Better Pricing Strategies for ATM?

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***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.**

Keywords-market-based mechanisms; pricing; ATM; pricing environment; centralised scenario; decentralised scenario.

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I. INTRODUCTION

A. *The challenges of congestion*

At the current rate of growth, EUROCONTROL estimates that air traffic in Europe is likely to increase by 50% in the next 20 years [1]. Today, demand-capacity imbalances are an issue for several airports and area control centres (ACCs), despite numerous initiatives to mitigate this problem.

In Europe, the provision of air navigation services (ANS) is paid through the route charges that represent the remuneration for the costs of en-route ANS provision, including EUROCONTROL costs, applying a harmonised route charging system in the EUROCONTROL area. The common system for billing and collection of route charges is operated by the EUROCONTROL's Central Route Charging Office (CRCO).

Signatory states of the Single European Sky (SES) agreement, set unit rates based on recovery of *a priori* determined costs for given 'reference' periods within their en-route charging zone (the so-called 'determined' cost system). The other nine EUROCONTROL states base their unit rates on a full cost recovery system.

Currently, demand-capacity imbalances are mainly managed through strategic and tactical capacity-side interventions, followed by tactical demand management measures where needed (mostly air traffic flow (and capacity) management – ATF(C)M – slot delays). Not only are substantial costs thus imposed on airspace users [2], often coupled with unfair effects of capacity allocation methods, but users are also typically left with no choice but to comply with the imposed solutions.

B. *Objectives of this paper*

Effective use of already available resources is a less costly alternative to infrastructure capacity expansion. The current regulatory setting [3] allows the modulation of route charges in order to deal with airspace congestion. This is one way of applying market-based demand management [4, 5]. Other mechanisms include, but are not limited to, tradable permits, and yield management. All these principles are already known in various forms to the air transport industry at large, although not yet to the management of air traffic demand-capacity imbalances *per se*.

In this context, the objective of the WP-E SATURN (Strategic Allocation of Traffic Using Redistribution in the Network) project is to propose and test realistic ways to use market-based demand-management mechanisms to redistribute air traffic in the European airspace. The project is exploring centralised and decentralised, deterministic and non-deterministic, pure and 'hybrid' pricing mechanisms to alleviate demand-capacity imbalances. Before summarising the objectives of this paper, we make some basic definitions.

- *Operational environment* – an operational framework for ATM (including who controls the pricing), the system's objectives / policy goals (e.g. with respect to cost recovery and congestion), and the regulatory setting;
- *Pricing* (framework) – type and modulation (if any) of the tariffs, how the prices are set strategically and collected tactically;
- *Scenario* – combined context of the environment and pricing (usually refers to a *future case*);
- *Mechanism* – protocol (set of rules) for implementing a scenario (more than one mechanism may be effected within a given scenario).

Figure 1 below depicts the relations between the terms defined above. The upper part of the figure shows operational

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environments. Operational environment is not something we control, but it is our choice of probable future operational environments. The choices are rather high-level and take into account only the control and the pricing strategy objectives. Turning to the bottom part of the figure, shown mechanisms result in the pricing framework. Pricing framework and operational environment are input to, or better to say they define a given scenario. The scenarios are further developed in mathematical models. It is important to note that a given mechanism could result in more than one pricing framework. On the same note, the same pricing framework could be input in more than one scenario.

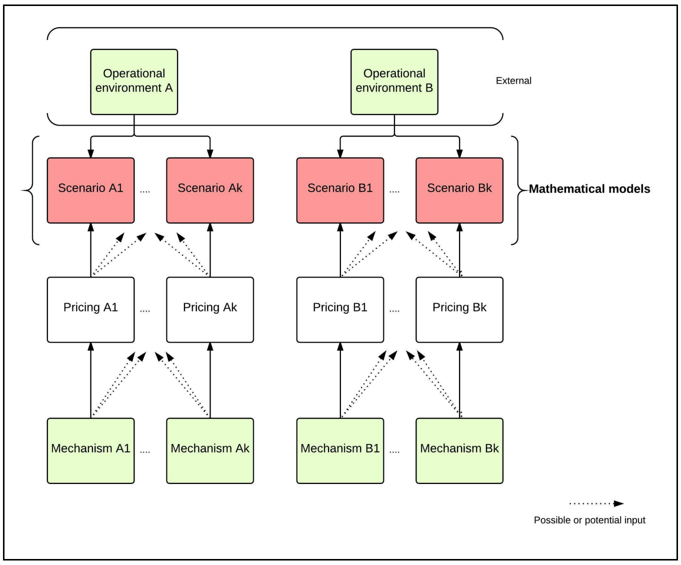

Figure 1. Relations between operational environments, scenarios, pricing and mechanisms.

The objectives of this paper are to first set the policy and pricing context in Section II, briefly examining solutions applied in other settings, before focusing on ATM policy goals. In Section III, current practice in Europe is summarised before *two scenarios* are presented in some detail, which we intend to investigate in SATURN. Section IV outlines the implementation plan, discussing both the modelling challenges and the parallel consultation and validation processes. The paper concludes with a look ahead in Section V.

It is to be emphasised that SATURN addresses the post-SESAR situation, e.g. with respect to a 2030 time horizon – that is, solutions that may be implemented in the longer term. We are thus not constrained by current operational limitations or the policy climate.

II. POLICY AND PRICING CONTEXTS

A. *Network pricing mechanisms*[1]

The market in network industries is generally composed of an infrastructure manager/owner (who may also act as a regulator), one or more service providers, and the consumers. This structure is similar to the theoretical model of a monopolistic market.

Congestion in a network occurs whenever one or more links or nodes are tasked to carry more flow than they are able to accommodate. As a consequence, the quality of service deteriorates, leading to various disadvantages for the users, such as: delays, increases in transport costs and, ultimately, denial of service.

In general, users are willing to minimise their cost for using the network (in terms of time and money) and congestion generates externalities. Marginal cost pricing is usually regarded as the way to internalise the cost of congestion. A negative externality (referred to as ‘user externality’), results from the difference between the marginal social cost and the marginal private cost. In network industries, the ‘first-best’ pricing principle states that a toll equal to the user’s externality (a Pigovian tax) should be charged on each link in order to obtain the optimal network traffic-flow configuration [6].

However, estimating marginal costs for actual implementation is, in general, difficult. The required information includes consumers’ price elasticities and cross-price elasticities. Nevertheless, consumers are usually very reluctant to (directly) reveal their willingness to pay. If marginal costs are considered only in the short term, they do not cover the costs of upgrading the infrastructure, for example.

So-called ‘second-best’ pricing regimes are thus generally preferred for pricing in real networks. One example is Ramsey pricing (RP), the aim of which is to maximise social welfare under the constraint of deficit coverage. RP relies on the fact that the service can be differentiated across the area of the network, time, and customers’ needs. This is difficult to implement since it also relies on marginal cost information.

Peak load pricing, commonly applied in utilities and public transport, is a simplified case of RP. Users are charged for marginal and capacity costs in an environment where demand peaks, and consequently capacity shortages, are easy to predict. The resulting pricing scheme is usually differentiated by off-peak, peak and (sometimes) shoulder periods.

Fully distributed cost regimes take marginal costs as a starting point and cover the economic deficit by allocating the remaining costs proportionally (e.g. by considering users’ utilisation, revenues, or the marginal costs themselves). This approach ignores demand elasticities and delivers lower theoretical revenues than RP.

Congestion charges are common in urban transport contexts, for example. It is often argued that they tend to penalise users with lower income. Hence, several non-monetary pricing schemes have been proposed in order to grant equal rights to all users. These schemes, in general, initially endow freely the credits or travel permits that are then used for travel in peak times. The equity issue is thus transferred to the initial endowment of credits or permits among users. An overview of non-monetary pricing schemes for road transport can be found in [7]. We used the

[1] This section presents a brief summary of the work undertaken so far in SATURN exploring numerous pricing theories. (We will subsequently publish other works on this topic in greater detail, drawing on the project deliverables.)

classifications proposed in [8] and [9] to build a simplified set of criteria for categorising pricing techniques across network industries, specifically data transmission networks, electricity generation, distribution and retail, road, air and rail transport, with the goal to determine which of the techniques are adaptable and applicable for air traffic management. Table I, shown in [10], details the classification criteria included in the pricing framework. (All options per criterion are mutually exclusive, with the exception of criterion 8.)

TABLE I. PRICING FRAMEWORK

Criterion	Options
Operational environment-related	
1. Control	a. Centralised; b. Distributed administrative; b. Market-based; c. Market-based with a regulator
2. Pricing strategy objective	a. Revenue/cost oriented; b. Resource consumption oriented; c. Both 2(a) and 2(b)
Pricing-related	
3. Type of tariff	a. Flat: a fixed fee gives unrestricted access to the network
	b. First-best: based on exact marginal costs i.e., users pay proportionally to the load they impose to the network
	c. Second-best: not based on exact marginal costs, i.e., average tariff for all users
	d. Multi-part: any combination of 3(a)-(c)
4. Modulation of the tariff	a. Time and space invariant: the network is tariffed in the same way all the time
	b. Time-dependent, space invariant: prices can vary according to time
	c. Time-invariant, space dependent: prices can vary according to location in the network
	d. Time and space dependent: the network is tariffed according to location and time
5. Users classification	a. No differentiation: all users are equal
	b. Users are differentiated, e.g. by classes
6. Price setting strategy	a. Customer-perceived value: willingness to pay determines the price
	b. Resource-estimated value
	c. Both 6(a) and 6(b)
7. Payment	a. Monetary
	b. Non-monetary: e.g. credits or permits
	c. Hybrid monetary/non-monetary
8. Quality of service	a.i. Best effort; a.ii. Guaranteed service; a.iii. Variable
	b. Capped service, e.g. capacity-constrained
	c. Compensation for service denial

The first two criteria of the pricing framework describe the network industry's operational environment in which the pricing technique, or pricing mechanism is applied. Other criteria are pricing-related. First pricing criterion (3) is related to the Type of tariff applied in the network: flat, first-best, second-best or the multipart, which is the combination of the previous types. The Modulation of the tariff classifies different methods that can be applied for tariff modulation.

It is important to see how the network users are treated. Are they all equal, or a differentiation of users in different classes is applied (criterion 5)? Price setting strategy criteria describes the scheme behind the price setting for network use: customer willingness to pay, resource estimated value, or the mix of both schemes.

Payment of the use of network resources can be monetary (most common), non-monetary (i.e. credits or permits), or a hybrid. Each pricing-related method is linked with a certain quality of service provided to the network users. Such levels of service could be broadly categorised as: best effort; guaranteed (minimum) service; variable; capped service (capacity cap); or, compensation for service denial. Quality of service is often reflected through performance metrics and key performance indicators (KPIs), as we will pick up again in Section IV(B).

B. ATM policy goals

Building on initiatives in the late 1990s, proposals were formed to create a Single European Sky (SES), to reform the architecture of European Air Traffic Control, to meet future capacity and safety needs. The SES is designed to remove national boundaries in the air, i.e. to create a single airspace, and to bring about: (i) improving safety tenfold; (ii) tripling airspace capacity; (iii) reducing air traffic management costs by 50%; (iv) reducing the environmental impact of each flight by 10%.

In 2004, the Single European Sky I (SES I) package was adopted, with the launch of the technological programme, SESAR, in 2007, to enable the envisioned objectives. A second SES package (SES II), adopted in 2009, brought additional tools to drive performance and expedite the desired reform of the European ATM system: a revised approach to stimulate integrated service provision, a process of target-setting for performance objectives and the establishment of the Network Manager (NM) to coordinate actions at the European network level [11]. Two inter-related implementing regulations stem from these efforts, and are already in effect (partially): IR 390/2013, laying down a performance scheme for air navigation services and network functions, and IR391/2013 laying down a common charging scheme for air navigation services. Performance scheme introduces the feature of incentives that are aimed at all stakeholders, with the goal to better the overall performance of ANS provision. Coupled with that, the charging scheme allows the creation of charging zones that are different from the current State zones, and offers a possibility of modulation of route charges to deal with the capacity shortage in the peak-demand periods.

The European ATM Master Plan describes "the agreed roadmap connecting research and development with the deployment within the SES technological pillar" [12] thus delineating the intended improvements to be brought about through SESAR deployment. The Plan describes four implementation phases: the deployment baseline, Step1, Step 2, and Step3. Each of the steps foresees improvements building on the previous steps.

The goal of these changes is thus to increase capacity and safety, and to reduce emissions and the cost of provision of services. However, an assessment of the impact of various pricing strategies in different environments is still notable by its absence. This underlines the need to consider and evaluate appropriate pricing frameworks, to which we turn our attention in the next section.

III. Current and future ATM strategies

Here, we apply the pricing framework of Table 1 to describe the current European ATC setting and to introduce two possible future scenarios (a term defined in Section I(B)), to be explored in SATURN. Several others are also under consideration, the characteristics of which we will briefly mention in Section III(B). As mentioned in the introduction, SATURN addresses the post-SESAR situation – i.e. solutions that may be implemented in the longer term. We are thus not constrained by current operational limitations or policy.

A. Current pricing scheme in Europe

Currently, EUROCONTROL's CRCO is responsible for collecting en-route charges and redistributing them to national air navigation service providers (ANSPs) in European airspace. Charge setting was outlined in Section I(A). From the economic point of view, the current environment is a monopolistic competition, where competitors (ANSPs) are differentiated on a location basis (country boundaries) and competitors' pricing policies are not taken into account.

Current pricing scheme – key features

Operational environment

1.(b). Decentralised control (distributed administrative): unit rates are *formally* set by the ANSPs and collected by CRCO. So, effectively, ANSPs provide an input in terms of their determined costs, and have hardly any other impact on the setting of unit rates. It is also to be noted that the SES performance scheme has established compulsory cost-efficiency targets, which, in turn, effectively drive unit rates.

2(a). Objective of cost recovery: en-route charges are collected to recover operational costs of national ANSPs for ANS services. Linked to binding performance targets.

Pricing

3(c). Consumption-proportional: yearly adjusted unit rates;

4(c). Space dependent and time independent: unit rates vary by country (although EU Reg. 391/2013 Art. 16 allows national unit rate modulation and alignment among countries belonging to the same Functional Airspace Block [5]);

5(a). No differentiation among customers: all airlines are equal;

6(b). Prices are set according to resource value: cost of ANS services;

7(a). Monetary payment;

8(a) and (b). Guaranteed service, capped by ATC sector capacity by imposing ATF(C)M delays (applied on the day of operation).

The current pricing scheme of European airspace, is conceptually similar to distance-based pricing (road transport) [6] and simple charges (rail transport in many states) [13]. Edge pricing in telecommunications [14] also shares similar concepts, with the notable difference of usually being location-independent.

B. Exploring future scenarios

SATURN is exploring several future scenarios and possible pricing mechanisms, ranging from pure pricing to "hybrid" ones. Here we present two scenarios: centralised and decentralised one, along with key features of two pure pricing mechanisms. We then further discuss other relevant aspects of pricing strategies for ATM that are being investigated in SATURN.

1) Centralised tariff control

This scenario represents an operational environment where prices are set and controlled by a central authority whose objectives are cost recovery of ANS expenses and reduction of network congestion, through the optimisation of *network performance* – primarily from *capacity*, *environment* and *cost-efficiency* perspective, with no deterioration of *safety*. Network congestion being an operational problem inducing costly delays in the system, which are likely unevenly distributed thus jeopardising the *equity* in the system. This scenario represents a monopolistic environment having a central planner, ANSPs as operators and airlines as customers; this configuration is similar to that of rail transport in most European countries.

Centralised tariff control – key features

Operational environment

1(a). Centralised control: tariff modulation is set and applied by the central planner;

2(c). Objective of cost recovery & congestion reduction.

Pricing

3(c). Tariff is proportional to sector capacity; a second-best charging scheme is plausible;

4(d). Modulation of tariff is space and time dependent, where modulated tariff is assigned to each sector-period, where period can be, e.g. 30 or 60 minutes. The modulation is chosen to reach desired network equilibrium conditions, reflecting resource scarcity;

5(a). Equity is a priority; hence, user classes among airlines are not welcome;

6(b). Prices are set according to resource value: cost of capacity provision;

7(a). Payment is monetary;

8(a) and (b). Guaranteed service, capped by ATC sector capacity (this could be applied before the day of operation).

This is a centralised "optimal-mix" tolling scenario, where the central planner is setting tariff modulation on the whole network, with the goal to balance the demand with available capacities and, ultimately, optimise the network performance. "Optimal-mix" tolls are originally defined as those designed to encourage a fixed number of users to allocate themselves along the routes available to them so as to minimise total cost of travel [15]. The tariff modulation is set for each sector-period, based on the demand. When filed traffic load for some network segments is likely to exceed their declared capacity during certain periods, the central planner modulates ANS charges to alleviate the upcoming capacity problem. By assigning positive or negative tolls (revenue neutral in sum) against users' original route filings, the planner provides incentives for them to accept alternative routings. Thus, the planner takes advantage of available network capacities, and consequently maximises network performance. Network performance to be optimised, can be quantified as a vector of several key performance areas/indicators: capacity (reducing en-route ATFM delays), environment (seeking most direct routes) and cost-efficiency (minimising the cost of capacity provision). [16] These performance areas are a part of the current SES performance scheme. Airspace Users (AUs) respond to the pricing policies (tariffs) by choosing a routing option that minimises their operating and route charges costs.

2) Decentralised tariff control

In this scenario each ANSP is setting its own en-route tariffs - peak and off-peak, fixed to recover operational costs and reduce congestion within its own airspace. The ANSPs are acting independently. The central planner has a limited role (e.g., acting as a regulator in disputes between ANSPs).

The main objective of this scenario is to reduce the load on the network by redistributing traffic in a balanced way, and to reduce the amount of delay on the network, by decisions on local level. Local level can be either ANSPs or Functional Airspace Blocks (FABs). This is basically decentralised peak load pricing scenario, where each ANSP or FAB is setting tariffs on the subset of the network it controls, with the goal to balance the demand with the available capacity. The ANSP/FAB sets the peak and off-peak tariffs based on the traffic demand over time. ANSPs/FABs have no influence on the actions of neighbouring ANSPs./FABs Airspace Users respond to the pricing policies (tariffs) of the ANSPs/FABs by choosing a routing option that minimises their operating and navigation costs.

Decentralised scenario has some characteristics that are worth noting. The principle that allowing users to minimise their individual delays does not lead to a solution where the global network delay is minimised holds here as well, although on a regional scale. Optimising on regions of the network independently also does not lead to a system-level optimum. Therefore, this scenario cannot result in the system-optimum solution.

Decentralised tariff control – key features

Operational environment

1(d). Market-based control with a regulator: each ANSP is responsible for setting its own tariffs, the regulator applies them and acts in disputes between ANSPs.

2(c). Objective of cost recovery & congestion reduction: each ANSP is responsible for its own airspace.

Pricing

3(c). Proportional to travelled distance, yearly adjusted rates. This is the off-peak tariff;

4(b) and/or (d). The peak tariff is set for the peak periods, and/or network segments;

5(a). Equity is a priority; hence, user classes among airlines are not welcome;

6(b). Prices are set according to resource value: cost of ANS services in peak and off-peak periods;

7(a). Payment is monetary;

8(a) and (b) Guaranteed service, capped by ATC sector capacity.

Furthermore, the level of knowledge each ANSP/FAB has on other ANSPs'/FABs' actions and policies and the degree of collaboration and/or competition between neighbouring ANSPs/FABs are not specifically addressed within the described scenario, as we assume that ANSPs/FABs act independently. However, since ANSPs/FABs set peak and off-peak tariffs influenced by both operational costs and users' route choices while having no direct influence in setting other ANSPs' pricing strategies, such a configuration represents, in fact, a competition with no information sharing. Which would be the case in the current setting, if the ANSPs would start applying peak load pricing.

3) Further pricing options

The two scenarios we presented here are pure pricing scenarios, mainly exploiting the modulation of charges. Modulated charges presented here, are a possible pricing instrument, already available under the current regulation IR391/2013 [5]. The modulation could be applied at national or FAB level, the objective of which is to deal with the capacity shortage in the peak-demand periods.

More liberal pricing options can be thought of, aligned with the assumed role of the central planner and the foreseeable evolution of the ATM system. For instance, the application of the yield management techniques to the ATM. The main yield management task is the capacity management through an appropriate pricing strategy. In general, as the resource is consumed and time gets closer to its expiry date (i.e. for a flight, the scheduled departure date, after which no more tickets can be sold) the value of the residual capacity increases and, in order to maximise revenues, prices should reflect that. As discussed in [17] European airspace shares most features of markets where yield management is successfully applied. An example of a simple yield management policy could be applied to the sector capacity as the resource to be optimally allocated. Then, the airspace congestion is the negative externality coming from this allocation. Applying the yield management, the price for transit is increased after each accepted request to reflect the cost of the added congestion.

As another example of more liberal pricing options, prices could be trajectory-based, i.e. attached to routes, rather than to airspace volumes (as today). Trajectory-based pricing would be more in line with the forthcoming trajectory-based paradigm of operations.

Hybrid mechanisms are an option too, where a mix of non-monetary and monetary options could be applied. For example, the cap-and-trade logic using the tradable mobility permits can be applied [18]. The permits can be distributed based on available capacity onto a known demand. The distributed permits can then be traded, if an airline wishes to obtain a better solution, which could be preferred routing, or giving up a preferred routing in return for compensation.

Equity of all such measures is a key consideration. Interestingly, neither equity, nor related notions such as "equality" or "fairness" are explicitly addressed in current EC high-level policy statements. "Equity of access" is mentioned in passing in [19]. Mentions closest to equity include "access(ibility)" and "mobility" [20].

However, a number of concepts are at hand for an equitable air traffic assignment. Firstly, one might establish "equality of outcome" as a principle [21]. Here users who save time, for example those assigned premium 4D routes, should pay higher charges and those who spend more time, (users re-routed in space and/or time) should be paid by those causing their delay (or "displacement"). It is thus a delay versus "tolls" trade-off. Effectively, this means a willingness-to-pay principle on the "high end", and a "congestion damages" mechanism [22] on the "low end", where displaced users are partly compensated in monetary terms for their displacement. One of the results of the SATURN stakeholder consultation is the notion that the airlines would not be adverse to paying premium charges to get the premium service (e.g. priority and no delay in the case of bad weather), and thus offering a guaranteed service to premium customers.

Another equity preservation option can be a *system with memory* over certain time horizon. Practically, this means taking account of broader perspective (e.g. by treating an airline as a user, rather than each flight individually). One would hereby try to make sure that all users (airlines) are treated as far as possible in an equitable manner over a chosen time horizon (e.g. peak period, a day, a week). Therefore, for example, an airline being assigned a "suboptimal" (less preferred) route for one of its flights would get some of its other flights "prioritised" as a compensation.

IV. Implementation of the SATURN models

A. *Towards model deployment*

The two described scenarios, as well as other scenarios, the characteristics of which were mentioned in the previous section, are currently being developed into mathematical models. All models share the same basic pricing rationale: charges are adjusted (by central planner and by ANSPs in the centralised and decentralised case, respectively) based on time and location of service consumption (resource use), in order to reach desired network equilibrium conditions.

This equilibrium is usually reached through a bilevel optimisation approach [23] aiming to reconcile the perspectives of the network (system) as a whole and of network users. Preliminary studies relying on bilevel optimisation have already shown the appropriateness of such an approach to represent the interactions between ANSPs and airspace users [24]. The key assumptions shared by all mechanisms are listed below:

- Fixed demand matrix, that is, fixed number of flights between any airport pair in the network. The intention of the proposed pricing mechanisms is not to scale down the total demand but to modify its spatial/temporal pattern to bring it in line with available capacities.
- Infrastructure capacity constraints are known in advance, in terms of pre-defined airspace sectorisation and maximum number of aircraft which can enter each network segment (sector) per given period of time.
- The finite set of possible (reasonable) 4D trajectories for each system client, meaning that a flight can only be "assigned" a 4D route from a pre-defined finite set of possible 4D routes. A 4D trajectory is a combination of a departure time and a physical route to be flown. Practically, one might interpret such an assumption in a following way: the set of possible 4D trajectories for each flight may consist of a "primary" trajectory (preferred by the carrier) and "reserve" trajectories, in case that the original one is unattainable for whichever reason. One could conceive a system in which carriers would submit more than one 4D trajectory during flight plan submission, linking to the notion of Alternate User Preferred Trajectories, as introduced in [25], or Ranked 4D Trajectory, as introduced in [26] that is, they could themselves propose a few alternatives to their preferred trajectory, in case it becomes unattainable. It should thus be noted that the mechanisms also allow for routes that accrue some ground delay from the very beginning (meaning that two flight alternatives can differ solely in temporal dimension).
- Users are rational decision makers aiming at minimising their operational costs. A deterministic approach is employed, assuming perfect users' knowledge regarding route attributes (path choice). Therefore, it is assumed that carriers inevitably choose the cheapest 4D trajectory available.
- Revenue neutrality is established as a desired principle, meaning that the adjustment of tariffs is not to generate

profit or deficit for ANS, but to recover the cost of ANS provision.

- Sector-period based tariffs. Since sector represents a primary operational component of airspace structure and can be considered an elementary component of ATM system, the capacity violations (i.e. the excess demand) are tackled by setting tariffs that vary both per sector and per time period.
- Heterogeneous demand in terms of different aircraft types. Flights using different aircraft types will have different costs and consequently different sensitivities to imposed sector-period tariffs.

The models are to be tested through computational experimentations on small- to large-scale instances (up to tens of thousands of flights) on regional and finally European scale. Performance of different pricing mechanisms, in terms of the validation plan introduced in Section IV(B), will be assessed relying on the same input instances, based on real data. The impact of SATURN strategic choices on tactical flight decisions will be assessed through the CASA algorithm, currently used by the Network Manager to allocate Air Traffic Flow Management slots in case of congestion on the tactical level. The assessment will rely on the ISA/CASA algorithm available in the NEST software provided by EUROCONTROL.

B. Consultation and validation

As mentioned in Section II(A), quality of service is often reflected through general performance metrics and KPIs. In order to demonstrate the validity of the designed mechanisms, a quantitative assessment framework has been developed. This framework comprises new indicators and established indicators that are aligned with the EU Performance Scheme (second reference period) and SESAR Performance Targets [27, 28]. (Note that safety is out of scope in SATURN.) As shown in Table II, this set of indicators will measure environmental, cost-efficiency, capacity, punctuality/predictability and cost performance (cost of delay values will be furnished by updates made to [29]). Where possible, network-level values will be obtained from independent sources (primarily EUROCONTROL) for the above indicators for 2014, or reasonable estimations thereof will be made from external data.

Fully developed models will be implemented on the traffic data of the chosen baseline days (2014). The implementation of the model will result in traffic distribution, and costs (as an example of an indicator) different from the current/baseline ones, as a particular mechanism and its instruments are applied through the model. The presented indicators will be calculated for the baseline (chosen days in 2014), and for each fully developed scenario/model. Therefore, the baseline, and each model will be described by a set of indicators that demonstrate the integrity of the model and/or mechanism, the difference between the model results and the baseline, and the differences between different models. It will be interesting to analyse how diverse market-based mechanisms impact interrelated indicators (e.g. capacity and horizontal flight efficiency).

TABLE II. QUANTITATIVE INDICATORS

<table>
<tr><th>Potential assessment indicator</th><th>Performance Scheme</th><th>SESAR Performance Target</th><th>Included in SATURN?</th></tr>
<tr><td>Environmental: horizontal flight efficiency</td><td>✓</td><td></td><td>✓</td></tr>
<tr><td>Cost efficiency: direct ANS cost per flight</td><td></td><td>✓</td><td>✓</td></tr>
<tr><td>Cost: en-route service units</td><td>✓</td><td></td><td>✓</td></tr>
<tr><td>Capacity: en-route ATFM delay</td><td>✓</td><td></td><td>✓</td></tr>
<tr><td>Sector capacity utilisation</td><td></td><td></td><td>✓</td></tr>
<tr><td>Distribution of charges across airlines</td><td></td><td></td><td>✓</td></tr>
<tr><td>Cost of delay</td><td></td><td></td><td>✓</td></tr>
<tr><td>Departure punctuality</td><td></td><td>✓</td><td>✓</td></tr>
<tr><td>Arrival punctuality</td><td></td><td>✓</td><td>✓</td></tr>
<tr><td>Reactionary delay: rotational</td><td></td><td rowspan="2">✓</td><td>✓</td></tr>
<tr><td>Reactionary delay: non-rotational</td><td></td><td></td></tr>
<tr><td>Cancellations</td><td></td><td>✓</td><td></td></tr>
<tr><td>Variation in block-to-block times</td><td></td><td>✓</td><td>✓</td></tr>
<tr><td>Flight operation cost estimation</td><td></td><td></td><td>✓</td></tr>
</table>

The project team is consulting with stakeholders using a two-stage process. The recently completed first phase consulted stakeholders during the developmental and design stage of the project, before the mechanisms were finalised. For example, feedback from this stakeholder workshop indicated a willingness from airlines to pay a premium charge in order to receive a premium service (as mentioned previously) and, in principle, airlines would not oppose the modulation of charges provided the process is fair and transparent. In 2015, a second workshop will be held to consult with stakeholders on SATURN's early results, to validate the indicators and modelling rules.

V. CONCLUSIONS

The expected outcome of SATURN is to provide major European ATM stakeholders with a clear understanding of the benefits and shortcomings, of the various pricing mechanisms available to be introduced mostly at the strategic and pre-tactical level to smooth-out imbalances on the day of operations. This qualitative and quantitative analysis of the applicability of the designed models in the near future draws upon extensive quantitative computational experimentations performed on regional and European scale airspace networks.

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