018-08-21
Production & Logistics Information Lab.
Solution algorithm: A three-stage math-heuristic framework

Stage (2). Flight re-scheduling

Input of this stage: New feasible flight schedule + Aircraft rotation solution

✓ Step 1: The flight arc generation module

(a) The departure time of a flight arc must be equal to or later than the initial scheduled departure time.

(b) The arrival time of a flight arc must be earlier than or equal to the latest allowable arrival time.

(c) The schedule of a flight arc cannot violate the aircraft’s maintenance requirement.

✓ Model

Minimize

\[ \sum_{f \in FC} c_{f} x_{f} + \sum_{f \in F} \text{cancel}_{f} y_{f} \]

Subject to

\[ n_{\text{input}}^{e} + \sum_{f \in FC^{e}_{n}} x_{f} + \sum_{g \in GC^{e}_{n}} z_{g} = \sum_{f \in FC^{e}_{l}} x_{f} + \sum_{g \in GC^{e}_{l}} z_{g} \quad \forall e \in E \forall n \in \text{Node}_{e} \]

\[ \sum_{f \in FC_{l}} x_{f} + y_{f} = 1 \quad \forall f \in F \]

\[ \sum_{f \in FC_{s}} x_{f} \leq \text{Cap}_{s} \quad s \in \text{Slot} \]

\[ x_{fc} = 1 \quad \forall fc \in FC_{m} \]

Output of this stage: Fixed flight schedule + Disrupted passenger connection
Solution algorithm: A three-stage math-heuristic framework

Stage (3). Passenger re-accommodation

- Input of this stage: Fixed flight schedule + Disrupted passenger connection

- Step 1: A Multi-commodity network flow model

- Step 2: An iterative algorithm

Output of this stage: New passenger itineraries + The remainder of the disrupted passengers

Model 3

Minimize \( \sum_{i \in \Phi} \sum_{i \in \mathcal{N}_d} c_{d_i,a} x_{d_i,a} + \sum_{i \in \Phi} \sum_{d \in \mathcal{N}_d} \text{cancel}_i \cdot \tau_{d,i} + \sum_{i \in \mathcal{E}_f} \text{cancel}_i \cdot y_{i,f} \)

s.t.

\( \sum_{\text{genc}_{\text{input}}} z_{d_i,a} + \sum_{\text{load}} x_{d_i,a} = \sum_{\text{genc}_{\text{output}}} z_{d_i,a} + \sum_{\text{load}} x_{d_i,a} \quad \forall i_d \in \Phi \forall n \in \mathcal{N}_d \)

\( z_{d_i,a} + \tau_{d,i} = V_i \quad \forall i_d \in \Phi \forall a \)

\( e_{i,f} + y_{i,f} = V_i \quad \forall i_f \in \mathcal{E}_f \)

\( \sum_{i \in \mathcal{N}_d} \sum_{i \in \mathcal{E}_f} x_{d_i,a} + \sum_{i \in \mathcal{E}_f} e_{i,f} \leq \text{cap}_{d,i} \quad \forall a \in \mathcal{A}_d \)

ILOG CPLEX 12.1.0

2018-08-21
Computational results

Integrated model for aircraft/passenger

- $Z(M,I)$: Objective function value
- $zb(I)$: The best objective function value
- $wb(I)$: The worst objective function value

The normalized score is calculated as:

$$ \text{Normalized score} = \frac{zw(I) - z(W,I)}{zw(I) - zb(I)} $$

### Table 2
Description of dataset A.

<table>
<thead>
<tr>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>A5</th>
<th>A6</th>
<th>A7</th>
<th>A8</th>
<th>A9</th>
<th>A10</th>
</tr>
</thead>
<tbody>
<tr>
<td>608</td>
<td>608</td>
<td>608</td>
<td>608</td>
<td>608</td>
<td>608</td>
<td>608</td>
<td>608</td>
<td>608</td>
<td>608</td>
</tr>
<tr>
<td>85</td>
<td>85</td>
<td>85</td>
<td>85</td>
<td>85</td>
<td>85</td>
<td>85</td>
<td>85</td>
<td>85</td>
<td>85</td>
</tr>
<tr>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>63</td>
<td>107</td>
<td>83</td>
<td>41</td>
<td>0</td>
<td>63</td>
<td>107</td>
<td>83</td>
<td>41</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 3
Description of dataset B.

<table>
<thead>
<tr>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>B5</th>
<th>B6</th>
<th>B7</th>
<th>B8</th>
<th>B9</th>
<th>B10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1422</td>
<td>1422</td>
<td>1422</td>
<td>1422</td>
<td>1422</td>
<td>1422</td>
<td>1422</td>
<td>1422</td>
<td>1422</td>
<td>1422</td>
</tr>
<tr>
<td>255</td>
<td>255</td>
<td>255</td>
<td>255</td>
<td>255</td>
<td>255</td>
<td>255</td>
<td>255</td>
<td>255</td>
<td>255</td>
</tr>
<tr>
<td>44</td>
<td>44</td>
<td>44</td>
<td>44</td>
<td>44</td>
<td>44</td>
<td>44</td>
<td>44</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>11214</td>
<td>11214</td>
<td>11214</td>
<td>11214</td>
<td>11214</td>
<td>11214</td>
<td>11214</td>
<td>11214</td>
<td>11214</td>
<td>11214</td>
</tr>
<tr>
<td>229</td>
<td>229</td>
<td>229</td>
<td>229</td>
<td>229</td>
<td>229</td>
<td>229</td>
<td>229</td>
<td>229</td>
<td>229</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 4
Description of dataset C.

<table>
<thead>
<tr>
<th>X01</th>
<th>X02</th>
<th>X03</th>
<th>X04</th>
<th>X010</th>
<th>X020</th>
<th>X030</th>
<th>X040</th>
<th>X010</th>
<th>X020</th>
<th>X030</th>
<th>X040</th>
</tr>
</thead>
<tbody>
<tr>
<td>2178</td>
<td>2178</td>
<td>2178</td>
<td>2178</td>
<td>2178</td>
<td>2178</td>
<td>2178</td>
<td>2178</td>
<td>2178</td>
<td>2178</td>
<td>2178</td>
<td>2178</td>
</tr>
<tr>
<td>618</td>
<td>618</td>
<td>618</td>
<td>618</td>
<td>618</td>
<td>618</td>
<td>618</td>
<td>618</td>
<td>618</td>
<td>618</td>
<td>618</td>
<td>618</td>
</tr>
<tr>
<td>168</td>
<td>168</td>
<td>168</td>
<td>168</td>
<td>168</td>
<td>168</td>
<td>168</td>
<td>168</td>
<td>168</td>
<td>168</td>
<td>168</td>
<td>168</td>
</tr>
<tr>
<td>21308</td>
<td>21308</td>
<td>21308</td>
<td>21308</td>
<td>21308</td>
<td>21308</td>
<td>21308</td>
<td>21308</td>
<td>21308</td>
<td>21308</td>
<td>21308</td>
<td>21308</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>82</td>
<td>0</td>
<td>82</td>
<td>0</td>
<td>0</td>
<td>82</td>
<td>0</td>
<td>82</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 5
Scores and ranks for dataset A.

<table>
<thead>
<tr>
<th>Team</th>
<th>Average score (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our algorithm</td>
<td>100.00</td>
</tr>
<tr>
<td>Bisaillon et al. (2011)</td>
<td>96.46</td>
</tr>
<tr>
<td>Hanafi et al.</td>
<td>92.90</td>
</tr>
<tr>
<td>Acuna-Agost et al. (2009)</td>
<td>83.86</td>
</tr>
<tr>
<td>Darlay, Kronek et al.</td>
<td>80.36</td>
</tr>
<tr>
<td>Jozeelowicz et al. (2012)</td>
<td>73.70</td>
</tr>
<tr>
<td>Eggermont et al.</td>
<td>60.50</td>
</tr>
<tr>
<td>Dumassey et al.</td>
<td>52.57</td>
</tr>
<tr>
<td>Dickson et al.</td>
<td>46.93</td>
</tr>
<tr>
<td>Estellon et al.</td>
<td>46.45</td>
</tr>
<tr>
<td>Eggenberg et al.</td>
<td>2.92</td>
</tr>
</tbody>
</table>

### Table 6
Scores and ranks for datasets B and C.

<table>
<thead>
<tr>
<th>Team</th>
<th>Average score (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our algorithm</td>
<td>98.16</td>
</tr>
<tr>
<td>KS10</td>
<td>97.63</td>
</tr>
<tr>
<td>KS5</td>
<td>96.83</td>
</tr>
<tr>
<td>Jozeelowicz et al. (2012)</td>
<td>82.37</td>
</tr>
<tr>
<td>Bisaillon et al. (2011)</td>
<td>74.66</td>
</tr>
<tr>
<td>Hanafi et al.</td>
<td>59.69</td>
</tr>
<tr>
<td>Acuna-Agost et al. (2009)</td>
<td>57.96</td>
</tr>
<tr>
<td>Eggermont et al.</td>
<td>56.89</td>
</tr>
<tr>
<td>Darlay et al.</td>
<td>56.57</td>
</tr>
<tr>
<td>Peekstok and Kuipers (2009)</td>
<td>88.61</td>
</tr>
<tr>
<td>Dickson et al.</td>
<td>33.73</td>
</tr>
<tr>
<td>Eggenberg et al.</td>
<td>16.64</td>
</tr>
</tbody>
</table>
Computational results

(1) Efficiency analysis

- Serious disruption scenarios
- More flights involved
- Disrupted passengers

(2) Solution quality

- 20 instances in dataset B, X
  - The proposed algorithm yields the best solution in thirteen of these instances.

Fig. 7. Adjusted computing time (in minutes) to account for different CPU capabilities.
Computational results

- Sensitivity analysis of $n_p$

Fig. 8. Sensitivity analysis with respect to the number of disrupted itineraries $n_p$. 
Computational results

- Comparisons between two different sequence

The relative cost improvement = \( \frac{C_{rtt} - C_{out}}{C_{rtt}} \)

Fig. 9. Flow chart depiction of the reserved three-stage algorithm.

Fig. 10. Solution cost and CPU time comparisons between the proposed and RTT algorithms.
Computational results

Impact of disruption scenarios on the solution quality

Table 7
Computational results displaying the performance of the proposed and KS10 algorithms.

<table>
<thead>
<tr>
<th>Initial flight delay time (Minutes)</th>
<th>Initial number of cancelled flights</th>
<th>Airport capacity reduction (Volume/ Hour)</th>
<th>Aircraft broken period (Minutes)</th>
<th>Objective difference rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1 9820</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10.57</td>
</tr>
<tr>
<td>B2 9820</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13.66</td>
</tr>
<tr>
<td>B3 9759</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7.28</td>
</tr>
<tr>
<td>B4 9820</td>
<td>0</td>
<td>0</td>
<td>1795</td>
<td>6.02</td>
</tr>
<tr>
<td>B5 9820</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-36.35</td>
</tr>
<tr>
<td>B6 9820</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>129.24</td>
</tr>
<tr>
<td>B7 9820</td>
<td>0</td>
<td>0</td>
<td>1795</td>
<td>104.51</td>
</tr>
<tr>
<td>B8 9820</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>124.80</td>
</tr>
<tr>
<td>B9 9820</td>
<td>0</td>
<td>0</td>
<td>21</td>
<td>78.09</td>
</tr>
<tr>
<td>B10 9820</td>
<td>0</td>
<td>0</td>
<td>411</td>
<td>-29.06</td>
</tr>
<tr>
<td>XA01 4719</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>-28.98</td>
</tr>
<tr>
<td>XA02 4719</td>
<td>0</td>
<td>0</td>
<td>2161</td>
<td>-32.53</td>
</tr>
<tr>
<td>XA03 4719</td>
<td>4</td>
<td>0</td>
<td>6840</td>
<td>7.21</td>
</tr>
<tr>
<td>XA04 4719</td>
<td>0</td>
<td>0</td>
<td>2161</td>
<td>1.66</td>
</tr>
<tr>
<td>XA01 9759</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-5.07</td>
</tr>
<tr>
<td>XA02 9759</td>
<td>0</td>
<td>0</td>
<td>411</td>
<td>-36.56</td>
</tr>
<tr>
<td>XA03 9749</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>52.60</td>
</tr>
<tr>
<td>XA04 9749</td>
<td>0</td>
<td>0</td>
<td>411</td>
<td>-25.93</td>
</tr>
<tr>
<td>XA01 9749</td>
<td>0</td>
<td>0</td>
<td>85</td>
<td>-26.42</td>
</tr>
<tr>
<td>XA02 9749</td>
<td>0</td>
<td>0</td>
<td>2340</td>
<td>-125.97</td>
</tr>
<tr>
<td>XA03 9749</td>
<td>0</td>
<td>0</td>
<td>1680</td>
<td>120.01</td>
</tr>
<tr>
<td>XA04 9749</td>
<td>0</td>
<td>0</td>
<td>1740</td>
<td>436.52</td>
</tr>
</tbody>
</table>
Conclusion

✓ Integrated aircraft and passenger recovery problem
  ▪ Minimizing aircraft recovery and operating costs, passenger itinerary delay cost, and passenger itinerary cancellation cost.

✓ A three stage math-heuristic algorithm
  ▪ Stage1. Aircraft rotation recovery
  ▪ Stage2. Flight reschedule
  ▪ Stage3. New passenger itinerary

✓ Computational results
  ▪ Realistic data provided by the ROADEF 2009 Challenge
  ▪ Several experiments

Adv. vs Disad.
Thank you!