European route choice determinants

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Examining fuel and route charge trade-offs

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***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.**

***Keywords*— airspace en-route charges; route selection; aircraft operators' behaviour**

I. INTRODUCTION

The saturation of the air traffic management system is countered by the application of air traffic flow management (ATFM) regulations. Aircraft are delayed at departure to meet the capacity of the system along their route. With this system airlines are a passive actor, as they are just required to delay their flights and, even if some flexibility is possible (e.g., requesting a modification of their route, or indicating that the flight is ready to try to get allocated an earlier slot), they are not involved in the solution process of capacity demand balancing.

Previous research has studied the possibility of adding a monetary cost to the use of congested airspace in order to involve airlines in the capacity demand imbalance decision making process. By allocating a price to the resources an economical optima can be achieved. For example [1] investigates the possibility of using sector pricing to influence airlines' choices; in [2] pricing market-based demand management mechanisms are considered; [3] propose an anticipatory, time-dependent modulation of air navigation charges to bring the traffic demand more in line with available network capacities, in such a way that the total cost to airspace users is minimised. The project SATURN is exploring market-based mechanisms for strategic air traffic re-distribution to avoid congestion [4-5]. An understanding of the aircraft operators' behaviour when confronting with different en-route

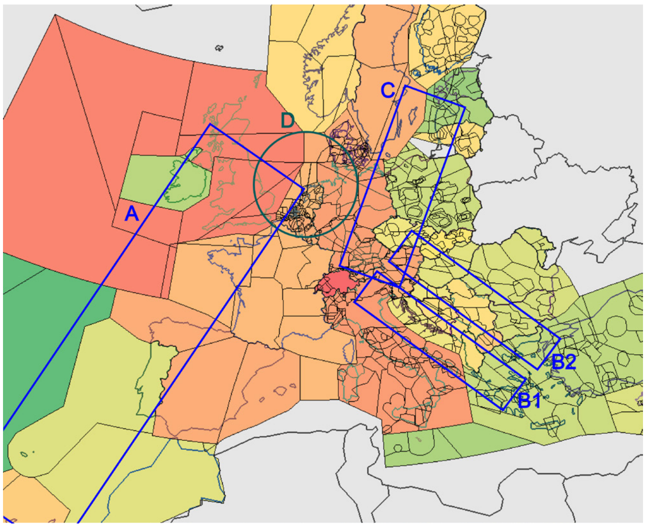


Figure 1. Airspace charging zones (coulour indicates unit rate relative price).

charges is required by these projects.

In the current concept of operations airlines are charged for their use of the airspace. In Europe those charges are centralised in the Central Route Charging Office (CRCO) of EUROCONTROL. As it is explained in Section II.A, currently there are in Europe different charging zones. These zones are to a greater extent country-related (see Fig. 1), which means that the different charging policies are not applied at a fine level of airspace (e.g. sector), even if the current regulation allows member states to define a more specific region [6]. The current variability on the charges already allows airlines to select different routes between origin and destination with different total en-route charges. These different options will also have a different total route length and, hence, a difference in fuel consumption and total cost: a trade-off exists.

This paper analyses the routes submitted by the airlines to be operated, i.e., routes used to compute the en-route charges, with the shortest available route at the flight time (SCR route). We expect that different airlines types will show different behaviour on their preferred routes. Different variables have been selected and analysed in order to understand what drives the behaviour of the aircraft operators when selecting a route with respect to the en-route charges.

Section II presents the required background on route charges within Europe and the route selection process. The methodology and data used for the analysis are presented in Section III. Section IV compiles the results and its analysis. Finally the paper summarises the main findings and highlights further research in Section V.

II. ROUTE CHARGES AND ROUTE SELECTION

A. Route Charges in Europe

Aircraft operators are charged for the use of the airspace to contribute towards the costs incurred by states and air navigation services providers for their en-route services. In the EUROCONTROL area a harmonized route charging system has been defined. The Central Route Charging Office is responsible for billing and collecting the route charges generated by flights within the members states.

The total charge per flight (R) equals the sum of the charges (r_i) generated in the charging zones defined by the different states, as in (1).

$$R = \sum r_i \tag{1}$$

The individual charge (r_i) is equal to the product of the distance factor (d_i), the weight factor (p) and the unit rate (t_i).

$$r_i = d_i \times p \times t_i \tag{2}$$

Where the distance factor is defined as one hundredth of the great circle distance, expressed in kilometres, between the aerodrome of departure within (or the point of entry into) the charging zone (i) and the aerodrome of first destination within (or the point of exit from) that charging zone.

$$d_i = \frac{Entry - Exit\ points\ GCD\ (km)}{100} \tag{3}$$

The entry and exit points are the points at which the lateral limits of the charging zone are crossed by the route described in the last filed flight plan. This flight plan includes modifications due to any ATFM measure. The total distance considered is reduced by twenty kilometres for the take-off and landing within its respective charging zone.

The weight factor (p) is the square root of the quotient obtained by dividing by fifty the maximum certificated take-off weight of the aircraft in tones.

$$p = \sqrt{MTOW/50} \tag{4}$$

The system is based on full cost recovery, forecast data are considered to define the unit rates of the different charging zones. The unit rate defined per charging zone is in Euros and formed by the ratio between the en-route facility forecast cost-base of the charging zone and the forecast number of service units ($d_i \times p$) for the same period, plus an administrative fee equal to all zones to cover the CRCO costs. These unit rates are defined yearly by each member state and adjusted monthly when the national currency is not the Euro [7].

B. Route Selection and Evolution

Aircraft operators intend to plan the most efficient route. Generally, this route is as close as possible to the shortest available. However, the shortest route might be impeded by some operational constrains [8].

Due to the mix use of airspace between civil and military users, parts of the airspace and airways cannot be always used when planning and operating a route. This civil-military coordination is ensured with the flexible use of airspace (FUA) [9]. Conditional routes are air traffic service routes that are only available for use and flight planning under specified conditions. Category 1 conditional routes (CDR1) can be used for flight planning, category 2 routes (CDR2) may be available and flights can only considered for planning in accordance to the information published daily. Finally, conditional routes category 3 (CDR3) cannot be used for planning purposes but ATC may issue tactical clearances on such segments [10].

The environmental (weather) conditions, particularly the wind, are relevant when establishing the most optimal route. This is more relevant for long haul flights [11-12]. Weather can also have a significant effect at a local level as it affects the runway configuration that is in use, which might affect which is the fastest route to approach the airport.

The congestion of the airspace leads to the need of ATFM regulations that are translated into delay. Airlines might try to avoid given areas that are congested or re-route their flights to avoid a regulation [13-14].

Finally, the fact that different areas have different unit cost might incentivise airlines to file longer flight plans with cheaper en-route charges. In this case, the additional length might lead to extra fuel consumption might be compensated with different flight speed and/or the tactically use of CDR3 routes and direct routing when available.

With all the previous considerations, the flight plan route evolves from the strategic and pre-tactical phase to its operation:

- Intended original route: This is the route that the airline would like to operate.
- Last filed route: The airline might modify its intended original route based on the operational situation.
- Regulated route: The last filed route will be analysed by the Central Flow Management Unit (CFMU) who will approve the route 30 minutes before take-off. In case of need, the flight might be issued a regulated time of departure (i.e. delay) to deal with air traffic flow management initiatives. The airline might then decide to modify the route. The finally approved route will be used by the CRCO to compute the flight en-route charges.
- Route flown: Tactically, the pilot might try to reduce the route by requesting direct to waypoints and/or the use of CDR3 routes. In some cases, however, the actual flown route might be longer than the last filed or regulated one, this is the case in some flights when

holdings and/or vectoring is required to tactically deal with arriving flows.

C. *Possible Trade-offs*

Fig. 2 presents an example of two routes between Manchester and Tenerife Sur flown on the 12th September 2014 with less than two hours difference; both flights used the same aircraft type. Route A was filed by a low-cost operator while route B, 68 NM shorter, was flown by a charter carrier.

The charging areas that are over-flown and the duration within them are different for both flights. Flight A stays within the airspace of EG for longer; EG airspace is the one with the highest unit rate of the areas used. However, it overflies the AZ charge area that has a very low unit cost (1,060). By flying over the Atlantic the airline is avoiding the airspace of continental Portugal (LP (3,889)), Spain (LE (7,184)) and France (LF (6,592)). The total cost of the en-route charges is 1,758 EUR. Route B is the shortest route that was available at the time of the flight, but it has a total cost of 2,110 EUR (352 EUR more expensive than route A). Note that the oceanic airspace controlled by EG has been computed at the nominal rate of EG whilst a different rate applies; thus this difference might actually be higher.

Even if route A is longer than route B, the actual difference between the two is reduced to 53 NM as flight A is able to reduce the flight length more than flight B at the tactical stage.

This is an example of different route options where the economic cost of the airspace seems to be playing an important role in the route selection process. Flying 53 NM longer than the flight using route B will have an effect on the total fuel consumed and therefore this total benefit might be reduced. A trade-off exists between route length, route flight time (related with passengers, maintenance and crew costs) and fuel consumption.

The incentive for selecting a longer route to reduce the en-route charges expenses exists when adjacent areas have significant different unit rate. Fig. 1 presents the three main flows that are in this situation:

- Flights to-from the north of Europe (e.g. United Kingdom) to-from the Canary Islands (Zone A). In this case it might be economically worthwhile to select a longer route via Portuguese oceanic airspace (AZ) instead of a more direct route via France and Spain.
- Flights to-from central and north Europe to-from Greece – Cyprus – Turkey area (Zone B1). In this case, the airspace of Italy is more expensive than the adjacent countries of Croatia, Serbia, Albania and Bosnia-Herzegovina. In turn, the airspace of Croatia and Bosnia-Herzegovina are more expensive that the adjacent Hungarian and Romanian airspace (Zone B2).
- North-south routes in Easter Europe, where it could be possible to select longer routes using the airspace of countries such as Poland and the Czech Republic instead of Germany (Zone C).

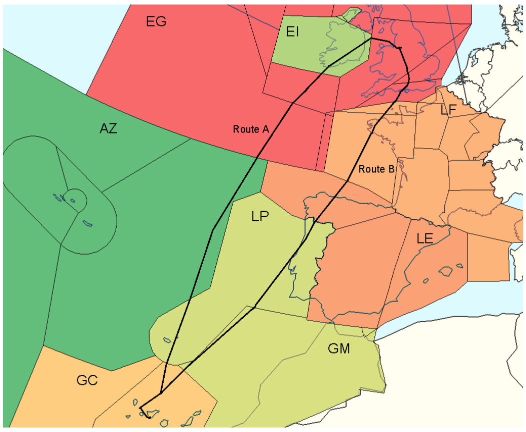


Figure 2. Example two routes between Manchester and Tenerife (EGCC to GCTS) using different airspaces.

In some cases the routes might change significantly leading to a modification of the demand in the airspace.

III. METHODOLOGY

In order to analyse the effects of airspace charges on the route selection and the trade-off between route length, airspace and fuel cost, a given day has been studied.

A. *Data*

The flights within Europe on 12th September 2014 have been analysed. Friday 12th September 2014 has been selected as the busiest traffic day in 2014 without major disruption due to ATC/airline strikes or unusually adverse weather conditions. The data has been obtained from the EUROCONTROL data demand repository (DDR2) dataset [15].

Only intra-European flights are considered. The main reason is that the cost of using the airspace is computed, therefore if a flight overflies a region that is not integrated in the CRCO system the cost would be zero for that region and the results would be not valid. The costs of the airspace of Estonia and Morocco have been added.

The flights have been classified between airlines types: full service (FSC), low-cost carrier (LLC), charter flights (CHT) and regional (REG). This classification is not unambiguous as the airline strategy can be in some cases in-between purely defined models. Only commercial passenger flights are considered. Circular (i.e., origin same as destination) and diverted flights (i.e., real destination different to filed destination) have been removed from the dataset.

Finally, when distance and charges are only considered all flights are included in the analysis, but when fuel cost are also analysed only flights in the BADA performance model database are considered, as BADA has been used to estimate the fuel (see Section III.C).

With the previous restrictions, and after removing some flights due to route and fuel consumption issues (see Section III.B and Section III.C), from 33,810 flights that arrived or departed from Europe the day under study, the CRCO charges have been computed for 13,496 flights (39.9%) and the fuel consumption estimated for 10,331 flights and their shortest available route (30.6%).

B. Reference route

The DDR2 dataset provides for each flight a set of trajectories and airspaces:

- FTFM profile: Filed tactical flight model.
- RTFM profile: Regulated tactical flight model, FTFM affected by ATFM measures.
- CTFM profile: Current tactical flight model.
- SCR: Shortest constrained route, which is the route profile corresponding to the shortest route available at the time of flight, with all restrictions validated and using CDRs, if open at the time. This type of route is meant to be compliant with the flight plan processing system.

The final route that is approved and agreed is the RTFM, therefore this is the route that has been used to compute the air navigation charges incurred by the airline. When the flight has not been regulated, this route is not available, and the FTFM route is considered as the finally filed one.

The CTFM route is the flown route and is not used for the charges computation. This route allows us to determine if the extra distance flown has been modified. This route might also be affected by detours due to holdings and/or vectoring.

The SCR route is considered, in this paper, to be the reference route. This reference route allows us to compute the difference in airspace charges that a given flight is experiencing and the difference in flight plan distance and fuel consumption. SCR has been used instead of all the routes filed from a given origin-destination pair, as SCR includes the restrictions that were in place at the moment of the flight.

In some cases the shortest route is longer than the CTFM or the FTFM. Those flights have been discarded in the analysis. The majority of these flights are to/from small airports and the error might be due to how the SCR route has been generated.

C. Fuel estimation

To consider that fuel consumption is directly related with flight plan distance implies that longer flight plans always represent higher fuel consumption. This is, however, not always the case as the speed profile used might be different.

The flight levels and speeds requested by the airline are recorded in the RTFM profile. With this information an average flight level and cruise speed is estimated for each flight. For the reference route (SCR) the cruise speed is assumed to be the reference speed as defined by BADA for each aircraft type [16].

The fuel flow in (kg/km) is estimated based on flight level and cruise speed. For some flights, the average speed estimated exceeded the maximum, or was below the minimum, for the fuel models, those flights are not considered in the results. This is the case for some long haul flights with several climb steps.

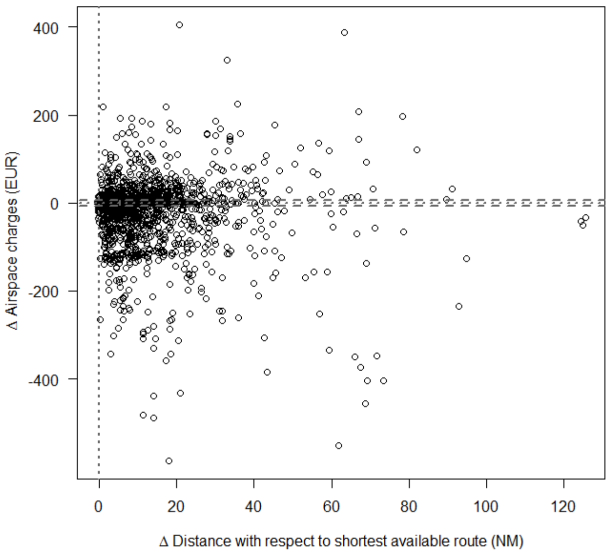


Figure 3. Difference in airspace charges with respect to extra length of filed flight plan.

For this reason from 11,070 flights that fuel has been computed, only 10,331 have been used in the final analysis.

Finally, the whole flight is considered to be flown at that fuel flow rate. There is an over-estimation of the fuel due to the consideration of the whole flight length at the average fuel flow. However, this over-estimation is shared in the reference and the filed trajectories and only results of difference in fuel consumption are presented and analysed. Note that the wind profile has not been considered.

IV. Analysis and Results

The flights are compared with the shortest available route at the flight time. Particular examples are extracted and presented.

A. Route Charges and Distance Flown

Fig. 3 represents how much longer the filed flight plans are with respect to the SCR route and what is the effect on the airspace charges. The flight plan distance is generally increased less than 40 NM and that can represents savings on charges of up to 500 EUR. Four categories of flights are observed:

- Flights that follow the shortest route available (i.e., Δ flight plan distance with respect to shortest available < 5 NM and |Δ CRCO charges| < 5 EUR). 83.4% of all the analysed flights are in this category.
- Flights that select a longer route and save some en-route charges (i.e., Δ CRCO charges ≤ -5 EUR). 6.4% of the flights are in this category.
- Flights that select a longer route but have en-route charges higher than the shortest available route (i.e., Δ CRCO charges ≥ 5 EUR). 5.6% of the flights are in this category. In these cases other parameters beyond the charges cost should be considered (e.g., regulations, or weather) to understand that behaviour.

- Flights that have a route longer than the shortest available but the en-route charges are similar (i.e. Δ flight plan distance with respect to shortest available ≥ 5 NM and |Δ CRCO charges| < 5EUR). This accounts for 4.6% of the flights.

Only 16.6% of the flight on the day under study selected a route different from the shortest available and it seems that the total amount of flights that save charges or have an extra cost are evenly distributed (6.4% and 5.6% respectively). However, the mean of CRCO charges difference for those flights is 17 EUR on savings, i.e., the flights that save charges saved more than the ones that expend extra en-route charges (see Fig. 4).

B. Distance Flight Plan and Distance Flown

As explained in Section III.B, once the flight takes-off the total flown distance might be different than the submitted in the flight plan. Generally the pilot tries to select the shortest possible route tactically available. In some cases this might lead to a reduction of the total flown distance. Fig. 5 presents the difference in actual flown distance with respect to the filed flight plan, and the extra distance that the filed flight plan was with respect to the SCR route.

In some cases the actual distance flown is longer than the one submitted in the flight plan. These flights are generally affected by holding and/or vectoring. In general, as expected, the routes flown are shorter than the filed ones. In some cases, the actual flown route is even shorter than the SCR route; this is the case of 63% of the flights.

Fig. 6 shows the difference between the flown route and the SCR route and the difference in en-route charges with respect to the SCR route. In many cases the aircraft selects a route that is longer than the shortest available and by doing so is charged a lower airspace fare, however, the actual flown route is shortest than the shortest available. 51.7% of the flights that save charges also end up flying a route shorter than SCR.

Table I presents the percentage of traffic divided by the different possibilities: fly longer, the same or shorter than the shortest available route and being charged more, the same or less en-route airspace charges. The majority of the traffic (51.3%) flies a route that is shortest that the SCR route as some of the segments can be tactically reduced; and only 22.2% of the traffic operates a route longer than the SCR.

It does not seem to be a strong relationship between the flight plan length and the difference in distance flown with respect to the filed flight plan. The possibility of reducing the flight length is relatively limited (below 100 NM) independently of the flight plan distance.

C. Charges/Fuel Trade-offs

The amount of extra fuel that each filed route is estimated to consume with respect to the shortest available route has been translated into its economic impact by applying a factor of 0.8 EUR/kg fuel. This factor is an average into-plane fuel cost that has been derived from the global average Jet A-1 fuel spot price for September 2014 [17].

Fig. 7 presents the trade-off between the extra fuel cost and

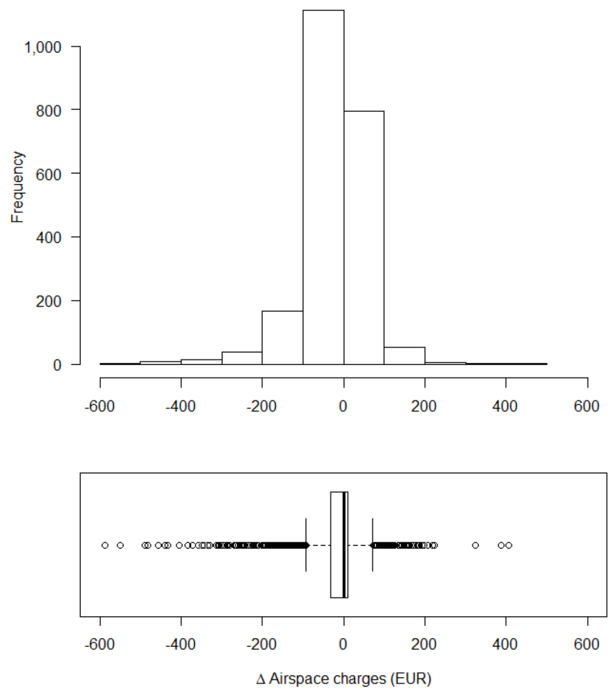


Figure 4. Frequency of difference in airspace charges for flights that selected a longer route than the shortest available.

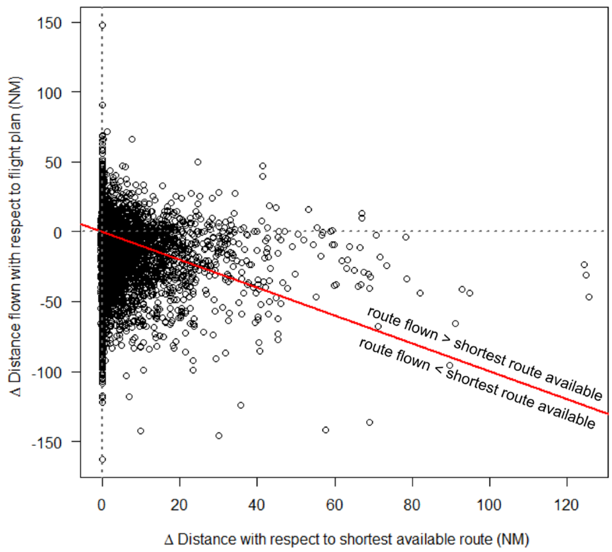


Figure 5. Difference in actual distance flown with respect to filed flight plan and shortest available route length to filed flight plan.

the extra en-route charges for each filed flight plan with respect to the shortest available route at the time of the flight. Note that to improve the plot readability, fuel variation is shown in the -1,000 to 1,000 EUR range. Six regions that can be identified:

- Zone A: flights that have an extra cost on airspace charges and also on fuel consumption. Generally in this case, the selected route is longer and more expensive than the shortest available. Other reasons

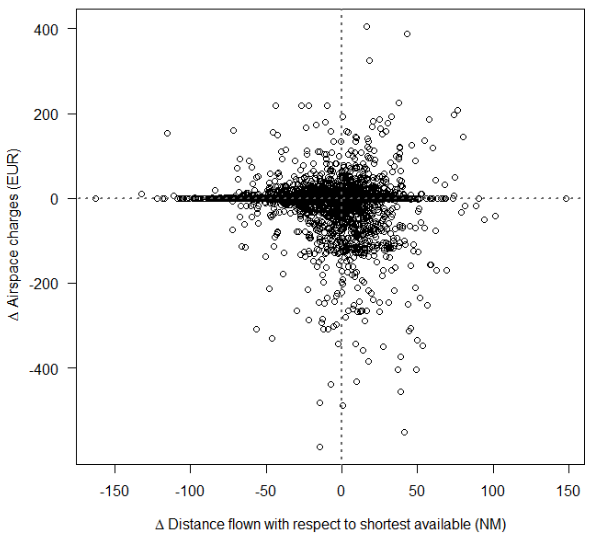


Figure 6. Difference in airspace charges with respect to difference in distance flown with respect to filed flight plan.

TABLE I. PERCENTAGE OF TRAFFIC BY DISTANCE FLOWN AND EN-ROUTE CHARGES

	∆ Distance flown with respect to SCR < -5NM	**∆ Distance flown with respect to SCR ϵ [-5,5]NM**	**∆ Distance flown with respect to SCR > 5NM**	
∆ Airspace charges with respect to SCR > 5 EUR	2.4%	1.2%	2.0%	**5.6%**
∆ Airspace charges with respect to SCR ϵ [-5,5] EUR	46.7%	23.7%	17.7%	**88.0%**
∆ Airspace charges with respect to SCR < -5 EUR	2.2%	1.7%	2.5%	**6.4%**
	51.3%	**26.5%**	**22.2%**	

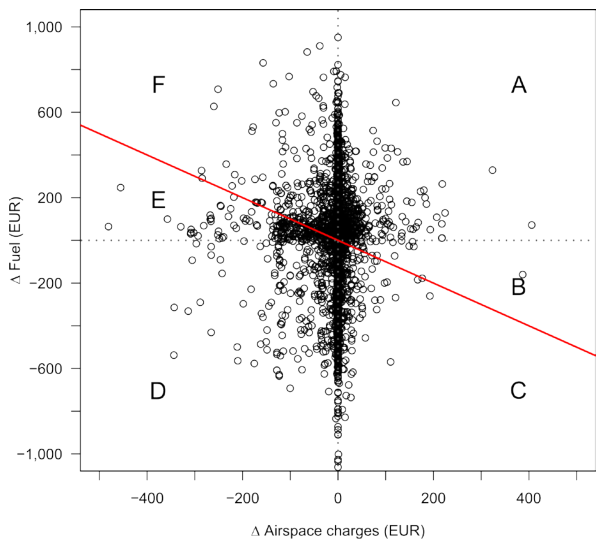


Figure 7. Trade-off between extra fuel and extra airpace charges cost of filed route with respect to shortest available.

rather than the airspace charges might be involved in this case (e.g., regulations or weather). Another reason for aircraft operators to submit a route that is longer than the shortest available could be that the shortest available is computed considering the conditional routes that are available at the time (CDR1 and CDR2); in some cases airlines might not consider these conditional segments, leading to longer routes, higher fuel and higher en-route charges.

- Zone B: In this case the airline incurs extra airspace charges but also has some fuel savings with respect to the SCR. It might be that the selected speed is different (slower) than the one considered as reference in the SCR. However, in zone B, the savings due to fuel do not compensate the expenses on en-route charges.
- Zone C: There is a trade-off between fuel and charges. The airline is incurring higher costs on charges but saving on fuel.
- Zone D: In this case the airline is both saving on charges and on fuel.
- Zone E: The route has higher expenses in terms of fuel but the benefit of reduced en-route charges compensates for that fact and brings some savings.
- Zone F: In this case, the saving on charges is lower than the extra expenses incurred on fuel consumption.

The majority of the traffic is close to the origin (Fig. 7) as many flights are similar to the SCR route. There is also a significant amount of traffic that has the same charges as the SCR route but different fuel cost. This is mainly traffic flying the shortest available route at different speeds. Finally, it is worth noticing that a significant amount of traffic does not have a variation on fuel consumption but instead have savings on en-route charges.

D. Individual Examples

One could expect to find different airline types with different behaviours in the different regions that have been identified in the previous section. In Fig. 8 some of the areas have been magnified and some flights selected for individual study.

Table II summarises the results for the selected examples of Fig. 8. Note that there are flights with similar characteristics but operated by different airlines types.

Flight A (LGSA–EGNX) is operated by a low cost carrier that by selecting a longer route is able to save more than 340 EUR on en-route charges. The aircraft operator avoids the airspace of Italy (7,898 unit rate) and uses the parallel airspace of Croatia which a lower unit rate (4,311). The trajectory is presented in Fig. 9(a). Flight B is operated by a charter airline with similar origin and destination than route A (from Greece to the United Kingdom (LGZA–EGBB)) and in this case a similar strategy is used. In this case, the airspace of Italy and Switzerland is completely avoided by flying further west, this means that the airspace of Germany is used, but savings are

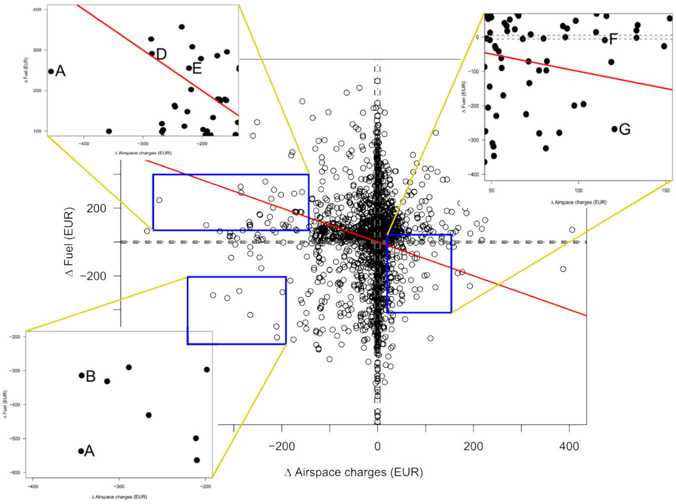


Figure 8. Trade-off between extra fuel and extra airpace charges cost of filed route with respect to shortest available.

TABLE II. EXAMPLE OF FLIGHTS

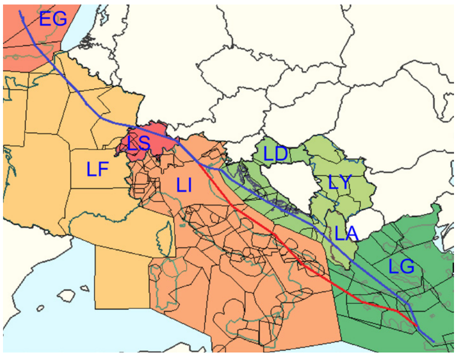
Flight ID	Δ En-route charges (EUR)	Δ Fuel consumption (EUR)	Total cost difference in cost with respect to SCR[a] (EUR)	Airline type
A	-344	-537	-881	LCC
B	-343	-313	-656	CHT
C	-456	247	-209	FSC
D	-285	290	5	CHT
E	-222	255	33	LCC
F	115	-9	106	LCC
G	121	-268	-147	LCC

a. Negative represents savings with respect to the shortest available route

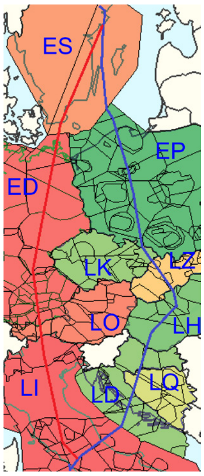
achieved by using the cheapest airspaces of Croatia, Bosnia-Herzegovina, Serbia and Albania; in this case the route is only 18 NM longer than the SCR.

Flight C, operated by a full service carrier, saves around 200 EUR on charges by selecting the cheapest airspaces available in its route between Italy and Sweden (LIRF–ESSA): Croatia, Bosnia-Herzegovina, Hungary, Slovak Republic, Czech Republic and Poland; instead of stay longer in Italy and using the German airspace (see Fig. 9(b)). This represents an extra 69 NM; however, the aircraft is able to tactically recover 30 NM ending up being only 39 NM longer than the SCR route.

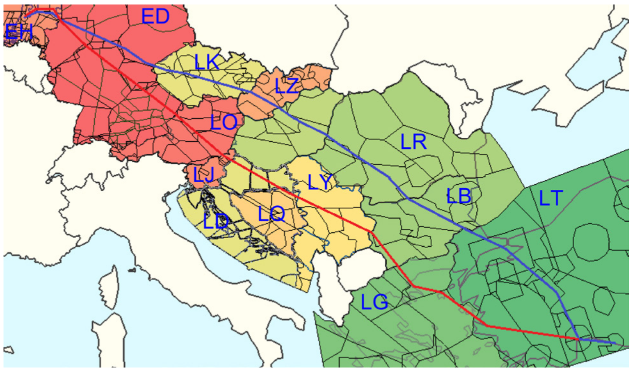
Flight D is another example of a flight avoiding the Italian airspace to use the Croatian one in a flight from Greece to the north of Italy (LGKP–LIPX). In this case, the saving on charges is balanced by extra fuel consumption. Flight E (LTFG–EHAM) is an example of a flight that is further shifted to the East as the shortest route would use the airspace of Serbia (4,683) the route is shifted to use the cheapest airspace of Hungary (4,014) and Romania (3,834) (see Fig. 9(c)). Note how in comparison with flight A or C (Fig. 9(a) and Fig. 9(b)),



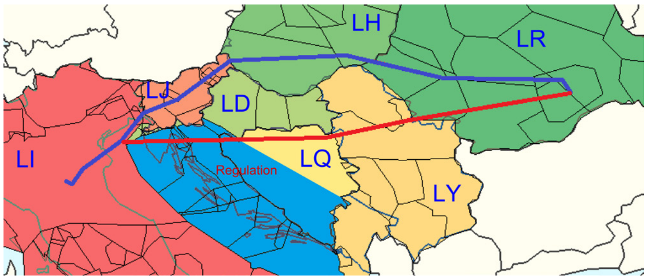
(a) Flight A, (LGSA–EGNX)



(b) Flight C, (LIRF—ESSA)



(c) Flight E, (LTFG—EHAM)



(d) Flight G, (LROP—LIPE), with regulation

Figure 9. Example flights.

now the airspace of Croatia and Serbia are the expensive that can be avoided.

Flights F and G select a route longer than the SCR with an extra cost on charges. For flight F (LEPA–EKBI), the shortest route uses the airspace of France and Belgium, which are cheaper than the German airspace that was filed. However, once in the air, the flight was able to recover 39 NM, leading to an actual flight of 37 NM shorter than the SCR route. Other airlines types are found also in the same region.

In the case of flight G (see Fig. 9(d)), the selected route was more than 120 EUR more expensive than the SCR route. However, at the time when the flight was scheduled there was a regulation in the Croatian airspace due to ATC capacity. This seems to be the trigger of the change of the route as the same flight selected a more direct and cheaper route two weeks before when there was no regulation in place.

E. Maastrich Upper Area Control Centre example

The Maastricht Upper Area Control Centre (MUAC) is unusual in that, even if the traffic is controlled from a centralised ACC, the airspace belongs to three different countries: Belgium, Netherlands and Germany; with different unit charges; see Fig. 10 and zone D in Fig. 1. The effect of the relatively cheaper airspace of EH leads to traffic preferring the use of that airspace than the surroundings. 41 flights do not have EH airspace crossed by their SCR route, but in their filed route select that airspace, whilst only 21 flights did not file over EH while their SCR routes do. Fig. 10(b) shows an example of a flight that purposely filed to use the EH airspace; notice how the flown route is shortened.

F. Hub operations

The FSC flights have been divided between flights going to the hub, flying from the hub and flying spoke-spoke legs. The idea is that when operating a hub it is important to maintain the connections, thus in order to keep the flight on time, the possibilities of choosing longer routes to save charges might be limited.

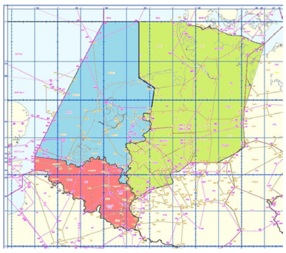
In the majority of the operations the airline selects the SCR route and it seems there are higher savings in routes to the hub when the route is increased. When depicted the actual route flown with respect to the shortest available (see Fig. 11), it can be observed that there are more flights flying routes longer than the shortest available when flying to the hub obtaining some savings in terms of en-route airspace fees. However, these results are based on a small sample and the selection of a longer route when flying to the hub might be motivated to avoid regulated areas, such as in the example of flight G. Moreover, as stated in Section III.B, the flown route might be affected by vectoring and/or holding which might be reflected in the results in longer routes produced due to the hub congestion on arrival.

G. Discussion of Results

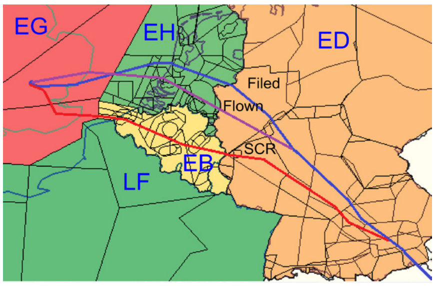
From the results presented in the previous points it can be concluded that it is difficult to establish the behaviour in terms of route selection based only on the airline type category. Fig. 12 presents a boxplot of the difference in cost of the routes filed with respect to the SCR for the different aircraft types. The regional airlines have a smaller dispersion in costs, but this is related to the fact that the flights are shorter and therefore, fewer possibilities to select different airspace charging zones are available for their flights.

Fig. 13 presents the trade-off between fuel cost and en-route charges costs for the different flights categorised by airlines types. As it can be observed there are examples of each one of the categories in all the regions. Therefore it is difficult to extract a pattern in the total cost based purely on the airline type.

It seems that the fact that an airline will select a given airspace motivated by the charging zone is related with opportunity (i.e., parallel airspace with different charges, such as in the Italy, Croatia, Bosnia, Serbia case) rather than airline type.



(a) MUAC airspace [18]



(b) Charging zones in MUAC airspace

Figure 10. MUAC airspace and charging zones with example flight.

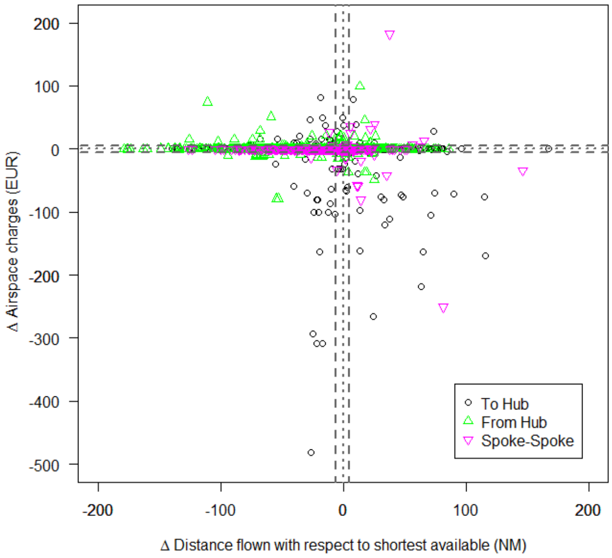


Figure 11. Difference in airspace charges with respect to the difference between distance flown and the shortest available route.

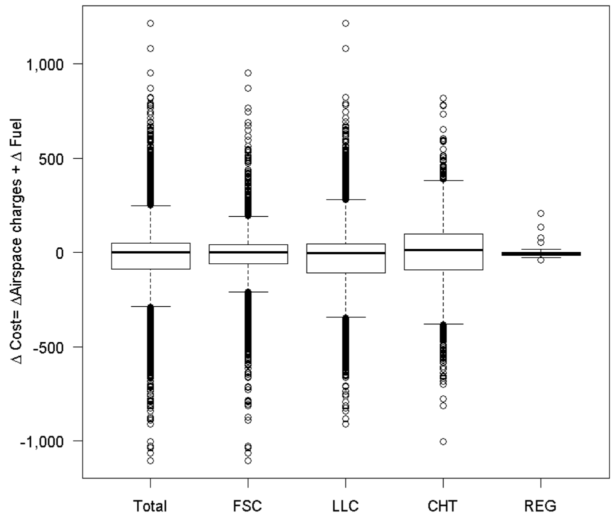


Figure 12. Δ Costs (Δ Airspace cost + Δ Fuel costs) by aircraft type.

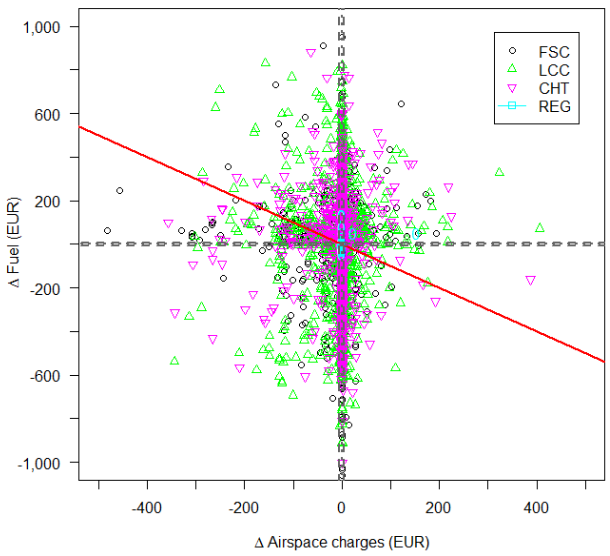


Figure 13. Trade-off between extra fuel and extra airpace charges cost of filed route with respect to shortest available.

As presented in the examples, there are other parameters such as the regulation of a given part of the airspace that might have a higher impact on the selection of a given route.

In April 2015 there is a variation on the unit rate since September 2014. In some cases the Euro exchange rate explains a significant variation (e.g., United Kingdom has increased by 14.3% its unit rate, but the exchange variation is -9.3%). These changes might make some airspace more or less demanded. For example, Germany has increased its unit rate by 16.5% while the surrounding airspace has stayed on similar values: Belgium 1.9%, Netherlands 0.1% or -0.87% Poland. The traffic increase for the MUAC region done by STATFOR indicated a forecasted increase of 2.2% with a variation of 1.6%, 2.3% and 3.1% in the regions of Brussels (EB), Deco (EH) and Hannover (ED), respectively. However, the increase in unit rate of the Germany airspace leads to currently observed values of a total increase in the ACC of 2.2% of the traffic, but very un-evenly: 4.8% in Brussels, 2.0% in Deco and a decrease of 2.0% in Hannover [18]. The en-route charges are modifying the traffic flows affecting the predictability of flows based purely on origin-destination demand and SCR routes.

V. Conclusions and Further work

The research presented in this paper shows that in the selection of a route by an aircraft operator the cost of the charging zones can be a factor. This impact is maximised around adjacent areas where differences in price are significant. This is a promising factor for projects that envisage regulating the traffic by imposing price mechanisms for the use of the airspace. The route variation might be relevant in terms of demand variability, as the selected route can be shifted significantly with respect to the shortest available.

However, modelling the behaviour of airlines is more complex than airline strategy categorisation. There is no direct relationship between the type of airline and operation and the preference or not for a route with lower charges (FSC, LCC, CHT or REG and to, from hub or spoke-spoke). All airlines benefit from routes where airspace in the filed flight plan are carefully selected to save some charges. For some routes the variation in route required to save en-route airspace charges is overcome by the variation in fuel price needed to cover the extra distance; strategies where longer routes and speed variations are combined to maximise benefits are apparent from the results.

The route actually flown is in the majority of the cases shorter than the filed one in the flight plan. This is due to the use of tactical conditional routes (CDR3) and direct routes when possible. This means that in some cases airlines can submit a longer flight plan, which ensures lower charges, and actually fly a shorter one. For some of those longer routes the possibility of tactically reducing it during the flight is higher than for the shortest available ones.

Many factors are involved in the selection of a particular route and as it has been proven that the regulation of airspace plays a relevant role on shifting traffic to adjacent sectors and potentially adjacent charging zones.

The reference route considered in this paper is the one provided in the dataset DDR2 as the shortest constrained route; however, we currently do not have information regarding the fact that that route might be affected by a regulation. The dataset provides the final flight plan submitted, but we do not have access to the intended initial one, which will not be affected by the regulations. That initial one would be based on an airline operational preference, and would therefore be a better route to consider the effect of charging zones. The computation of the fuel consumption should also be reviewed and only the cruise phase considered when computing the flight plan distance and fuel consumption.

Other factors that will need to be incorporated in the analysis are information such as meteorology, and particularly the wind fields, regulations and even factors such as the runway configuration in use at the departure and arrival airports. All these parameters might have an impact on the preference on the airline to select a given route and might allow us to differentiate within a given category of airline different behaviours.

Factor analysis technique seems adequate to be applied to these extended data. This technique attempts to express a set of observed, independent variables, as a new set of independent variables – these ‘factors’ are always linear combinations of the original variable set. The technique was originally developed in psychology to simplify the description of behavioural traits, for example. It shares its underlying principles with multivariate, linear regression. This established, powerful technique has been hitherto relatively little used in ATM. (For good introductions to the methodology see [19] and [20]. [21] provides helpful practical guidelines.)

One of the key differences is that factor analysis (usually) deals with the issue of (multi-)collinearity associated with the independent variables, an issue clearly apparent in Section IV. This is true especially of the technique known as principal components, usually considered a variant of factor analysis.

There cannot be more factors in the 'solution' than there were variables in the original set and it is obviously preferable that there will be rather fewer of them.

A key indication of the quality of the solution, is the percentage of the original variance between the original variables, which is described by the (fewer) factors. In our analyses of route choice determinants, we may expect significant proportions of variance to be left unexplained in such solutions, hidden in non-parameterised effects such as dispatch workload, plus personal preference and experience.

It is not acceptable to obtain a purely 'mathematical' solution in the analysis, i.e. whereby the analyst is not able to assign real meaning to the factors. The analyst often 'rotates' the factors, to increase loadings on some of the original variables, and decrease them on others, in order to improve the interpretability and simplicity of the solution.

Herewith may lie particular interest in terms of analysing outputs relating to determinants of airline behaviour. In psychology, multiple input variables have been used to classify generalised, condensed traits such as 'judging' versus 'perceiving'. In understanding airline route choice determinants, we may be challenged to classify new behavioural factors, previously considered as largely heterogeneous (as aligned with [22]), comprising both LCCs and FSCs, and flights early in the day and before the evening peak. This process may furnish the analyst with new insights into behaviour through more practically useful characterisations along generalised dimensions such as 'mission criticality' and 'reroute opportunity'. Often, the less expected and more challenging factors to interpret offer the greatest insights.

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