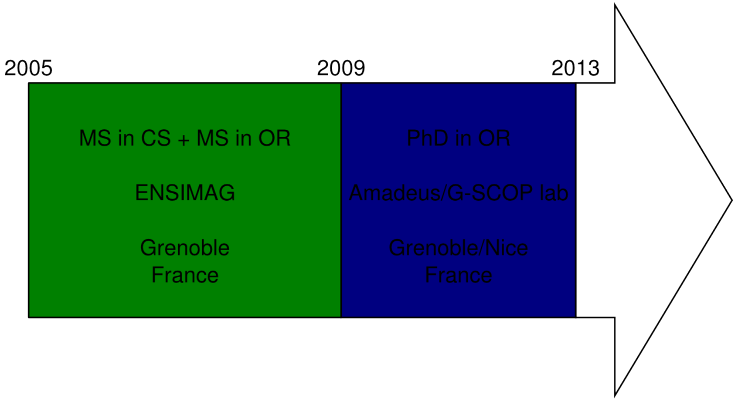
Market Driven Fleet Assignment

Christophe-Marie Duquesne

June 17, 2013

A word about me



Advisors: Denis Naddef, Olivier Briant / Manager: Semi Gabteni

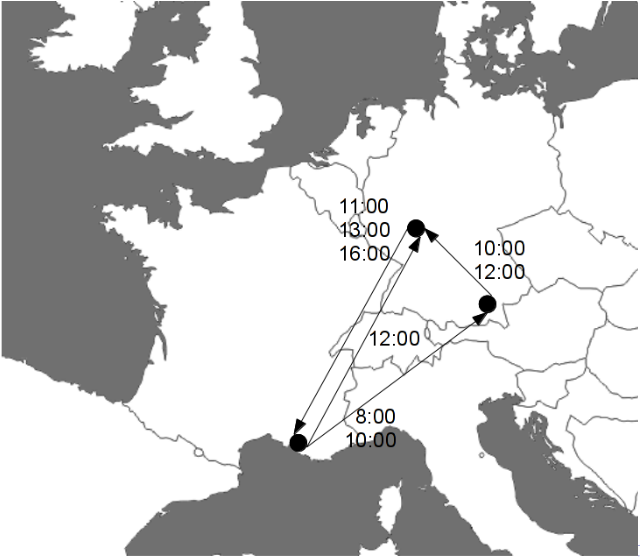
Fleet Assignment: One simple question

Which **aircraft type** should I put on each $\underbrace{\textbf{flight leg}}_{\text{1 take off - 1 landing}}$?

Example

50 seats (2)

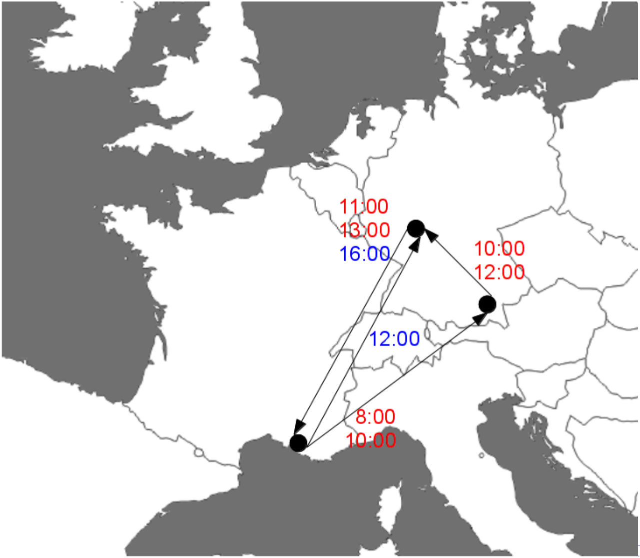
100 seats (1)



Example

50 seats (2)

100 seats (1)



What is optimized?

Profit = Revenue − Costs

Depends on

- Fares
- Bookings
- Capacities
- Sales

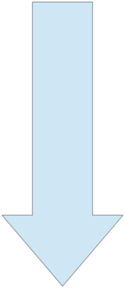
- Fuel
- Gate rental
- ...

Context

One step of **Airline Planning**, which decides everything about:

- The flights
- The fleet
- The crew


Airline Planning

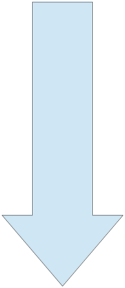


Operations

1. **Schedule Design**
2. Fleet Assignment
3. Aircraft Routing
4. Crew Pairing
5. Crew Rostering

Decide of the flights to operate.

Airline Planning



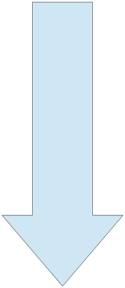
Operations

1. Schedule Design
2. **Fleet Assignment**
3. Aircraft Routing
4. Crew Pairing
5. Crew Rostering

Decide the type of aircraft to operate each flight

(Implies a schedule)

Airline Planning



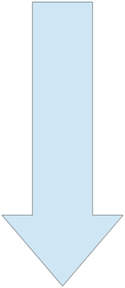
Operations

1. Schedule Design
2. Fleet Assignment
3. **Aircraft Routing**
4. Crew Pairing
5. Crew Rostering

Decide the route of each aircraft

(Implies a fleet assignment)

Airline Planning



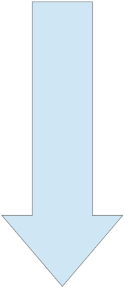
Operations

1. Schedule Design
2. Fleet Assignment
3. Aircraft Routing
4. **Crew Pairing**
5. Crew Rostering

Decide of the crew types to be assigned on each flight

(Implies an aircraft routing)

Airline Planning



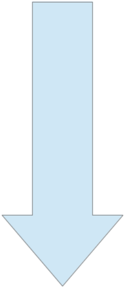
Operations

1. Schedule Design
2. Fleet Assignment
3. Aircraft Routing
4. Crew Pairing
5. **Crew Rostering**

Decide of the timetables of individuals

(Implies a crew pairing)

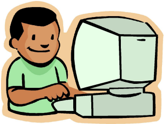
Airline Planning



1. Schedule Design
2. **Fleet Assignment**
3. Aircraft Routing
4. Crew Pairing
5. Crew Rostering

Focus of my thesis

Revenue Management



After Airline Planning, next logical step.

- Control seat availability **dynamically**.
- **Capacities** are essential.
- Makes the revenue **hard** to accurately estimate!

Summary

Fleet Assignment:

- Determines major costs (easy)
- Sets capacities for the revenue (hard)

Summary

Fleet Assignment:

- Determines major costs (easy)
- Sets capacities for the revenue (hard)

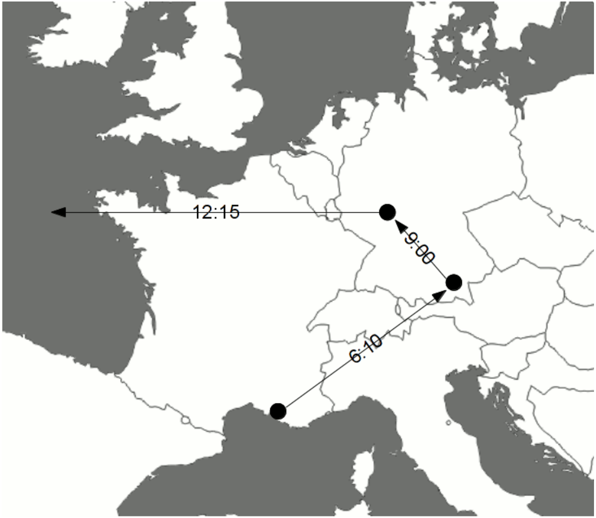
Goals of this thesis:

- Generally improve the existing models
- Focus on estimating the revenue better

Outline

Some definitions

- legs
- itineraries
- spill
- recapture



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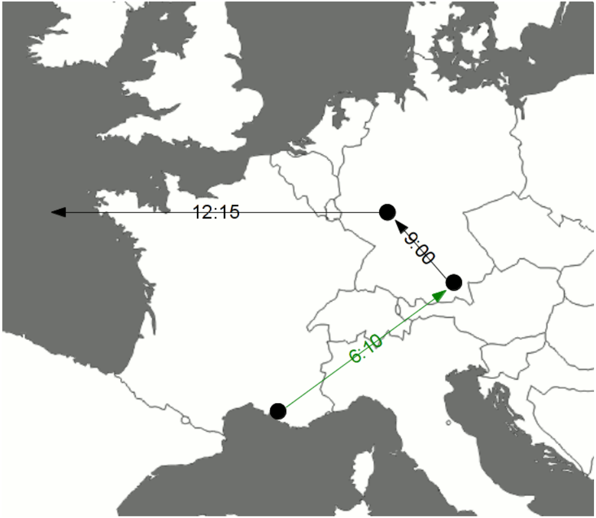

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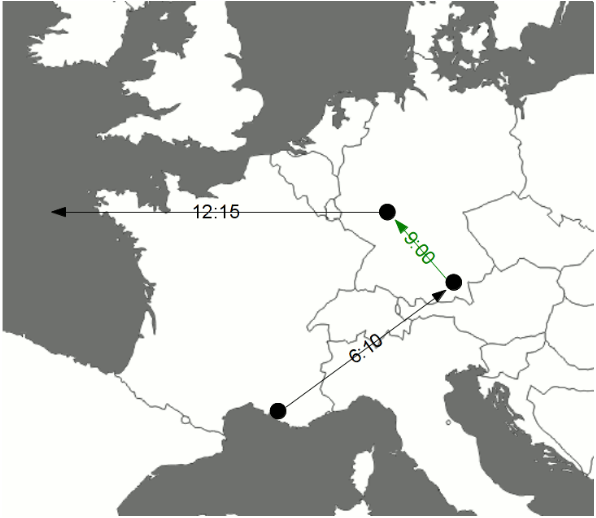

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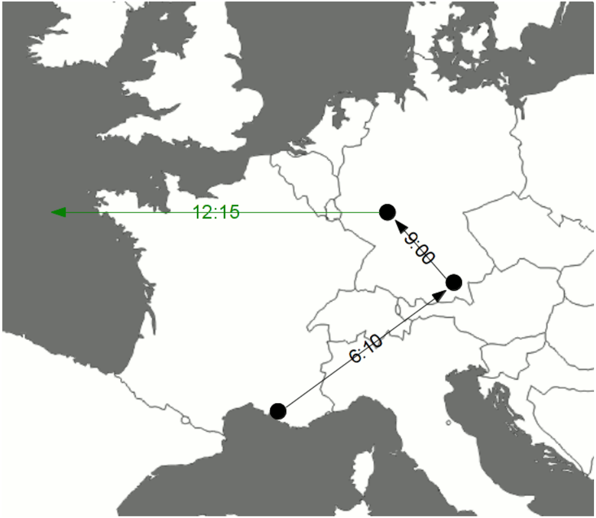

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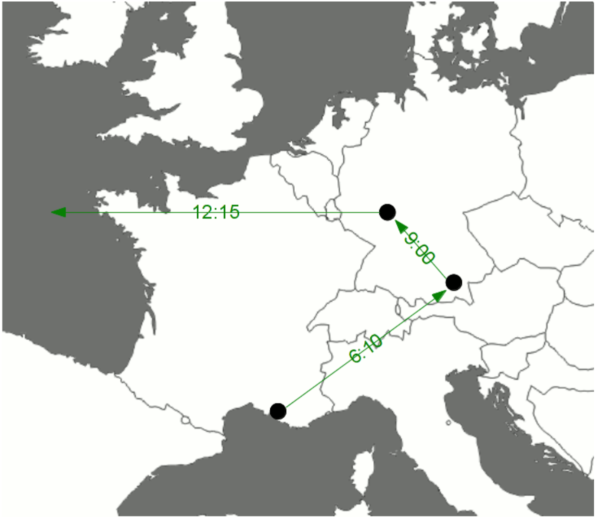

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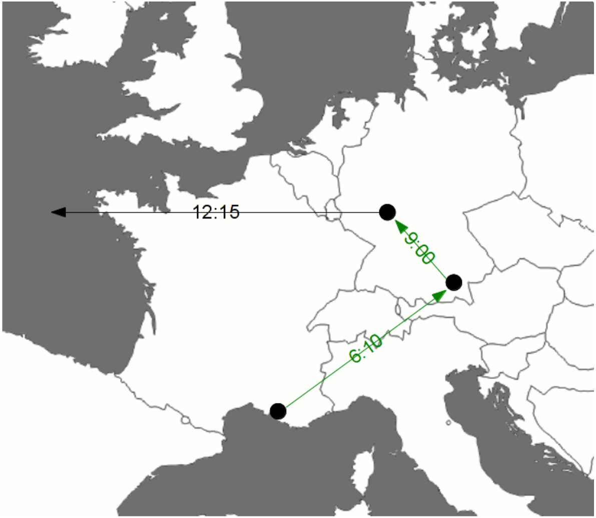

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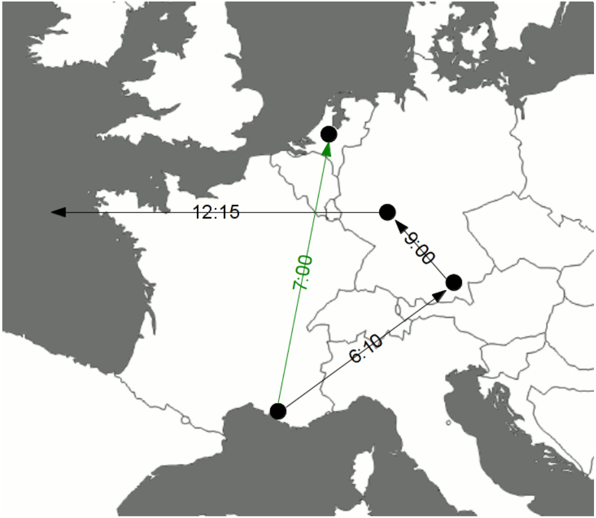

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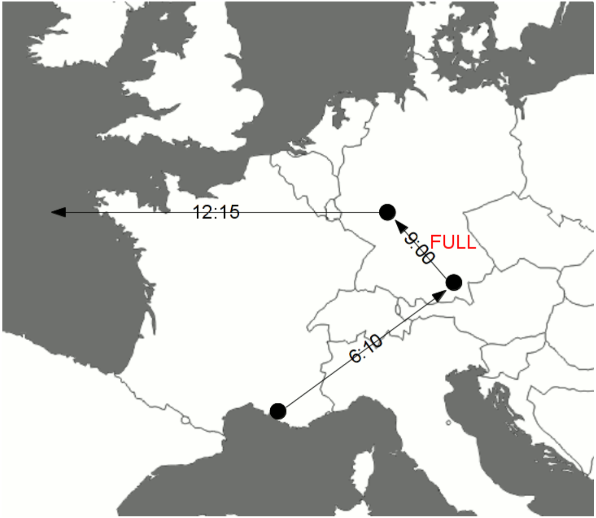

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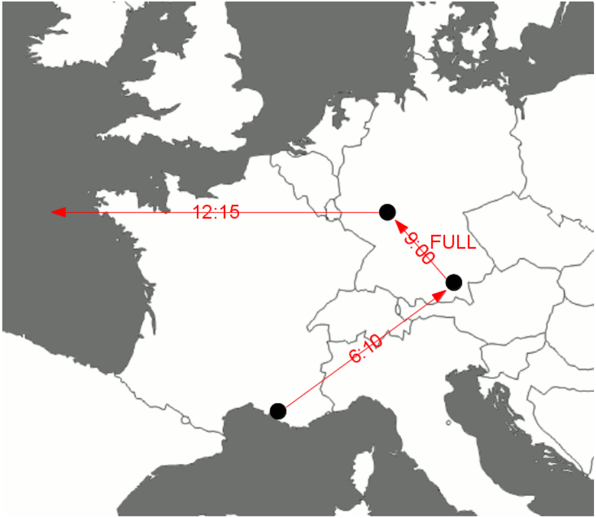

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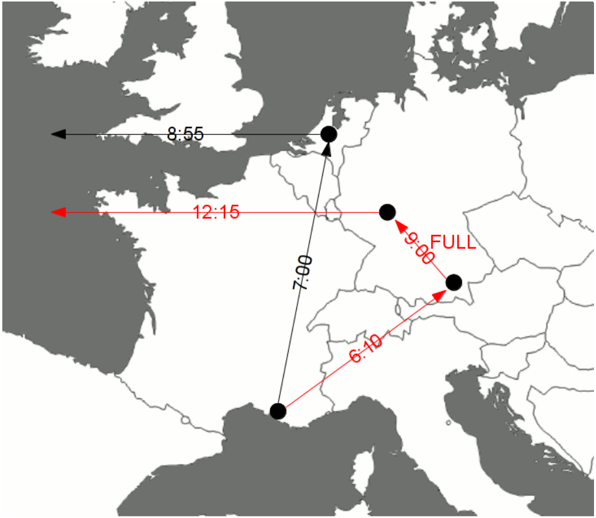

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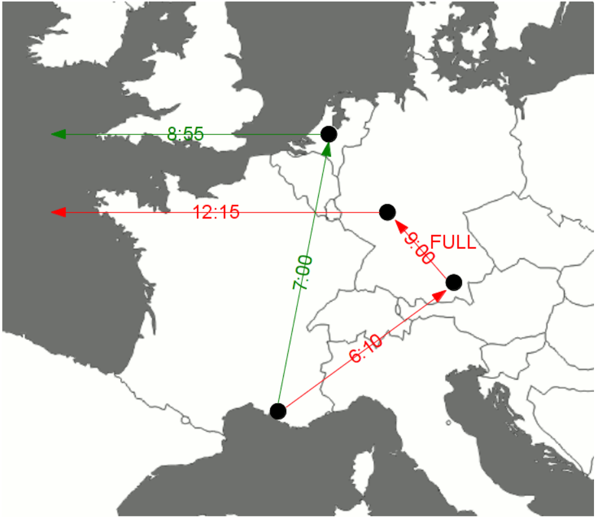

Summary

- **legs**: 1 takeoff - 1 landing
- **itineraries**: sequences of legs
- **spill**: unsatisfied demand
- **recapture**: demand satisfied elsewhere

Major models

Fleet Assignment Models (for assigning fleet):

- FAM (Abara, 1989)
- IFAM (Barnhart et al, 2002)

Passenger Mix Model (determining revenue fleeted network):

- PMM (Barnhart et al, 2002)

Major models

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- PMM (Barnhart et al, 2002)

Fleet Assignment Model (FAM)

- MIP to find the best assignment
- **Leg-based** costs
- Revenue included as spill cost

Fleet Assignment Model (FAM)

Costs:

- c: costs (type, leg)

Constraints:

- network

Variables:

- x: assignment (type, leg)

Fleet Assignment Model (FAM)

$$
\begin{array}{lll}
\min & cx & \\
\text{s.t.} & x \in X & = \left\{ \begin{array}{l} \text{cover} \\ \text{aircraft flow} \\ \text{fleet size} \end{array} \right.
\end{array}
$$

Fleet Assignment Model (FAM)

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Leg Costs:

$$C_{l,t} = C_{l,t}^{\text{operating}} + C_{l,t}^{\text{spill}}$$

Fleet Assignment Model (FAM)

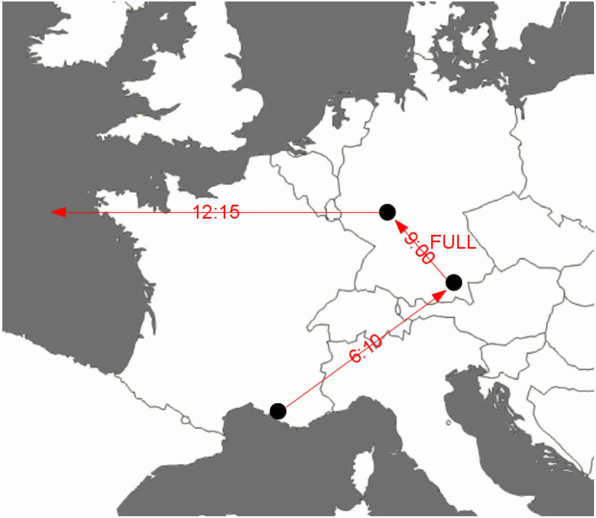
$$
\begin{aligned}
\min \quad & cx \\
\text{s.t.} \quad & x \in X = \begin{cases} \text{cover} \\ \text{aircraft flow} \\ \text{fleet size} \end{cases}
\end{aligned}
$$

Leg Costs:

$$C_{l,t} = C_{l,t}^{\text{operating}} + C_{l,t}^{\text{spill}}$$

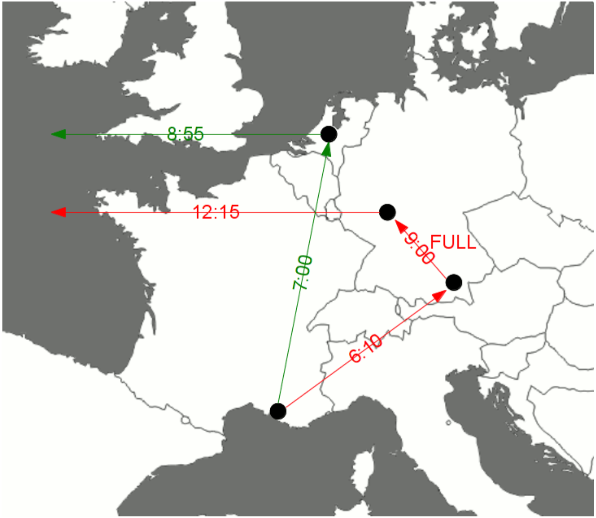
Problem of FAM

- Leg-based costs, but spill costs are not local



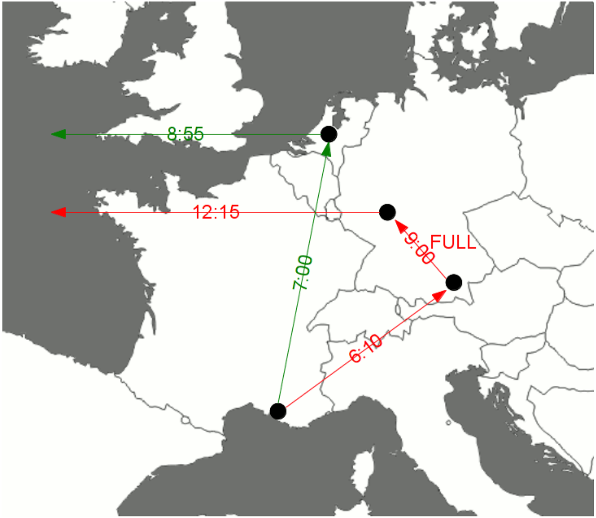
Problem of FAM

- Leg-based costs, but spill costs are not local
- Recapture is ignored



Problem of FAM

- Leg-based costs, but spill costs are not local
- Recapture is ignored
- Poor revenue estimation



Passenger Mix Model (PMM)

- Computes the revenue of a **fleeted network**
- Minimizes the spill cost
- Based on demand forecasts

Passenger Mix Model (PMM)

Costs:

- f: fares (itinerary)

Constraints:

- **x: fleet assignment**, demand

Variables:

- s: spill (itinerary)

Passenger Mix Model (PMM)

Costs:

- f: fares (itinerary)

Constraints:

- **x: fleet assignment**, demand[, recapture rates]

Variables:

- s: spill (itinerary[$\times$itinerary])

Passenger Mix Model (PMM)

$$
\begin{array}{lll}
\min & fs & \\
\text{s.t.} & s \in S(x) & = \left\{ \begin{array}{l} \text{capacity(x)} \\ \text{population size} \end{array} \right.
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$$

Passenger Mix Model (PMM)

$$
\begin{aligned}
\min \quad & fs \\
\text{s.t.} \quad & s \in S(x) \quad = \quad \begin{cases} \text{capacity(x)} \\ \text{population size} \end{cases}
\end{aligned}
$$

- Can be embedded in a Fleet Assignment Model (IFAM)

Itinerary-based Fleet Assignment Model (IFAM)

- Combines FAM and PMM
- Find the best assignment **and** the spill solution
- Embeds a simulation of the passenger flow

Itinerary-based Fleet Assignment Model (IFAM)

Costs:

- c: operating costs (type, leg)
- f: fares (itinerary)

Constraints:

- network, demand [,recapture rates]

Variables:

- x: assignment (type, leg)
- s: spill (itinerary[$\times$ itinerary])

Itinerary-based Fleet Assignment Model (IFAM)

$$
\begin{aligned}
\min \quad & \overbrace{cx}^{\text{operating cost}} && + \quad \overbrace{fs}^{\text{spill cost}} \\
\text{s.t.} \quad & x \in X && = \begin{cases} \text{cover} \\ \text{aircraft flow} \\ \text{fleet size} \end{cases} \\
& s \in S(x) && = \begin{cases} \text{capacity(x)} \\ \text{population size} \end{cases}
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Itinerary-based Fleet Assignment Model (IFAM)

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 & s \in S(x) & = & \left\{ \begin{array}{l} \text{capacity(x)} \\ \text{population size} \end{array} \right.
\end{array}
$$

- Better models the revenue
- But forecasting demands (and recapture rates) is delicate

Outline

Idea

- Itinerary demands are highly variable
- Grouped demands are easier to forecast (law of large numbers)

We thus include the demands as decision variables, and we constrain them

MDFAM

Costs:

- c: operating costs (type, leg)
- f: fares (itinerary)

Constraints:

- network, constraints on demand

Variables:

- x: assignment (type, leg)
- s: spill (itinerary)
- d: demand (itinerary)

MDFAM

$$
\begin{array}{llcl}
\min & \overbrace{cx}^{\text{operating cost}} & + & \overbrace{f(s-d)}^{\text{revenue loss}} \\
\text{s.t.} & x \in X & = & \left\{ \begin{array}{l} \text{cover} \\ \text{aircraft flow} \\ \text{fleet size} \end{array} \right. \\
 & s, d \in SD(x) & = & \left\{ \begin{array}{l} \text{capacity(x)} \\ \text{population size} \\ \text{market constraints} \end{array} \right.
\end{array}
$$

MDFAM

$$
\begin{array}{lllll}
\min & \overbrace{cx}^{\text{operating cost}} & + & \overbrace{f(s-d)}^{\text{revenue loss}} & \\
\text{s.t.} & x \in X & = & \left\{ \begin{array}{l} \text{cover} \\ \text{aircraft flow} \\ \text{fleet size} \end{array} \right. & \\
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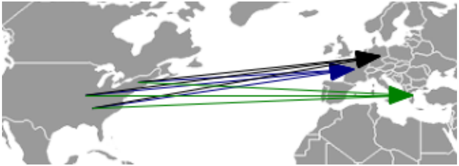
\end{array}
$$

- With fixed demands, this is exactly IFAM (without recapture)
- Demand is chosen as a best case scenario.

Examples of market constraints

Matching a geographical criterion



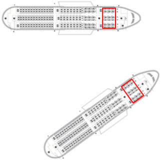
$$D^{\text{min}}_{\text{France}} \leq \sum_{i \in I_{\text{France}}} d_i \leq D^{\text{max}}_{\text{France}}$$

$$D^{\text{min}}_{\text{Germany}} \leq \sum_{i \in I_{\text{Germany}}} d_i \leq D^{\text{max}}_{\text{Germany}}$$

$$D^{\text{min}}_{\text{Greece}} \leq \sum_{i \in I_{\text{Greece}}} d_i \leq D^{\text{max}}_{\text{Greece}}$$

Examples of market constraints

Matching based on the fare class



$$D^{\text{min}}_{\text{First class}} \leq \sum_{i \in I_{\text{First class}}} d_i \leq D^{\text{max}}_{\text{First class}}$$

Examples of market constraints

Enforcing correlations between demands

$$-\epsilon \leq d_i - d_i' \leq \epsilon$$

Examples of market constraints

Leg based

$$D_l^{\text{min}} \leq \sum_{i \in I_l} d_i \leq D_l^{\text{max}}$$

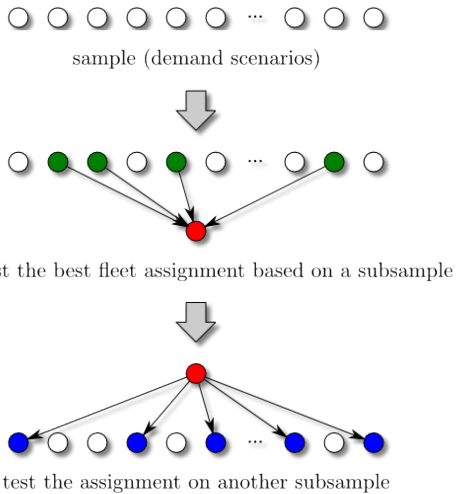
Many possibilities

Flexible: any linear expression can be used

$$D^{\min} \leq \sum_i \alpha_i d_i \leq D^{\max}$$

Outline

Comparing the models

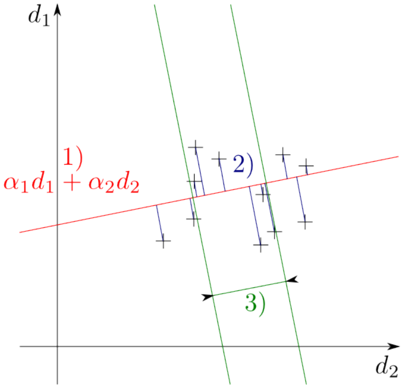


Forecasting the best Assignments

FAM and IFAM: solve according to average demands

MDFAM requires ranged constraints. How to proceed?

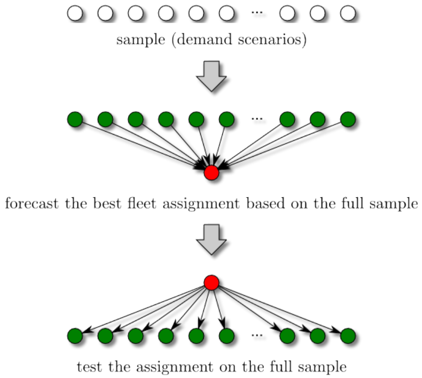
Market Constraints Forecast



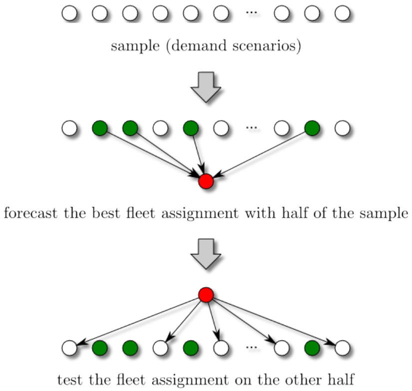
Bounds are determined from the occurrences of $\sum_i \alpha_i d_i$

Tests

Whole season



2-fold cross-validation



Results

Compared to IFAM:

Whole season	$+4\%$
2-fold cross validation	-0.67%

- With perfect forecasts, MDFAM would perform very well
- With less information, it needs improvement (but not too far)

Effects of the market constraints (Profit%IFAM)

About this work

MDFAM will be improved: as a generalisation, it can be IFAM.

- Part of my thesis, defended in January
- Positive comments from Barnhart: It simplifies the whole recapture concept.
- Amadeus has 2 master students working on it.

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Speaking about code...

Related Achievements

I will now present 3 open source projects related to this thesis.

Outline

Story

- Needed to implement FAM, IFAM, PMM...
- Wanted to benchmark different solvers
- Already knew Coin-OSI

PuLP-OR

- Solver-agnostic Python Linear Programming library
- COIN-OR project, actively maintained, Growing user base
- Support 5 solvers
- Interpreted, but 90% time = solver

What I got out of it

A solver that could do

```
cat FAM.json | assignfleet --solver=cplex -
```

Contributions:

- support for python-glpk
- support for cplex runtime licenses

Outline

Story

- OSI is ugly, but supports many solvers
- Let's make a python binding

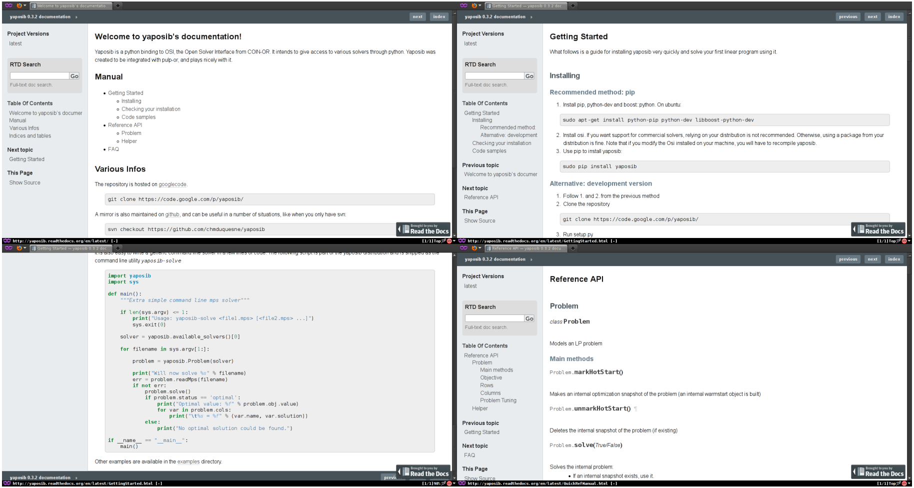
Yaposib

- Integrated in PuLP-OR

```
problem.Solve(YAPOSIB("Clp"))
```

- Can be used standalone (startup **Prediction Appliance**)
- Extended documentation, examples, and a test suite
- Should become COIN-OR when they support git

Yaposib



yaposib 0.3.2 documentation
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RTD Search
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Show Source
Welcome to yaposib's documentation!
Yaposib is a python binding to OSI, the Open Solver Interface from COIN-OR. It intends to give access to various solvers through python. Yaposib was created to be integrated with pulp-or, and plays nicely with it.
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Getting Started
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Checking your installation
Code samples
Reference API
Problem
Helper
FAQ
Various Infos
The repository is hosted on googlecode.
git clone https://code.google.com/p/yaposib/
A mirror is also maintained on github, and can be useful in a number of situations, like when you only have svn:
svn checkout https://github.com/chmduquesne/yaposib
http://yaposib.readthedocs.org/en/latest/
yaposib 0.3.2 documentation
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Getting Started
What follows is a guide for installing yaposib very quickly and solve your first linear program using it.
Installing
Recommended method: pip
1. Install pip, python-dev and boost::python. On ubuntu:
sudo apt-get install python-pip python-dev libboost-python-dev
2. Install osi. If you want support for commercial solvers, relying on your distribution is not recommended. Otherwise, using a package from your distribution is fine. Note that if you modify the Osi installed on your machine, you will have to recompile yaposib.
3. Use pip to install yaposib:
sudo pip install yaposib
Alternative: development version
1. Follow 1. and 2. from the previous method
2. Clone the repository
git clone https://code.google.com/p/yaposib/
3. Run setup.py
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Reference API
http://yaposib.readthedocs.org/en/latest/GettingStarted.html
command line utility yaposib-solve
import yaposib
import sys
def main():
"""Extra simple command line mps solver"""
if len(sys.argv) <= 1:
print("Usage: yaposib-solve <file1.mps> [<file2.mps> ...]")
sys.exit(0)
solver = yaposib.available_solvers()[0]
for filename in sys.argv[1:]:
problem = yaposib.Problem(solver)
print("Will now solve %s" % filename)
err = problem.readMps(filename)
if not err:
problem.solve()
if problem.status == 'optimal':
print("Optimal value: %f" % problem.obj.value)
for var in problem.cols:
print("\t%s = %f" % (var.name, var.solution))
else:
print("No optimal solution could be found.")
if __name__ == "__main__":
main()
Other examples are available in the examples directory.
Reference API
Problem
class Problem
Models an LP problem
Main methods
Problem.markHotStart()
Makes an internal optimization snapshot of the problem (an internal warmstart object is built)
Problem.unmarkHotStart()
Deletes the internal snapshot of the problem (if existing)
Problem.solve(True/False)
Solves the internal problem:
If an internal snapshot exists, use it.
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Problem
Main methods
Objective
Rows
Columns
Problem Tuning
Helper
Previous topic
Getting Started
Next topic
FAQ
http://yaposib.readthedocs.org/en/latest/QuickRefManual.html
Brought to you by Read the Docs

Outline

Rationale

- Yaposib builds on OSI: let's package both
- Solver support: compile time
- Users do not have every solvers (e.g. cplex)

lazylpsolverlibs

- Fake libraries proxying to cplex, gurobi, xpress:

```
-lcplex -I$INCLUDE_DIR -L$LINK_DIR
# versus #
$(pkg-config --libs --cflags lazycplex)
export LAZLPSOLVERLIBS_CPLEX_LIB=$LINK_DIR/libcplex.so
```

- Man page, solver availability test tool
- Debian package on the way

Outline

Conclusion

- 3 active years
- Very happy to talk about them
- I am looking forward to doing new projects!

Thank You

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