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Resident air transport subsidy impact on airport ground operations: Gran Canaria airport case study

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ABSTRACT

This paper seeks to analyze the impact of regional aviation subsidies for Gran Canary airport; specifically, the effect on airport capacity, air carrier economics and the environment. It was found that aircraft taxiing operations time increased producing negative effects on airport capacity management, air carrier economies and the environment in terms of decreasing airport capacity available and the increased fuel and emissions costs. However, those losses have to be balanced against the social benefit of increased resident mobility.

1. Introduction

Air transport is key to improving the mobility of people, in order to guarantee economic and social cohesion across the European Union (EU). However, some air transport routes in the EU are far from profitable, mainly those located in island regions. In light of this, the European Commission has established a public service obligation (PSO) mechanism and subsidy for those routes. The number of PSOs routes has expanded in several European countries. France and Norway are the countries with the greatest number of PSO routes in Europe (Williams and Pagliari, 2004). In Spain, PSO routes have been imposed on inter-island transport services since 1998. Together with the PSO, Canary Islands residents enjoy subsidies on fares to improve connectivity and accessibility to services on the main islands and mainland Spain (Santana, 2009).

Economic interventions, such as subsidies, aim to lower market prices and raise demand (output). Specifically, subsidies in the aviation market can lead to expansion in the aviation system. One of the objectives of market intervention can be to improve populations' air mobility within and from peripheral regions. Benefits from improved mobility can include better job opportunities, easier access to health services and increased leisure travel and tourism for the region, among others. The EU's long-term policy is to enhance economic and social cohesion across the EU. However, the results depend on the way in which the PSO mechanism and subsidies are adopted with respect to air transport services (Williams and Pagliari, 2004).

According to Fageda et al. (2016), some studies have examined the effects of PSOs and subsidies on the efficiency of operators, others have studied their design in several countries in EU. Those studies found that PSOs reduce the level of competition on protected routes and increase the operation cost of European carriers; they also identified weaknesses in the regulation of PSOs in some countries. Fageda et al. (2012) compared subsidised routes (domestic flights from Gran Canaria) with unsubsidised international flights from Gran Canaria and found that non-residents pay more than international passengers. Valido et al. (2014) showed that non-resident passengers could be driven out of the market if the flow of resident passengers was high. Santana (2009) found that European airlines subject to the PSO mechanism have higher costs. Calzada and Fageda (2014) analysed the effects of PSOs on the level of competition and flight frequency offered by airlines in the European aviation market and found that routes protected by PSOs offer a high flight frequency in Spain with respect to unprotected routes with similar characteristics. The relevant finding of this study is that PSOs increase market concentration.

Much less attention has been paid to the effects of PSO mechanisms and subsidies on airport infrastructure. Aviation subsidies can lead to the creation of additional airport capacity and encourage regional development in peripheral areas (Gössling et al., 2017). However, these policies can also produce perverse effects on airport services management. For instance, delays caused by congestion in airports can cause economic losses for airlines and environmental impacts. If an airport is close to its 'saturation level' or has a highly seasonal traffic flow, main operational issues, such as aircraft taxiing for landing and take off, can become more congested.

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This paper seeks to close this gap by analysing the impact of aviation subsidies on Gran Canaria Airport (airport code LPA). Air transport growth from subsidies can exacerbate the need to invest in additional airport capacity and can produce collateral effects on air carriers' economies in terms of increasing their operational costs. Therefore, as air transport incrementally increases at local levels, its environmental impact and economic effects have to be readdressed. In this context, this study contributes to the literature on the impact of subsidies on airport operations, specifically taxiing operations, at LPA. Delays in taxiing affects the economics of air carriers, as well as producing environmental impacts in terms of increased greenhouse gas emissions. Queue-based modelling is generally used to analyse aircraft processes at an airport and specifically ground operations congestion (Kariya et al., 2011; Itho and Mitici, 2019).

The structure of this paper is as follows: Section 2 describes the analytical approach applied in this case study. Section 3 defines the background of the case study and discusses the results, specifically analysing the impact of subsidies on LPA's taxiing operations by estimating taxiing delay due to congestion in ground operations. Likewise, this section calculates the environmental and economic impact of delays in ground operations. Finally, the conclusions highlight the main findings of the study.

2. Analytical approach

Different aircraft types interact at airports and compete for use of airport capacity. Thus, the mix of aircraft is crucial in optimising capacity and adequately controlling air services (Yu and Lau, 2013). Subsidised regional traffic can exacerbate congestion and may produce delays at airports. Therefore, to quantify how much the increased traffic from subsidies makes airport ground operations delay flights, the conflicts between aircraft types must be considered.

The analytical approach is as follows: first, congestion that causes bottlenecks (in terms of average waiting time) before take off will be estimated using queuing theory (Kariya et al., 2011; Itho and Mitici, 2019). On the other hand, the conflicts between aircraft will be evaluated employing a simple model of landing intervals (Harris, 1974) considering two aircraft types (i.e., ATRs and the Boeing 737 and Airbus 320 (B737/A320) aircraft families). Using these procedures, taxiing time will be estimated.

2.1. Airport ground operations delay model using queuing theory

In this paper, delays in airport ground operations are analysed through aircraft congestion during taxiing departure operations. Congestion occurs due to the concentration of departures near to the runway. This congestion phenomenon can be studied using queuing theory to specifically analyse take off waiting time at LPA. To apply the theory to aircraft taxiing, various parameters for the operational modelling of aircraft have to be established. The number of aircraft that arrive on the runway at the unit time (arrival rate) is called λ. The number of aircraft that take off at each unit time (processing rate) is called μ. The take off density is assumed to be $\rho = \lambda/\mu$ $(0 < \rho < 1)$. The queue process is described using the Kendall sign, as shown in Table 1.

Kendall's notation in the form of A/S/c means that A describes the aircraft distribution between each arrival to the runway, S the distribution of processing time and c the number of the servers. In this case, the arrival at the runway is a general distribution, and the processing distribution of aircraft is a constant distribution. For one server, the parameters of the Kendall sign would be G/D/1 (Kariya et al. 2011). This model is shown in Fig. 1.

Table 1
Parameters of Kendall sign. Source: Kendal (1951).

Parameter	Arrival distribution	Processing distribution
M	Poisson	Exponential
D	Constant	Constant
G	General	General

For this case, the average waiting time for take off W_q in the stationary state[1] is derived by the following equation:

$$W_q = \frac{\rho}{\mu(1-\rho)} \times \frac{C_\lambda^2 + C_\mu^2}{2} \tag{1}$$

In Eq. (1), C_λ and C_μ are the coefficients of variations of the arrival distribution on the runway and the processing distribution, respectively. Those coefficients of variation are derived by the division of the standard deviation and the average value of distribution. According to the diagram processing shown in Fig. 1, the coefficient of the variation of the arrival distribution is $C_\lambda = 0$ due to the arrival rate at the runway being constantly distributed. Moreover, the coefficient of processing distribution (C_μ) needs to be estimated due to the absence of direct observation or simulation. This later parameter has been estimated using a landing-intervals model for a sample of several approach speeds, for both aircraft family. The estimated value of C_μ is equal to the ratio among standard deviation and the average value of the sample (Kariya et al., 2011).

2.2. Landing-intervals model

A simple model of landing intervals was developed to estimate the average rate of processing aircraft on runways (Harris, 1974). This methodology gives an approximation of the average processing rate for take off using the 'ultimate capacity concept' for a mix of aircraft landing on a single airport runway. The landing-intervals model assumes error-free approaches and that pilots are able to precisely maintain the required separations and speeds using instrument flight rules (IFR). Two situations were considered: the 'overtaking case' (Fig. 2a), in which the trailing aircraft has a speed equal to or greater than that of the lead aircraft, and the 'opening case' (Fig. 2b), in which the speed of the lead aircraft exceeds that of the trailing aircraft. The following minimum separation function can be applied. In this function aircraft are grouped into *n* discrete speed classes and a matrix of minimum intervals, so that the minimum time separation for each combination of approach speeds can be estimated by the following equations (Ashford and Wright, 1992):

$$m(v_j, v_i) = \frac{\delta}{v_j}(v_j \geq v_i) \tag{2}$$

$$m(v_j, v_i) = \frac{\delta}{v_j} + \gamma\left(\frac{1}{v_j} - \frac{1}{v_i}\right)(v_j < v_i) \tag{3}$$

where v_i is the speed of aircraft *i*, γ is the length of common approach path, δ is the minimum safety separation between aircraft and $m(v_j, v_i)$ is the error-free minimum time separation over the threshold for aircraft *j* following aircraft *i*. The matrix of minimum intervals can be formed for aircraft with speed class *i* following aircraft with speed class *j*:

$$M = \left[m(v_i, v_j)\right] = \begin{bmatrix} m_{i,i} & m_{i,j} \\ m_{j,i} & m_{j,j} \end{bmatrix} \tag{4}$$

Fig. 1. Kendall sign for take off process: G/D/1.

[1] Stationary state is an operational concept in which the processes merely reproduce themselves with no changes.

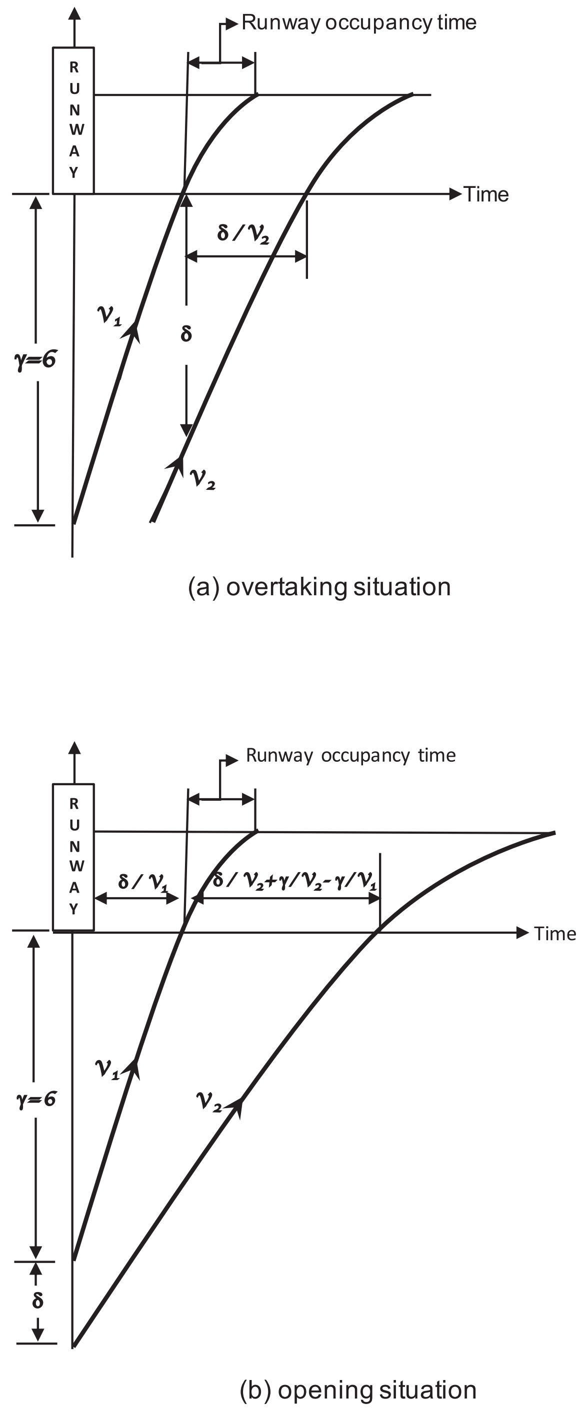

Fig. 2. Landing interval model 'overtaking case' (a) and opening case' (b).

This matrix associates each one of the n speed aircraft classes with a probability of occurrence $[P_1, \cdots, P_n]$. These probabilities are the percentages of the various speed classes in the aircraft mix divided by 100. Thus, the expected minimum landing interval or weighted mean service time can be approximated by the following formula:

$$\overline{m} = \sum_{ij} P_i m_{ij} P_j \tag{5}$$

Parameter $\overline{m}$is approximate to the processing rate of aircraft before take off. Finally, the hourly saturation capacity is the inverse of the weighted mean service time:

$$C = \frac{1}{\overline{m}} \tag{6}$$

This model assumes that runway occupancy time during landing is less than the time separations during approach and has no effect on capacity.

2.3. Taxiing time in route

Next, considering the aircraft mix at LPA, the taxiing time in route has to be estimated for two kind of aircraft: ATR aircraft and the other narrow-body aircraft, specifically from the B737/A320 families. The expression used to estimate taxiing time in route for both kinds of aircraft was as follows:

$$\text{Taxiingtime} = \frac{\text{Distance}}{\text{taxispeed}} + (\text{powerback} \times \%\text{powerbackperformance}) \tag{7}$$

Next, this analytical approach (formulas 1 to 7) was used to analyse the impact of subsidies on congestion at LPA. The environmental and economic impact of the subsidies will be estimated for LPA for the peak month of December 2018. First, the analytical approach determines the delay in taxiing operations; second, the environmental and economic effects resulting from that delay will be derived in terms of the annual increase in tons of carbon dioxide emissions and fuel costs, respectively.

3. Case study

3.1. Background

For Canary Islanders, it could be said that their proximity to the mainland is essential for a better quality of life. The connectivity of the Canary Islands to large cities in Europe and Africa tempers the remoteness of the islands and, at the same time, means that they can be competitive with other European regions. Tourism depends on people's mobility and has a strong role to play in the economic development of the islands, and air transport is essential to support this. Thirty-five per cent of the Canary Islands' GDP (gross domestic product) is generated by national and international tourist flows, which support 40.4% of jobs in the region (Impactur Canarias, 2018). Therefore, there is a strong argument for subsidising aviation in the Canary Islands.

In this sense, residents' mobility, whether for leisure, work or health, makes the transport sector crucial to guaranteeing proximity, not only to the mainland of Spain but also between islands. For this reason, air and sea transport from the islands to the mainland, and between islands, has been subsidised since 1982 under a compensation scheme to reduce the extra costs incurred by freight and passenger traffic as a result of the islands' remoteness from the Spanish mainland and EU territories.[2] Recently, this allowance has been increased from 50% to 75% of the travel price. This new subsidy began in early June 2018, and within the following six months, interisland air traffic volume increased by 19.8%, compared to the same period in 2017. In contrast, traffic from the Canary Islands to mainland Spain increased in the same period by only around 2.5%. In percentage terms, subsidies for air traffic stimulated more interisland air traffic than that from the Canary Islands to the Iberian Peninsula (Table 1 - Aeropuertos Españoles y Navegación Aérea-AENA, 2019). This increase in interisland traffic has been mainly for *Avions de Transport Régional* (ATR) turboprop aircraft flow, and because of the special operational characteristics of these kinds of aircraft, it could affect operational issues for any airport on the islands

One of the main characteristics of air traffic in the Canary Islands is the importance of regional or interisland air traffic. The preponderance of turboprop airplanes (ATR families) operating at Canary Islands airports may have implications for airport capacity management. Table 2

[2] Real Decreto 1316/2001

Table 2
Traffic evolution (ATMs) for LPA airport. Source: Compiled by authors with data from AENA.

Aircraft type/ year	2016	2017	2018	2019
Turboprop[1]	34,898 (9.9%)*	37,068 (6.2%)	48,175 (30%)	50,746 (5.3%)
Narrow-body[2]	77,102 (14%)	81,483 (5.7%)	82,852 (1.7%)	75,706 (-8.6%)
Total traffic	112,000	118,551	131,027	126,452

*In brackets percentage increase of the ATM (Air transport movement) by aircraft type.
[1] ATRs 72 and 42.
[2] Boeing 737 and Airbus 320 families.

shows the traffic evolution for LPA over the last four years for different aircraft types, mainly ATRs 42 and 70, and narrow-body airplanes such as the B737/A320 families. It is apparent from Table 2 that ATR traffic has steadily increased. The subsidy increase became available in June 2018, and in the following six months, the percentage of ATR aircraft traffic increased by 30% in contrast to the same period in the previous year. This means that regional aviation absorbed most of the subsidy increase. As is apparent from Table 2, 2018 is the best moment to estimate the impact of the subsidy increase in air transport movement at LPA.

The Canary Islands have eight airports, including two on Tenerife. Those airports can be classified into two groups: those with heavy international traffic (Gran Canaria, Tenerife Sur, Fuerteventura and Lanzarote) and the other four (Tenerife Norte, La Gomera, El Hierro and La Palma) servicing mainly national and local traffic. The Spanish Civil Aviation authority ranks the Canary Islands as the third Spanish region in terms of passenger traffic in 2018: its airports accommodated 45.3 million passengers, which represents 17% of total passenger traffic in the Spanish airport network. (The top two regions are Madrid (22%) and Catalonia (20%).) The AENA top 10 ranking of greatest passenger volume in 2018 included the airports of Lanzarote (7.3 million), Tenerife Sur (11 million) and Gran Canaria (13.6 million) (AENA, 2019).

In 2018 Canary Islands airports received more than 18 million non-interisland passengers (foreigners and from the rest of Spain). Nearly 14 millions of these inflows were from Europe. However, the interisland passenger volume for the same year was about 4.4 million. This represents an increase of at least 40.6% from the previous year (AENA, 2019). The entrance into the interisland air market of two new air operators, Canaryfly, at the end of 2012, and Air Europa, at the end of 2017—the latter attracted by the subsidy increase—is one of the factors that explains this continued growth in interisland traffic. However, Canaryfly has been absorbed by Binter (although it maintained its brand image) and Air Europa has stopped operating in the Canary Islands' interisland air market. Hence, Binter exerts real monopoly power in the Canary Islands' interisland air traffic market. Calzada and Fageda (2014) found empirical evidence of market concentration in routes protected by PSOs in European countries. All Interisland routes in the Canary Island have been operated under public service obligations (PSOs) since this type of subsidy started in 1998 (Santana, 2009). All PSO routes are operated by one operator, Binter Canarias. Table 3 shows some characteristics of PSOs routes.

As is apparent from Table 3, the main PSO routes have an average load factor of about 70%. The route with most traffic density has an average daily frequency of 20 flights and is the route that generates most subsidies. The average subsidy per passenger for those PSO routes was €44. Gössling et al. (2017) point out that due to the lack of a competitive tender, the subsidy might not be set at the most efficient level. In addition, Santana (2009) found evidence that airlines employing the PSO programme have higher costs. Consequently, airlines operating the PSO service have incentives to establish higher airfares than those specified by the administering authority. Calzada and Fageda (2012) found also that the benefit of the price discount is transferred to the airlines to the detriment of both island residents and other passengers on these routes. Hence, control of the flight price becomes necessary to guarantee PSO service at the 'right price'.

Table 3
Main PSO route characteristics (December 2018). Source: Compiled by author with data from the website of Binter and AENA.

PSO routes	F_D[1]	ATM[2]	Pax[3]	L_F[4]	S_E[5]
Gran Canaria (LPA) -Tenerife Norte (TFN)	20	1152	79,319	68.8	€40
Gran Canaria (LPA) -Tenerife Sur (TFS)	4	224	11,630	52	€42
Gran Canaria (LPA) – Lanzarote (ACE)	14	776	64,236	82.8	€46
Gran Canaria (LPA) – Fuerteventura (FUE)	12	680	51,314	75.4	€50

[1] Average daily frequency.
[2] Monthly air traffic movements of ATR aircraft.
[3] Monthly resident passenger number.
[4] Average load factor.
[5] Average fare subsidies: (ticket price for non-resident – ticket price for resident).

Binter Canarias also connects the Canary Islands with the Iberian Peninsula (Murcia, Palma de Mallorca, Pamplona, Vigo, Zaragoza, Santander and Victoria) and a few years ago started its international expansion to Africa, flying to destinations such as Agadir, Casablanca, El Aaiún, Marrakech, Banjul, Punta Delgada, Dakar, Nouakchott and Dakhla. The airline also runs flights to Lisbon and Madeira. Similarly, air traffic from the Iberian Peninsula to the Canary Islands has steadily increased in recent years, as it has also been influenced by an increase in fare subsidies. However, this air market has strong competition regarding price from low-cost airlines such as Air Europa, Ryanair, Vueling and Norwegian. In fact, these four airlines account for 93.5% of the market (Gundelfinger-Casar and Coto-Millán, 2018).

The subsidies that the Spanish government gives to regional air transport carriers flying between islands, and from the Canary Islands to the Iberian Peninsula, are considered cash funding. This is in essence a transfer of money from the government to the transport sector, which uses it as revenue. This market intervention, as is apparent from Table 2, incentivises air traffic and therefore impacts airport capacity management.

LPA is open during the whole year and 24 h per day, which represents 8,760 h per year of available capacity. The saturation level is about 53 ATMs/peak-hour (Plan Director del Aeropuerto de Gran Canaria, 2005). However, it is a seasonal airport and has peak periods during which demand is very close to the saturation level. Currently, LPA is far from being a congested infrastructure. However, this does not mean that taxiing operations are not congested at peak periods, resulting in air carriers wasting time, increasing fuel consumption and greenhouse gas (GHG) emissions.

LPA has two parallel runways (designated 03L/21R and 03R/21L); however it does not allow simultaneous take off and landings. The airport uses only one runway (03L/21R), since it is adjacent to the terminal area and is available the whole time. LPA has a competitive use between short-range aircraft and regional turboprops. This distribution is understandable because of the environment in which the airport is placed, that is, on an archipelago where aircraft are of great importance in the transportation of people and cargo. This is one of the main operational characteristics of LPA that must be considered. In 2018 there were 48,175 ATM (turboprop aircraft) flights, mainly from the ATR-72 and ATR-42 families. In contrast, short-range aircraft, mainly B737s and A320s, accounted for 82,852 ATMs (AENA, 2018). In terms of percentage, 36.8% of all aircraft movements at LPA were ATR aircraft.

This study focuses on the operations of B737s, A320s and ATRs because together they represent 89.4% of the aircraft types operating at LPA (Lorenzo-Aparicio and Rendeiro Martín-Cejas, 2017). It is apparent from Table 1 that ATR traffic has increased steadily. Turboprop aircraft have some characteristics, such as slow-speed landing, that might affect operations of other aircraft families at LPA and cause congestion. Delays mainly occur during the taxi-out phase due to departure congestion and due to interference among aircraft flying the final approach path and landing (Ignaccolo, 2003).

3.2. Estimation of the subsidy impact on LPA ground operations

An analytical approach was implemented for a peak month (December), which was established by inspecting the flow data at LPA for the last three years. Thus, the model was implemented for the peak period of 2017 and 2018, that is, before and after the subsidy increase. To estimate Equation 1 of the analytical approach, the parameters (C_μ), λ, μ and ρ have to be calculated. The coefficient of variation of arrival distribution is $C_\lambda = 0$, due to the arrival rate at the runway being constantly distributed. To do that, the landing interval model was applied next.

According to the wake vortex categorization, the aircrafts' landing and take offs at LPA airport belongs to category C (lower heavy) in RECAT-EU wake turbulence separation based on ICAO Doc 4444 PANS-ATM. In this sense, the minimum separation to guarantee safety separation (δ) would be of 3 nautical miles (Rooseleer et al, 2016). The matrix of minimum intervals for the airports was estimated using 6 nautical miles as the length of common approach path (γ). The approach speed for ATRs was in the interval of 85–130 knots (approach speed units) and 115–160 knots for B737/A320 families. The probabilities of occurrence for ATRs and B737/A320 families were 0.368 (36.8%) and 0.632 (63.2%), respectively. Using the above dates, the complete matrix *M* (minimum time separation between aircraft for each combination of approach speeds) and the ultimate capacity for LPA are as follows:

$$M = \begin{bmatrix} 127 & 193 \\ 28 & 94 \end{bmatrix}$$

$$C_{LPA} = \frac{1}{\overline{m}} = \frac{1}{(127 \times 0.368 + 28 \times 0.632 + 193 \times 0.368 + 94 \times 0.632)} = 18.5 arrivals/h$$

The results of the landing interval and queue models for year 2018 are summarised in Table 4.

Before starting the estimation of taxiing time in route, certain aspects must be clarified. ATR aircraft very often have a 'power-back unassisted', in contrast to the B737/A320 aircraft families. It will be assumed that ATRs take 31.89 s on each power-back and that on 30% of occasions ATR aircraft perform power-backs before taxiing, while B737/A320 aircraft families take 205.83 s and perform power-back on 50% of occasions (Lorenzo-Aparicio and Rendeiro Martín-Cejas, 2017). With respect to other ground operations on taxiing, both ATRs and B737s/A320s are restricted to a maximum speed of 20 m/s. This is a reasonable restrictions according to ICAO standards that suggest a speed of 25.8 m/s (50 knots) for aircrafts on straight taxiways such as those at LPA airport (Doc 9830-Advanced Surface Guidance and Control System, 2004). The estimation of taxiing time was performed by taking as a reference the distances to the farthest parking stand from the runway for the two types of aircraft. The ATR parking stands are distant from the terminal building; the farthest stand (P00) (see Appendix B) is about 1,200 m from the runway (see the green line in Fig. 2). For the B737/A320 family of aircraft, the farthest finger (T01) is 2,375 m from the runway (see the blue line in Fig. 3). In these calculations, the farthest parking stand was selected considering the worst scenario for compensating an aircraft common route without conflicts effects which were not considered.

Table 4
Results of landing interval and queue models for year 2018.

Parameters	Waiting time (s.)
λ = 16 ATM/hours = 0.267 ATM/min. μ = (ultimate capacity/60 min.) = 18.5/60 = 0.308 arrival/min. ρ = λ/μ = 0.267/0.308 = 0.8668 (take off density) $C_\lambda = 0 C_\mu = 0.5876$*	W_q = 219 s.

*Coefficient of variation of the arrival distribution estimated for different combination of approach speeds (low, medium and high) as approximation to the rate of aircraft before takeoff: $\frac{1}{\overline{m}}$. (while aircraft is landing takeoff is prevented).

The configuration of taxiing at LPA implies the existence of a common route where a conflicts between aircraft might occur. However, if a natural segregate subsystem to separate the taxiing of ATRs from B737/A320 families is applied (see Fig. 3), potential interference between taxiing aircraft is removed. Hence, to estimate taxiing time in route for both aircraft families, the 'no conflict scenario is considered. In this case, the taxiing time in route only depends on the distance from the parking and the aircraft's taxiing speed. Therefore, the taxiing time in route without aircraft interference and for the dates already established, for both years of the study, would be as follows:

Taxi time in route $_{\text{ATR}}$ = (Distance / taxi Speed) + (Power-back Time × 0.3) = 69.57 seg.

Taxi time in route $_{737s/A320s}$ = (Distance / taxi Speed) + (Power-back Time × 0.5) = 221.66 seg.

The cumulative effect of taxiing time in route, the time spent waiting for take off, the increase in fuel costs for air carriers and CO_2 emissions are shown in Tables 5 and 6. As shown in Table 6, an increase in time spent waiting for take off represents significant losses for both air carriers and the airport. These are primarily associated with the increase in fuel consumption and unwanted CO_2 emissions. According to data published by Avions de Transport Régional (2000), the fuel consumption for taxiing, for ATRs aircraft families, was approximately 6 kg/min. For the B737/A320 aircraft families, the fuel burned in taxiing was, on average, 13.6 Kg/min (Lorenzo-Aparicio and Rendeiro Martín-Cejas, 2017). The relationship of 3.15 kg of CO_2 per kg of fuel burnt allows us to estimate the increase in CO_2 emissions. Additionally, the evolution of the fuel price published in IATA (2019), for December of 2017 and 2018, was 1.86 €/kg and 1.81 €/kg,[3] respectively. Using the values estimated previously (see table 4), it is therefore possible to compare the values for waiting time, taxiing time, fuel cost and CO_2 emissions at LPA for the periods before and after the subsidy increase. These results are shown in Table 5. Table 6 shows the annual losses due to the subsidy increase. This is an overestimation because it considers a peak month (December) as a representative month for both years (2017 and 2018). The annual estimation uses the ATM flow from Table 1. However, this could be compensated, because the conflicts in taxiing route operations between aircraft types was not considered, and thus the waiting time before taking off may have been greater.

3.3. Discussion

Subsidising PSO air routes in the Canary Islands has shown significant perverse effects in terms of increased fuel consumption and emissions. As is apparent from Tables 5 and 6, the potential economic and environmental loss for Canary Islander due to the implementation of the subsidy increase is clear. It could have also a negative effect on the use of the main runway (03L/21R) at LPA (due to space constraints, though this is not quantified in this study). LPA airport has two parallel runways (03L/21R, 03R/21L) however only one is currently in use 95.7% of the time, due to annual weather conditions. Further, these two runways do not allow for mixed and simultaneous operations of take offs and landings because the separation is insufficient (210 m) to guarantee

[3] According to the average fuel price for December 2017 and 2018, using a conversion factor of \$1 = 0.87€ for 2017 and \$1 = 0.84€ for 2018 and a kerosene density of 817 kg/m^3.

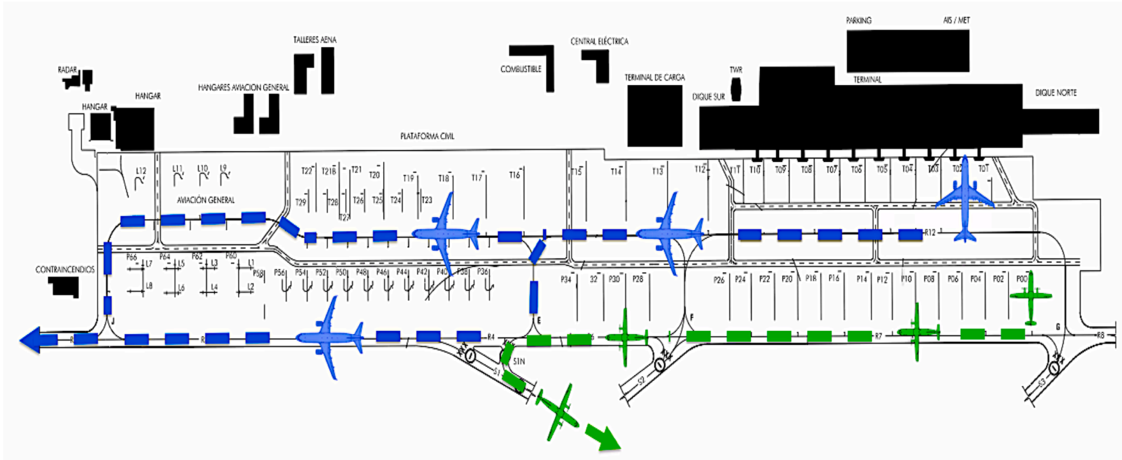

Fig. 3. Segregate subsystem for taxiing.

Table 5
Subsidy impact per ATM and aircraft type at LPA airport.

Year	Aircraft type	Waiting time[3] (s.)	Taxiing time[4] (s.)	Fuel (kg)	Fuel cost (€)	CO_2 (kg)
2017	ATRs	168	69.57	23.76	44.2	74.84
	B737s/ A320s	168	221.66	88.32	164.27	278.21
2018	ATRs	219	69.57	28.85	52.23	90.89
	B737s/ A320s	219	221.66	99.88	180.78	314.62

[3] For each year 'waiting time before takeoff' is considered the same for both aircraft types.

[4] Taxiing time does not vary from one year to the next because of the segregated subsystem for taxiing (see Fig. 2).

Table 6
Annual losses of subsidy increase per aircraft type for taxiing operations.

Aircraft type	Annual fuel cost increase (€)	Annual increase in CO_2 (tons)
ATRs*	877,775	1,604.9
B737s/A320s	1,592,772	3,397.51
Total	2,470,547	5,002.4

*Annual increase in CO_2 for ATRs: (48,175 × 90.89) – (37,068 × 74.84) = 1,604.9 tons. CO_2.

being out of wake vortex influence (Lorenzo-Aparicio and Rendeiro Martín-Cejas, 2017). Regarding runway capacity and considering the two aircraft types, it is apparent from Table 5 that the runway occupancy time (waiting plus taxiing time) for 2017–2018 has increased by about 16.2% of its available time.

There are many other factors that can potentially affect service time in the taxiing phase, such us runway configuration, limited capacity due to weather conditions or air traffic control (ATC). The study has demonstrated that those effects are linked to the competitive use between short-range aircraft and regional turboprops at LPA. As pointed out above, this is one of the main operational singularities of LPA. As is apparent from Table 2, the percentage increase of the ATM by turboprop aircraft (ATRs) in 2018 was higher than the narrow-body families, because of the subsidy effect.

The optimisation of airport operations is one of the main ways to reduce congestion, increase capacity and decrease fuel consumption and emissions. This problem can be approached in specific ways, by considering the characteristics of airport operations. In this sense, one of the main features of an airport using queuing theory is its strong dependence on aircraft types (traffic homogeneity). The most significant part of the total delay occurs during the taxiing phase, and the service time is strongly correlated with the degree of the homogeneity of the traffic mix (Ignaccolo, 2003).

In addition, from Table 3 and for the PSO route between LPA and Tenerife Norte Airport (TFN), the subsidy for December 2018 was about €3,172,760. This revenue from the subsidy could create an incentive to develop new routes from the islands to mainland Spain or to increase the frequency of existing ones. The interisland routes are operated by Binter Canarias S.L. under the Public Service Obligations (PSO) regime (Santana, 2009). Currently, there are two air operators on the Canary Islands, Binter and Canaryfly; however, the latter has been a Binter subsidiary since 2017. In 2019, three new routes to the Iberian Peninsula were created, to Murcia, Pamplona and Zaragoza. In the current year Binter was planning to introduce more peninsula destinations. However, the emergence of COVID-19 could halt Binter's expansion strategy, which for year 2020 perhaps has to be postponed depending on the evolution of the pandemic and the response to it.

In summary, two main effects from the subsidies can be pointed out: a more intensive use of LPA's capacity and an incentive to develop new routes from the Canary Islands to the Iberian Peninsula or/and to increase the frequency of existing interisland routes. Two main consequences should be considered: first, the need to invest in additional airport capacity or to improve it to accommodate an increase in traffic, and, second, the improvement of Canary Islanders' mobility. For the first, a smart solution using LPA's design features could be to separate the operational flow according to aircraft type, that is, creating a turboprop-regional subsystem (airport-within-airport), minimising conflicts between aircraft types in the taxiing phase (Lorenzo-Aparicio and Rendeiro Martín-Cejas, 2017). For the second, cost-benefit analyses would be required if the social and economic value of the subsidy has to be estimated.

4. Conclusion

The subsidy applied to travel between the islands, and from the Canary Islands to mainland Spain, now represents about 75% of the market price. As mentioned above, the subsidy increased from 50% to 75% in June 2018. As a consequence, traffic flow at LPA increased and ground operations became more busy due the conflicts between turboprop-regional aircraft and narrow-body aircraft. Thus, congestion may appear to be a perverse effect, at LPA. An analytical approach was developed to estimate the subsidy's impact on LPA ground operations.

The study showed that the implementation of a subsidy increase for Canary Islands residents has produced substantial economic and environmental losses. From the perspective of the airlines, this subsidy causes an annual fuel cost increase of about 2.47 million euros and an increase in CO_2 emissions of about 5,002 tons. In addition, it has to be pointed out that this subsidy produces an increase in ground operations time (waiting plus taxiing time) and, therefore, an increase in 2018 of the runway occupancy time as it is apparent from table 5. These losses, however, have to be balanced with the social and economic benefits that each regional inhabitant derives from the subsidy in terms of improvement in mobility for any purpose. Nevertheless, as I have pointed out above, these losses are underestimated, because the conflicts in taxiing route operations between aircraft were not considered.

A natural extension of this work would be to implement a cost-benefit analysis of the mobility improvement that this subsidy increase produces for Canary Islands inhabitants. Also, further work needs to quantify the reduction in LPA's available runway capacity at peak periods. This would allow us to determine how this subsidy increase affects the quality of airport service. Finally, a more technical analysis might explore the implementation of similar procedures while considering conflicts between aircraft in taxiing route operations.

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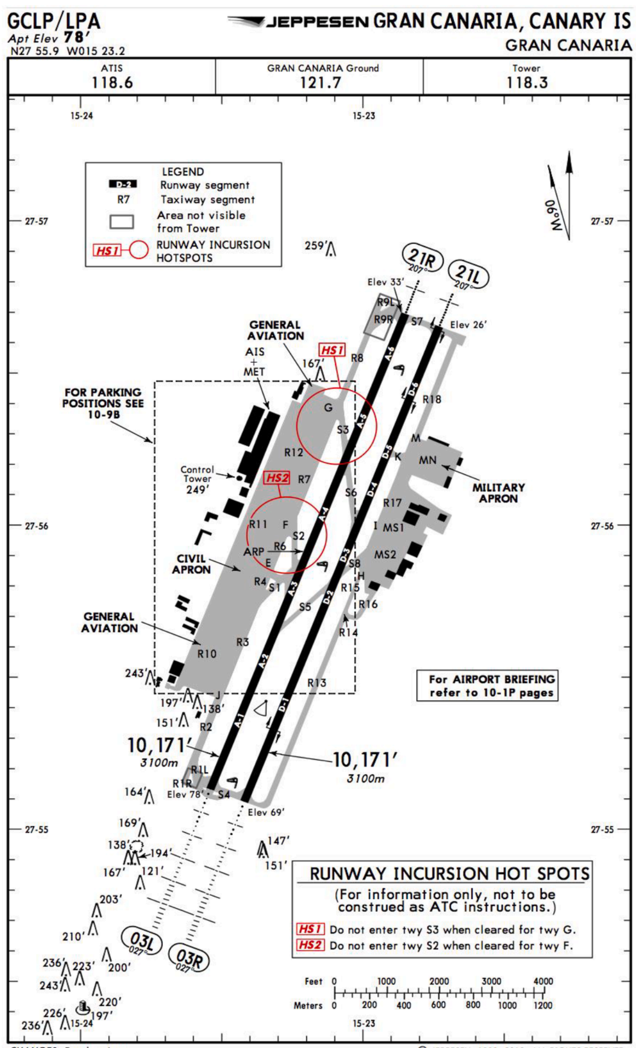
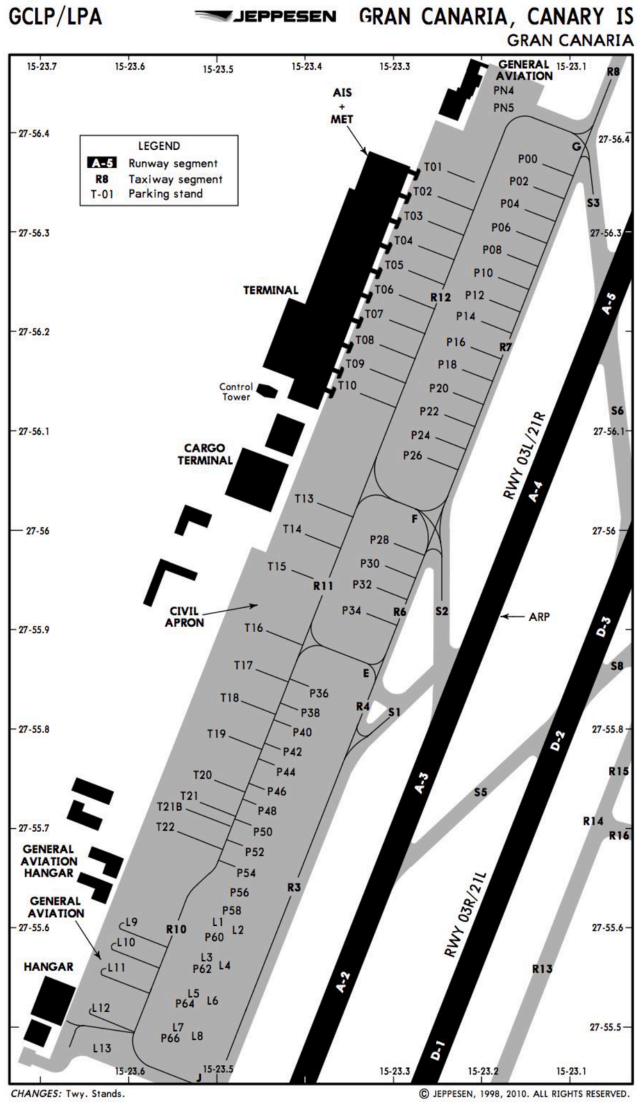
Appendix. Gran Canaria Airport Plan





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Glossary

AENA: Aeropuertos Españoles y Navegación Aérea
ATM: air transport movement
ATR: Avions de Transport Régional
GDP: gross domestic product
GHG: greenhouse gas
Knots: approach speed units
LPA: Las Palmas Airport (Gran Canaria Airport)
PSO: public service obligation