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EVALUATION OF CONGESTION COSTS FOR MADRID AIRPORT (1997-2000)

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Executive Summary

- Airport congestion is a phenomenon different from the traditional concept of congestion when applied to roads. Even though the users of airports' basic infrastructure (airlines) do not enter randomly into the system, there are also evident congestion effects in air transport.

- Flight delays are originated by a number of factors, which are generally difficult to disentangle if the exact causes of the problem are to be determined. When a plane is delayed, it must be moved out of its original arrival/departure schedule. Each delayed plane imposes changes in departing or arrival times for other flights, which subsequently generate additional delays in a cascade-type of effect.

- The intensive use of airports' infrastructure aggravates congestion, but it is not its ultimate cause. A different problem to that of congestion is the lack of airports' capacity to accommodate demand, which is summarised under the concept of 'scarcity'. Scarcity costs are those costs related to the existence of unsatisfied demand (potential revenues lost by airlines, sub-optimal use of landing slots, limited competition among incumbents). These costs are related to infrastructure capacity, while congestion costs are related to the provision of services.

- Airport congestion has a negative impact on passengers, cargo shippers, and airlines. This case study analyses congestion problems at Madrid airport, using data on programmed and actual arrival/departure times for passenger flights. Two basic objectives are pursued: (i) understand the phenomenon of airport congestion; and (ii) evaluate congestion costs both for passengers and airlines, in total and marginal terms.

- Data used consists of information on all flights arriving and departing from Madrid airport, during a month of reference (July), which is studied for the period 1997-2000. Data was obtained directly from AENA (*Aeropuertos Españoles y Navegación Aérea*), the public institution that owns and manages the main Spanish airports. Variables used are: scheduled and actual arrival/departure times for flights; cities of origin and destination, type of aircraft and number of passengers for each flight.

- The period of reference is quite interesting for the analysis, because Madrid airport has enlarged its capacity between 1999 and 2000 (from 50 to 68 maximum flight movements per hour). It is then possible to analyse what is the impact of this expansion over delays and congestion costs. The number of passenger flights per month (arrivals+departures) increased from 20,800 in July-1997 to 29,377 in July-2000 (41.2%).

- A total of 3.8 million passengers passed through the airport of Madrid in July 2000. By origin/destination, about half of total activity corresponds to domestic flights; 35% to EU countries, and 15% to destinations outside EU, basically concentrated in North- and South-American cities. It is remarkable that the airport enlargement has resulted in a rapid expansion of flights to/from destinations at EU Member States, which have doubled their numbers between 1997 and 2000. This has been done both by opening routes to new destinations, and by providing more services in existent ones.

- A descriptive analysis of flight delays provides interesting information to understand the process of delay generation. Three main findings can be highlighted:

  (i) *arrival and departure delays are highly correlated*, even though average arrival delays are generally higher than those of departures.

  (ii) *there exist spill-over effects between one-hour intervals*, when there are problems at some point during a day, all the subsequent periods are affected.

  (iii) *expansion of capacity at Madrid airport has slightly eased congestion*, the percentages of delayed flights and total number of hours lost by passengers were smaller in 2000 than in 1999. However, the magnitude of the benefits is quite small compared to that of the capacity expansion. The airport enlargement has solved –at least partly– the problem of scarcity of infrastructure, but not congestion problems.

- There are two alternative definitions used in the sector for a flight delay: arrivals/departures 15 minutes later than scheduled, or 30 minutes later. For the quantification of total congestion costs, reported results are based on the second definition. Calculations performed using both definitions show that the bulk of lost hours and costs is due to long delays (flights delayed between 15 and 30 minutes constitute a minor part of total lost hours). However, for calculation of marginal effects of each delayed flight, the first definition (>15 minutes) is used.

- Total amounts of time lost by passengers and airlines is considerable. In July 2000, estimated lost time for passengers who were delayed more than 30 minutes amounted to more than one million hours, equivalent to 7,426 hours lost by airlines. In terms of total flight movements, around 20% of flights experienced delays in 2000. This figure is slightly better than the average for the four-year period 1997-2000.

- Results obtained for passenger congestion costs reveal the magnitude of the problem suffered at Madrid airport. In July-2000, total passenger costs amounted to 16.2 million €. Average costs are estimated between 4.5-5 € per passenger.

- Taking July-2000 as a month of reference, total congestion costs in 2000 amounted to 55.4 million € per month (16.2 million corresponding to passenger costs, 39.2 million to airlines). In annual terms, assuming that July could be considered a representative month of the activity of Madrid airport, total congestion costs are evaluated at **664.8 million €.**

- In marginal terms, each delayed flight at Madrid airport caused congestion costs estimated around **7,000 €** in July 2000; (b) marginal congestion costs seem to have improved after the enlargement or airport capacity.

- The amount of total congestion costs shows the importance of new investments on airport infrastructure, and/or a better management of existent capacity. A complete elimination of congestion problems is probably not an option, because it would require enormous amounts of investments for airports and airlines (e.g. more personnel and fleet), which could prove more costly than the problem to solve. On the other hand, results from this case study of Madrid airport indicate that construction of more infrastructure does not guarantee elimination of congestion, because of scarcity problems.

- Solutions to air congestion problems in Europe need a better management of existent capacity (together with expansion of some saturated airports). Further integration of air traffic control systems, better systems of slot allocation and pricing at airports, and incentives for airlines to promote punctuality, are all measures which could help to ease substantially the problems of congestion that European air travellers are currently suffering.

1. Objectives of the case study

Congestion is a phenomenon that is present in air transport, similarly to any other transport modes. Although there exists some economic literature in this area, surprisingly, airport congestion has attracted much less attention than the case of roads, as pointed out by Quinet (1997). This is probably due to the fact that congestion started first to be analysed for road transport, and it is for this mode where the random nature of the problem exactly fits the definition of what is generally known as *congestion*: negative external effects that the entry of an additional car causes over the rest of road users.

Even though the users of airports' basic infrastructure (airlines) do not enter randomly into the system, there are also evident congestion effects in air transport. Flight delays are nowadays a common feature suffered by most European air travellers, and many of these delays are not directly caused by the same company that operates a delayed flight (the situation fitting then exactly with the definition of congestion just presented). Delays are originated by a number of factors, which are generally difficult to disentangle if one wants to determine the exact causes of the problem. And, additionally, when a plane is delayed and must be moved out of its original schedule, it involuntarily imposes changes in departing or arrival times for other flights, which are subsequently delayed in a cascade-effect.

Congestion is thus as relevant for air transport as it is for roads, although in the first case it does not have the characteristic of random entry of users into the system. The entry (exit) of planes into an airport is perfectly programmed according to the demand from airlines, the available infrastructure and the capacity of air traffic control (ATC). But, when some unexpected event distorts the flights' schedule within any period of a day, not only all flights in that period are affected by the external shock, but probably most of flights scheduled for the next periods during the day. The frequent intensive use of airports' infrastructure aggravates this problem.

Airport congestion has a direct impact on final users –mainly passengers, but also freight shippers– and on airlines' costs. This case study analyses in detail the process of generation of flight delays at Madrid airport, using data of scheduled and actual arrival/departure times. The objective pursued with this case study is twofold:

- Try to understand the phenomenon of airport congestion through the analysis of flight delays.
- Evaluate congestion costs both for passengers and airlines.

Even though congestion costs are suffered by passengers and also by freight shippers (Chartered Institute of Transport, 1992), this case study is restricted to passengers' flights , because it is much more difficult to try to estimate the value of time associated to delays suffered by goods, due to the scarce information on cargo flights.

As it is the case in most studies concerning congestion costs, our results are approximations to the real costs that ideally one would want to measure, which in practice are extremely difficult to calculate accurately. Most costs associated to congestion problems are opportunity costs –i.e. the value of time and resources lost due to delays– and therefore highly subjective for the case of passengers. Also for airlines, it is relatively easy to determine what are the monetary costs caused by delays (extra time of personnel, consumption of fuel, and so forth), but there are also other indirect costs which are harder to measure. Among these, for example, we should include: (a) opportunity costs of grounded aircraft, which could be generating some revenues in another route, which are lost because of delays; (b) loss of users, who are diverted to other airlines or to alternative modes of transport when available; and (c) damages to the image and name of an airline.

Nevertheless, even though all these caveats must be kept in mind, estimated congestion costs from this study are sufficiently high for it to offer some valuable information for policymakers. At the light of our results, the main implication would be an urgent need for solutions in the short-term for the problems of European air traffic, in terms of better management of existing capacity (both of airports and ATC systems). In the long-term, estimated congestion costs provide a benchmark to evaluate the desirability of investments in new capacity. Additional capacity can be a solution to airport congestion problems, but it must be studied jointly with the question of scarcity of airport infrastructure (see next section for a precise definition of congestion and scarcity for airports).

The analysis of delays and evaluation of congestion costs presented here are based on the particular case of Madrid airport. However, the methodology used for the study of delays, and the calculation of total costs are directly transferable to other airports, provided the existence of databases with detailed information on scheduled/actual departure and arrival times, number of passengers per flight and type of planes. Similarly, the methodology could easily be transferable to other scheduled transport modes, for which it could be possible to obtain information on programmed and actual departure/arrival times.

The structure of the paper is as follows: section 2 discusses the concepts of airport congestion and scarcity from a theoretical perspective. Section 3 discusses the requirements of information to evaluate airport congestion costs in practice, and presents the values of time for passengers and airlines chosen for this study. Section 4 presents the data used for the case study, and offers some indicators of Madrid airport's activity. Section 5 analyses the process of flight delays by examining how average departure/arrival times evolve through the different one-hour intervals within a day. The evolution of average delays across the four-year period studied here (1997-2000) is also examined and contrasted with the capacity expansion during the same period. Section 6 is devoted to the calculation of total and marginal congestion costs, presenting the main results obtained in the case study. Transferability of results and methodology are discussed in section 7. Finally, section 8 summarises the main findings and concludes.

2. Concepts of congestion and scarcity for airports

Airport congestion has been a common feature in Europe during the 1990s. Delays at main European airports have been increasing with their undesirable effects in terms of higher traveller and producer costs, directly through an increase of generalised costs of travel and indirectly through the reduction of air transport competition due to scarce infrastructure. Some previous analyses of questions related to airport congestion can be found in Fisher (1989); Oum and Zhang (1990); Daniel (1995); and Wolf (1998).

Airport capacity is determined by basic ground infrastructure components such as runways, aircraft stands, fingers, etc., and the ATC infrastructure. Capacity is defined as the ability of a component in the airport system to handle aircrafts, and it is usually expressed in terms of plane movements per hour. Airport capacity is therefore the maximum number of operations than can be accommodated within an hour, taking into account the prevailing conditions of visibility, air traffic control, aircraft mix and nature of operations (Reynolds-Feigan and Button, 1999).

Among all components of airport capacity, runways are usually the main constraint, because they are the key element determining the number of take-offs and landings per hour. If for any reason the scheduled flights in a particular hour fail to use their slots in the programmed time, capacity cannot be expanded in the next hour and so congestion starts to build up. According to IATA and AEA[1] these delays are classified as follows:

- internal airline problems or schedule discrepancies
- passenger and baggage
- cargo and mail
- aircraft and ramp handling
- technical and aircraft equipment
- damage to aircraft and automated equipment failure
- flight operations and crewing
- weather
- airport and government authorities (including air traffic control)
- reactionary (delays caused by late arrival of scheduled planes)
- miscellaneous

The causes listed above imply delays and costs for passengers and companies and it is common to name all these costs as congestion. However, all these extra costs are not a direct consequence of congestion, as this concept is usually defined in the economic literature, but they also reflect a shortage of capacity.

A formal distinction between congestion and scarcity can help to clarify the causes and the economic effects of airport delays. Airport infrastructure is fixed in the short-run and, in contrast with road infrastructure, only qualified users are allowed to enter the system. The allocation of scarce infrastructure to demand is done through an *ex ante* procedure of slot assignment. The additional costs of unscheduled delays are not necessarily caused by an inefficient behaviour of the system management, but generated by a need to accommodate within any given period those flights which are delayed from the previous period.

A distinction between the concepts of congestion and scarcity would be the following (Doll et al, 2000): congestion refers to the costs arising from crowding effects (too many users in the system), and scarcity is a situation of exclusion of some firms from the system due to lack of capacity. Thus, congestion is related to transport services while scarcity is related to transport infrastructure.

The concept of scarcity is the main difference between air and road transport (it is also a concept directly transferable to railways). Air transport services are provided by a reduced

[1] These are two associations of airlines: IATA (International Air Transport Association) has a long tradition in the sector, and in the past played a central role as co-ordinator for the determination of fares and revenue-sharing agreements between carriers. AEA (Association of European Airlines) brings together the main European carriers to defend their common interests.

number of carriers, which must be co-ordinated by airport authorities for the use of scarce capacity (number of landing slots). The usual equilibrium, at main airports, is that more operators would like to enter the system but must be excluded. In this situation, scarcity costs arise when a particular slot assigned to an incumbent could have a higher value if used by another carrier.

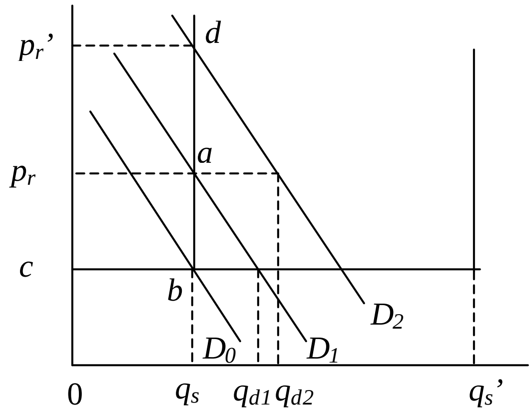
It is difficult to estimate scarcity costs, because one would need to determine what is the best use of landing slots, which will be related to foregone revenues by potential users compared to revenues earned by airlines that currently use them. Moreover, as pointed out by Nash and Samson (1999) for the case of railways, these costs are strictly only an externality if borne by another operator. When the next best use is by the same operator, scarcity costs are internalised, because the incumbent airline will already have considered the alternative uses of the slot (possibly assigning it to schedule flights for a different route).

Therefore, scarcity is a concept that applies to transport systems where a number of firms share some common infrastructure, and there is an excess of demand. This idea does not apply to road transport, where users (motorists, trucks, buses) directly enter the system with their vehicles without any external coordination. If road capacity leads to a situation of excess demand, then congestion costs arise, because users cannot generally be ex-ante excluded from entering the road.

Congestion for the case of airports (and railways) is different from roads. It is a situation where occasionally the system is overload due to some exogenous problems, which causes allocated users per hour to fail to use their slots and congestion builds up into the next hours.

Figure 1, adapted from Starkie (1988) illustrates the concepts of congestion and scarcity, and their relevance for the economic analysis of airports' activity.

Figure 1. Airport Congestion and Scarcity



When demand is D_0, at the declared runway capacity (q_s), the market equilibrium price is equal to c. This price level both keeps demand equal to available capacity and it covers total costs of supply, including a reasonable rate of return on the capital invested (constant average costs are assumed).

Consider that infrastructure capacity is kept constant at q_s and assume that demand grows to D_1. Two main options are feasible: one is price-rationing, increasing the price up to p_r; the other consist of allowing an excess of demand (q_{d1}-q_s) to exist, with the associated extra costs to passengers and airlines caused by delays. Nevertheless, a further consideration of the problem shows that the second option is not realistic as long as the nature of D_1 is taken into account. Let us assume that D_1 is the known *expected* demand. It seems clear that at price *c,* excess demand means that more *passengers* than the maximum capacity of the airport want to use it, so the airport manager could increase the price of the allocated slots up to p_r.

The normal practice is quite different, as pointed out by Starkie (1988). Many airports do not charge rationing prices but even use charges which are below the average cost of supply. That means that at a price lower than p_r there are more air travellers than seats available, inducing profit maximising airlines to increase their fares to accommodate the excess of demand and to earn an extra rent, equal to area $p_r abc$ in Figure 1, when airport charges are equal to *c.*[2]

Assume now that, despite expected demand D_1 has been accommodated to the existing capacity through the market clearing price p_r, the actual demand (D_2) exceeds capacity in the *t* hour due to some flights failing to take-off or land as originally scheduled in the *t-1* hour. The negative external effects on passengers and airlines are the costs of congestion for air transport.

To avoid inefficiencies in the airport system, a solution would be to try to internalise these external effects. Because the shift from D_1 to D_2 can be affected by a number of factors, including random effects (weather, incidents, others), but also some variables which can be controlled (landing charges, slot pricing, capacity expansion), it would be interesting to measure the external costs of delays at airports. The next step after quantification would be to analyse who causes delays and who suffers the costs, although this is a much more complex exercise.

Changes in passengers' generalised costs and airlines' costs

The measurement of airport congestion can be approached through an evaluation of changes in user and producer surpluses. The simple framework developed above allows to identify what are the basic variables that should be included to study congestion costs. According to the available data, the evaluation in practice can be afterwards be more or less accurate.

With actual demand at D_2 (see Figure 1), and the impossibility of applying a rationing price p_r', the excess demand (q_{d2} - q_s) will create external costs both for airlines and passengers. Users' generalised cost of travel can be expressed as:

$$g = p + v_t t + g \tag{1}$$

[2] There is some evidence about the size of this economic rent. The RUTCASE report suggested that the difference between p_r and *c* for Heathrow meant a fare premium charged by the airlines of 20 sterling pounds.

where p is the air fare; t is travel time (waiting and in-flight time); v_t is the value of time; and g is some measure of quality (user's perception related to reliability, comfort and safety).

Producer surplus can be expressed as:

$$PS = pq - (c + q)q \qquad (2)$$

where q is the number of passengers; c is the marginal cost per passenger; and q is the compensation (assumed constant) paid by the airline to each passenger.

The change in users' surplus is then:

$$D\mathbf{US} = -\boldsymbol{(}D\mathbf{p} + \mathbf{v}_t D\mathbf{t} + Dg - q\boldsymbol{)}\ \mathbf{q} \qquad (3)$$

where Δ represents the change in each variable between period 1 and period 0. Demand q is assumed to be constant, and also the utility obtained by travellers from used services, even though price and other components of generalised costs may vary between the two periods. The negative sign of expression (3) indicates that the variation of users' surplus is simply equal to the change of total generalised costs.

The change in producer surplus when there is a system overload is:

$$D\mathbf{PS} = \boldsymbol{(}D\mathbf{p} - Dc - q\boldsymbol{)}\ \mathbf{q} \qquad (4)$$

Change in social surplus is obtained by the sum of DUS and DPS (adding expressions (3) and (4)). Without any modification of fares, change in total social welfare would be equal to (minus) total congestion costs:

$$D\mathbf{W} = -\boldsymbol{(}\mathbf{v}_t D\mathbf{t} + D\mathbf{c} + Dg\boldsymbol{)}\mathbf{q} \qquad (5)$$

When airlines are able to pass their additional congestion costs to passengers through prices then $Dp = Dc + q$, and we could then evaluate total congestion costs simply as the effects borne by passengers. In that case, congestion costs, measured as the reduction of social surplus, are:

$$(Dp - q + v_t Dt + Dg)q \qquad (6)$$

Thus, theoretically congestion costs could be evaluated by computing the change in fares (induced by extra costs on airlines), the value of extra time spent by travellers and the loss of quality that they suffer, and deducting the monetary compensation q received from airlines.

What can be measured in practice?

It is unrealistic to consider that expression (6) could be applied in practice to evaluate congestion costs. First, there is a large number of elements which affect to air fares, apart from extra costs borne by airlines because of congestion problems. For example, changes in prices of production factors, or in the competitive environment are likely to have a more important effect on fares than congestion costs. Second, quality changes for passengers –

which are mainly derived from uncertainty related to flight unreliability – are probably as important as difficult to measure in the context of a study of congestion costs.

Expression (5) is more useful than (6) in practice to evaluate congestion costs. One required simplification is to assume that quality effects are reflected in a higher valuation of time for passengers (considering that discomfort caused by delays results in a value of time v_t’, so that $v_t' Dt = v_t Dt + Dg$). Total congestion costs (TCC) can then be evaluated as:

$$\boldsymbol{TCC} = \boldsymbol{v_t}' D\boldsymbol{t}\,\boldsymbol{q} + D\boldsymbol{c}\,\boldsymbol{q} \qquad (7)$$

Expression (7) provides the theoretical background for this case study. It reflects the fact that total congestion costs can be evaluated from two separate parts: costs borne by passengers in terms of extra time spent at airports, and extra costs assumed by airlines. Compensations paid to passengers by airlines should be excluded from calculation of airlines’ costs to avoid double counting, because compensations are destined to cover part of the value of passengers’ time, which is already included as passengers’ costs in TCC.

The increase in airlines’ costs per delayed passenger (Dc) is difficult to estimate. The approximation used in this work is to evaluate extra costs for airlines per hour of delay. Formally, we assume a value for airlines’ extra time (V_t), derived from studies performed by airlines, so that the term $Dc\ q$ can be substituted by $V_t\ Dt$. The valuation of time used for passengers (v_t’) is obtained from the conventions established for UNITE for different travel purposes, assuming that 15% of passengers are business travellers and 85% leisure travellers.

3. Information requirements for evaluation of congestion costs

Evaluation of congestion costs based on expression (7) above for a particular airport system, requires the use of detailed information about the number of flights and passengers using that system, and actual delays that all flights experience during some period of reference (week, month or year).

The existence of data on delays allows the computation of total time lost by passengers and airlines, which can be translated into monetary terms. However, there are some issues that need to be considered before directly applying valuations of time to the data on delays to calculate congestion costs. This section discusses three points: (a) what should be included and excluded when computing delay times; (b) how to evaluate value of time for passengers; and (c) how to calculate airlines’ costs due to congestion.

3.1 What flight delays should be included?

The first step to carry out a study of congestion costs is to define what system is the object of study. The nature of air transport involves the interaction of several agents in the process of moving passengers (cargo) from a city A to another city B. Apart from the airline that actually operates the plane, we will have to include the managers of airport A and those of airport B, for matters related to ground operations (assignment of stands, handling, fuel, catering and so forth). In addition, other agents in charge of air traffic control (ATC) in the areas of A and B, and all ATC centres that control the flight during its journey between A and B will also have an effect on its performance.

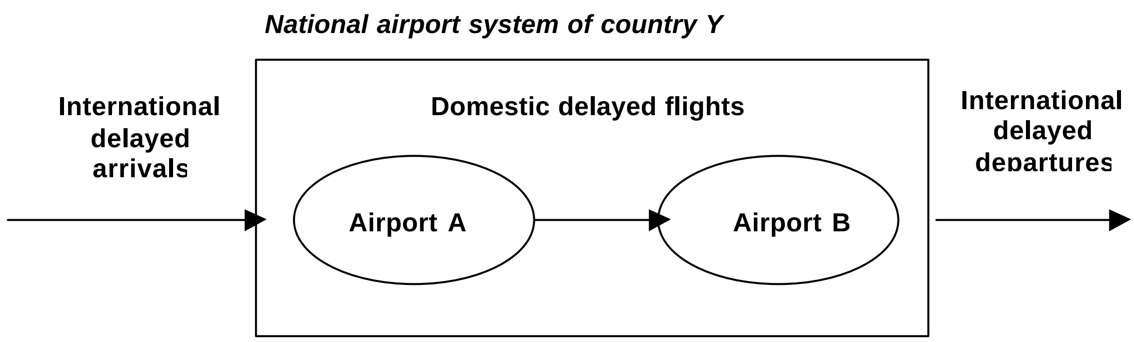
When a flight arriving at B is delayed *x* minutes, there are many reasons which can have caused that delay. Airport A could have experienced problems with its departures, so the plane did not take-off on its scheduled time. The same situation could be caused not by airport problems, but by the own carrier. This is not an infrequent event: airlines design their routes in such a way that an aircraft does not necessarily operates only in the route A-B-A, but it can rotate so that during the same day the plane provides services for example in the routes A-B-C-D-A. If difficulties arise in any of the 'legs' of this journey (say, airport C has problems and induces a delay in the flight), all the rest of the journey stages can be affected (in the example, the plane will arrive late at D, subsequently also at A, and all the next cycle A-B-C-D-A could also be affected).

If the airline cannot make up the initial delay, by recovering time in-flight, or by substituting the scheduled aircraft by another, all the airport system in which it operates receives the impact of the original delay at C. This is precisely the nature of airports' congestion: all users (airlines and passengers) are affected by problems experienced at any point in the system, and not directly caused by them.

The delay analysed in the former example could also be originated not by problems at the airport A of origin, but from difficulties at destination B. When airports are co-ordinated, flights which are expected to be delayed at B will be held at A instead of allowing them to depart on time, and subsequently have to wait in the air until a landing slot is available at B. Ground delays are cheaper for airlines than having planes waiting in the air, therefore this practice is optimal both for companies and passengers. The consequence is that departure delays at A will be directly connected with arrival delays at B, so one should be careful when computing total delay times that an airport system is experiencing.

If the object of study were a single world-wide airport system, it is clear than adding up arrival and departure delays would not be correct, because delay times would then be included twice (assuming all airport being co-ordinated, and discarding delays caused en-route by ATC congestion). However, when the idea is to study congestion costs for example for a national airport system, this double-counting effect would only be relevant for domestic flights, but all arrival and departure delays should be included for international flights.

Figure 2. Measuring total flight delay times for an airport system



Even if there existed detailed data about all delays experienced by airports within the national system of some country Y, it will be difficult to accurately estimate those congestion costs generated exclusively by perturbations within the system. It is clear that all delays computed for domestic flights (those represented by the arrow inside the box in Figure 2), which will be calculated by adding all departure delays or alternatively all arrival delays, could be assigned to reasons originated within the system: problems at any of the national airports, or ATC restrictions in the national airspace.

However, international arrival delays will reflect congestion costs suffered by passengers using country Y's airport system, but not necessarily caused by the own system. Late arrivals could well have being originated by problems experienced by the airport system of the country of origin (this will be more likely the farther is located the departing airport). Similarly, congestion costs computed from delayed international departures will not necessarily have been caused by the studied system. International flights departing from Y could be held at airports of origin because of difficulties experienced at destinations. Although in the case of departure delays it is probable that a high percentage of them will be caused by problems at Y's airports, it cannot be directly inferred that all of them should be assigned to the national system as the ultimate origin of congestion problems.

This simple example intends to illustrate the difficulties that a study on the causes of congestion will necessarily experience, unless there exists detailed information on the reasons explaining why each plane is delayed. The number of interactions between all agents involved and the complex process of spill-over effects among flights makes it extremely difficult to determine causes. However, even if it is almost impossible to accurately determine who *causes* delays, it is not so complex to evaluate who *suffers* those delays and to obtain approximations to the costs involved.

This is the basic objective that we pursue in this case study. Given the data available, which are restricted to delays experienced by flights at Madrid airport, it is not feasible to try to estimate congestion costs for the whole Spanish airport system. Moreover, even if data on all national airports could be used, the fact that Spanish airports are co-ordinated with their main destinations (at least within Europe) would make it extremely difficult to separate what part is caused by national problems and what other by difficulties at international destinations.

Thus, here we intend to measure congestion costs experienced by users of Madrid airport, regardless if the causes of congestion are a responsibility of the own airport, other national airports, or other international systems. The role as a hub that Madrid plays within the Spanish national airport system, and the known situation of demand reaching its maximum capacity during peak-hours, imply that most of estimated congestion costs for domestic flights could in principle be attributed to lack of more capacity at Madrid. However, we are aware that figures provided would tend to overestimate costs whether the objective be to evaluate what congestion is exactly caused by Madrid. Even if there were excess capacity at the airport of Madrid, some flights could arrive/depart late due to problems at London, Paris, Frankfurt or Milan, for example.

The option chosen then has been to add up all delays experienced by flights using Madrid airport during some periods of reference. Nevertheless, information is presented separately for arrival and departures, and it is also feasible to determine what part of total congestion costs refers to national and international flights.

3.2 Congestion costs for passengers

Once that total flight delay times are calculated, in order to calculate costs suffered by passengers, it is required to have the number of travellers affected by each delay. Ideally, one should have the exact number of passengers on each flight, so that the number of minutes of delays can be translated into total passengers' time.

If this information is not available, it is always possible to approximate it by the type of aircraft that each company allocates to provide services in a particular route. Knowing the average number of seats per type of aircraft, and using some assumption on load factors, it is possible to obtain good approximations to total numbers of passengers.

In the case of Madrid airport, detailed data on actual number of passengers per flight exists for 1999 and 2000. For the other two years in the sample (1997 and 1998), the other approach based on aircraft types was used. Overall, the quality of data on total passengers' extra time due to flight delays is quite satisfactory.

The valuation of time for passengers is based on the values established for UNITE (Nellthorp et al, 2001): 21 €/hour for business passengers and 15 €/hour for leisure travellers. Under the assumption of 15%-85% weights, this results in an average value of time of **15.9 €/hour**.

3.3 Congestion costs for airlines

The evaluation of congestion costs for airlines involves the determination of all extra costs per hour of flight delay, which a company would have not faced if the aircraft had departed/arrived on time. Some of these costs are relatively easy to calculate, because airlines have some hourly cost estimates for personnel, fuel, aircraft use, airport fees, and so forth. Studies performed by airlines to evaluate their congestion costs generally consist of a detailed description of items involved.

An example of this list of extra costs for a typical airline would be the following:

- Personnel: Extra hours from pilots and other cabin crew members (technical staff) are required almost regardless of the size of the delayed aircraft. For the rest of the crew, the aircraft size is a key determinant of the cost per hour of delay. It is obvious that a delay of a large plane (e.g. 747, DC-10) will be for an airline much more costly than a delay for a smaller aircraft (e.g. a 50-seat plane), in terms of personnel costs.

- Handling costs: Extra time spent by aircraft at airports involves a higher use of infrastructure (boarding doors, planes stands, and so forth), and handling services.

- Fuel: Extra costs are generated when an aircraft is instructed to speed up in medium- and long haul routes, where it is possible to recover part of delayed time during the flight.

- Cargo: Airlines that perform cargo services must offer compensation to shippers for long delays, and also face extra storage fees. Additionally, there is an opportunity cost for the available space that an airline may own within an airport for cargo operations.

- Compensation to passengers: Airlines must pay some compensatory payments to passengers in the case of long delays (in the case of EU, these are determined by the Commission), and pay the costs of hotels, transport and boarding of travellers which are forced to spend nights without reaching their destinations. Other associated costs are those of rebooking passengers, and transport of delayed luggage.

Casual evidence from figures provided by airlines suggest that the first and the last item of the list above form the bulk of the direct congestion costs assumed by airlines (around 30% each of them). Handling costs will have a share of 10-20%, and the other components between 5-10%, depending on the type of company.

Much more difficult to estimate are the indirect costs borne by airlines because of flight delays, in terms of lost revenues and opportunity costs. These costs are extremely subjective, which explains the variability of estimates presented by airlines in their studies of congestion costs. Thus, for example, British Airways reports a cost around 7,500 €/hour, while Lufthansa quotes a much lower figure around 3,500 €/hour (ATAG, 1999). The type of routes and aircraft employed by each airline undoubtedly have an impact on its average costs per hour. In a study on European ATC congestion problems, Eurocontrol (1999) considers a value of 22 €/minute for direct costs borne by airlines for primary delays. To this, an additional 70% is added because of 'reactionary' delays, (i.e. induced by late arrival of incoming aircraft due to primary delays). In total, direct costs are valued at 2,250 €/hour. This figure does not include any opportunity costs for airlines for alternative uses of grounded aircraft, or any value assigned to the loss of passengers because of delays.[3]

Given the uncertainty about hourly rates to evaluate congestion costs for airlines, and the large number of companies using the airport of Madrid, a value of 5,000 €/hour is used in this case study. This assumption is based on an approximate average of the existent studies quoted above, and it is considered a reference for the average plane using the airport (around 135 seats). As information on the type of plane suffering delays is available, airlines' congestion costs are calculated based on different hourly rates for groups of aircraft classified according to size. Values used are: 1,302 €/hour (planes with less than 70 seats); 4,276 €/hour (71-160 seats); 8,570 €/hour (161-300 seats); and 13,478 €/hour (more than 300 seats).

[3] The Eurocontrol study evaluated total social cost (passengers+airlines) induced by ATC delays for Europe at 5.7 billion euros in 1999.

4. Data

Information used for this case study are data on all arrivals and departures from Madrid airport, during a month of reference (July), which is studied for each of the four years within the period 1997-2000. Data was obtained from AENA (*Aeropuertos Españoles y Navegación Aérea*), a public institution that owns and manages the system of main Spanish airports. AENA is also responsible for air traffic control in the Spanish airspace.

Information on flights using Madrid airport is collected on a daily basis, for some basic variables such as arrival/departure times, type of service (passengers, cargo, others), number of passengers, type of aircraft providing services, origin/destination, and so forth. Data does not allow to identify the company providing each flight, to safeguard confidentiality issues.

There is an on-going project, developed together with the main carrier using the airport (Iberia) to include in the computerized information system some codes to try to evaluate the causes of delays. Although in the databases provided by AENA, part of this information on causes was available for departures of years 1999 and 2000, it was finally not used in this case study, because it appeared only in four broad groups or causes of delays (airport, ATC, airlines, aircraft turnover, and others), and most delays were assigned to the unspecific miscellaneous group of causes named as 'others'.

Even though data contain information about cargo flights and other non-commercial flights (training, emergencies, military planes, and so forth), it was decided to restrict the use of information on flight delays to passengers' flights. Cargo flights amount only to a small fraction of total plane movements at Madrid (around 5%). The number of flights included in the dataset for estimation of congestion costs are presented in Table 2:

Table 2. Number of flights using Madrid airport (1997-2000)

	July 1997	July 1998	July 1999	July 2000
Arrivals	10,334	11,100	12,741	14,684
Departures	10,466	11,132	12,752	14,693

The number of arrivals and departures at Madrid airport has increased during this four-year period. This corresponds to the implementation of some phases of a long-term project to expand airport capacity (construction of a new runway, a second ATC tower, and enlargement of terminal buildings). Thus, the period of analysis is particularly interesting, because it allows to study the impact of capacity expansion on congestion and also reveals the situation of infrastructure scarcity, through the observed entry of more airlines and/or increases in existent services after expansion.

The month of July as a period of reference was chosen because this is one of the months of high airport activity at Madrid, and it is not significantly affected by adverse meteorological effects. Airport activity is approximately homogeneous during working days through the week (the number of arrival/departures is only slightly higher on

Mondays and Fridays), while weekends exhibit a lower level of activity. Due to this fact, only data on working days is used to evaluate marginal effects, although for the estimation of total congestion costs, weekends have been included.

Table 3 presents some basic indicators of Madrid airport's activity:

Table 3. Basic indicators of Madrid airport (1997-2000)

	July 1997	**July 1998**	**July 1999**	**July 2000**
Total movements *(% annual change)*	23,002 -	23,036 *(0.1%)*	26,948 *(17.0%)*	31,292 *(16.1%)*
Total passengers *(% annual change)*	3,204,290 * -	2,990,599 * *(-6.7%)*	3,375,865 *(12.9%)*	3,825,089 *(13.3%)*
Capacity ** *(% annual change)*	50 -	50 *(0%)*	68 *(36%)*	68 *(0%)*
Number of airports of origin	149	148	143	148
Number of destinations	152	146	148	152

Notes: * As indicated in the text, in 1997 some flights did not report the actual number of passengers, and figures were estimated from aircraft types. The reduction in the number of total passengers between 1997 and 1998 can then be justified by an overestimation in the number of passengers in 1997.

** Maximum number of movements (arrivals and departures) per hour. This information was provided by AENA.

Analysis of flight movements by origin/destination

By groups of origins/destination, the activity of Madrid airport is distributed as shown in Table 4. Domestic flights amount to around 50% of total movements, both for arrivals and departures (using figures of July-2000). Meanwhile, flights with origin/destination in EU countries have a 35% share in the activity of the airport, (28% Schengen-zone, 7% non-Schengen). Origins and destinations outside EU amount to 15% of total movements, and are basically concentrated in North- and South-American cities.

Over the period 1997-2000, it is remarkable the rapid increase that EU-flights have experienced, specially those within the Schengen zone. Domestic flights grew at rates around 15%, while flights to European destinations have increased by rates above 20%. The effect is that total number of movements with origin/destination in the Schengen zone has doubled between 1997 and 2000. The expansion of non-EU flights in the same period has been much more discrete.

When individual routes' density is studied, it is found that 15 origins/destinations concentrate around 50% of total activity, while the main 30 origin/destinations amount to almost 70% of Madrid airport' movements.

Table 4. Distribution of traffics by origin/destination

	July 1997	July 1998	July 1999	July 2000
Arrivals *(number of flights, % change)*				
Domestic flights	5,257	5,628 *(7.1%)*	6,416 *(14.0%)*	7,393 *(15.2%)*
Non-EU flights	1,743	1,849 *(6.1%)*	2,021 *(9.31%)*	2,085 *(3.2%)*
EU-Schengen flights	2,011	2,800 ***(39.2%)***	3,383 ***(20.8%)***	4,094 ***(21.0%)***
EU-Non-Schengen	1,323	823 *(-37.8%)*	921 *(11.9%)*	1,112 *(20.7%)*
Departures *(number of flights, % change)*				
Domestic flights	5,299	5,654 *(6.7%)*	6,415 *(13.5%)*	7,388 *(15.2%)*
Non-EU flights	1,797	1,863 *(3.7%)*	2,008 *(7.8%)*	2,084 *(3.8%)*
EU-Schengen flights	2,018	2,771 ***(37.3%)***	3,395 ***(22.5%)***	4,230 ***(24.6%)***
EU-Non-Schengen	1,352	844 *(-37.6%)*	934 *(10.7%)*	991 *(6.1%)*

5. Analysis of delays

After computing delays for all observations included in the sample (97,902 flights), by comparing scheduled and actual arrival/departure times, some descriptive statistics reveal interesting information to understand the process of flight delays at Madrid airport.

Three main findings can be highlighted, and are discussed below in more detail:

1. *Arrival and departure delays are highly correlated*. Even though average departure delays are generally higher than those of arrivals, when a particular day is difficult for arrivals, it is also problematic for departures.

2. *Spill-over effects between one-hour intervals are present*. The cascade-type of effects described above in the theoretical discussion of congestion are reflected in the data. When several delayed flights arrive/depart at some point within a day, planes scheduled for the next hours are also delayed. Statistically, the impact of a delayed flight is observed in the next two hours.

3. *Expansion of capacity at Madrid airport has slightly eased congestion*. The analysis of percentages of delayed flights and total number of hours lost by passengers show that year 2000 was slightly better than 1999. Marginal congestion costs also exhibit some slight improvement, as a result of the expansion of capacity introduced at the airport.

5.1 Correlation between arrival and departure delays

Table 5 presents correlation coefficients between arrival and departure delays, for each of the four years included in our sample. Correlations are calculated based on averages of daily data.

Table 5. Correlation coefficients between arrival/departure delays

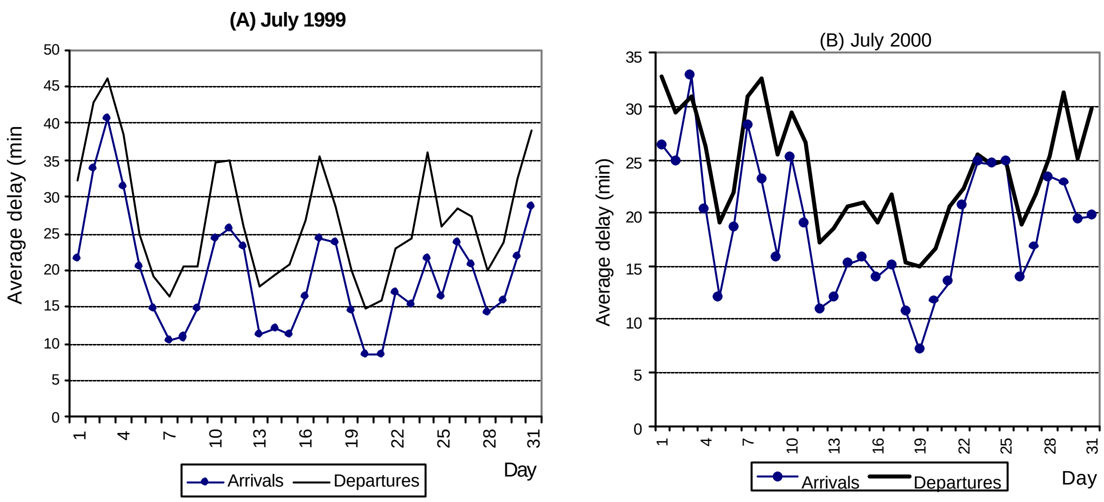
	corr (arriv./ depart. delays)
1997	0.810
1998	0.960
1999	0.946
2000	0.755

The high positive correlation observed reveals that whenever there are problems for departures at the airport, the situation is also complicated for arrivals, and vice versa. ATC and ground infrastructure serve simultaneously both to incoming and outgoing flights, thus the result is not surprising.

This finding also justifies adding up all delays (arrivals and departures) to compute congestion costs suffered at Madrid, because it indicates that most problems of delays are generated by the interaction of agents *at* the airport. If delays were caused mainly by other domestic or international airports –and the causes of arrival delays had then to be found at the cities of origin of flights– it could be expected that correlation between the series of arrival and departure delays to be much lower.

Figure 4 presents average daily delays for July-1999 and July-2000, respectively, comparing arrivals and departures. As it can be observed, average delays for departures are consistently above arrival delays. This is another indicator that the congestion problems that we aim to evaluate are mainly caused at the airport of Madrid, and not imported from other airports.

Figure 4. Average delays by day of the month (arrivals & departures)

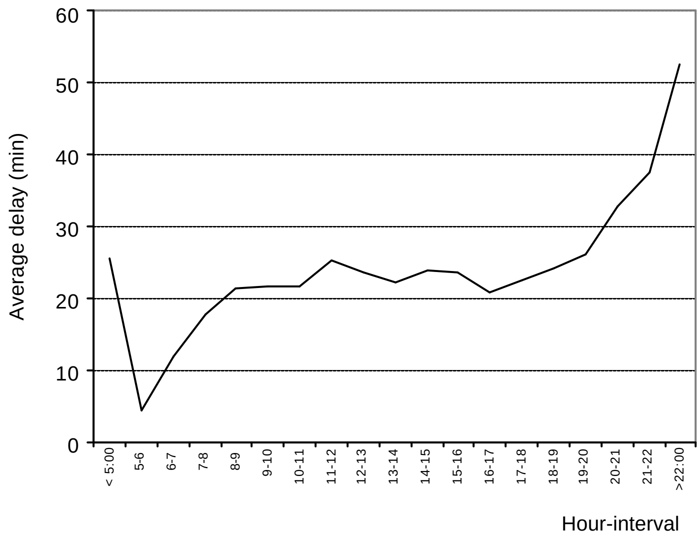


5.2 Spill-over effects between one-hour intervals

The analysis of average delays suffered by all flights using the airport within one-hour intervals illustrates how airport congestion develops through the day. Figure 5 shows how departure delays during the first hours in the morning are low (excluding those flights taking-off before 5:00 am, which are probably delayed due to exogenous causes[4]), but delays follow an accumulating pattern as the day evolves

This pattern is explained by the fact that when flights within a given one-hour interval cannot be allocated into their scheduled slots, they are passed into the next hours, subsequently causing displacements of the scheduled flights. Valley-hours (from 10:00 to 16:00) serve as a buffer against this effect, but do not seem to eliminate it completely. Average departure delays start to rise from 16:00 onwards, and follow an increasing pattern until the end of the day.

Figure 5. Congestion spill-over effects
Departure average delays by one-hour intervals, July 2000



Data presented in Figure 5 correspond to average departure delays, taken over all working days in the month (delays experienced at weekends have a different pattern, because the level of airport activity is lower). Arrival delays follow the same accumulating process as that of departures.

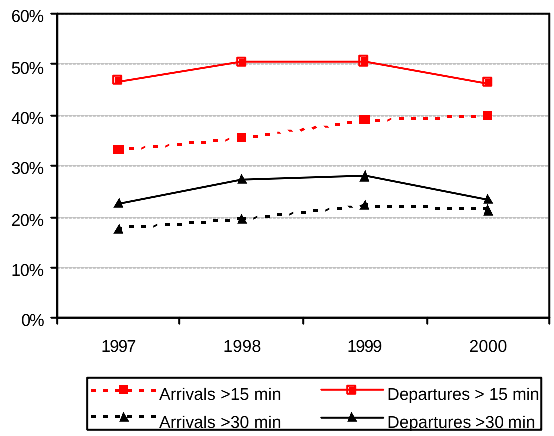
[4] The number of flights using Madrid airport before 5:00 am and after 22:00 pm is small. The arrival/departure of a flight with a long delay may then easily induce the average to be very high. These flights are considered not representative, and have been excluded for the computation of marginal effects.

5.3 *Effects of capacity expansion at Madrid airport*

Another point which has been examined is the evolution that congestion problems had during the period of reference (1997-2000). The objective is to check whether the expansion of airport capacity has significantly altered average delays.

The evolution of average delays, computed separately for arrivals and departures, and using in both cases the two definitions used in the air sector for delays (> 15 minutes and >30 minutes), is presented in Figure 6.

Figure 6: Percentage of delayed flights over total movements, 1997-2000



The decreasing trend observed between 1999 and 2000 indicates that capacity expansion seems to have had a positive effect on congestion problems. This is specially relevant for longer delays (more than 30 minutes), where the impact is observed both on arrivals and departures, with both percentages being reduced. However, given the magnitude of the capacity enlargement (see Table 3), it could have been expected that the reduction in the percentage of delayed flights would have been more important. On the other hand, capacity was significantly expanded between 1998 and 1999, but no effects on congestion ease are observed between those years.

Combining this finding with the increase in the number of flights for some particular origins/destinations (see Table 4), one conclusion is that capacity expansion at Madrid has served mostly to accommodate new services, which the airport was not able to attend before the capacity expansion. The infrastructure enlargement thus seems to have solved at least partly the scarcity problems suffered by the airport, but has not had a major impact in solving the existent situation regarding congestion. Data on total number of hours lost by passengers confirm this result.

In order to see whether the solution of scarcity problems has aggravated congestion suffered by travellers for particular groups of origins/destinations, the evolution of average delays for arrivals and departures for these groups is studied. Results are presented in Table 6.

Table 6. Evolution of average delays by groups of origin/destination
(minutes)

	July 1997	July 1998	July 1999	July 2000
Arrivals				
Domestic flights	13.1	16.0	15.0	16.3
Non-EU flights	25.9	23.9	26.0	20.6
EU-Schengen flights	15.4	16.2	**20.6**	**21.6**
EU-Non-Schengen	17.6	23.8	23.0	20.1
Departures				
Domestic flights	18.7	25.2	21.1	20.7
Non-EU flights	38.3	36.4	40.6	30.2
EU-Schengen flights	20.2	22.7	**25.8**	**25.1**
EU-Non-Schengen	27.8	31.3	34.8	25.9

It is remarkable that precisely those flights in the group that has experienced a more rapid growth (origins/destinations at EU-Schengen zone) are the ones that present a worst evolution in terms of average delays. A possible interpretation is that the management of Madrid airport assigns infrastructure and other resources at the airport using some zone division by destination. The increase in the number of flights made possible by the capacity expansion has then allowed the scarcity problem to be at least partly solved, but, at the same time, it has aggravated congestion problems already present for operators providing services to that group of destinations.

Meanwhile, the entry of these additional new services has left unaltered the situation for the rest of the groups regarding their average delays, or they have even improved their performance (see, for example, changes in delays experienced by flights in the EU-Non-Schengen zone between 1999 and 2000).

6. Quantification of congestion costs

As discussed above in the theoretical background to this case study, congestion costs can be evaluated with data on flight delays, computing total extra time spent by passengers and airlines. This can be easily done with the available dataset, given the information on delay per flight, and number of passengers transported at each flight. The type of aircraft used is also known, which allows to apply different hourly rates per plane to evaluate airlines' congestion costs.

Two exercises have been performed with data on delays of Madrid airport. First, total congestion costs are evaluated, considering the 30-minutes definition of delay (both the 15 and 30-minutes were initially used for computations, but it is found that most of congestion costs are due to longer delays). Second, the marginal effect that one delayed flight generates for the rest of flights using the airport during the day is estimated. For this second exercise, the 15-minutes definition has been used, because the impact of all delayed flights is equally significant.

6.1 Total congestion costs

Table 7 presents a summary of the total number of hours lost by passengers, both for arrival and departure delays.

Table 7. Total number of hours lost by passengers (1997-2000)

	July 1997	**July 1998**	**July 1999**	**July 2000**
Arrivals	404,050	464,876	548,034	556,019
Departures	499,748	480,370	541,026	461,692
Total	*903,798*	*945,246*	*1,089,060*	*1,017,711*

Note: Only those flights delayed more than 30 minutes are used to compute delays

The evolution of hours lost due to air congestion during the period 1997-2000 shows again that the situation of Madrid airport was improved with the capacity expansion. The volume of total hours lost in July-2000 was smaller than the figure of 1999, and it can be observed that the improvement if basically due to departures.

Table 8 presents the translation of these lost hours into monetary terms, to evaluate total passenger costs. As it was already mentioned, the hourly rate used for the value of time is 15.9 €/hour. Average costs per passenger are also presented for reference.

Table 8. Total and average passenger congestion costs

	July 1997	July 1998	July 1999	July 2000
Total costs (million €)				
Arrivals [1]	6.42	7.39	8.71	8.84
Departures [1]	7.94	7.64	8.60	7.34
Total flights [1]	***14.36***	***15.03***	***17.31***	***16.18***
Average costs (in €/passenger)				
Arrivals	4.04	4.36	4.51	4.01
Departures	4.91	5.89	5.95	4.53
Total flights	***4.49***	***5.02***	***5.14***	***4.24***

Notes: [1] Total monthly costs

Results obtained for passenger congestion costs reveal the magnitude of the problem suffered at Madrid airport. In July-2000, total passenger costs amounted to 16.2 million €. Average costs are estimated between 4.5-5 € per passenger. Data on passengers for 1997 and 1998 are partially based on estimates derived from plane sizes for some flights, therefore they are less reliable. On the other hand, the process of airport expansion contributes to some reduction in the average cost per passenger obtained for July-2000 in comparison with previous years.

For the case of airlines' costs, calculations are performed according to the procedure described in Section 3. Total number of hours lost by airlines due to congestion is classified according to four groups of aircraft size, and applied different hourly rates derived from the assumed rate of reference of 5,000 €/hour for and average plane.

Table 9 presents the results obtained for the monetary valuation of extra time lost by airlines due to congestion problems, again separately for arrivals and departures.

Table 9. Airlines' congestion costs (July-2000)

	July 1997	July 1998	July 1999	July 2000
Arrivals	14.7	16.7	20.3	22.0
Departures	18.0	17.6	20.4	17.2
Total flights	***32.7***	***34.3***	***40.7***	***39.2***

Note: Total monthly costs

Adding the estimated congestion costs associated to flight delays borne by passengers and airlines, it is possible to provide some figures which can help to quantify the problem of congestion experienced at Madrid airport. Taking July-2000 as a month of reference, total congestion costs in 2000 amounted to 55.4 million € per month (16.2 million corresponding to passenger costs, 39.2 million to airlines). In annual terms, assuming that July could be considered a representative month of the activity of Madrid airport[5], total congestion costs are evaluated at **664.8 million €**.

6.2 Marginal congestion costs

After evaluating the volume of total costs, a second exercise performed with the dataset of delays suffered at Madrid airport is to evaluate the marginal effect that each delayed flight causes over the rest of flights (in terms of extra time imposed).

A detailed analysis of the effect of delayed flights using data on average delays calculated over one-hour intervals shows that *each* delayed flight generates an impact that lasts significantly during at least two hours since the moment the flight is authorized to use the airport out of the initially planned schedule. The definition used for delayed flight is the one of 15-minutes, and the average extra time is calculated over all flights arriving/departing within the one-hour interval considered.

[5] This assumption is not unrealistic: Madrid is not affected significantly by summer seasonal peaks so acute as other Spanish airports (e.g. Majorca).

This spill-over effect can be observed, for example, in the following equation (e.g. estimated with data on arrivals for July 1997):

$$T_H^{av} = -3.30 + 1.325\ N_H\ + 0.86\ N_{H-1}\ + 0.54\ N_{H-2}$$
$$(-2.46) \quad (10.51) \quad (6.56) \quad (3.78) \quad (t - ratios)$$

$$R^2 = 0.489$$

where T_H^{av} is the average extra time over scheduled arrival (departure) of all flights landing (departing) within the one-hour interval *H*, expressed in minutes, and N_H is the number of flights with delays higher than 15 minutes arriving at (departing from) the airport in the period *H* (respectively N_{H-1} and N_{H-2}).

Equations of the form presented above are useful to understand the process of airport congestion generation, but are not extremely useful to compute representative marginal effects. The interpretation of the coefficients shown above is that each delayed flight arriving at the *H* hour is causing an excess of time of 1.325 minutes to all flights within that *H* hour interval, and will also have an impact of 0.86 minutes for the next hour-interval *H+1*, and 0.54 for the next *H+2*.

However, the number of flights and passenger varies at each hour-interval *H*. Therefore the impact of a delayed flight entering the airport at 10:00 am is different to that of a delayed flight at 21:00 pm (the impact is much lower for the latter, because airport activity slows down after 22:00 pm).

The solution adopted has been then to estimate simple equations of the effects of delayed flights over total extra times for all flights, taking complete days as the unit of reference. Equations of the following form have been estimated:

$$T_{day} = a + b\ \ N_{day}$$

where T_{day} is the average extra time of all flights using the airport during each day included in the sample, and N_{day} is the number of delayed flights that used the airport through the same day.

Weekends were eliminated from the sample, because the process of congestion developing is different for those days. Equations are estimated separately for arrivals and departures, and using annual samples. Results indicate that the marginal effects of delayed flights have changed over the period 1997-2000, due to the airport enlargement, so it is considered that observations from different years cannot be pooled together.

Table 10 presents the obtained results, which show slight differences between arrivals and departures for each year, and indicate over time how marginal effects seems to be lower in 1999 and 2000 compared to the previous years.

Table 10. Results of estimated equations for marginal effects*

	July 1997	July 1998	July 1999	July 2000
Arrivals	0.158 (15.03) $R^2 = 0.89$	0.197 (11.67) $R^2 = 0.87$	0.145 (21.99) $R^2 = 0.96$	0.113 (11.05) $R^2 = 0.86$
Departures	0.151 (11.10) $R^2 = 0.85$	0.201 (12.10) $R^2 = 0.88$	0.167 (13.69) $R^2 = 0.90$	0.117 (5.55) $R^2 = 0.62$

Note: * The values presented are the β coefficients in the equation above, which can be interpreted as minutes imposed on average by a delayed plane over all flights using the airport during the day (between parenthesis, t-ratios).

The estimated coefficients presented in Table 10 can be used to derive marginal congestion costs for air transport. Multiplying those coefficients by the total number of flights and passengers using Madrid airport on average during one day of each of the periods of reference, it is possible to calculate the amount of total extra time that one delayed flight imposes on airlines and passengers.

Table 11 shows the obtained results, both in terms of hours and valuation of marginal congestion costs, based on the hourly rates of 15.9 € for passengers and 5,000 € for airlines.

Table 11. Marginal congestion costs generated by each delayed flight*

	July 1997	July 1998	July 1999	July 2000
Time lost by passengers (hours)				
Arrivals	135.2	190.1	161.1	143.8
Departures	140.1	148.1	139.0	109.4
Time lost by airlines (hours)				
Arrivals	0.88	1.25	1.06	0.96
Departures	0.91	1.27	1.23	0.99
Marginal congestion costs (thousand €)				
Arrivals	**6.59**	**9.25**	**7.88**	**7.07**
Departures	**6.76**	**8.72**	**8.34**	**6.71**

Note: * Marginal costs are estimated on a daily basis, i.e. represent the impact caused on all passengers and airlines using the airport during one day.

The conclusions that can be obtained from these results are: (a) each delayed flight at Madrid airport causes congestion costs estimated around 7,000 € in July 2000; (b) marginal congestion costs seem to have improved after the enlargement or airport capacity.

7. Transferability of results

Values obtained for total congestion costs caused by flight delays on the users of Madrid airport are only indicative of what might be the situation for other European airports of similar size. Although we suspect, at the light of punctuality statistics, that results would not be very different for some cases as Milan, Lisbon, Athens, Brussels or Rome (just to quote some congested airports of similar size to Madrid), it would be necessary to obtain data and perform the calculation of congestion costs for each case.

However, both the methodological approach and the required information are simple enough for this paper to offer some guidance for future work in other countries. On the other hand, the characteristics of air transport are not in essence very different to other scheduled transport modes which might suffer from congestion problems (e.g. railways, or ports). Therefore, this type of study could even be extended to analyse congestion in other modes. This section offer some guidance on the main issues to be tackled with when carrying out a study on congestion costs.

7.1 Information requirements

The basic limitation to analyse the effects on congestion on passengers and companies is the availability of data. For scheduled transport modes, it is usually easy to have access to programmed arrival/departure times, but in order to measure delays, it is necessary to have also statistics on *actual* arrival/departure times. For the case of airports, this information is usually collected by airport authorities, and the only limitation is to have access to it. Another issue is the large volume of information to handle (for a medium/large airport like Madrid, the number of flights per month will be easily around 40,000). The best strategy is then to select a representative period –a month, or a week– to have manageable databases.

When both type of data exist (programmed and actual times), delays can be calculated simply as the difference between these. It is interesting to have some basic complementary information for each flight, as origin/destination or the airline providing the service. The type of aircraft assigned to the flight is generally a variable that is recorded in airports' databases, and it proves to be extremely useful to approximate the number of passengers.

Data on delays already offers some interesting possibilities to make descriptive analysis about what type of flights are more delayed (by origin/destination, company, or type of aircraft, for example). Another point of interest is to check the distribution of delays over a representative day, to study what periods are specially prone to suffer problems. Section 4 in this paper offers examples of the usefulness of this type of simple descriptive analysis to study the process of congestion.

The evaluation of congestion costs demands more information. A key variable is the exact number of passengers on board at each flight, in order to evaluate total time lost by travellers. If one is lucky and this information is available, the conversion of hours lost by companies into hours lost by passengers is immediate (simply multiplying the number of minutes of flight delay by the number of passenger yields total passenger-minutes lost at each flight). However, this type of variable is only recorded when information systems are well developed, and it will be more common to find out that the exact number of passenger is unknown, specially if the study is done for other transport mode than airports.

It is possible, however, to approximate the number of passengers if we know at least the capacity of the aircraft serving the route. If the type of aircraft is known, there exist detailed statistics on the average number of passengers that each model of aircraft may accommodate[6]. Making some assumption on load factors (preferably, derived from information on the route analysed; otherwise, standard values of 60-80% can be taken), the number of seats can be translated into expected number of passengers.

The availability of information on the type of plane used in the route allows additionally to make more refined calculations of the cost of delays for airlines, as it has been done in this work. It is obvious that the cost of a small plane for an airline will be much smaller than the cost of a very large aircraft, which will require a larger crew, more fuel consumption and will pay higher landing fees, for example. The usual situation when asking airlines for data on costs will be to obtain little, apart from the strategic value of that information for the companies, it is difficult even for them to have accurate estimates on the exact costs of moving a single plane. It is then extremely useful to have at least an idea of the type of aircraft delayed at each route. Based on that information, it is possible to make relatively good approximations to the costs of delays for companies.

7.2 Value of time

A key point in any study intending to evaluate congestion costs is the issue of the value of time to use both for passengers and for companies.

The value of time for passengers must be generally derived from existent studies which, from direct surveys or other methods, had evaluated what is the cost per minute for a passenger stranded at an airport terminal, or inside a delayed plane. This variable is crucial, because the monetary valuation of congestion hinges on it, and it may be a hot issue of debate in cases of negotiation about the payment of compensations to passengers.

Ideally, one would like to have information about the wage rate earned by travellers, which is a good reference from which to derive the opportunity cost of time lost due to delays. But, unfortunately, in most cases this will be hard to obtain, unless the analysis corresponds to some local or regional transport, in which case it could be possible to use some average wage rate to approximate passengers' earnings. In case of absence of information about value of time, the solution is to draw information from other studies or assume some ad hoc values.

If the transport mode analysed has some division between different classes of passengers (e.g. first class/business/tourist), another point to be considered is that the value of time will not be generally equal for all passengers. To that respect, it is interesting to try to obtain information about the distribution of passengers across classes, in order to derive afterwards some weighted average for the value of time.

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[6] For example, IATA and other airline associations have statistics on the fleet of companies, and the number of seats that each of them offers with a particular type of aircraft. Even though there are slight variations among seat configurations for the same model of plane (e.g. an Airbus-320 may have 140, 145, or 150 seats) the average capacity size of each type of aircraft is basically known.

The valuation of time for companies, required to calculate the costs assumed by them, is another crucial element for the results of an study on congestion. The best strategy is to obtain this information directly from the companies, but two types of difficulties generally arise. The first one is the reaction of firms when they are solicited to provide data on internal information. The second one, even if companies are cooperative and offer the information, is that the criteria to evaluate the cost per minute might vary widely across companies. As it was discussed above, it is relatively easy for an airline (or any transport firm) to calculate accounting costs generated by delays. However, all those indirect costs assumed by an airline, in terms of loss of reputation and lower value for its network, are much harder to measure. A possible solution, if facing a situation of lack of information from companies, is to take some average figures for the sector, or to work with data on revenues per hour as an approximation to the opportunity cost for a company of a lost hour.

8. Conclusions

This paper analyses empirically the problem of congestion suffered by users of Madrid airport. Both passengers and airlines are affected by flight delays, which are caused by a number of factors that are difficult to evaluate separately. When a flight experiences a delay (i.e. arrives or departs later than the time it was initially programmed), this can be due to problems at the airport of origin or at the airport of destination, and also the causes could be located in the air traffic control centres that control and aid the plane during the journey.

Congestion tends to be associated with lack of sufficient infrastructure to accommodate the required demand for landing and take-offs. However, the causes of congestion, although related with demand being close to maximum capacity, are external effects that an airport's user (airline) causes over all the rest of users when it experiences a problem. Thus, airport congestion shares the same features as in other transport modes –like roads– although in airports the users do not enter the system randomly. Even though the number of flight movements is carefully scheduled by airport management, any perturbation introduced in the system by exogenous factors causes congestion in terms of cascade-effects and accumulation of delays during the next periods.

A related concept is the one of 'scarcity'. If there exists more demand than supply of infrastructure (i.e. there are airlines that would like to use an airport, but must be excluded), then a different type of cost arises, because then there are potential gains from expanding the existent infrastructure. Thus, for the case of airports, congestion is a concept linked to the provision of services, while scarcity is linked to the provision of infrastructure.

Using data from AENA, public institution that owns and manages the main Spanish airports and air traffic control, this paper has evaluated total and marginal congestion costs, by adding passengers and airlines' costs associated to congestion. Data does not allow to assign precisely what are the causes of flight delays, therefore the approach is to evaluate costs of users of Madrid airport, with the caveat that some of the problems suffered by travellers might be originated at other airports.

Some preliminary work with the series of average delays within the period of reference (month of July, years 1997 to 2000), shows that there is a high correlation between arrival and departure delays at Madrid, and the average departure delay is always higher than the average arrival delay. This is considered as evidence that most of congestion costs evaluated in this work are indeed originated at Madrid. Another interesting results stem from the analysis of the distribution of average delays across a typical day. This shows how, on average, flight delays follow an accumulative process during the day, due to the cascade effects that some perturbation at a particular point generates for all the next scheduled flights.

Adding up all flight delays above 30 minutes, during the month of July, it is found that passengers using Madrid airport (arrivals and departures) lost more than 1 million hours. Meanwhile, airlines suffer a total loss of around 7,500 plane-hours. (These figures correspond to July-2000). A monetary valuation of all these external effects borne by airport users yields a total amount of **664.8 million €** per year.

Marginal congestion costs have also been estimated, using the number of flights delayed by more than 15 minutes and working with daily averages taken for working days (since delays at weekends follow a different pattern). Results obtained are that each delayed flight generated in July 2000 a marginal cost of **7,100 €** (arrivals) or **6,700 €** (departures). These costs are lower than estimates for previous years, thus reflecting the improvement achieved by the enlargement or Madrid airport.

9. References

ATAG (Air Transport Action Group) (1999): 'The Economic Benefits of Air Transport', website *www.atag.org.*

Chartered Institute of Transport, Faculty of Freight (1992): 'Congestion Report', Working Party Report no. 1, Coopers & Lybrand.

Daniel, J.I. (1995): 'Congestion Pricing and Capacity of Large Hub Airports: A Bottleneck Model with Stochastic Queues', *Econometrica*, 63 (2), 327-370.

Doll, C. et al.(2000): *User costs and benefits (external) categories*, working paper, UNITE.

Eurocontrol (1999): *Special Performance Review Report on Delays,* Performance Review Commission, PRR2, November; Brussels.

Fisher, J.B. (1989): 'Managing Demand to Reduce Airport Congestion and Delays', *Transportation Research Record,* 1218, 1-10.

González-Savignat, M. (1999): 'El Valor del Tiempo', *Papeles de Economía Española,* 82, 262-275.

Nash, C. and Samson, T. (1999): 'Calculating Transport Congestion and Scarcity Costs', *Final Report of the Expert Advisors to the High Level Group on Infrastructure Charging.*

Nellthorp, J., Sansom, T., Bickel, P., Doll, C. and Lindberg, G. (2001) *Valuation Conventions for UNITE*, UNITE (UNIfication of accounts and marginal costs for Transport Efficiency). Contained in Link et al. (2001), *Pilot Accounts – Results for Germany and Switzerland*. Funded by 5th Framework RTD Programme. ITS, University of Leeds, Leeds, April.

Oum, T.H. and Y. Zhang (1990): 'Airport Pricing: Congestion Tolls, Lumpy Investment and Cost Recovery', *Journal of Public Economics*, 43, 353-374.

Quinet, E. (1997): 'Full Social Cost of Transportation in Europe', in Greene, D.L.; Jones, D.W. and Delucchi, M.A. (eds): *The Full Costs and Benefits of Transportation*, Springer, London.

Reynolds-Feigan, A.J. and K.J. Button (1999): "An assessment of the capacity and congestion levels at European airports". *Journal of Air Transport Management*, 5:113-134.

Starkie, D. (1988): "Allocating airport slots: a role for the market?, *Journal of Air Transport Management,* 4:111-116.

Wolf, H. (1998): 'Airport Regulation: Tackling Congestion and Environmental Problems', Working Paper no. 876, Institut für Weltwirtschaft, Kiel.