Clip-Air: a modular air transportation system

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Outline

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1. Introduction
2. Clip-Air
3. Itinerary-Based Fleet Assignment Models
4. Results

Motivation

ACARE (Advisory Council for Aeronautic Research in Europe) has set ambitious objectives for 2020[1]:

- Lower CO_2 emissions by 50%

[1] European Aeronautics: A vision for 2020 - EU 2001

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- Lower NO_x emissions by 80%

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- Decrease of noise by one half

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- Max of 15-30 minutes of delay

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- Five-fold reduction in the average accident rate (fatalities)

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- Decrease of noise by one half
- Max of 15-30 minutes of delay
- Five-fold reduction in the average accident rate (fatalities)
- To answer all these issues an innovative approach is needed!

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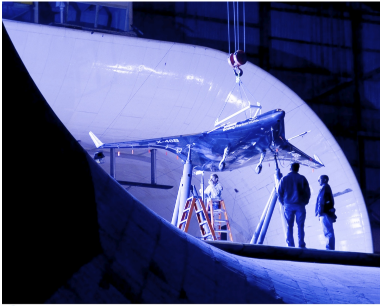
X-48B - Boeing/NASA



NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: ED06-0070-1 Date: May, 2006 Photo By: Boeing

Technicians inspect the sub-scale X-48B Blended Wing Body concept demonstrator in the full-scale wind tunnel at NASA's Langley Research Center.

(+) reduced fuel consumption, because of reduced drag.
Some open issues for cargo (shape), frontal surface still important.

NACRE - Airbus

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Clip-Air

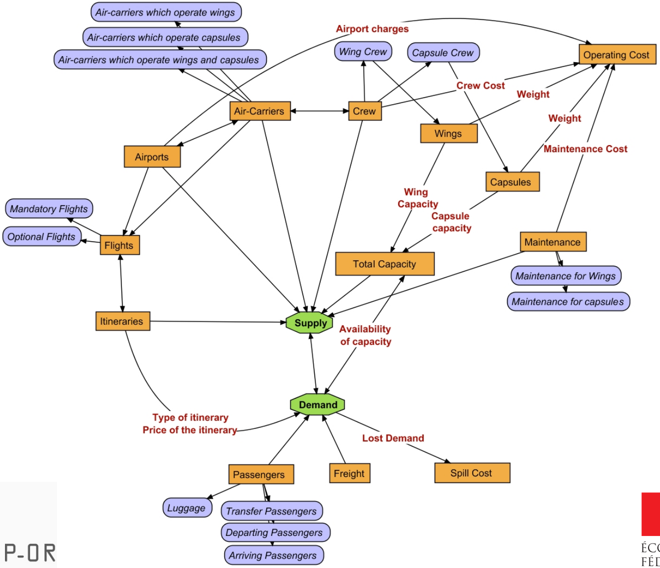
Key ideas

Mixed air-land transportation system (*Passenger Container*): A passenger from Lausanne can travel to London without living his/her train wagon

Modular-detachable transportation unit (capsule): flexibility, security, reduced storage and maintenance costs

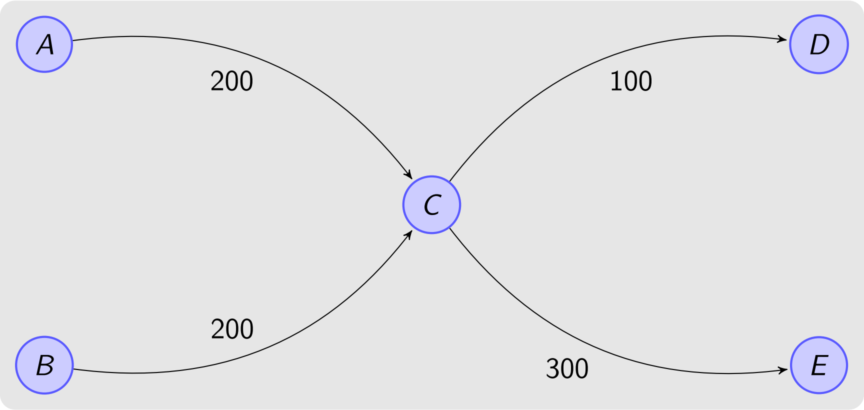
Carrier unit (wing): Carries the capsules (max 3) and the engines, improved aerodynamic structure and less fuel consumption with decreased total weight

Clip-Air - Main entities in the system



Modularity

Enhanced potential in capsule routing:



Configuration - Comparison with Airbus A320

		Clip-Air	**A320**
Maximum Capacity		3x145 (435 seats)	150 seats
Engines		**3** engines	**2** engines
Maximum Aircraft Weight	1 (plane/capsule)	126t	77.5t
	2 (planes/capsules)	153t	2x77.5t (155t)
	3 (planes/capsules)	180t	3x77.5t (232t)

When Clip-Air flies with 2 or more capsules it becomes advantageous in terms of weight, therefore fuel consumption.

Operating Costs

*operatingCostsOfFlight=flightRevenues * (1 - profitMargin)*

where *flightRevenues* is average fare times the total number of sold seats.

Operating costs compose of:

- **16%** Fuel
- **14%** Crew cost
- **14%** Aircraft cost
- **11%** Maintenance
- **10%** Airport and Air Nav charges
- **35%** Others

C.J. Smith - **Airline operating costs - the variations** in Managing airline operating costs - SH&E (2004)

Operating costs for *Clip-Air*

- Based on standard flight operating costs
- Fuel costs (16%) and Airport and air navigation charges (10%) are separated for wings and capsules, corrected with the weight differences
  - A saving of 1.3% and 23% is obtained when Clip-Air flies with 2 and 3 capsules respectively.
- Crew cost (14%) is separated between wing (flight crew) and capsules (cabin crew):
  - Wing (flight crew): 8%
  - Capsules (cabin crew): 6%

  Since for A320 it is found out that flight crew constitutes 60% of crew cost.

Objectives of the study

Comparative analysis of Clip-Air and standard fleet.

- Estimate operating costs: Detailed cost structure for Clip-Air is not yet known $\rightarrow$ advantage standard fleet to have a fair comparison.

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- Itinerary based fleet assignment model which minimizes the operating costs and spill costs.

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Comparative analysis of Clip-Air and standard fleet.

- Estimate operating costs: Detailed cost structure for Clip-Air is not yet known → advantage standard fleet to have a fair comparison.
- Itinerary based fleet assignment model which minimizes the operating costs and spill costs.
- Analyze demand satisfaction: Demand analysis is needed for the new system.

Assumptions

- Every capsule has the same capacity
- Fleet's configuration on the airport network is the same at the beginning and end of the period
- All assumptions regarding the operating costs

Outline

Considered literature

Papers:

- *FAM: solving large scale IPs* - Hane et al - MP (1995)
- *Itinerary based FAM* - Barnhart, Kniker and Lohatepanont - TS (2002)
- *Integrated schedule design and FAM* - Barnhart and Lohatepanont - TS (2004)
- *Periodic FAM with TW, spacing, time dependent revenues* - Bélanger, Desaulniers, Soumis, Desrosiers - EJOR (2006)
- *Market-oriented airline service design* - Shoen - Tech.Rep. (2007)

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Considered literature

Barnhart and Lohatepanont (2004)

Key concepts:

- Optimizes operational costs and loss of revenue
- Schedule design is modeled with two subsets of **mandatory** and **optional flights** (exogenous)
- Itinerary based demand (average unconstrained, exogenous)
- Schedule evaluation model (exogenous)
- Demand **adjustment** and **recapture** (deletion and spill)
- Based on time-space network to represent the schedule

Parameters

A:	Set of airports indexed by a
F:	Set of all flight legs indexed by f
I:	Set of all itineraries indexed by i or j
c_f^k:	Operational cost for a capsule for flight leg f
c_f^w:	Operational cost for the wing for flight leg f
N_w:	Number of available wings
N_k:	Number of available capsules
k_{max}:	maximum number of capsules on a wing
s^k:	Capacity of capsule in number of seats available
D_i:	Number of passengers requesting itinerary i
Q_f:	Number of passengers requesting flight leg f

Parameters

$fare_i$:	Average fare for a passenger to fly on itinerary i
b_i^j:	The rate of passengers that can be redistributed from itinerary i to j when i's capacity is full
δ_f^i:	1 if itinerary i includes flight leg f, 0 otherwise
T:	Sorted set of all events on the time-line, indexed by t
$N(a,t)$:	Set of nodes in the time-line network
CT:	Set of flight legs flying through the count time
$In(a,t,f)$:	Set of inbound flight legs to node (a,t)
$Out(a,t,f)$:	Set of outbound flight legs from node (a,t)
$minE_a$:	First event in the time-line at airport a
$maxE_a$:	Last event in the time-line at airport a

Decision Variables

x_f^k:	number of capsules on flight f, $x_f^k \in \{0, ..., k_{max}\}$
x_f^w:	1 if a wing is assigned to flight f, 0 otherwise
y_{a,t^+}^k:	number of capsules on the ground at airport a just after time t
y_{a,t^-}^k:	number of capsules on the ground at airport a just before time t
y_{a,t^+}^w:	number of wings on the ground at airport a just after time t
y_{a,t^-}^w:	number of wings on the ground at airport a just before time t
t_i^j:	number of passengers redirected from itinerary i to j

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Model

Itinerary based fleet assignment model

- minimizing the operating and spill costs

$$Min \sum_{f \in F} (c_f^w \; x_f^w + c_f^k \; x_f^k) + \sum_{i \in I, j \in I} t_i^j \; (fare_i - b_i^j fare_j)$$

$$s.t. \; x_f^w = 1 \qquad \forall f \in F^M$$

$$x_f^k \geq 1 \qquad \forall f \in F^M$$

$$x_f^k \leq k_{max} \; x_f^w \qquad \forall f \in F$$

$$y_{a,t^-}^w + \sum_{f \in I(a,t)} x_f^w = y_{a,t^+}^w + \sum_{f \in O(a,t)} x_f^w \qquad \forall [a,t] \in N$$

$$\sum_{a \in A} y_{a,t_n}^w + \sum_{f \in CT} x_f^w \leq N_w$$

$$y_{a,minE_a^-}^w = y_{a,maxE_a^+}^w \qquad \forall a \in A$$

Model

$$y^k_{a,t^-} + \sum_{f \in I(a,t)} x^k_f = y^k_{a,t^+} + \sum_{f \in O(a,t)} x^k_f \qquad \forall [a,t] \in N$$

$$\sum_{a \in A} y^k_{a,t_n} + \sum_{f \in CT} x^k_f \leq N_k$$

$$y^k_{a,minE^-_a} = y^k_{a,maxE^+_a} \qquad \forall a \in A$$

$$s^k \; x^k_f \geq Q_f + \sum_{i \in I, j \in I} \delta^j_f b^j_i t^j_i - \sum_{i \in I, j \in I} \delta^i_f t^i_j \qquad \forall f \in F$$

$$\sum_{j \in I} t^j_i \leq D_i \qquad \forall i \in I$$

$$x^w_f \in \{0,1\} \qquad \forall f \in F$$

$$x^k_f \in \{0,1,...,k_{max}\} \qquad \forall f \in F$$

$$y^w_{a,t} \geq 0 \qquad \forall [a,t] \in N$$

$$y^k_{a,t} \geq 0 \qquad \forall [a,t] \in N$$

$$t^j_i \geq 0 \qquad \forall i,j \in I$$

Outline

Towards Results

- Input: data from a major European airline company
  - set of optional and mandatory flights
  - set of airports
  - set of itinerary demands and fares
  - set of aircrafts for the standard fleet
- C++ program to format input data
  - data resizing to study specific instances
  - operating costs and spill rate computing
  - instances generation
- Problem resolution with GLPK+CPLEX solver
- output: an optimized schedule design and fleet assignment for the given instances
- Results comparison

Instances

- Airport pairs
- Airport hubs
- Special cases
- Larger instance

Airport Pairs

	Clip-Air	Standard 6 aircrafts	Standard 3 aircrafts
Operating costs	85%	84%	87%
Spill costs	15%	16%	13%
Total costs	**160,150 €**	**+2,678 €**	**+2,781 €**
Fleet size (in seats)	295	295	295
Transported passengers	1,272	1,260	1,289
Flight count	9	12	12
Average pax/flight	141	105	107
Flight Hours / cap unit	1h57	2h36	2h36

	Clip-Air	Standard 6 aircrafts	Standard 3 aircrafts
Operating costs	93%	90%	94%
Spill costs	7%	10%	6%
Total costs	**156,906 €**	**+2,247 €**	**+4,226 €**
Fleet size (in seats)	328	328	328
Transported passengers	1,118	1,085	1,118
Flight count	12	14	14
Average pax/flight	93	77	79
Flight Hours / cap unit	1h56	2h15	2h15

	Clip-Air	Standard 6 aircrafts	Standard 3 aircrafts
Operating costs	89%	88%	84%
Spill costs	11%	12%	16%
Total costs	**173,556 €**	**+3,566 €**	**+4,302 €**
Fleet size (in seats)	380	380	380
Transported passengers	1,268	1,254	1,216
Flight count	14	18	16
Average pax/flight	90	69	76
Flight Hours / cap unit	1h45	2h15	2h00

Airport Pairs

Airports	2
Flights	12
Capsule capacity	59
Passengers	1,425
Std Deviation (pax)	16.9
Av. Pax/Flight	118.8

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Airports	2
Flights	14
Capsule capacity	41
Passengers	1,173
Std Deviation (pax)	16.14
Av. Pax/Flight	83.8

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Airports	2
Flights	18
Capsule capacity	38
Passengers	1,368
Std Deviation (pax)	23.05
Av. Pax/Flight	76.0

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Airport Pairs

Same fleet size

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Average pax/flight	141	105	107
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Less flights, smaller costs

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More passengers/flight

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Airport Hubs

	Clip-Air	Standard 6 aircrafts	Standard 3 aircrafts
Operating costs	82%	73%	75%
Spill costs	18%	27%	25%
Total costs	**406,188 €**	**+7,016 €**	**+7,882 €**
Fleet size (in seats)	858	858	858
Transported passengers	2,876	2,593	2,642
Flight count	32	32	32
Average pax/flight	89	81	82
Flight Hours / cap unit	1h44	1h44	1h44

	Clip-Air	Standard 6 aircrafts	Standard 3 aircrafts
Operating costs	83%	81%	77%
Spill costs	17%	19%	23%
Total costs	**280,487 €**	**+10,562 €**	**+11,646 €**
Fleet size (in seats)	540	540	540
Transported passengers	1,836	1,811	1,746
Flight count	22	26	26
Average pax/flight	83	69	67
Flight Hours / cap unit	1h48	2h07	2h07

	Clip-Air	Standard 6 aircrafts	Standard 3 aircrafts
Operating costs	85%	83%	83%
Spill costs	15%	17%	17%
Total costs	**359,696 €**	**+5,021 €**	**+4,789 €**
Fleet size (in seats)	713	713	713
Transported passengers	2,077	2,062	2,068
Flight count	33	36	36
Average pax/flight	62	57	57
Flight Hours / cap unit	1h57	2h06	2h06

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Airport Hubs

Airports	4
Flights	45
Capsule capacity	39
Passengers	3,511
Std Deviation (pax)	37
Av. Pax/Flight	78.0

		Standard	
	Clip-Air	**6 aircrafts**	**3 aircrafts**
Operating costs	82%	73%	75%
Spill costs	18%	27%	25%
Total costs	**406,188 €**	**+7,016 €**	**+7,882 €**
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Flight count	32	32	32
Average pax/flight	89	81	82
Flight Hours / cap unit	1h44	1h44	1h44

Airports	4
Flights	29
Capsule capacity	36
Passengers	2,131
Std Deviation (pax)	37.46
Av. Pax/Flight	73.5

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Total costs	**280,487 €**	**+10,562 €**	**+11,646 €**
Fleet size (in seats)	540	540	540
Transported passengers	1,836	1,811	1,746
Flight count	22	26	26
Average pax/flight	83	69	67
Flight Hours / cap unit	1h48	2h07	2h07

Airports	5
Flights	38
Capsule capacity	31
Passengers	2,362
Std Deviation (pax)	34.94
Av. Pax/Flight	62.2

		Standard	
	Clip-Air	**6 aircrafts**	**3 aircrafts**
Operating costs	85%	83%	83%
Spill costs	15%	17%	17%
Total costs	**359,696 €**	**+5,021 €**	**+4,789 €**
Fleet size (in seats)	713	713	713
Transported passengers	2,077	2,062	2,068
Flight count	33	36	36
Average pax/flight	62	57	57
Flight Hours / cap unit	1h57	2h06	2h06

Airport Hubs

Same fleet size

	Clip-Air	Standard 6 aircrafts	Standard 3 aircrafts
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Spill costs	18%	27%	25%
Total costs	**406,188 €**	**+7,016 €**	**+7,882 €**
Fleet size (in seats)	858	858	858
Transported passengers	2,876	2,593	2,642
Flight count	32	32	32
Average pax/flight	89	81	82
Flight Hours / cap unit	1h44	1h44	1h44

Less flights, smaller costs

	Clip-Air	Standard 6 aircrafts	Standard 3 aircrafts
Operating costs	83%	81%	77%
Spill costs	17%	19%	23%
Total costs	**280,487 €**	**+10,562 €**	**+11,646 €**
Fleet size (in seats)	540	540	540
Transported passengers	1,836	1,811	1,746
Flight count	22	26	26
Average pax/flight	83	69	67
Flight Hours / cap unit	1h48	2h07	2h07

More passengers carried

	Clip-Air	Standard 6 aircrafts	Standard 3 aircrafts
Operating costs	85%	83%	83%
Spill costs	15%	17%	17%
Total costs	**359,696 €**	**+5,021 €**	**+4,789 €**
Fleet size (in seats)	713	713	713
Transported passengers	2,077	2,062	2,068
Flight count	33	36	36
Average pax/flight	62	57	57
Flight Hours / cap unit	1h57	2h06	2h06

Airport Hubs - Separated costs for wing and capsules

Higher improvement in cost

	Clip-Air	Standard 6 aircrafts	Standard 3 aircrafts
Operating costs	82%	73%	75%
Spill costs	18%	27%	25%
Total costs	**390,956 €**	**+22,248 €**	**+23,114 €**
Fleet size (in seats)	858	858	858
Transported passengers	2,807	2,593	2,642
Flight count	32	32	32
Average pax/flight	88	81	82
Flight Hours / cap unit	1h44	1h44	1h44

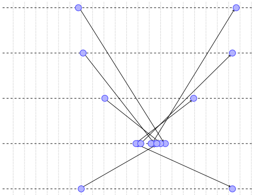
Less flights

	Clip-Air	Standard 6 aircrafts	Standard 3 aircrafts
Operating costs	83%	81%	77%
Spill costs	17%	19%	23%
Total costs	**269,132 €**	**+21,917 €**	**+23,001 €**
Fleet size (in seats)	540	540	540
Transported passengers	1,836	1,811	1,746
Flight count	22	26	26
Average pax/flight	83	69	67
Flight Hours / cap unit	1h48	2h07	2h07

More transported passengers

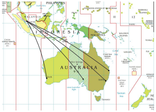
	Clip-Air	Standard 6 aircrafts	Standard 3 aircrafts
Operating costs	85%	83%	83%
Spill costs	15%	17%	17%
Total costs	**349,460 €**	**+15,257 €**	**+15,025 €**
Fleet size (in seats)	713	713	713
Transported passengers	2,110	2,062	2,068
Flight count	35	36	36
Average pax/flight	60	57	57
Flight Hours / cap unit	2h04	2h06	2h06

Special Case



		Standard	
	Clip-Air	**6 aircrafts**	**3 aircrafts**
Operating costs	69%	68%	67%
Spill costs	31%	32%	33%
Total costs	**3,420,403 €**	**-130,540 €**	**-111,097 €**
Fleet size (in seats)	1,512	1,512	1,512
Transported passengers	1,501	1,508	1,501
Flight count	8	8	8
Average pax/flight	187	188	187
Flight Hours / cap unit	4h32	4h32	4h32

Special Case



		Standard	
	Clip-Air	**6 aircrafts**	**3 aircrafts**
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Spill costs	31%	32%	33%
Total costs	**3,420,403 €**	**-130,540 €**	**-111,097 €**
Fleet size (in seats)	1,512	1,512	1,512
Transported passengers	1,501	1,508	1,501
Flight count	8	8	8
Average pax/flight	187	188	187
Flight Hours / cap unit	4h32	4h32	4h32

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ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Special Case

Airports	5
Flights	8
Capsule capacity	126
Passengers	2,025
Std Deviation (pax)	88.49
Av. Pax/Flight	253.1

		Standard	
	Clip-Air	**6 aircrafts**	**3 aircrafts**
Operating costs	69%	68%	67%
Spill costs	31%	32%	33%
Total costs	**3,420,403 €**	**-130,540 €**	**-111,097 €**
Fleet size (in seats)	1,512	1,512	1,512
Transported passengers	1,501	1,508	1,501
Flight count	8	8	8
Average pax/flight	187	188	187
Flight Hours / cap unit	4h32	4h32	4h32

Special Case

Unable to use capsule's modularity

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Cost separation between wing and capsules

Better but still higher costs

	Clip-Air	Standard 6 aircrafts	Standard 3 aircrafts
Operating costs	66%	68%	67%
Spill costs	34%	32%	33%
Total costs	**3,331,843 €**	**-41,980 €**	**-22,537 €**
Fleet size (in seats)	1,512	1,512	1,512
Transported passengers	1,414	1,508	1,501
Flight count	6	8	8
Average pax/flight	236	188	187
Flight Hours / cap unit	3h43	4h32	4h32

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Flight Hours / cap unit	4h32	4h32	4h32

Cost separation between wing and capsules

Less flights

	Clip-Air	Standard 6 aircrafts	Standard 3 aircrafts
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Spill costs	34%	32%	33%
Total costs	**3,331,843 €**	**-41,980 €**	**-22,537 €**
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Average pax/flight	187	188	187
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Cost separation between wing and capsules

More passengers per flight

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Illustration: if we confine standard fleet

1 type of aircraft for standard fleet (126 seats)

	Clip-Air	Standard 1 aircraft
Operating costs	69%	58%
Spill costs	31%	42%
Total costs	**3,420,403 €**	**+84,989 €**
Fleet size (in seats)	1,512	1,512
Transported passengers	1,501	1008
Flight count	8	8
Average pax/flight	187	126
Flight Hours / cap unit	4h32	6h49

Cost separation between wing and capsules

Improvement is more

	Clip-Air	Standard 1 aircraft
Operating costs	66%	58%
Spill costs	34%	42%
Total costs	**3,331,843 €**	**+173,549 €**
Fleet size (in seats)	1,512	1,512
Transported passengers	1,414	1,008
Flight count	6	8
Average pax/flight	236	126
Flight Hours / cap unit	3h43	6h49

Larger Instance

Larger Instance

Airports	82
Flights	432
Capsule capacity	111
Passengers	96,336
Std Deviation (pax)	72.85
Av. Pax/Flight	223.0

	Clip-Air	Standard 3 aircrafts	Standard 19 aircrafts (full fleet)
Operating costs	86%	84%	85%
Spill costs	14%	16%	15%
Total costs	51,502,004 €	**+102,825 €**	**-1,696,739 €**
Transported passengers	86,340	85,231	85,641
Flight count	378	420	407
Average pax/flight	228	203	210
Average seats/flight	246	216	219

Conclusion & Future Work

- The results give idea about the potential in decreasing the operating costs with *Clip-Air*.
- The aim of increasing the capacity seems to work with more number of transported passengers with less number of flights.
- CO_2 emissions will be studied to be able to assess the potential reduction.
- Improve operating cost function
- Cost separation between wing and capsule
- Scenario analysis for the operating cost
- Improve spill rate function (Discrete Choice Analysis)
- Extension of the model
  - Multi-modal transportation (passenger container)
  - Mixed passenger and cargo

Thanks

Any question?

Spill factor Approximation

Computing the spill factor from itinerary $it1$ to $it2$, 2 factors :

- Fare difference

$$fareRatio = \frac{fare_{it2}}{fare_{it1}}$$

- Time gap

$$timeGapRatio = 10\% \times \frac{|dep_{it1} - dep_{it2}| + |arr_{it1} - arr_{it2}|}{2}$$

$$spillRatio = fareRatio \times timeGapRatio$$