Pricing schemes based on air navigation service charges to reduce en-route ATFM delays.

Preliminary results.

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Abstract—**In this paper we analyze an incentive scheme based on air navigation service charges modulation that could help in reducing ATFM delays, inducing users to make a better and more uniform use of capacity, especially in those situations in which the distribution of traffic is known to be non homogeneous. A first experiment indicates the feasibility of implementing such a system and further investigations and refinements of the model are going to be performed in the next future.**

Keywords: En-route charges, Air navigation service charges; Incentive schemes; ATFM delays.

I. Introduction

Air transport is a key element for the world's prosperous evolution and represents a major pillar of its economy, as it sustains local national economies, global trade and tourism. In 2005 European Commission stated that "Air transport contributes €220 billion to European gross domestic product and employs 3.1 million people. It is also an important aspect of European cohesion ensuring the rapid and efficient movement of people and goods, but also providing essential access to remote region"[1].

In 2006 the EUROCONTROL Central Flow Management Unit (CFMU) recorded 9.6 million IFR movements in the European skies, which represent an increase of 4.1% with respect to the previous year and this trend is expected to continue in next years, reaching a total number between 15.5 and 18.9 million IFR flight movements in the EUROCONTROL Statistical Reference Area (ESRA) by 2025 [2].

Unfortunately these growth figures are coupled with a worsening in the performances of the whole system. During 2006 overall punctuality deteriorated for the third consecutive year (21.4% of flights arrived late in 2006, while they were 17.2% in 2003).

Part of these delays is due to ATFM measures. In fact when traffic demand is anticipated to exceed the available capacity in en-route control centers or at an airport, ATC units may call for "ATFM regulations" and all the aircrafts subject to ATFM regulations are held at the departure airport according to "ATFM slots" allocated by the CFMU. The ATFM delay of a given flight is consequence of the most constraining regulation applied either at one airport or over an en-route sector along its route. This imbalance between traffic demand and available capacity and resulting ATFM delays can have various ATM-related (staffing, etc.) and non-ATM related reasons (weather, airport scheduling, etc.).

Total number of minutes of delay caused by en-route ATFM measures has increased by 15% in 2006 and represents the majority of ATFM delays (56%). The average en-route ATFM delay increased from 1.3 minutes to 1.4 minutes per flight in 2006, meaning that the goal of 1 min/flight is still far to be achieved [3].

ATM has currently no mandate and limited scope to help improve punctuality and predictability, hence the opportunity of added value from ATM in air transport is currently underexploited.

In this paper we propose some possible incentive schemes based on en-route charges modulation that could help in reducing ATFM delays, inducing users to make a better and more uniform use of capacity, especially in those situations in which the distribution of traffic is known to be non homogeneous. We maintain consistency with the current charging regulations and do not propose new rules conversely to what proposed by [4]. Congestion pricing is widely viewed by economists as the most efficient mean to alleviate traffic congestion and to influence travelers' choice of route and travel mode. The traditional congestion prices policies are mainly based on a congestion toll imposed on each user which equals the external cost of congestion caused by the user on the system [5], [6], [7]. In economical terms the congestion toll objective is to make the user internalize the external cost caused by its own exploitation of the resource, which can be estimated for instance through the use of empirical data or with queuing theory [8].

Our approach differs from the traditional one, since we try to make the local objective of a selfish profit maximizing user coincide with the global objective of achieving the minimum total delay at system level. To achieve this goal we propose to

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provide to those users who contribute to improve the global efficiency (by modifying their demand) an incentive which offsets the increase of their cost.

A first preliminary simulation run on an actual operating environment has shown the potential offered by this system in consistently reducing global delay, with minor changes in flight paths. Further investigations and validation of the model are currently underway.

The remainder of this work is organized as follows. Section 2 gives a brief description of the European charging system. Section 3 describes the principles of re-routing aircraft to enhance capacity, while in Section 4 we propose two possible scenarios of implementation of an incentive scheme. Section 5 summarizes the conclusions.

II. The European Charging System

Current ATC service in Europe finances its operations by adequately charging airspace users in accordance with EC Regulation 1794/2006, which came into force on the 1st January 2007, laying down a common charging scheme for air navigation services ('the Regulation') [9]. Air navigation service charges are composed of en-route and terminal charges due to the provision of air navigation services for the en-route and terminal segments of the flight, respectively. In particular, the en-route charge r for a specific flight in a specific en-route charging zone is equal to $r = d \cdot p_r \cdot t$, where d is the distance factor, p_r is the en-route weight factor of the aircraft and t is the en-route unit rate of the en-route charging zone. A "charging zone" is defined as a volume of airspace for which a single cost base and a single unit rate are established. So far charging zones coincide with national boundaries, each under the control of an ANSP establishing its own cost base and unit rate. Nevertheless the Regulation states that a charging zone can be set regardless of national boundaries. The product of the distance and weight factors is referred to as en-route Service Unit (SU), i.e. $SU = d \cdot p_r$. These parameters are calculated as follows:

- d is the distance factor and is obtained by dividing by one hundred the number of kilometers flown in the great circle distance between entry and exit point of the en-route charging zone, according to the latest known flight plan filed by the aircraft operator. The distance to be taken into account is to be reduced by twenty kilometers for each take-off and each landing on the territory of a Member State.
- $p_r = \sqrt{MTOW/50}$, i.e., the en-route weight factor is equal to the square root of the quotient obtained by dividing by fifty the number of metric tons in the maximum certificated take-off weight (MTOW) of the aircraft.
- t is the unit rate for the en-route charging zone.

In all Contracting States except United Kingdom (which adopts a price cap mechanism), the unit rate is based on the Full Cost Recovery (FCR) principle stating that all en-route costs for ANS regulatory and supervisory functions are fully recovered through en-route charges. When the full cost recovery principle applies, the en-route unit rate is calculated by dividing the forecasted chargeable costs for providing en-route air navigation services by the forecast number of chargeable en-route service units for the relevant year. The balance resulting from under or over recovery of previous years is included in the forecast costs. The amount R of en-route charges due for a flight through states 1,…,n is equal to

$$R = \sum_{i=1}^{n} r_i \qquad (1)$$

where r_i is the amount due to the *i-th* ANSP for the en-route air navigation services provided, i.e.,

$$r_i = d_i \times \sqrt{\frac{MTOW}{50}} \times t_i = SU_i \times t_i \qquad (2)$$

Unit rates are set for each charging zone on an annual basis and can be modified during the course of the year only if unexpected major changes in traffic or costs occur (Article 13 of the Regulation).

Besides the new definition of charging zone, independent from national boundaries, another major innovation introduced by the Regulation is the first opening to incentive schemes based on en-route charges:

"Member States may establish or approve incentive schemes consisting of financial advantages or disadvantages applied on a non-discriminatory and transparent […] resulting in a different calculation of charges […] When a Member State decides to apply an incentive scheme […] in respect of users of air navigation services it shall, […], modulate charges incurred by them in order to reflect efforts made by these users to optimize the use of air navigation services, to reduce the overall costs of these services and to increase their efficiency, in particular by decreasing charges according to airborne equipment that increases capacity or to offsetting the inconvenience of choosing less congested routings." [9]

This new distinctive feature provides ANSPs with an operational instrument to exert some demand management which could help in dealing with the congestion problems systematically faced by them.

III. Re-routing to Reduce Airspace Delays

From an airline perspective en-route charges constitute a direct operating cost associated with the execution of the flight. In fact the direct operating costs of an airline can be divided into flight operations, maintenance and depreciation, where "flight operations" category generally comprehends three main sources of cost [10]:

- flight crew;
- fuel and oil;
- airport, terminal and en-route charges.

The delay also constitutes a cost for Aircraft Operators (AOs) and its unit value can widely vary depending on the type

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of aircraft, the type of delay and the total amount of delay experienced by a particular flight. The cost of delay has been deeply investigated by [11]. According to the direct operating cost-breakdown we can assume that an airline that decides to re-route a particular flight performing a longer route then the originally planned one, will experience in general higher fuel costs, while route-charges costs may increase, decrease or remain constant depending on the new entry and exit points of the charging zones overflown. The flight crew cost, expressed on a time rather than on a distance basis, can be included in the cost of delay, according to the methodology adopted in [11].

Thus a flight delayed by an ATFM regulation will experience a delay cost that may be higher than the cost of re-routing depending on the entity of the delay and the deviation of the re-routed path from the original one. On the other hand, the non homogeneous distribution of traffic in Europe can create as a consequence that different sectors of the same ANSP experience opposite congestion problems: one regulated and the contiguous one with spare capacity, thus implying that a limited rerouting action could make a flight avoiding the regulated sector and respecting its original time schedule. But which is the amount of delay that triggers the convenience point for an AO to re-route and what are the consequences that this re-routed flight generates on the system? We want to obtain some numerical figures that answer to these questions.

The idea is to identify a situation where 2 contiguous traffic volumes (TVs) have different accommodation capabilities: the first is affected by a regulation, meaning that the demand to flight over it exceeds its capacity, and the second without any active regulation, meaning that there is still spare capacity offered to users. We identified this particular situation in the 2 traffic volumes (LIPPNUX and LIPPSUX) under the control of Padova ACC, in Italy (See fig.1). In the period from 6 July to 2 August 2006 (corresponding to AIRAC[1] 284), the traffic volume of LIPPNUX was often affected by a regulation for ATC capacity reasons (see Fig. 2), limiting the maximum number of flights to 42-47 per hour, according to the different regulations. During the same period no regulations were registered on the contiguous traffic volume LIPPSUX. As one can see, during this particular period the call of a regulation on LIPPNUX is exercised almost on a daily basis, while for LIPPSUX there is no regulation in place. This means that the excess of demand over capacity systematically verifies, so this situation could be predicted with reasonable accuracy in the pre-tactical phase.

We reduced the scope of our analysis to a single day, 16 July 2006, when a regulation over LIPPNUX was capping the maximum number of flights to 44 per hour from 7.20AM to 14.30PM. With COOSAC[2] tool we identified that during the activation of this regulation 321 flights passed through LIPPNUX, 157 of them suffered a delay and the regulation active on LIPPNUX was the most penalizing one for 100 among them.

Figure 1. LIPPNUX and LIPPSUX traffic volumes.

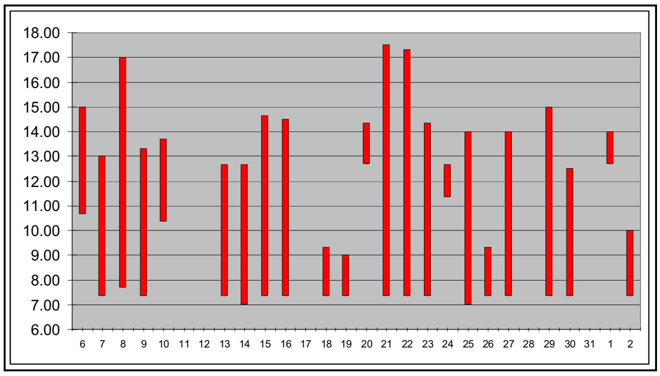

Figure 2. Regulations activated on LIPPNUX during the reference period.

We analyzed the FPLs corresponding to these 100 flights, as recorded by CFMU, and we identified that the option of re-routing through LIPPSUX, in order to avoid LIPPNUX, actually existed for just 2 among them, although this option was not chosen. Hereafter we will refer these 2 flights, respectively as AZA and SWR, according to the code of their operator. For all the other flights in the set, the re-routing option was either unfeasible or leading to an excessive extension of the trajectory, so we considered them as fixed.

Table I reports the direct operating costs associated with both AZA and SWR flights, where the cost of delay has been considered equal to 1 €/min according to [10] and the cost of jet fuel was fixed at 0.53 €/l according to the figures provided by IATA [12]. For each flight the fuel consumption was calculated according to the nominal performances reported by BADA model for the different types of aircraft [13]. Table I shows that both AZA and SWR chose the cheapest option in the original scenario, even if the cost of delay was included in it. Their delay was in fact just 17 and 12 minutes respectively, meaning that the cost associated with it was relatively small and the switch to a conditional route would have represented a less convenient option. Nevertheless the figures in Table II show that benefits accruing from a re-routing are larger if considered from a global traffic volume perspective than for the single flight.

[1] AIRAC (Aeronautical Information Regulation And Control) defines a series of common dates and an associated standard aeronautical information publication procedure for States. Each cycle lasts 28 days, always starting on Thursday.

[2] COSAAC is a tool initially developed at CENA, used to assess ATFM concepts such as flexible use of airspace and ATFM delays.

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TABLE I. DIRECT OPERATING COSTS OF THE SELECTED FLIGHTS

Route	Callsign (first 3 chars)	Dist (NM)	En-route charge Cost	Fuel Cost	Delay Cost	Total Cost
original	AZA	458	281	1409	17	1707
	SWR	746	982	5054	12	6049
rerouted	AZA	467	305	1436	0	1740
	SWR	772	1016	5230	0	6246

All values in €

TABLE II. EFFECTS OF RE-ROUTING

	Actual values on LIPPNUX	Values on LIPPNUX with AZA re-routed	Values on LIPPNUX with SWR re-routed	Values on LIPPNUX with AZA and SWR re-routed
N° Flights	321	320	320	319
N° flights Delayed	157	147	147	141
Total sector delay (mins.)	1795	1683	1696	1619
Delay difference (mins.)	/	-112	-99	-176

Source: COSAAC

A total reduction of 112 minutes is expected on the whole LIPPNUX TV if AZA re-routes through LIPPSUX, 99 minutes if SWR re-routes and 176 if both re-route.

The function that links the delay of the sector to the delay of a single flight is nonlinear and this fact means that the penalties suffered locally by the airline for re-routing its flight are more than compensated globally by the enhanced conditions that it allows in the airspace.

In the case that a reduction in the en-route charge cost would be offered to them, the re-routing could eventually represent the most convenient option and induce them to release their en-route ATFM slots over LIPPNUX, thus leading to a more than proportional benefit for the remaining traffic.

In the following, we estimate the reduction in route charges that has to be offered to these particular users in order to make profitable to them to re-route their flights.

IV. TWO CONGESTION PRICING SCHEMES

A. Each traffic volume as a different charging zone

The first proposed incentive scheme is based on the creation of two different charging zones each corresponding to a different traffic volume. Hence each traffic volume has its own unit rate associated. According to the formula for en-route charge calculation, dividing a charging zone in several smaller ones represents a general higher cost for users, since the distance factor would be calculated according to the great circle distance between entry and exit points of each charging zone rather than between the entry and exit points of the unique one (see Figure 3).

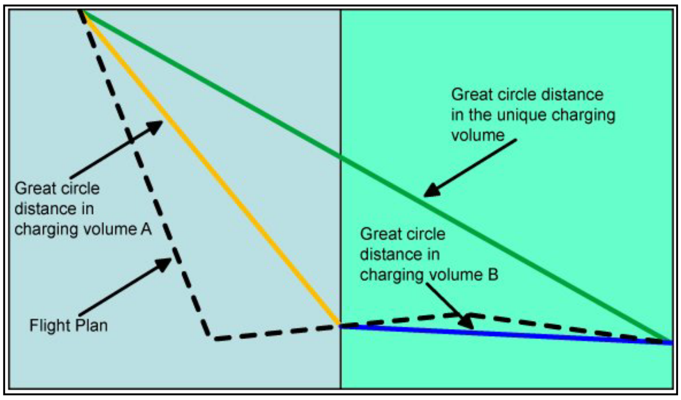

Figure 3. Distance factors under the different scenario

To determine the unit rate threshold values that make it convenient for each flight to re-route, we built the cost function associated to each route. Than we equalized the cost function relative to the original FPL to the one associated with the re-routed one and we obtained a new linear function linking the unit rate on LIPPNUX with the unit rate on LIPPSUX. By assuming that the direct cost of operating a flight is equal to the sum of delay costs, en-route charges and fuel, it follows that:

$$C_{dO}+C_{rO}+C_{fO} = C_{dR}+C_{rR}+C_{fR} \qquad (3)$$

where *d* refers to as the cost of delay, *r* to as the cost due to en-route charges, *f* to as the cost of fuel. The subscript *O* refers to as the original FPL and *R* to the re-routed one.
In accordance with Equations (1) and (2), and with little algebra, it follows that

$$t_{LIPPNUX} = a + b \cdot t_{LIPPSUX} \qquad (4)$$

where

$$a = \frac{c_{dR} + \sum_{i \neq LIPPSUX} c^{i}_{rR} + c_{fR} - c_{dO} - \sum_{i \neq LIPPNUX} c^{i}_{rO} - c_{fO}}{SU_{LIPPNUX}}$$

and $b = \dfrac{SU_{LIPPSUX}}{SU_{LIPPNUX}}$.

For each flight we have thus determined the indifference curve, a straight line with slope *b* and intercept *a*, formed by that pairs of unit rate values, according to which the 2 options of re-routing and maintaining the original trajectory, are equally preferred by the user as they imply the same direct operating cost (see Fig.4).

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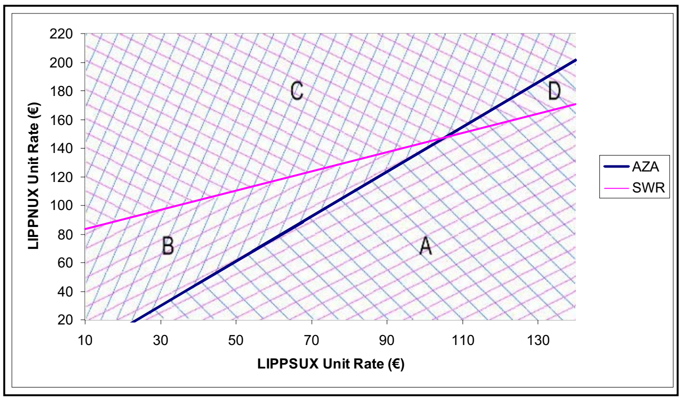

Figure 4. Unit rate values scenario A

For each flight the correspondent function divides the plane into 2 regions, one in which each pair of unit rate values make it cheaper to fly according to the original route and the other containing the pairs of values that make it convenient to fly the re-routed one. We thus defined a total of 4 different regions, identified as *A*,*B*,*C* and *D* in Figure 4. According to the region in which the pair of values is chosen, the flights will be induced to re-route or to maintain the original flights, in order to comply with capacity constraints also on the other sectors. For instance unit rate values in region A would not promote re-routing by any of the two flights, whereas points in region C would foster re-routing for both flights.

The points on one line correspond to those unit rate pair of values that equal the cost of performing the original route and the cost associated to the modified one.

For example, considering that the Italian unit rate for the sample period was fixed at 67.67 €, the increase of LIPPNUX unit rate to 90€ and the decrease of LIPPSUX unit rate to 40€ triggers the convenience point for AZA to re-route but not for SWR, whereas 155€ and 60€ values would drive both to re-route.

If we decide to maintain the unit rate of LIPPNUX equal to the reference national unit rate at 67.67 €, LIPPSUX unit rate value that makes it cheaper the re-route has to decrease until 54.45 € for the AZA, and to inadmissible negative value for SWR. Otherwise if we would charge a sort of congestion toll on LIPPNUX, leaving the original unit rate on LIPPSUX unchanged, we should rise LIPPNUX unit rate up to 88.50 € before AZA prefers to re-route and up to 122.50 € before both AZA and SWR prefers to re-route.

Even though the impact on total delay is straightforward, these results show that re-routing is achieved by means of really high en-route unit rate values, thus limiting the feasibility of such approach. Previous studies as [14] also claim that "Even if route charges were an important component of airline operating costs they can hardly be used as the sole means of demand management without being associated with any other incentive like punctuality". In addition, with the implementation of this incentive scheme, the flights which maintain their planned FPL on LIPPNUX have to pay a higher amount of en-route charges due to the changes in the unit rate values. This situation could be considered as unfair because users would generally pay more for receiving the same ATC services during the execution of their flight. On the other hand this surcharge could be considered as a charge on the externality cost they generate in exploiting a limited resource like capacity. In any case, it is still a challenging issue to mathematically model the impact of such new charges on the route choices of all the TV users.

B. A different unit rate per flight

Another way of implementing the incentive scheme would be to maintain the charging zones as they are defined in the actual situation (e.g. one single charging zone for Italian FIR) and proposing a discount in en-route charges amounts to all the fights that decide to re-route in order to avoid a congested sector (e.g. LIPPNUX). Anyway this would eventually lead to a less controllable behavior of the AOs since a flight that performs most of its flight on Italy would prefer to re-route in order to pay less not only in the contingency sector (i.e. LIPPSUX), but during all the execution of the flight within the national FIR. Under this scenario the link functions between unit rate values modify, and they are reported in Figure 5. With little algebra from Equation (3), for each flight the formula for calculating the unit rate under this incentive scheme B is the following:

$$t_{LI}^{I} = \frac{1}{SU_{LI}^{I}} \cdot \left(c_{do} + c_{rO} + c_{fO} - c_{dR} - \sum_{i \neq LI} c_{rR}^{i} - c_{fR} \right) \quad (5)$$

where LI refers to the Italian airspace under consideration.

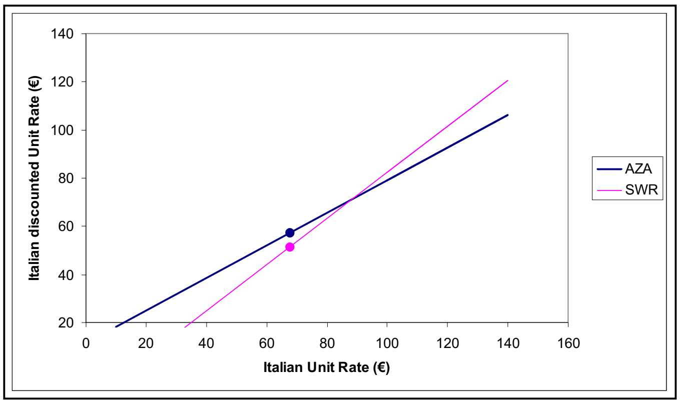

Figure 5. Unit rate values scenario B

Under this second implementation scenario, given the reference national unit rate value at 67.67€, this value should be discounted to 57.07 € and 51.20 € to induce respectively AZA and SWR to re-route in order to avoid the congested airspace. These values are slightly higher than the ones found under scenario A, because now the discount offered to the AOs would be applied along the whole route segment internal to Italy and not only on the LIPPSUX segment.

This scenario could be seen by users as fairer as it does not introduce penalization for flights which does not re-route, but just a benefit to the cooperating AOs, which decide to re-route

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their flight to enhance the global situation. On the other hand the ANSP would experience a loss of income since the lower charge collected from the two flights would not be counterbalanced by a higher cost imposed on other users.

To ensure a balance between ANSP experienced cost and revenues, the Full Cost Recovery principle could provide a solution, just as in the present system. Any gap between the actual costs of ANSP and its income would be treated exactly as today when establishing the national unit rate, including it as an under-recovery in the formula, thus sharing the cost of the incentive among all users who can potentially experience the benefits of its implementation.

The ANSP would be responsible for the adoption of such an incentive scheme, establishing in advance its form of implementation and the related unit rate modulation, in order to allow the users to schedule in advance their flight according to the chosen scheme.

V. Conclusions

We have assessed 2 different potential implementations of an incentive scheme, whose objective is to drive users in making a better usage of capacity resource from a system perspective, by reconciling the single user objective (the minimum cost) with a global one (the minimum total delay). The very first results obtained from a simulation based on a real traffic sample indicate the potential of such a system, which can notably reduce the delay on a specific sector by rerouting a very few number of flights. We assume that the re-route action can not be imposed by a central authority but has to be induced through a modulation of en-route charges amount that each user has to pay for the air traffic services it receives.

En-route charges can be modulated to provide a demand management tool both from a legislative perspective, as this is permitted by the Regulation, and from an operative one, as indicated by the simulation results.

Implementation scenario A represents a finest tool to drive the demand according to the global objective of minimum delay, as the decomposition of a larger charging zone into smaller ones allow to better control the behaviour of single users and to closely bind the unit rate of a TV with its level of traffic. Nevertheless it would require some major changes with respect to the present charging system which, though compliant with the Regulation, could give rise to some objections from users about equity and cost effectiveness. On the other hand the implementation scenario B requires only minor changes to the present system but could eventually lead to less deterministic responses of users' behaviour as well as less cost reflectivity.

Other implementation scenarios and their impact on stakeholders deserve further study, especially the assessment of the consequences of the scheme on the Full Cost Recovery principle and the estimation of the non-linear function that links the presence of an aircraft with the total ATFM-delay of the sector.

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