Analisi dei modelli di programmazione matematica per la gestione ottimale della congestione dello spazio aereo

1 – Literature review.

**Bertsimas and Stock-Patterson 1998**

The paper presents an integer programming model for the ATFM (Air Traffic Flow Managment) that aims to improve system efficiency by minimize the total delay cost across all flights. This work has been used as a basis for model evolution and refinement in several subsequent publications.

**Vossen and Ball 2006 a**

The work formalizes the inter-airline slot exchange procedure (Compression) used in Ground Delay Programs and demonstrates how it corresponds to an appropriately defined optimization model. It also discusses an alternative interpretation of the process, in which the inter-airline slot exchange corresponds to a mediated bartering process.

**Vossen and Ball 2006 b**

Introduces a slot-exchange mechanism that allows the airlines to submit AMAL (at-most, at-least) trade offers. An AMAL offer is of the form (f1, t1; f2, t2), which means that the airline is willing to move flight f1 to a later time period, but no later than t1, in return for moving flight f2 to an earlier time period, but no later than t2.

**Lulli and Odoni 2007**

Presents a deterministic optimization model for the EU ATFM (European Air Traffic Flow Management) problem that can be seen as a “macroscopic version” of the model presented in Bertsimas and Stock-Patterson (1998) in that it omits certain details. The paper points out that the network structure of the EU ATFM (composed of many different national ATM systems) leads to fundamental conflicts between efficiency and equity in the solutions of the model.

**Sherali et al. 2011**

Extends APCDM (airspace planning and collaborative decision-making model) developed by Sherali et. al. (2003,2006) by incorporating in the model the concept of the FCA (flow constrained area) and the AMAL type of slot exchange mechanism (Vossen and Ball 2006 b).

Defines three different equity measures:

* EM1 is from the previous model, considers total fuel and delay cost;
* EM2 considers the total average delay realized per passenger;
* EM3 based on a binary on-time performance index.

**Bertsimas et al. 2011**

This work is based on the model in Bertsimas and Stock-Patterson (1998) and provides a model that allows rerouting, ground holding, airborne holding and speed control.

With respect to the model in Bertsimas and Stock-Patterson (1998) this model presents the formulation of rerouting decisions in a more compact way that doesn’t require any additional variables but only introduces some additional constraints.

The objective function has super-linear cost coefficients to increase equity in the delays distribution among flights.

The APCDM model presented in Sherali et al. (2003,2006) is defined as a

complementary model since its scope is far more local, but the level of detail in flight trajectory representation and planning far greater.

**Barnhart et al. 2012**

This work is based on the model in Bertsimas and Stock-Patterson (1998) and develops a fairness metric that measures the schedule fairness with reference to the FSFS (first-scheduled, first-served) ordering. Introduces two different optimization approaches of the trade-off between fairness (measured with the defined metric) and efficiency (based on the total system delay). The first uses as fairness term a convex approximation of the defined metric. The second introduces an exponentially growing delay penalty to enforce fairness and has considerable computational advantages yet sacrifices little in terms of fairness achieved.

**Bertsimas and Gupta 2016**

The model presented in this work is an adaptation of the Bertsimas and Stock-Patterson (1998) model that incorporates fairness considerations by generalizing the RBS principle and controlling the number of reversals and total amount of overtaking. It introduces the possibility for companies to submit AMAL (at-most, at-least) slot exchange offers (Vossen and Ball 2006 b, Sherali et al., 2011).

The objective function of the model is an adapted version of the one used in Bertsimas et al. (2011).

2 – Comparison with UDPP

**UDPP**

UDPP (user driven prioritization process) uses the mechanism called SFP (selective flight protection) which uses slot swapping and departure reordering techniques.

The core of the algorithm is to suspend some flight thus earning Operating Credits (OC). These credits can be re-allocated/re-distributed to minimize the delay of other flight. The number of fights that the operator can prioritize depends on the severity of system congestion and on his amount of credits.

This approach is different from what can be found in literature.

**Barnard et al. 2012**

The model defined in Barnhart et al. (2012) does not include the possibility for companies to make slot exchange offers, so from this point of view it is far from the central idea of UDPP.

There are two main models that incorporate the concept of slot exchange offers submitted by the companies. One is derived from the ATFM model presented in Bertsimas and Stock-Patterson (1998) and one from the APCDM introduced in Sherali et. al. (2003,2006). Both models implement the slot exchange offers mechanism by adopting the AMAL structure proposed in Vossen and Ball (2006).

**Vossen Ball 2006a**

The model proposed to formalize the Compression procedure for the slot exchange has specific constrains to ensure that each not cancelled flight can’t be assigned to an arrival slot after the arrival slot from the given initial assignment. The UDPP idea of suspension of a flight with its slot moved to the end of the hotspot is therefore not modellable with this model.

The model is equivalent to a greedy procedure that minimize the total delay like the compression procedure but dominates the solution produced by compression in that the greedy solution gave a greater benefit in exchange for a cancelled flight. The UDPP model rewards airlines with credits for flight suspension and not for cancellation.

The cost coefficients of the objective function minimize the total delay but don’t take account for any type of cost delay.

**Vossen Ball 2006b**

AMAL type of exchange in the form of one flight for one flight is more restrictive than the UDPP model. For example, an airline with three flights in the hotspot can directly manage only two of them. In UDPP the only limitation is the number of credits owned by the airlines. Another issue is that by rewarding the suspension of a flight with a reduction of the delay of another flight there isn’t any kind of reward for an airline that is willing to suspend its only flight in the hotspot. The same kind of issue reappears when an airline would like to protect a flight that is the only flight owned by the airline in that hotspot or when the airline is not willing to penalize any of the other flight it owns. The UDPP model, with the introduction of the credits and the single protection or suspension of a flight, allow the airlines to manage these situations.

**Bertsimas et al. 2011**

In the model the AMAL offers are modelled with directed arch in the connected exchange graph where the nodes represent the slots, a variable x(f, p) is associated with each arc and corresponds to a proposed flight plan (f, p) for a flight f. The fisible slot swap are in the form of directed cycles and a specific set of constraints ensure that the trades prompted by the selected circuits satisfy the AMAL-type trade restrictions, a delay-reducing move cannot by itself compensate for more than one delay increasing move. This structure leads to the limitation discussed above and intrinsically linked to nature of the structure of AMAL offers.

**Bertsimas and Gupta 2016**

The model has a two-stage approach, the result of the first stage is an assignment that minimize the number of reversals and total amount of overtaking. In the second stage, given this assignment from the first stage, the airlines can submit their slot exchange offers. The offers are in the form of the AMAL offers, this lead to the same considerations previously made on the AMAL structure. A key feature of the model is the use of reversals and overtakings, but this imply the introduction of variations from the FPFS schedule without any active participation from the airlines. In UDPP reversals can occur only if accepted by the involved airlines.

3 – Conclusions

The idea of slot exchange with the airlines collaboration has been implemented in different models. What makes different the UDPP model is the introduction of the new mechanisms of the assignment of the operating credits and the single protection or suspension of a flight, this give more flexibility to the airlines and allow them to increase control over their flights and to improve their internal objective functions.

Barnhart, C., Bertsimas, D., Caramanis, C., & Fearing, D. (2012). Equitable and efficient coordination in traffic flow management. Transportation Science, 46(2), 262-280.

Bertsimas, D., Gupta, S. (2016). Fairness and collaboration in network air traffic flow management: an optimization approach. Transportation Science, 50(1), 57-76.

Bertsimas, D., Lulli, G., Odoni, A. (2011). An integer optimization approach to large-scale air traffic flow management. Operations research, 59(1), 211-227.

Bertsimas, D., Stock-Patterson, S. (1998). The air traffic flow management problem with enroute capacities. Operations research, 46(3), 406-422.

A. Cook, G. Tanner, R. Jovanovic, A. Lawes, The cost of delay to air transport in Europe - quantification and management, 13th Air Transport Research Society (ATRS) World Conference, 27-30 June 2009, Abu Dhabi, United Arab Emirates, Paper No. 107

Lulli, G., A. Odoni. 2007. The European air traffic flow management problem. Transportation Sci. 41(4) 431–443.

Sherali, H. D., Hill, J. M., McCrea, M. V., Trani, A. A. (2011). Integrating slot exchange, safety, capacity, and equity mechanisms within an airspace flow program. Transportation science, 45(2), 271-284.

Vossen, T., Ball. M. O. (2006) a. Optimization and mediated bartering models for ground delay programs. Naval Research Logistics 53(1) 75–90.

Vossen, T., M. O. Ball. (2006) b. Slot trading opportunities in collaborative ground delay programs. Transportation Sci. 40(1) 29–43.