E.02.33-SATURN-D0.10 Final Project Report

Document information	
Project Title	SATURN
Project Number	E.02.33
Project Manager	Università degli Studi di Trieste
Deliverable Name	Final Project Report
Deliverable ID	D0.10
Edition	01.01.00
Template Version	03.00.00

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Abstract

The final report of the SATURN project provides a publishable summary of the results. In addition it lists all deliverables, dissemination activities, eligible costs, deviations, bills and lessons learned.

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Document History

Edition	Date	Status	Author	Justification
01.00.00	20/12/2015	Release	[redacted]	New document for review by EUROCONTROL
01.01.00	15/02/2016	Release		Review comments addressed

Intellectual Property Rights (foreground)

This deliverable consists of SJU foreground.

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Publishable Summary

Introduction to the project and problem statement

The objective of the SATURN (Strategic Allocation of Traffic Using Redistribution in the Network) project is to make novel and credible use of market-based demand-management mechanisms to redistribute air traffic in the European airspace.

The project is motivated by frequent demand and capacity imbalances in the European airspace network, which are forecast to continue in the near future. The present and foreseen ways of dealing with such imbalances mainly concern strategic and tactical capacity-side interventions, such as re-sectorisation and opening of more sectors to deal with excess demand. These are followed by tactical demand management measures, if needed. As a result, not only do substantial costs arise, but airspace users (AUs) are also typically left with no choice but to comply with imposed air traffic flow management measures.

The project shows how economic mechanisms could be applied involving AUs and air navigation service providers (ANSPs) to improve capacity-demand balancing, and capacity usage.

Explanation of approach and methodology

Approach. European ANSPs finance their operations through air navigation service (ANS) charges, according to EC Regulation 391/2013. ANS charges are composed of en-route and terminal charges, for the respective portions of the flight. They play a pivotal role in the economics of the European air traffic management (ATM) industry as they represent 76% and 14% of the ANSPs' revenues, respectively. ANS charges are a non-negligible operational cost (sometimes higher than 10%) for AUs, especially when fuel costs are low. For these reasons, understanding how much AUs' route choices depend on ANS charges, en-route charges in particular, and to what extent the charges could then be used as an effective tool to balance demand and capacity is of great importance. Currently, the en-route charges depend on the distance flown in the airspace of a state, on the weight of the aircraft and on a unit rate set by each state (annually). Article 16 of EC Regulation 391/2013 allows the use of modulation of charges for dealing with congestion. Thus, Member States and hence, ANSPs, are given the opportunity to use pricing as an instrument to reduce recurring congestion problems. SATURN explores different ways of pricing that can be applied.

Methodology. First, a simplified set of criteria for classification of pricing techniques across network industries, specifically data transmission networks, electricity generation, distribution and retail, road, air and rail transport was compiled. This classification framework was then used to choose pricing mechanisms that may be adapted to the European air traffic system, and to propose a set of performance areas and indicators for their comparative evaluation. Three pricing mechanisms were chosen: peak-load pricing, rewarding predictability and a tradable flight permit system (these are described in more detail later).

All chosen mechanisms were tested on the entire European airspace for one of the busiest days of 2014 that was not unduly disrupted by unusual events. Additional tests were performed on a regional scale, exhibiting extremely challenging en-route demand/capacity imbalances. Computations used algorithms specifically designed for this purpose during the course of the project. The implementation of a geographic bespoke database for manipulation of the Demand Data Repository (DDR2) data proved to be a decisive factor for the success of the project. All mechanisms compared the *solution* scenario (with pricing applied) against an *ad hoc baseline* scenario, which represented how airlines would schedule and route their flights in a strategic setting (i.e., months ahead of the day of operations). The proposed mechanisms were refined using feedback from two stakeholder workshops involving more than 100 delegates from airlines, airports, ANSPs, regulators, consultants and research organisations, and from consultations with two major European ANSPs.

Highlights and key results

SATURN explores pure and hybrid pricing mechanisms, aimed at redistributing air traffic in Europe when the expected demand exceeds the nominal capacities of sectors and/or airports. Two pure ('peak-load pricing' and 'rewarding predictability') and one hybrid ('tradable flight permit system') pricing mechanisms are studied.

Peak-load pricing (PLP). PLP employs a variation of charges with regard to time and location of consumption, i.e., PLP assigns a higher rate where and when a peak in demand is expected, and a lower rate for off-peak areas and times. Thus, a part of the peak demand is redistributed to cheaper options. SATURN first focuses on a centralised approach to PLP (CPLP) where a central planner (CP) is responsible for setting en-route charges in the network and AUs assess the routing of each flight. Set en-route charges should guarantee that ANSPs are able to recover their operational costs, and AUs perform their flights avoiding demand-capacity imbalances. As in the current charging system, in CPLP AUs react to en-route charges (which are decided by the central planner instead of ANSPs) by choosing alternative and cheaper routes. The relationship between the CP and the AUs is modelled as a Stackelberg game where a leader (CP) makes its decision first, with complete knowledge of how the follower(s) (AUs) would react. The equilibrium is obtained by means of an optimisation problem, where the CP sets, for each ANSP, one peak and one off-peak en-route charge modulation and the AUs make their routing choice. Under a decentralised PLP policy, instead, each ANSP is in charge of setting rates in the network it controls and has little or no influence on the actions of neighbouring ANSPs. AUs respond to the pricing policies of the ANSPs by choosing a routing option that minimises their operating and navigation costs, as under the centralised PLP policy.

Rewarding predictability (RP). The idea behind the RP mechanism is to give AUs incentives to reduce uncertainties imposed on the CP / ANSPs by filing their flight intentions earlier and adhering to them as much as possible. Apart from employing the peak-load pricing rationale, such a charging system rewards earlier filing of flight intentions, since such user behaviour improves predictability for the CP / ANSPs and might thus improve the performance of the network as a whole. The RP mechanism employs the concept of inter-temporal pricing for the first time in ATM applications. Inter-temporal pricing uses time of service purchase as an additional basis for price variation (on top of the already employed time of use and location of use). Predictability in this context relates primarily to a reduction of uncertainty concerning the amount of resources (staff etc.) needed by ANSPs to manage the traffic at a targeted level of service.

Tradable flight permit system (TFPS). To complement pure pricing, SATURN developed the TFPS pricing mechanism that encompasses non-monetary features (hybrid pricing). TFPS uses time-place specific permits and consists of two distinct steps: a permit distribution and a permit exchange market. Permit distribution can be seen as a non-monetary traffic assignment problem, resulting in initial flight plans that respect strategic (declared) airspace capacities by re-distributing traffic in excess through the shifting of departure/arrival times and/or assignment of a different route. The assigned permit sets can then be traded (for money) through a centralised market mechanism, offering additional flexibility and the possibility of further flight cost reductions for airlines.

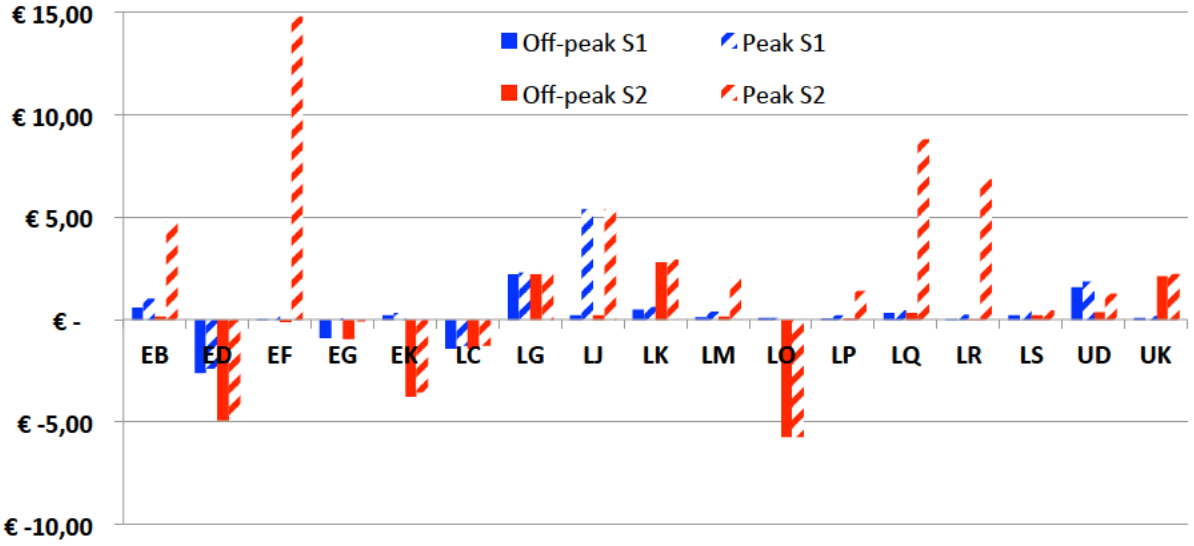

Figure 1. Peak and off-peak rates for selected ANSPs

Key results. All of the studied mechanisms re-distribute traffic (strategically) while respecting declared capacity constraints and imposing ANSP revenue neutrality. Interestingly, these results can be achieved through a limited number of shifted flights, in time and/or space, and of unit rate variations w.r.t. current unit rates. Figure 1 shows route charge variations for two different CPLP solutions (S1 and S2), for selected ANSPs. An effect of traffic redistribution is shown in Figure 2 (route 4, baseline; route 5, after modulation, solution S1).

Currently, declared airspace capacity is not enforced unless the flow manager activates a regulation. For example, on the test day, there were 131 regulations, a third of which were due to ATC capacity. In these cases, the declared sector capacity was imposed by regulations, creating a substantial delay to affected flights (9616 minutes, a third of total ATM delay on that day). About 9% of sector-periods were heavily loaded (>90% utilisation).

The percentage of heavily loaded sector-periods is around 5% across the various SATURN mechanisms. Even though these two levels of sector utilisation (5% vs 9%) cannot be directly compared, they indicate that strategic traffic distribution, in any of the mechanisms studied by SATURN, has a potential for decreasing tactically assigned delays due to ATC capacity. Taking into account that rough cost of one minute of delay is around 100€ according to European airline delay costs by Cook and Tanner (2015), decrease of tactical ATC capacity delay can result in significant savings for AUs.

Figure 2. Example of traffic redistribution

Future steps based on the outcomes of the project

While the SATURN project gives strategic insight in terms of network management, charging mechanisms and incentives, and ANSP regulation, the consortium is fully aware of the need of further work to draw robust conclusions and inform EC policy relating to the Single European Sky (Table 1).

Future consideration	Major benefit accrued to state of the art
Consideration of *flexible* capacity provision	Extends the scope of the model and could also be linked to evaluating cost-efficiency, quality of service and other SES Performance Scheme target impacts (including related changes to planned capital expenditure by ANSPs); could also include extending the integrity of the ANSP cost functions to include fixed and variable components
Alignment with 4D trajectory provision	Purchasers of tactical trajectories are l kely to seek compensation if the route is not flyable due to weather, in which case a system of compensatory credits might be incorporated into a wider European model, deploying disturbance models already used by the SATURN team

Enhanced pricing flexibility	More rates applied than simpler peak and off-peak, thus enabling the research team to explore enhanced pricing solutions
Using AU's originally-filed flight plans	Using originally-filed flight plan data available from EUROCONTROL's Integrated Initial Flight Plan Processing System (IFPS) would further improve the modelling of the true AU strategic demand and correspondingly reduce the dependency on the observed tactical situation
Extending AU route choices	Better modelling of AU route options and choice determinants (e.g. through interviews and factor analysis) would allow better representation of demand options
Including estimates of AU elasticities	Such elasticities could reflect AU responsiveness strategically and tactically to route extension / delay costs c.f. total route charges
Including an estimate of AU's tactical delay costs	Improves the extent of the full benefits accrued through improved demand management; could also be explored in terms of user equity
Incorporating AU's *network* impacts into KPIs deployed	Would allow a more comprehensive assessment of impacts such as the 'arrival shift', through network effects dependent on passenger and crew connectivities, turnaround buffers and airport slot availabilities

Table 1 - SATURN's future considerations

Conclusion

This study shows that pricing is a viable option to redistribute traffic in the European air traffic network. In particular, the modulation of en-route charges, as advocated by EC Regulation 391/2013, may produce changes in AUs' operational costs that may incentivise airlines to reroute some flights, or to request different departure times, to avoid expensive areas or to take advantage of reduced charges. The focus is on influencing future traffic patterns, not on tactical actions on the day of operations (see, e.g., the current increase in traffic over Belgium and the Netherlands most likely due to the 2015 unit rate increase in Germany). SATURN's real-size model capabilities (tested on the entire European network) allow for further studies, such as the quantification of benefits of a centralised planner compared with those of decentralised maximisation of self-interests (by the ANSPs and/or AUs) or the definition of a mechanism to influence the capacity offer to better match demand.

SATURN has major policy implications as it proposes a methodology that quantifies the impact of certain modulations of charges on AUs' costs, route choices, Network Management, charging mechanisms, incentives and ANSPs' regulations. However, the implementation of any SATURN mechanism would require some changes to the current system, such as the strategic filing of flight routes, which is in line with the future developments of SESAR (i.e. shared business trajectories).

1 Introduction

1.1 Purpose of the document

The purpose of this document is to:

- Summarise the technical results and conclusions of the project (Publishable Summary);
- Provide a complete overview of all deliverables;
- Provide a complete overview of all dissemination activities (past and in progress). Where appropriate, provide feedback from presentations. Describe exploitation plans.
- Provide a complete overview of the billing status, eligible costs, planned and actual effort (incl. an explanation of the discrepancies).
- Analyse the lessons learnt at project level.

1.2 Intended readership

The target audience of this document comprises:

- EUROCONTROL and SJU, in order to provide them with a comprehensive view of the project results, both from a technical and administrative point of view.
- Research community and aviation stakeholders concerned with an interest in strategic and pre-tactical planning in Air Traffic Management (Publishable Summary), in order to provide them with an overall view of the main results and conclusions of the project.

This document is intended for readers with good knowledge of air transport and Air Traffic Management.

1.3 Inputs from other projects

N/A

1.4 Glossary of terms

Term	Definition
ANS	Air Navigation Services
ANSP	Air Navigation Service Provider
ATM	Air traffic management
AU	Airspace User
CP	Central Planner
CPLP	Centralized Peak-Load Pricing
DDR2	Demand Data Repository (second phase)
EC	European Commission
IFPS	Integrated Initial Flight Plan Processing System
KPI	Key Performance Indicator
PLP	Peak-Load Pricing

Term	Definition
RP	Rewarding Predictability
SATURN	Strategic Allocation of Traffic Under Redistribution in the Network
SES	Single European Sky
TFPS	Tradable Flight Permit System

2 Technical Project Deliverables

Number	Title	Short Description	Approval status
D1.1	Data Management (main report)	As there are multiple challenges in collecting and processing the data SATURN's mechanisms and models require, D1.1 identifies the main sources of such data that have been used by the models and provides numerous detailed examples to explain key concepts and project-developed bespoke capabilities.	Approved
D1.2	Data Management (update report)	Building upon the earlier data management report D1.1, D1.2 provides an update of data management activities that run throughout the project.	Approved
D2.1	Future airspace congestion - a users' discussion guide	Since the objective of SATURN is to propose and test realistic ways to use market-based, demand-management mechanisms to redistribute air traffic in the European airspace, D2.1 presents a review of the literature on mechanisms, current policy goals, instruments available for their application, and possible future policy goals, from the point of view of their impact on the project. It also includes a review of passenger fare elasticities and introduces a number of pricing scenarios and candidate mechanisms for capacity redistribution. Finally, this deliverable describes the design and processes of a dedicated workshop (eventually held in London, 20 March 2014) where stakeholders reviewed the whole SATURN's approach.	Approved
D3.1	Pricing mechanisms	D3.1 presents the set of strategic pricing mechanisms for demand-capacity balancing. Four research avenues are pursued, branching into five centralised and two decentralised pricing mechanisms. A comprehensive assessment framework is introduced, which has facilitated the demonstration of the validity of designed mechanisms.	Approved
D4.1	WP4 interim deliverable	D4.1 focuses on the mathematical and numerical modelling of centralised and deterministic pure pricing mechanisms. The mathematical formulations of the optimisation models underlying three mechanisms and the algorithmic description on another mechanism are explained in detail. The proposed mechanisms are numerically tested on various regional instances, each of which having been extracted from historical air traffic data in Europe.	Approved
D4.2	Pure Pricing Mechanisms	Building upon D4.1, D4.2 focuses on pure pricing mechanisms. The mathematical formulation of the optimisation model underlying one mechanism (peak-load pricing) and the algorithmic description of another mechanism (rewarding predictability) are both explained in detail. Variant of the mechanisms are also presented that are decentralised or stochastic. The proposed mechanisms are numerically tested on various large-scale instances, which have been extracted from historical air traffic data in Europe. The mechanisms behaviour is studied and compared, and	Submitted

		future steps toward further development are described.	
D5.1	WP5 interim deliverable	D5.1 focuses on hybrid pricing mechanisms. The mathematical formulation of two optimisation models is discussed in detail. The proposed models are tested on a set of seven problem instances, each considering a day's worth of air traffic in Europe from a week in November 2013. Different performance indicators are studied for the solutions found.	Approved
D5.2	Hybrid Pricing Mechanisms	Building upon D5.1, D5.2 describes a hybrid pricing mechanism termed Tradable Flight Permit System. The mechanism consists of two phases: initial permit endowment and the exchange market, each of which is formulated as an optimisation model. The mathematical formulation of two models is presented in detail. The proposed models are tested on a set of instances, each considering a day's worth of air traffic in Europe. Different aspects of the models are analysed, and the future steps to be taken towards the further development of the mechanism are indicated.	Submitted
D6.1	SIDs 2013 Contribution	D6.1 includes a poster and a teaser with general information about the project	Approved
D6.2	Communication and Dissemination Report	D6.2 summarises the SATURN project's targeted communication and dissemination activities up to the project mid-point, between two London stakeholder consultation workshops (20MAR14 and 21APR15). These current and planned activities have been reported in the quarterly progress reports. This document also updates the information and provides further details.	Approved
D6.3	SIDs 2014 contribution	D6.3 consists in the paper *Better pricing strategies for ATM?* (see ref. [1])	Approved
D6.4	SIDs 2015 contribution	D6.4 consisted in the papers • *Modulation of En-route Charges to Redistribute Traffic in the European Airspace* (see ref. [3]) • *Efficiency vs. Flexibility in ATM: Can Pricing Help?* (see ref. [9])	Approved
D6.5	Final Report (Dissemination)	D6.5 gives an overview of the main mechanisms designed and implemented during the course of the project and presents the key findings. The purpose is to clearly demonstrate the success of SATURN's novel approaches to reduce demand-capacity imbalances and save airspace users operational costs. In fact, this study shows that pricing is a viable option to redistribute traffic in the European air network and quantifies the trade-offs between system, ANSP and airspace user requirements.	Submitted

Table 2 - List of Project Deliverables

3 Dissemination Activities

3.1 Presentations/publications at ATM conferences/journals

3.1.1 Presentations (and associated publications) at ATM conferences

1. L. Castelli, T. Bolić, S. Costanzo, D. Rigonat, É. Marcotte, G. Tanner (2015). “Modulation of En-route Charges to Redistribute Traffic in the European Airspace”. Schaefer, Dirk (Editor) Proceedings of the SESAR Innovation Days (2015) EUROCONTROL. ISSN 0770-1268, Bologna, Italy, 1-3 December 2015.

   Abstract Peak-load pricing (PLP), a two-tariffs charging scheme commonly used in public transport and utilities, is tested on the European Air Traffic Management system as a means for reducing capacity-demand imbalances. In particular, a centralised approach to PLP (CPLP) where a Central Planner (CP) sets en-route charges on the network is presented. CPLP consists of two phases: in the first, congested airspace sectors and their peak and off-peak hours are identified; in the second, CP assesses and sets en-route charges in order to reduce overall shift on the network. Such charges should guarantee that Air Navigation Service Providers (ANSPs) are able to recover their operational costs while inducing the Airspace Users (AUs) to route their flights in a way that respects airspace capacity. The interaction between CP and AUs is modelled as a Stackelberg game and formulated by means of bilevel linear programming. Two heuristic approaches, based on Coordinate-wise Descent and Genetic Algorithms are implemented to solve the CPLP model on a data set obtained from historical data for an entire day of traffic on European airspace. Results show that significant improvements in traffic distribution in terms of shift and sector load can be achieved through this simple en-route charges modulation scheme.

2. R. Jovanović, O. Babić, M. Živanović, V. Tošić (2015). “Efficiency vs. Flexibility in ATM: Can Pricing Help?” Schaefer, Dirk (Editor) Proceedings of the SESAR Innovation Days (2015) EUROCONTROL. ISSN 0770-1268. Bologna, Italy, 1-3 December 2015.

   Abstract Driven by a number of uncertainties an appreciable share of airspace users (AU) look for “last-minute” 4D route choice gains, and thus exercise a fairly late submission of flight plans. Orders of magnitude of such gains, from AUs’ perspective, are in the range of tens or hundreds of Euros per flight. However, such AU behaviour amplifies uncertainty imposed on air navigation service providers (ANSP) and network manager (NM), which is difficult to be managed cost-efficiently. Due to lower traffic load predictability, ANSPs tend to declare more conservative sector capacities, which effectively means that additional sectors need to be open sooner (at lower traffic loads) than if predictability was better. Against such a background, this paper revisits and extends the “Rewarding Predictability” (RP) mechanism, introduced in [7]. The original idea of the RP is to design a pricing scheme which incentivises AUs to reduce uncertainties imposed on ANSPs and CP, so that they file their flight intentions earlier and stick with them as much as possible, aiming at improved network performance. In this paper, a stochastic module is incorporated into the RP mechanism, concerning route choice process, in line with recent findings presented in [6]. This arguably more realistic representation of AUs’ behaviour allows us to more credibly discuss the efficiency vs. flexibility trade-offs involved and the comparative performance of various route allocation methods in addressing those.

3. L. Delgado (2015) "European route choice determinants - examining fuel and route charge trade-offs", 11th USA/Europe Air Traffic Management Research and Development Seminar (ATM2015), Lisbon, Portugal, 23-26 June 2015.

   Abstract Different charging zones are found within European airspace. This allows airlines to select different routes between origin and destination that have different lengths and en-route charges. There is a trade-off between the shortest available route and other routes that might have different charges. This paper analyses the routes submitted by airlines to be operated on a given day and compares the associated costs of operating those routes with the shortest available at the time, in terms of en-route charges and fuel consumption. The flights are characterised by different variables with the idea of identifying a behaviour or pattern based on the airline or flight characteristics. Results show that in some areas of the European airspace there might be an incentive to select a longer route, leading to both a lower charge and a lower total cost. However, more variables need to be considered and other techniques used, such as factor analysis, to be able to identify the behaviour within an airline category.

4. R. Jovanović, O. Babić, V. Tošić (2015) "Pricing to reconcile predictability, efficiency and equity in ATM", 11th USA/Europe Air Traffic Management Research and Development Seminar (ATM2015), Lisbon, Portugal, 23-26 June 2015.

Abstract Driven by a number of uncertainties a considerable share of airspace users (AU) look for "last-minute" 4D route choice gains, and thus exercise a fairly late submission of flight plans. While orders of magnitude of such gains, from AUs' perspective, are in the range of tens or hundreds of euros per flight, such AUs' behaviour creates uncertainty which is difficult to manage cost-efficiently from the air navigation service providers' and network manager's perspective. Due to low traffic load predictability, ANS providers tend to declare more conservative sector capacities, which effectively means that additional sectors need to be open sooner (at lower traffic loads) than if predictability was better. Against such a background, the distinguishing idea of the proposed approach is to design a pricing scheme which incentivises AUs to reduce such uncertainties by filing their flight intentions earlier and sticking with them as much as possible, aiming at improved network performance. In a centralised environment a coordinated network pricing approach is employed. This paper exposes a conceptual "Rewarding Predictability" (RP) model. The obtained results are contrasted against the outcomes of both current flow management practice ("F scenario") as well as against those of Ad-hoc modulations method, proposed in [8]. The three methods involve notably different approaches to dealing with intrinsic efficiency vs. equity trade-offs.

5. T. Bolić, D. Rigonat, L. Castelli, R. Jovanović, A. Cook, G. Tanner (2014) "Better pricing strategies for ATM?", Schaefer, Dirk (Editor) Proceedings of the SESAR Innovation Days (2014) EUROCONTROL. ISBN 978-2-87497-077-1, Madrid, Spain, 25-27 November 2014.

Abstract Objectives of this paper are: briefly examine solutions applied in other network industries and based on that, set the policy and pricing context for development of market-based mechanisms for strategic air traffic re-distribution to avoid congestion, which is a main goal of SATURN project. Further, focus on current and possible future ATM pricing policy goals, by summarising current practice in Europe and introducing two possible future scenarios developed within the project. The implementation plan is outlined, discussing both the modelling challenges and the parallel consultation and validation processes. We conclude with a short look ahead.

6. L. Corolli, T. Bolić, L. Castelli, D. Rigonat (2014) "Tradable Mobility Permits for the Strategic Allocation of Air Traffic", 6th International Conference on Research in Air Transportation (ICRAT), Istanbul, Turkey, 26-30 May 2014.

Abstract Current strategic decisions involving air traffic flows are limited to the allocation of airport slots. In this work, a first strategic market-based mechanism for the allocation of en route resources, i.e., sector capacity, is proposed. Identifying en route capacity shortages at this phase can lead to strategic actions to reduce flight delays on the day of operations. Tradable mobility permits previously developed for roadway transportation are analyzed and adapted to the air transport case. A trading mechanism for the strategic alleviation of air traffic congestion that uses time-place specific permits is proposed, providing alternative implementations. We call this new approach Tradable Flight Permit System (TFPS). An example of its use is illustrated, showing how it can lead to cost reductions for the airlines competing for a single sector access permit. We also highlight the improvements it can provide compared to current practice and a variety of alternative methods.

7. D. Rigonat, L. Castelli (2014) "Pricing techniques for the European airspace", 6th International Conference on Research in Air Transportation (ICRAT), Istanbul, Turkey, 26-30 May 2014.

Abstract The present work lays down the roadmap for a Ph.D. research on methods for redistributing traffic demand through pricing policies in European airspace. First, the authors introduce a classification framework for pricing schemes in network industries. The framework is then applied for identifying relevant characteristics that a pricing scheme for European airspace should have. Finally, some guidelines are drawn on which pricing approaches in other industries may be suitable for each of the delineated configurations.

3.1.2 Presentations at ATM workshops

8. L. Castelli (2015) "Strategic traffic assignment and pricing". Presentation at the 2nd SATURN Workshop, London, UK, 21 April 2015.

9. R. Jovanović (2015) "Rewarding predictability", Presentation at the 2nd SATURN Workshop, London, UK, 21 April 2015.

10. T. Bolić (2015) "Better Pricing Strategies for Air Traffic Management". Presentation at "Roundtable on ATC and Research", EUROCONTROL HQ, Brussels, 24 March 2015.

A roundtable on what are the main policy issues in ATC and to which extent additional reform is needed. Discussion addressed, inter alia, how to direct research to get a better understanding of the policy issues and propose relevant recommendations to policy makers and how to organize research on ATC policy issues and options going forward. Hans-Martin Niemeier mediated the roundtable discussion. Other speakers included:

- Reform of ATC in Europe, US and Canada: An overview from a policy point of view. Xavier Fron, Eurocontrol
- Cost Benefit Analysis Approaches used in Eurocontrol. Paula Leal de Matos, Eurocontrol

11. L. Castelli (2014) "Airspace demand management – an introduction to the SATURN project". Presentation at the 1st SATURN Workshop, London, UK, 20 March 2014.

3.2 Presentations/publications at other conferences/journals

3.2.1 Presentations at other conferences

12. T. Bolić, L. Castelli, D. Rigonat "Peak-load pricing for the European Air Traffic Management system", presented at (for the abstract, see item 15 below):
    - 12th Aviation Student Research Workshop, Amsterdam, The Netherlands, 5-6 June 2015.
    - 18th EURO Working Group on Transportation, Delft, The Netherlands, 14-16 July 2015.
13. É. Marcotte, M. Labbé (2015) "Efficient use of Airspace through Monetary Incentives" 22nd International Symposium on Mathematical Programming, Pittsburgh, PA, 12-17 July 2015.

    Abstract We consider the problem of alleviating congestion in the European airspace through the modulation of the service charges imposed by the Air Navigation Service Providers on the airspace users. This is a bilevel optimization problem which can be formulated using a mixed integer programming representation, which we present. A heuristic based on Variable Neighborhood Descent is introduced to obtain approximate solutions of this model on real-life instances, which are often too large to be solved using linear programming techniques.

14. L. Corolli, T. Bolić, L. Castelli, D. Rigonat (2015) "A Mechanism for the Strategic Reduction of Air Traffic Congestion", INFORMS Annual Meeting, Philadelphia, PA, 1-4 November 2015.

    Abstract En route congestion is currently detected on the day of operation of flights. We develop a new strategic mechanism based on integer optimization that seeks to prevent en route congestion through an early redistribution of air traffic. The mechanism assigns flights departure and arrival times and routes, based on airline requests. The benefit of using this mechanism is shown on a real instance with 30.000 European flights that is solved in short computation times.

3.2.2 Publications at other journals

15. T. Bolić, L. Castelli, D. Rigonat "Peak-load pricing for the European Air Traffic Management system". *Under review*.

    Abstract This paper extends the use of peak-load pricing (PLP) to the context of the European Air Traffic Management system, as EU regulation No 391/2013 allows the modulation of en-route charges to avoid network congestion in a specific area or on a specific route at specific times. In particular, we propose a centralised approach to PLP (CPLP) where a Central Planner (CP) is responsible for setting en-route charges on the network and Airspace Users (AUs) assess the routing of each flight. Set en-route charges should guarantee that air navigation service providers (ANSPs) are able to recover their operational costs, and that AUs perform their flights avoiding imbalances between demand and available airspace capacity. Like in the current charging system, in CPLP AUs react to en-route charges (which are imposed by CP instead of ANSPs) by choosing alternative and cheaper routes. Hence, we model this relationship between the CP and the AUs as a Stackelberg game where a leader (CP) makes his decision first, with complete knowledge on how the follower(s) (AUs) would react to it. The Stackelberg equilibrium is obtained by means of an optimisation problem formulated as a bilevel linear programming model, where the CP sets, for each ANSP, one peak and one off-peak en-route charge and the AUs make their routing choice. Preliminary results on real data instances on a regional scale are presented.

16. L. Corolli, T. Bolić, L. Castelli, D. Rigonat "Initial Endowment of permits for the strategic mitigation of en route congestion". *Under review*.

Abstract Currently, the evaluation of en route congestion is performed on the day of operation of flights, sometimes resulting in costly delays. To reduce these tactical delays we develop a new strategic mechanism alleviating demand and capacity imbalances through an early redistribution of air traffic in space and time. Here, we show that an adaptation of Tradable Mobility Permits for road transport can be used to define such a strategic mechanism, and we apply it to the European air traffic system. In particular, we focus on the key step of this permit allocation scheme: permit endowment. We assume that permits are endowed for free, i.e., airlines do not have to pay to receive them. Permit endowment is performed through a linear optimization model that takes fairness issues into account. Two alternative objective functions for the model are proposed: minimization of the strategic shift assigned to requested flight times, and minimization of flight operational costs. Computational results based on historical flight data assess the impact of the proposed mechanism on tactical delays and flight costs. Results show that this mechanism may reduce tactical delays, up to 13%. Furthermore, the use of the minimum flight cost objective function can lead to the reduction of costs by around 2%.

3.3 Web presence

The project website launched in February 2014 to provide information about the project, event announcements, contact details and assist disseminate public deliverables, papers and other documentation produced by SATURN.

- www.saturn-sesar.eu (hosted by University of Trieste)

Two stakeholder consultation workshops have been organised – the first considered the design of SATURN mechanisms (Future demand management for Europe - meeting the airport and airspace challenges, jointly organised with the WP-E ACCESS project, 20 March 2014), whilst the initial model results were central to the second event (Future demand management for Europe - meeting the airspace challenges, 21 April 2015). Both workshops were supported by a web presence, initially to make material publically available in advance whilst helping promote the events. All workshop material remains available online.

- http://home.wmin.ac.uk/airspace/workshop_20MAR14.htm (hosted by University of Westminster)
- https://sites.google.com/a/my.westminster.ac.uk/atm-workshop (managed by University of Westminster)

3.4 Demonstrations

N/A

3.5 Exploitation plans

3.5.1 Università degli Studi di Trieste

The participation of UNITS in SATURN has already provided various benefits, which are expected to be enhanced in the near future.

At the scientific level, UNITS has significantly contributed to the development of peak-load pricing and hybrid pricing mechanisms. This has given to UNITS' research group a solid knowledge of potentialities and limitations of available air traffic data. Furthermore, since all mathematical models and solving algorithms have been formulated and implemented in-house, UNITS owns a tool that is capable to quantitatively simulate the behaviour of the air traffic demand, and its impact in terms of strategic network management, with respect to, *inter alia*, changes in airspace capacities, air navigation service charges, and any other operational cost. Furthermore, results from the hybrid pricing approach will benefit other on-going research activities on the management of demand-capacity imbalances, like the User Driven Prioritisation Process, in which UNITS is already involved. Various scientific publications are expected to be produced out of SATURN's findings.

At the policy level, the results of SATURN are the basis to draw robust conclusions and inform EC policy-makers on the role that economic interventions may play in the Single European Sky framework, notably to improve capacity-demand balancing, and airspace design and usage.

Finally, the participation in SATURN has allowed UNITS' research group to enhance its expertise in the air transport and ATM sector and build a number of links with different stakeholders, which will be certainly exploited for launching other research projects in the field.

3.5.2 Université Libre de Bruxelles

Participation in the SATURN project introduced a new field of applications for which ULB had limited prior experience. As such, the SATURN project led to a better understanding of the applicability of various optimisation techniques on the large-scale problems encountered in ATM. In particular, the heuristic methods developed by ULB for the peak-load pricing mechanisms are very likely to also be useful for other research problems of similar structure and scopes, especially in the domain of transportation research. In fact, the pure-pricing model developed for the SATURN project deserves additional theoretical and algorithmic attention. Due to the short duration of SATURN, it was only possible to develop a heuristic for the full-scale system. While this method gives very good results, there is still a wide field of investigation that has been opened by the SATURN project. Furthermore, the data collected and tested in SATURN will be of great interest in the future since they will constitute real data benchmarks on which it will be possible to test new methods and compare them to the heuristic developed.

Participating in the SATURN project also allowed ULB to make contact with both fellow researchers and stakeholders in the ATM field. Together with a much improved understanding of the airspace network and of the available data, this will allow ULB to tackle ATM research problems that it would not have been able to successfully and accurately study otherwise. Therefore, ULB is now much more apt at initiating new research projects in the field of airspace management than it was before joining the SATURN project.

3.5.3 University of Belgrade - Faculty of Transport and Traffic Engineering

The participation of UB-FTTE in SATURN, as a continuation of our previous efforts in the field of economic-based air traffic demand management, has contributed to deepening our comprehension of viability of pricing options for alleviating congestion in the European airspace network, not least in terms of improved understanding of (often confronted) positions of various stakeholders involved. This was particularly facilitated by two SATURN stakeholder consultation workshops, taking place in London, as well as by attending the Network Manager User Forum (Brussels, January 2015), with a number of useful links established with relevant airspace users' representatives, ANSPs, flight plan service providers, etc.

At the scientific level, inspired and helped by aforementioned better understanding of various stakeholders' objectives, UB-FTTE developed the rewarding predictability (RP) mechanism, aiming at a workable balance between flexibility for airspace users and predictability for ANSPs and the central planner. The mechanism was tested on different large-scale instances, including cases of both relatively mild and severe en-route demand/capacity imbalances. Given the inherent dynamism of the phenomenon of demand/capacity imbalances in the European network, tests conducted on qualitatively different instances can in turn contribute to providing a more reliable estimate of the benefits which could ultimately be expected from ATM pricing options acting solely on the demand side. Further extensions could, inter alia, incorporate the new findings concerning airline route choice determinants, as discussed in section 3.5.4 below. Various scientific publications are expected to be produced out of SATURN's findings.

3.5.4 University of Westminster

Our supporting analyses of airline route choice determinants, examining the trade-offs between the shortest available route and other routes that might have different charges (e.g. for fuel, crew, and maintenance costs) have produced interesting results. In some areas of the European airspace there might be an incentive to select a longer route, leading to both a lower charge and a lower total cost. During the SATURN project, we have also discovered that originally-filed flight plan data are available

from EUROCONTROL's Integrated Initial Flight Plan Processing System (IFPS). Furthering our modelling in this area would give better insights into true AU strategic demand and correspondingly reduce the dependency on the observed tactical data. Modelling of AU route options and choice determinants (through interviews and factor analysis of such data) would allow better representation of demand options, and help to build better forecasts for ANSPs, which are currently very limited and not sufficiently sensitive to route charges and fuel prices, inter alia. This further exploitation could directly feed into ANSP planning for the SES Performance Scheme Reference Period 3 and would preferably include estimates of AU cost elasticities.

4 Total Eligible Costs

Date	Deliverables on Bill	Contribution for Effort	Contribution for Other Costs (specify)	Status
22/04/2014	D0, D0.1, D0.2, D0.3, D2.1. D6.1	€ 63.126,30	€ 12.392,87	Paid
04/12/2014	D0.4, D0.5, D1.1, D3.1, D4.1, D5.1, D6.2	€ 206.697,42	€ 2.196,86	Paid
15/07/2015	D0.6, D0.7, D0.8, D1.2, D6.3	€ 47.185,33	€ 9.666,55	Paid
February 2016	D0.9, D10, D4.2, D5.2, D6.4, D6.5	€ 245.807,12 (TBC)	€ 6.922,55 (TBC)	To be billed upon approval of deliverables
GRAND TOTAL		€ 562.816,17 (TBC)	€ 31.178,83 (TBC)	

Table 3 - Overview of Billing

Company	Planned man-days	Actual man-days	Total Cost	Total Contribution	Reason for Deviation
UNITS	824	948 (TBC)	€ 192.000,00 (TBC)	€ 173.491,99 (TBC)	Much larger-than-expected effort for data analysis and elaboration, and for developing a multi-objective genetic algorithm as an alternative to exact methods that turned out to be unfit to satisfactorily address one busy day of traffic over Europe.
ULB	580	567	€ 140.251,24	€ 137.380,00	
UB-FTTE	290	286	€ 137.650,22	€ 137.650,22	
UoW	207	301	€ 212.000,00	€ 145.472,79	The organisation of the first stakeholder consultation workshop and pre-/post-event liaison with approximately 100 delegates (plus other interested parties) required substantially more effort than planned. Over the course of the project, WP0 Management and the Data Management component of WP1 have taken additional effort.
GRAND TOTAL	1911	2102 (TBC)	€ 681.901,46 (TBC)	€ 593.995,00 (TBC)	

Table 4 - Overview of Effort and Costs per project participant

Note: The effort and cost figures corresponding to the last invoicing period are not yet definitive, as the costs associated to the Project Close-out Meeting are not yet available.

5 Project Lessons Learnt

What worked well?
Partners' diversified background and their continuous commitment in all the research and dissemination activities are the key factors for the successful achievement of this project. The consortium gathers expertise in the knowledge and understanding of the European ATM system and airlines' behaviour, along with mathematical and computational capabilities to formulate the required models, implement the solving algorithms and manage large amounts of air traffic data.
The proposed research methodologies were found to be extremely appropriate to model interactions between central planner / ANSPs and airspace users in the various pricing mechanisms.
Despite the partners being based in multiple European locations, remote from each other, they collaborated very well together using on-line tools for deliverable preparation, data assessment, model development and project planning.
Feedback from stakeholders at the workshops organised was candid and instructive.
The Project Officer was supportive and flexible regarding appropriate planning and timescale changes and helped to keep the administrative burden down.
What should be improved?
Despite good access to EUROCONTROL data, on-line support/documentation remains very limited, extensive cleaning is required, and some fields are not fully reliable.
It might be useful if SESAR / EUROCONTROL could coordinate the purchase of key external (non-EUROCONTROL) data and licences for multiple project use, to save unilateral efforts from projects (often needing the same type of data).
Considerable effort has been devoted from all partners in developing and implementing sophisticated and detailed mathematical models, and in a meticulous analysis and management of available data to support modelling assumptions. As a consequence, perhaps relatively too much time is generally invested in writing long deliverables to keep a comprehensive track of the work performed. Since limited and rather non-technical feedback was received - SJU expert consultation process (deliverable review) did not work well -, it might be useful to limit deliverable number and length and put more emphasis on concise, technical progress reporting.
Insufficient budget was estimated at the proposal stage for organising the stakeholder workshops, which consumed vastly more effort than allocated.
Substantial additional effort (in time, budget, and data availability) is needed to extend current results (mainly valid for a centralised and deterministic approach) to decentralised and/or non-deterministic settings, and to widen the project's scope to include the impact of pricing policies on tactical flight planning measures to alleviate capacity-demand imbalances.

Table 5 - Project Lessons Learnt

6 References

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