Decision Theory concepts and algorithms (and how they are) used in Energy Management and Transportations

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Decision Theory concepts and algorithms used in Energy Management and Transportations.

Abstract : We will use hands-on experiences in the industry to illustrate the continuous back and forth interaction between modelling and algorithms in the "real world". In particular, we will focus on important "business concepts" that arose from an educated use of applied mathematics in the different domains. Such concepts, like "water value", "bid price", "options", have led to a better understanding of the business work and have provided a bridge between OR and the industry. So many more need to be invented !

To do this, we will investigate the following question :

-Why is it so difficult to make real-world applications ?
-What are the typically successful concepts ?

But before : a very quick presentation of Air France OR department !

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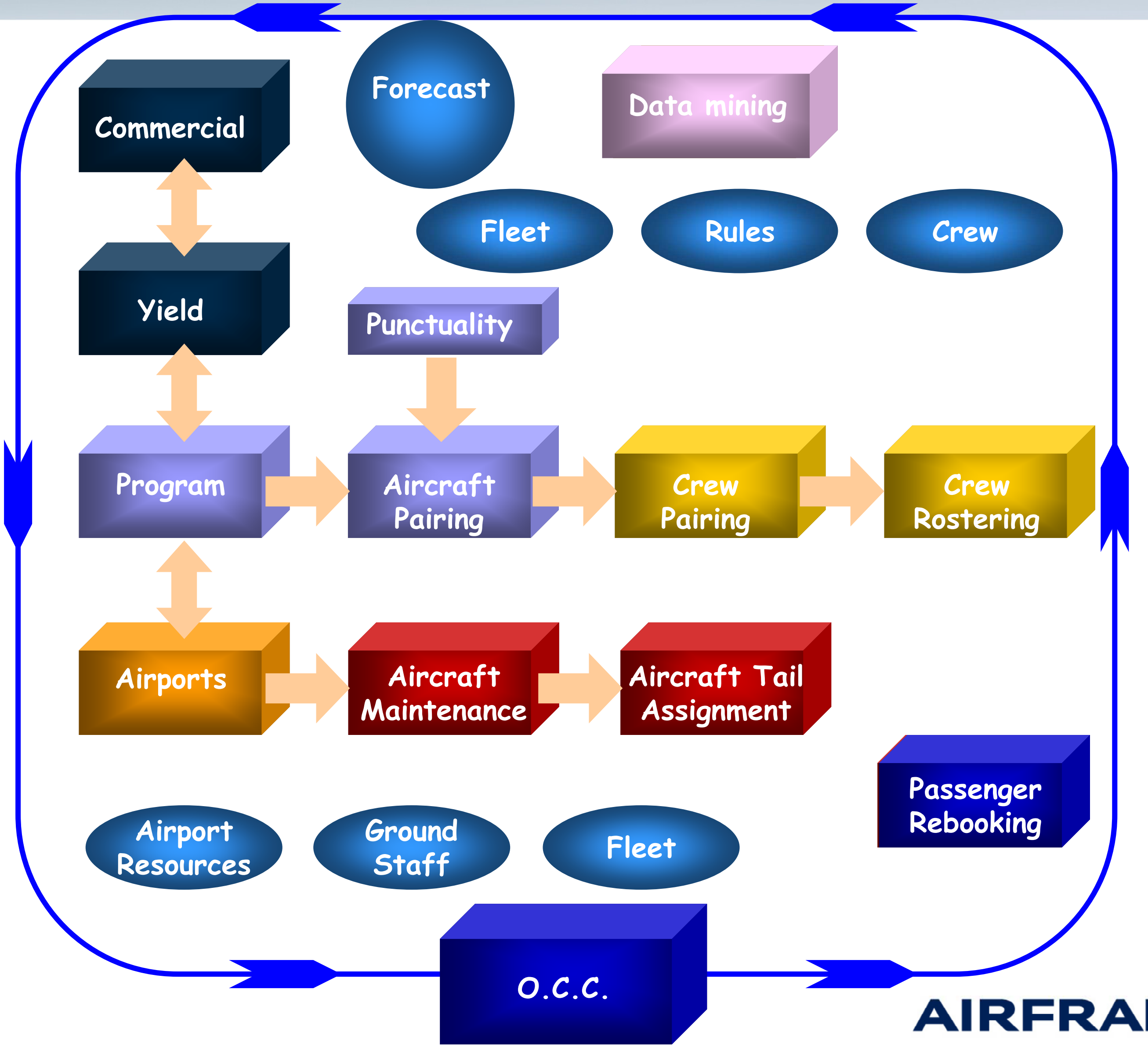
PART I : Optimization from earth to sky



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Algorithmic Decision Theory can be financially efficient

- AF OR Group costs less than $ 2 million / year
- The 5 top applications each save several $ millions / year
- Most applications have a return on investment of less than one year
- They significantly enhance the understanding and bottom lines of our customers.
- More than 40 applications are used
- The future Revenue Management system for AF and KLM is expected to improve by ***xx*** millions with respect to current revenue

Elements of a "Success Story"

- Young and senior motivated and well-educated people (many PHDs) :
  - **20 to 30 members including trainees and external staff**
- Very good cooperation with Business Analysts and IT development
- A paranoid will to serve the customers (and prove useful…)
- Demanding customers and full support from the Management (IT and executive VPs…)
- Three axis : development, studies ("consulting"), innovation

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Example 1 : "PALACE" Decision Making Tool

- PALACE is a tool used by our Schedule department
- Constructs aircraft rotations on short and medium haul fleets
- Covers flights and maintenance tasks respecting min ground times
- Takes into account operational constraints from other departments (crew, overhaul, MTOW, custom status' connections…)

- High stability between the forecast rotation and the achieved one
- Aircraft rotations reference for diffusion to other departments (schedule regulation, flight operations, maintenance and ground operations)
- Punctuality life-saver

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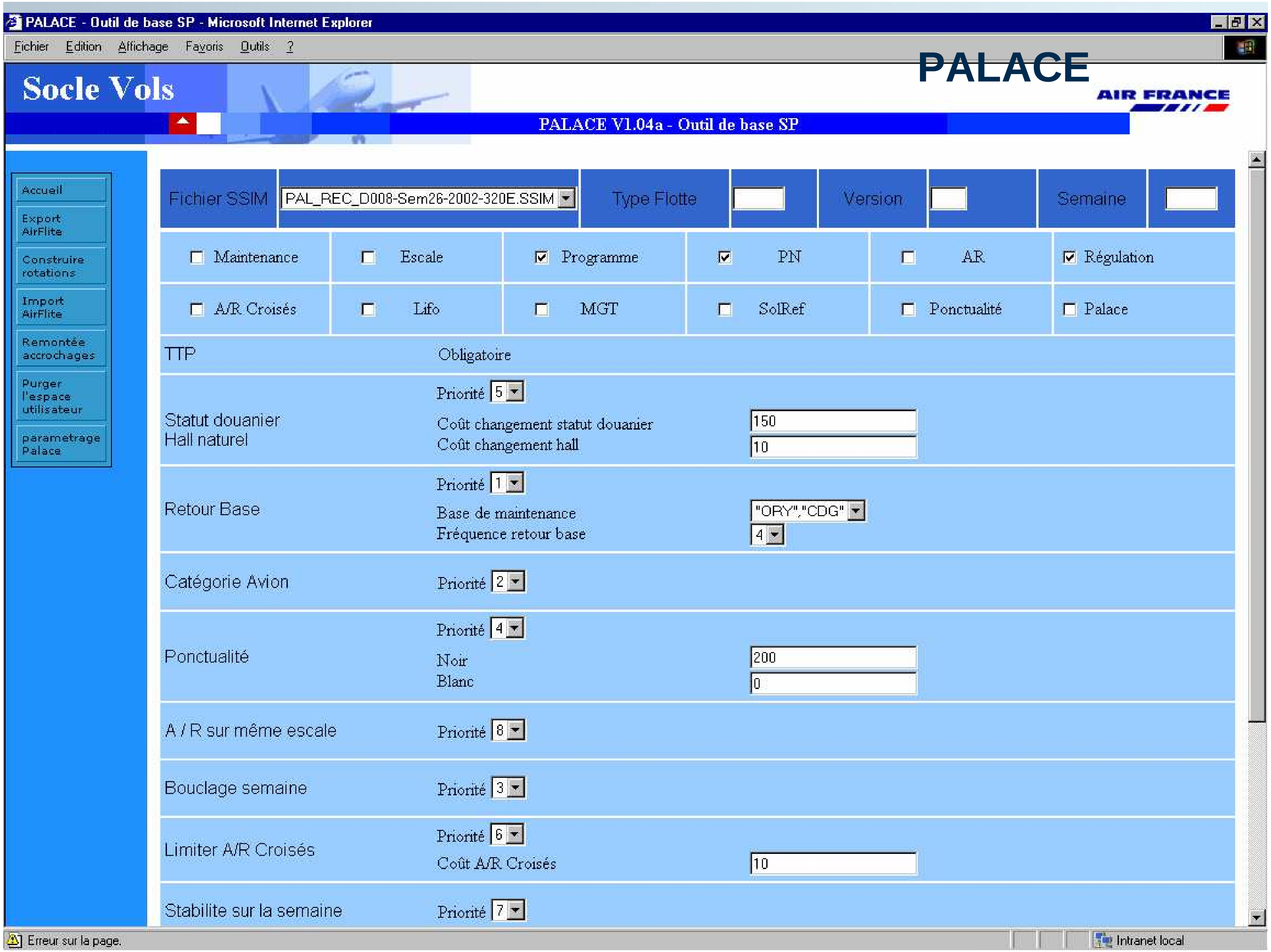
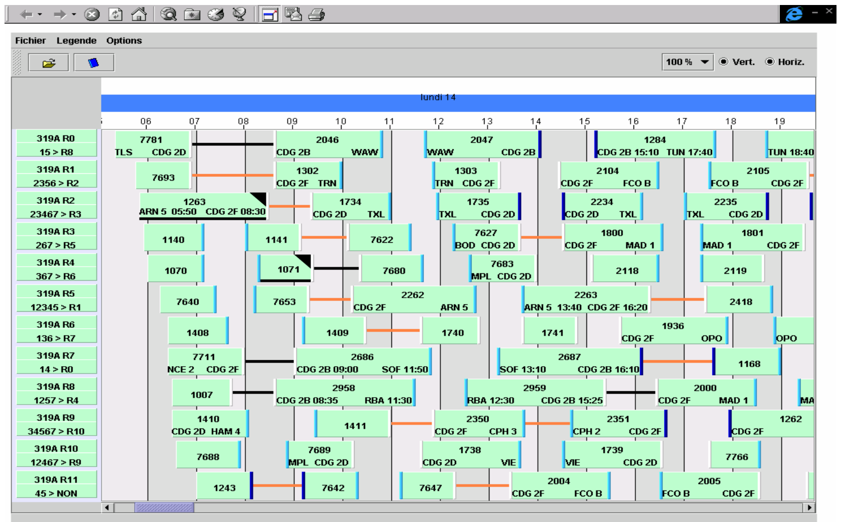
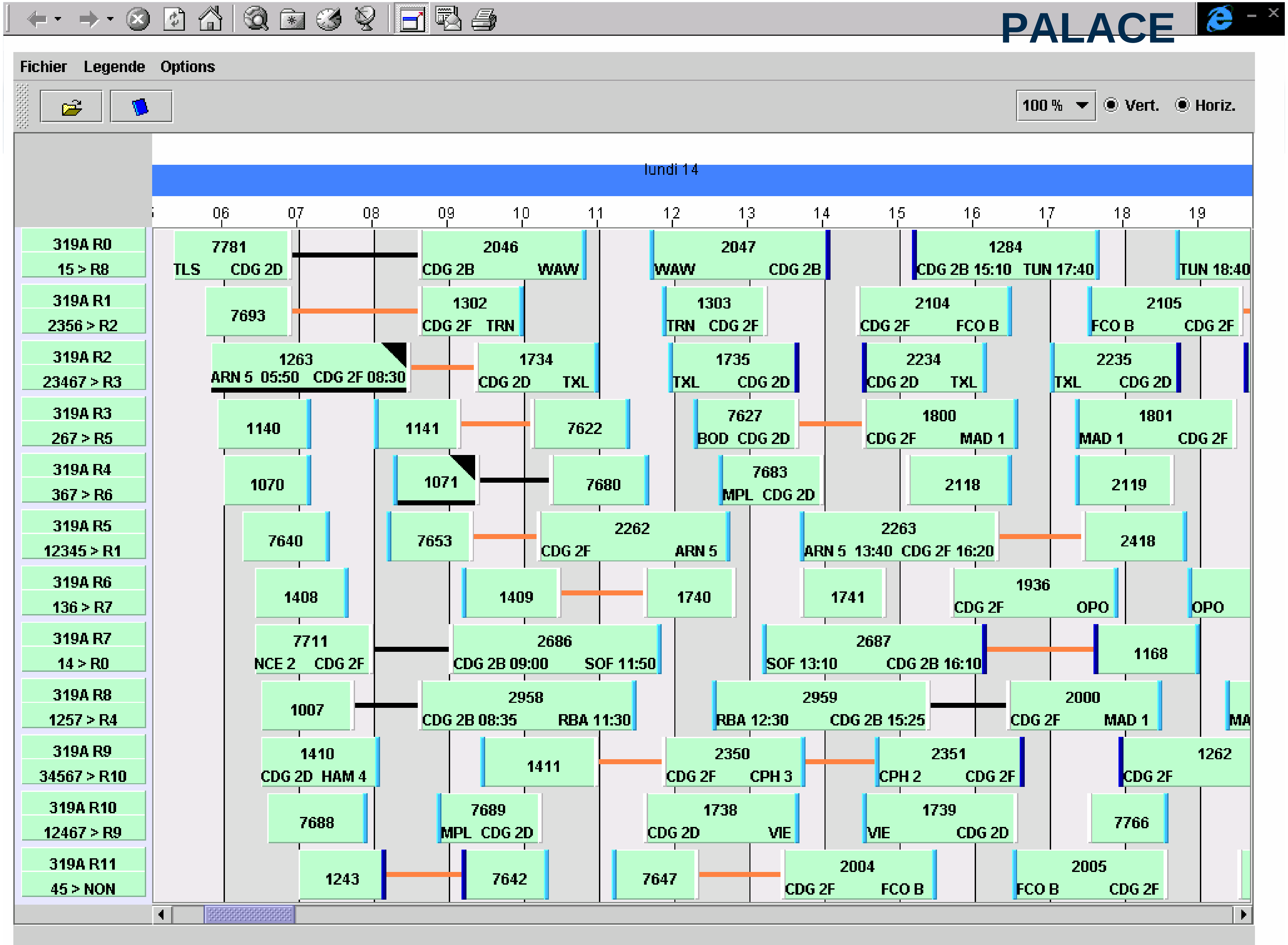

PALACE - Outil de base SP - Microsoft Internet Explorer
Fichier Edition Affichage Favoris Outils ?
Socle Vols
PALACE
AIR FRANCE
PALACE V1.04a - Outil de base SP
Accueil
Export AirFlite
Construire rotations
Import AirFlite
Remontée accrochages
Purger l'espace utilisateur
parametrage Palace
Fichier SSIM
PAL_REC_D008-Sem26-2002-320E.SSIM
Type Flotte
Version
Semaine
Maintenance
Escale
Programme
PN
AR
Régulation
A/R Croisés
Lifo
MGT
SolRef
Ponctualité
Palace
TTP
Obligatoire
Statut douanier
Hall naturel
Priorité 5
Coût changement statut douanier
150
Coût changement hall
10
Retour Base
Priorité 1
Base de maintenance
"ORY","CDG"
Fréquence retour base
4
Catégorie Avion
Priorité 2
Ponctualité
Priorité 4
Noir
200
Blanc
0
A / R sur même escale
Priorité 8
Bouclage semaine
Priorité 3
Limiter A/R Croisés
Priorité 6
Coût A/R Croisés
10
Stabilite sur la semaine
Priorité 7
Erreur sur la page.
Intranet local

PALACE

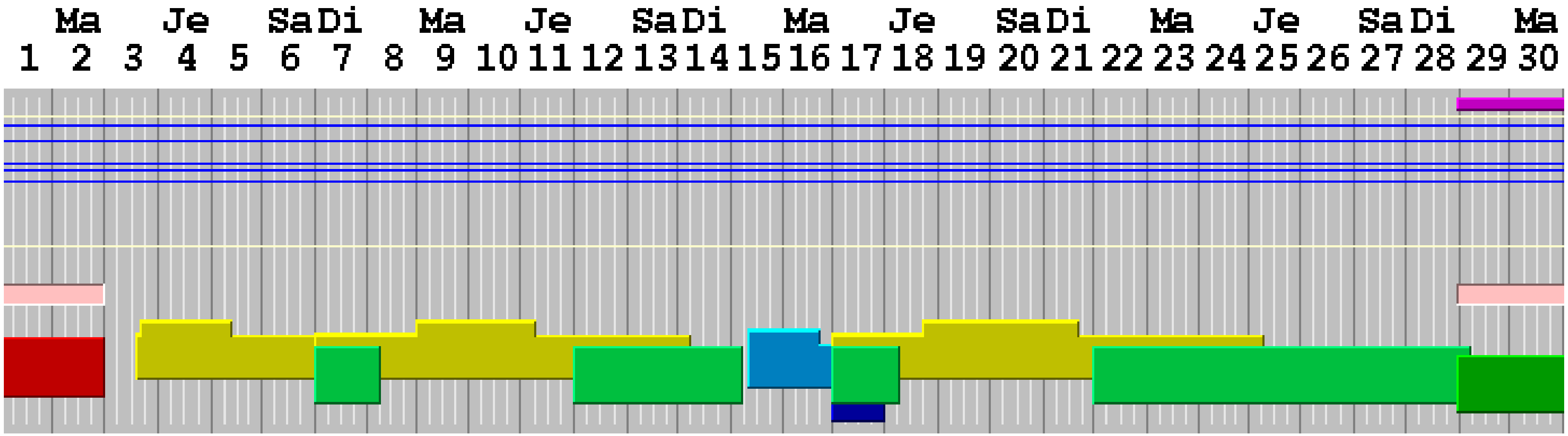
- Heuristic based on LP model and 2-opt swaps
- Computation time < 1 minute for the biggest fleets (38 aircrafts)
- PALACE vs FIFO algorithm: 30% decrease of bad connections (custom status', hall connections, delaying connection…), most operational constraints respected all the time, cpu time similar
- Option to use (almost-optimal) column generation with more cpu time





PALACE
Fichier
Legende
Options
100 %
Vert.
Horiz.
lundi 14
06 07 08 09 10 11 12 13 14 15 16 17 18 19
319A R0
15 > R8
7781 TLS CDG 2D
2046 CDG 2B WAW
2047 WAW CDG 2B
1284 CDG 2B 15:10 TUN 17:40
TUN 18:40
319A R1
2356 > R2
7693
1302 CDG 2F TRN
1303 TRN CDG 2F
2104 CDG 2F FCO B
2105 FCO B CDG 2F
319A R2
23467 > R3
1263 ARN 5 05:50 CDG 2F 08:30
1734 CDG 2D TXL
1735 TXL CDG 2D
2234 CDG 2D TXL
2235 TXL CDG 2D
319A R3
267 > R5
1140
1141
7622
7627 BOD CDG 2D
1800 CDG 2F MAD 1
1801 MAD 1 CDG 2F
319A R4
367 > R6
1070
1071
7680
7683 MPL CDG 2D
2118
2119
319A R5
12345 > R1
7640
7653
2262 CDG 2F ARN 5
2263 ARN 5 13:40 CDG 2F 16:20
2418
319A R6
136 > R7
1408
1409
1740
1741
1936 CDG 2F OPO
OPO
319A R7
14 > R0
7711 NCE 2 CDG 2F
2686 CDG 2B 09:00 SOF 11:50
2687 SOF 13:10 CDG 2B 16:10
1168
319A R8
1257 > R4
1007
2958 CDG 2B 08:35 RBA 11:30
2959 RBA 12:30 CDG 2B 15:25
2000 CDG 2F MAD 1
MA
319A R9
34567 > R10
1410 CDG 2D HAM 4
1411
2350 CDG 2F CPH 3
2351 CPH 2 CDG 2F
1262 CDG 2F
319A R10
12467 > R9
7688
7689 MPL CDG 2D
1738 CDG 2D VIE
1739 VIE CDG 2D
7766
319A R11
45 > NON
1243
7642
7647
2004 CDG 2F FCO B
2005 FCO B CDG 2F

Example 2 : AF Crew Rostering Tools



- MH (medium haul) cockpit crew rostering tool *(***Sextant** *delivered in Feb. 2000)*
  - 1300 cockpit crew, 7500 rotation tasks, 500 reserves tasks
- MH and SH cabin crew rostering tool *(***Opale 2** *delivered in Mars 2001)*
  - 2500 crew member, 30 000 tasks, 55 000 charges
- LH cabin crew rostering tool *(***Archipel** *delivered in Aug. 2002)*
  - 8000 cabin crew, 24600 rotation tasks, 88500 workloads, 2500 trainings and medical appointments, 230 legality rules and 35 quality rules
- Ongoing updates and evolutions

Solutions reached in less than 2 hours

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Crew Rostering = Typical Multi-criteria Problem

Legal schedule for month M

- minimize and smooth unassigned daily positions, minimize and balance overtime under AF rules and constraints

Equity between crew members

- balance specific criteria of pairing (early departure, 5 legs duty periods, deadhead flights …)

Quality of schedules

- individual level (voluntary long pairing or short pairing, voluntary alternate base…)

Checking of crew schedule legality

- check rosters after manual completions by planners

Ability to test new rules

- check and analyze the feasibility and cost of new rules

Example 3 : aircraft maintenance optimization

With a 245 aircrafts fleet

A 6% maintenance immobilization rate

Every day 14 aircrafts are on the ground for maintenance

Win 0,5 % in immobilization rate results in having

i.e. 1 more plane for exploitation

Alpha is an information system :

- That integrates databases and GUI to manage and historically record aircraft maintenances.
- That integrates a decision support tools to optimize immobilization rate.

Alpha's optimizer

Optimization engine :

- Plan aircraft stops for maintenance following aircraft specific maintenance rules.
- Integrates exploitation constraints and constraints on facilities, and manpower.
- different planning modes: medium term (<1yrs), long term (>1yrs).
- Interaction with users, ability to play 'what if' scenarios.

Techniques :

- Heuristic resolution for reactivity.
- Based on graphs for a better integration of core maintenance rules.
- Developed in C++, interface with java.

Results :

- 7 minutes for 1 season on A320/A340 fleet (66 aircrafts)

PART II : Lessons learned in a few years of "internal consulting" activity

- A/ The difficulty of making real world applications
- B/ Some useful concepts or point of views that make communication easier between scientists and practitioners

A/ The difficulty of making real world applications

Issues in translating a good theory into a good application can be :

- Reluctance of business people to let go some part of the power they have on their perimeter to other (OR) bright people
- Absence of faith / trust in mathematics

- Impossibility to model the situation at a level that enables tractable, useable, understandable solution and results

- Lack of data <u>or</u> too much data

- Lack of computing (algorithmic) <u>knowledge</u> of the <u>user</u>

- Lack of <u>IT</u> skills of the <u>scientists</u> : indeed we don't only solve a problem, we create an IT system, a decision-making tool

- Important constraint not given at first start

This is my domain, you OR guy can't get in so easily

Reluctance of business people to let go some part of their power

- Maths is a counter-power but it is not your enemy…
- Maths does not really go along with politics ("how can an optimum not be perfect ? What will the boss say ? ")
- Maths is a language of which only the four operations are known and accepted by many managers ("we have to optimize four criteria, lets add them!")
- Key performance indicators, statistics (averages, sometimes regression coefficients) often can't be computed ("I want to adapt to competitors decisions")
- Data mining is often misunderstood as only doing statistics on a data warehouse
- Very important constraints are sometimes not formalized (security, risk, employees objectives)

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Maths can't work on my problem

Absence of faith / trust in mathematics

Sometimes the practitioner feels or knows that his problem is more complex than the usual quadratic equations or linear ODE he used to solve at the University. He has no idea that optimization is not only sorting a list.

Maybe he even tried to *Excel* his problem -- without any success-- on a simplistic instance; or maybe *it was* successful ! (even worse for you when you have to solve a "non-toy problem")

Sometimes he has no clue in algorithmics or combinatorics (only taught to happy few during normal university syllabus)

At last, he thinks that the stochastic features can only be modeled by mean and standard error normal parameters ("random" means "gaussian").

You'll never grasp with few formula 10 years of work !

Impossibility to model the situation

Find a modeling level that enables tractable, useable, understandable results ?
Surprisingly : yes we (often) can !

It might take *a few months* of struggling with :

- first-order and second order effects,
- separation between what is transient and what is permanent,
- a study on data to find the right scale at which important phenomena occur (intra day, intra week or annual seasonality),
- maybe a total change of variables and introducing new concepts in that domain (that come from other domains)

➔ Dynamic programming concepts often help a lot the understanding (not necessarily the computations…)

We can't measure this / We can't manage all this data

- It is generally unknown in areas which are not the usual automatic control domains (typically rocket science, automobile technology, airplane technology, etc.) that *some data can be estimated quite accurately even if you can't measure them*, as long as you can use some "physics of the problem" and some "sensors"

- It is amazing how often Excel sheets tend to show smaller and smaller fonts, get printed on A3 sheets and are not used to *plot* data.

- Simple signal processing methods are widely assumed to be useful only for sound or image, not for revenue data, customer profiles or tariffs. For example, why not use Fourier transform to grasp seasonality effects in sales ?

Lack of computing skills, algorithmics knowledge

➔ Optimizing with multi-criteria is not successive sorting (nor adding them !)

Consider a bunch of flights that could be candidates for cancellation in D-day flight-OPS center.

For each flight, we have the following criteria : total expected revenue, total expected loss due to refunds, probability of being late, lateness impact on other flights, rebooking capability on other flights, number and type of passengers (possibly tagged with one to 5 stars), etc

Sorting with first criterion first, then second, etc., is a greedy nearest neighbor type algorithm and will be very poor… but it will be programmed first, and might be the only implementation.

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Lack of IT skills to produce an application…

… leads to :

- "thank you very much for this very nice study", we are going to purchase a package from the shelf and adapt to it… (a true white lie)

- we met some very bright consultants who are going to "industrialize" your study. (a true nightmare)

- of course, they will simplify the method… but we will keep 80% of the gain, according to the 80%-20% well-known theorem… (a true disaster)

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Beware Stochastics !

- Average, Standard deviation and Scenarios are the only stochastic concepts that are usually accepted by business people.

- Open-loop / Closed loop controls difference are usually unknown (at least with respect to "random" state values)

- Many things can be done with scenarios. It is generally the only entry-point to applications.

- Non-anticipativity constraints (even on a single scenario, the future is not totally known) need to be explained simply and lead to clear implementations.

B/ Very interesting concepts intuitively used by practitioners

1. Bid price : nothing else than a *dual variable* but an extremely powerful business concept [like generally any type of (marginal-) price]

2. Reserve : an insurance against random effects : the minimal version of the "recourse variable" in stochastic recourse problems

3. Water value : a super trick (again a dual value) that enables decomposition with respect to production space

4. Options : flexibility concept for tariffs, but also for business, enables to introduce secondary markets anywhere

B.1/ Airline Revenue management

DATA d(f) demand **for each O&D Point-of-sell fare class**

p(f) network contribution **of a seat sold in class f**

c(s) capacity **on segment s**

∂(s,f) 1 **if** segment s **is included in the path on which** fare f **is available**

VARIABLES x(f) number of seats **made available in each fare class**

CONSTRAINTS

$\forall s, \Sigma\, \partial(s,f)\, x(f) \leq c(s)$ ($A.x \leq c$) **(associated dual variables: b)**
On each segment, we must plan to sell fewer seats than capacity

$\forall f, x(f) \leq d(f)$ **(associated dual variables: w)**
We expect to sell fewer seats than expected demand

Maximize($p^T.x$)
Maximize network revenue

We use dual solutions to control inventories.

- If there is less demand than available seats on a segment, the capacity constraint is not binding in the optimal solution;

➔ We can let any passenger travel on this flight, the « entry » value is 0 and the dual associated with the capacity constraint is 0.

- If there is more demand than seats, the capacity constraint is binding. We must then determine how much we could get out of this seat before letting someone get in.

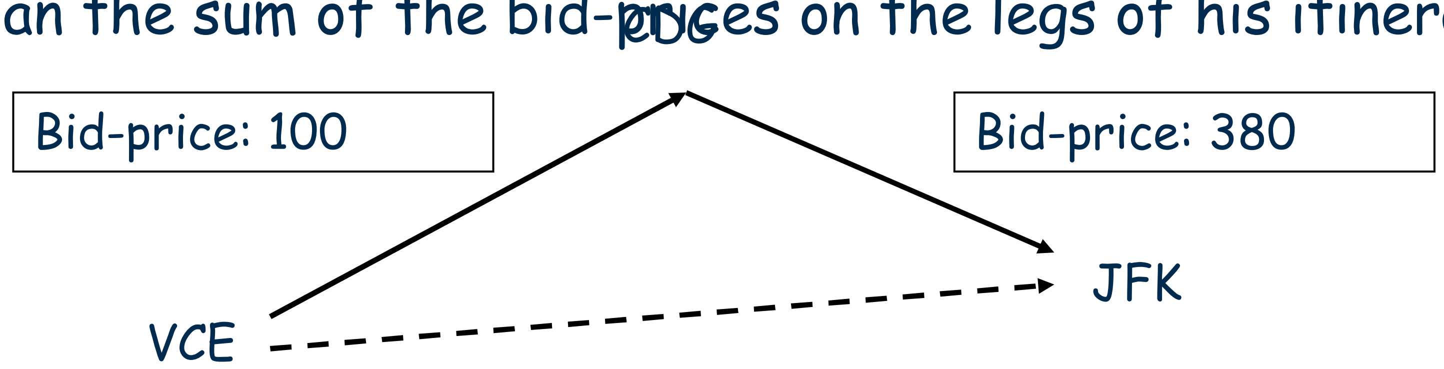
➔ We must set an entry-price. We can use reduced costs information to control passengers entry. We may also use dual information to compute a bid-price.

Bid-price Control

A bid price represent the minimal network value of a seat on a leg.

It is the minimum amount that should be requested to let someone book on that segment, according to expected demand and remaining capacities.

For example, a connecting passenger, will have to pay more than the sum of the bid-prices on the legs of his itinerary.



Fare = 450 < (100+380) : refused
Fare = 490 > (100+380) : accepted

B.2 RESERVE

- The general operations problem is solved on several horizons (time-scales) : long, mid- and short term (or D-day)
- To each time-scale corresponds a specific way of dealing with stochastic events.
- For long-term we work on "typical months, typical weeks, days" ➔ We then solve some "average" deterministic problems to obtain big trends – a very classical approach for sizing problems
- For mid-term, we define « resource reserves » that will enable us to cope with most random perturbations.
- For D-Day, specific procedures are optimized to exploit optimally these reserves.

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A few examples

- Staff sizing (long-term), staff reserves (mid-term and D-day)
- Crew rotations and Plane pairings (long and mid-term), then adaptation (called regulation) until D-3 or irregularities at D
- Investment plan (10-20 years) for plane, scheduling per season (Summer/Winter), tail-numbering (monthly, weekly), reserve computation (mid-term), reserve activation on D-day
- On a much smaller scale : average spaces between tasks (plane pairings, planning tasks, flights, etc.)

Formalization 1: clear link with the recourse problem

- initial problem is : $\min \mathbb{E} f(x, y, \omega), \quad s.t. \quad g(x, y(\omega)) \leq c(\omega)$

- long term (much before event realization, we have some statistic insight of the random data – average, standard deviation, quantiles, etc.
We try to find deterministic parameter X, solution of,

$$\min_x f(x, Y, \Omega), \quad g(x, Y) \leq c(\Omega)$$

with Ω some kind of average (not necessarily an expectation), and Y an average « recourse» (first-order of reserve size)

- mid-term (one month/week before), we have better estimation of Ω, and we improve the solutions : we get X and Y

- short term (we observe or know the random event) ϖ and we look for y such that

$$\min_y f(X, y) \quad s.t. \quad g(X, Y + y) \leq c(\varpi)$$

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Formalization 2: Optimal sizing of reserves

The typical problem is

$$\min \mathrm{E} f(x,[y],\omega) \quad s.t. \quad g(x,y,\omega) \le C$$

With y the recourse or the reserve that enables to « overcome » most bad events.

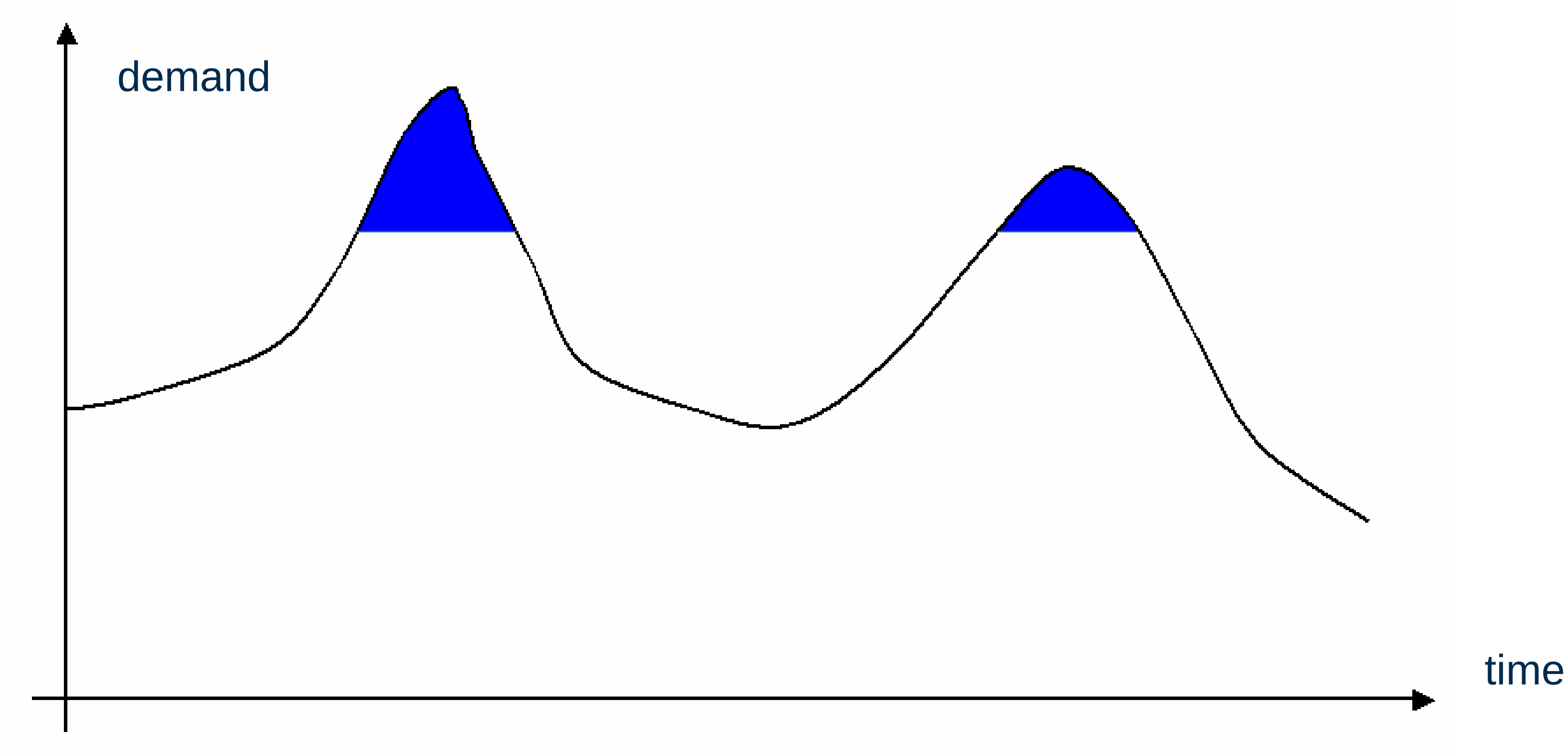
In practice, more intuitively, we often want to solve the following problem

$$\min \mathrm{E} f(x,[y],\omega) \quad s.t. \quad P(g(x,y,\omega) \le C) \ge 1-\varepsilon$$

With P a probability function and ε a very small value.

Mathematically speaking, this is often a difficult problem.

In energy production, water costs nothing but should be used whenever the energy demand is at its maximum.
You can consider it as a « Joker » : you use it when you are in real trouble. This is what makes its value !



Water value in Power production

- At each time period we can decide between using water now or later

- We compare immediate gain versus later gain

- This comes naturally from a dynamic programming model

- This water value is a marginal value obtained as the dual of the water stock constraint in the large power production problem

- Water value is very easy to use in a decentralized way, exactly like Bid-price.

B.4 OPTIONS

New products which are analogous to financial products or to insurance fees (or derivatives)

- the « call » : insure the price of some goods with respect to random occurrences.
- the « put » : retailer exchanges or re-buys the product to some customers
- last-minute upgrades

All these products are in fact "business recourses" against random events.

(See for example the work of Guillermo Gallego)

Thank you !