BENEFITS OBTAINED FROM THE ESTIMATION AND DISTRIBUTION OF REALISTIC TAXI TIMES

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Background

Airports are facing the challenge of constantly increasing air traffic, which makes their task of ensuring the safety and the efficiency of operations more and more complex. Additionally, the current weakness of operational coordination does not contribute to improve the situation and leads to inadequate amounts of delays and operating costs.

In this context, Collaborative Decision Making is seen as an important approach to make best use of available infrastructure and the scarce resources and as an important support for Air Traffic and Airport slot compliance. Several projects and companies in Europe and USA are working in the definition, implementation and validation of CDM processes.

In Europe, EUROCONTROL has launched the Airport CDM (Collaborative Decision Making) Project, part of the EATM Airport Operations Program, focused on the development of Airport CDM Applications. This project has described the Operational Concept of the Airport Collaborative Decision Making (CDM) Applications, outlining the necessary steps towards the Collaborative Airport [1]. Although it is out of question that all basic elements of CDM need to be implemented and that a European-wide approach is required to achieve full potential benefits, a phased, bottom-up approach is the only practical and possible solution.

First Level applications aim at achieving common situational awareness and improving both inbound and outbound traffic predictability. Second Level applications aim at improving punctuality, by introducing the required operational flexibility to cope with traffic changes and operators' preferences. Third Level applications will further enhance flexibility requirements and will optimise the use of airport resources, helping to orderly recover from disruptions.

In order to complement the work being done by EUROCONTROL and in close cooperation with them, the European Commission promoted a research project called LEONARDO, Linking Existing On Ground, Arrival and Departure Operations. In this project, companies from France (ADP, DNA and Air France), The Netherlands (NLR), Italy (Sicta) and Spain (Aena, Iberia, Indra, Ineco and Isdefe), participated together with Eurocontrol.

The objective of Leonardo was to demonstrate the feasibility of implementing Collaborative Decision Making (CDM) processes supported by the integration of existing tools for arrival (AMAN), departure (DMAN), surface (SMAN), stand allocation and turn-around management. In order to achieve this objective, CDM Applications covering Levels I and II as defined by Eurocontrol, were experimented at Madrid-Barajas and at Paris-Charles de Gaulle airports through shadow-mode trials.

One of the applications tested in Leonardo was the CDM Variable Taxi Time Calculation, which aims at improve airline adherence to scheduling by introducing and distributing realistic taxi times [1].

This paper is focused on the results obtained in Leonardo trials for CDM Variable Taxi Time Calculation. During these experiments, taxi times were not considered as fixed values (default taxi times), but they were calculated taking into account factors such as the runway in use, stand / gate location, aircraft type, operating procedures, taxiway usage, the traffic congestion, the weather, etc.

The paper begins with a description of how taxi times were estimated in Leonardo and potential benefits of such approach. Then it reports in detail the results of the experiments carried out, highlighting figures for the benefits achievable and finally, the paper concludes with an overview of what has been developed and what would be the best areas for continuing these research activities.

Leonardo approach to taxiing time estimates

Prior to focus on how taxiing times were estimated in Leonardo, it is essential to review briefly the terminology used in the project in order to understand the acronyms that will be mentioned in this paper.

After clarifying the acronyms used, the need for CDM Variable Taxi Time Calculation at Madrid-Barajas airport is briefly elaborated, followed by a description of the two different taxiing-time estimates provided by the LEONARDO system at Madrid-Barajas airport. In addition, the potential benefits and disadvantages of each approach are introduced. The two mechanisms used for estimating taxiing times at Madrid-Barajas airport are the followings:

- Static tables that contain statistical values of taxiing times at the airport as a function of the stand and the runway.
- A dynamic model that calculates taxiing times taking into account the planned ground traffic[1]. This model calculates holding times at intersections and in the departure queue.

Common Terminology

The need to define a common terminology regarding time, duration (or time period) and event data within the project was clearly identified from the beginning of the project. This common terminology was first derived from the CDM at Barcelona Airport project [12] and made compliant with the Eurocontrol Standards Acronyms and Definitions [7].

1. Acronym Structure

The Acronyms follows the standardisation rules based on 4 letters:

- The second and third letters defines the event (for instance, IB for in-block, LD for landing, OB for off-block TO for Take-Off),
- the fourth letter defines the type (Time event –T- or Time Period –P- or Time Slot –S-),
- the first letter status of the value the acronym refers to (for instance, A for Actual, E for estimate).

2. Basic time periods related to aircraft movement:

- For departure flights, The Time Period between the Off-Block Time event and the Take-Off time event is called the Ground movement Outbound Time Period (**GOP**). It is compounded of the Push-Back Time Period (**PBP**), The unimpeded Taxiing-Outbound Time Period (**XOP**), Cross runway Holding Time Period (**CRW**), the likely Cross-taxiway Holding Time Period (**CXW**), the likely Runway Holding Time Period (**RHW**) and the Runway Outbound occupancy Time Period (**ROP**).
- For arrival flights, The Time Period between the Landing Time event and the In-Block time event is called the Ground movement Inbound Time Period (**GIP**). It is compounded of the unimpeded Taxiing-Inbound Time Period (**XIP**), the likely Cross runway Holding Time Period (**CRW**), the likely Cross taxiway Holding Time Period (**CXW**), the likely Parking Holding Time Period (**PHW**) and the Runway Inbound occupancy Time Period (**RIP**) [6].

Taxiing Time dispersion at Madrid-Barajas Airport

In order to calculate realistic taxiing times, first we need to make sure of the factors that affect taxiing times. It is obvious that taxiing times will depend on factors such as the runway in use, stand location or traffic congestion. However depending on the airport layout and traffic pattern we are considering, the influence of such factors will be more or less significant.

In the case of Madrid-Barajas airport, if we look at the current airport map, we easily realize that its layout is very linear which greatly impacts on the taxiing times. The difference in distance between the closest stand to the runway and the furthest is around 6000m which can implies time differences of more than 15 minutes.

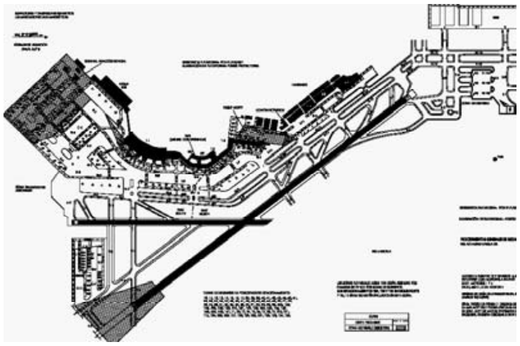

Figure 1. Madrid-Barajas airport layout

Furthermore, if we analyse the traffic pattern we appreciate differences not only among different hours of the day, but also among different days of the week.

Madrid-Barajas traffic pattern and level are different during weekdays and weekends. During weekdays, the traffic pattern and level are quite stable and the number of operations vary between 80 and 60 movements per hour. Since Madrid-Barajas is operating very close to its maximum capacity, differences in traffic volumen provoke significant

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[1] Whenever the taxi planner is mentioned in the paper, we are referring to the dynamic model that calculates taxiing times taking into account the planned ground traffic.

differences in taxiing times (from no ground delay to an average ground delay of more than 5 minutes).

The following figure illustrates the week seasonality at Madrid-Barajas airport. Data correspond to the week from 07/10/03 to 13/10/03.

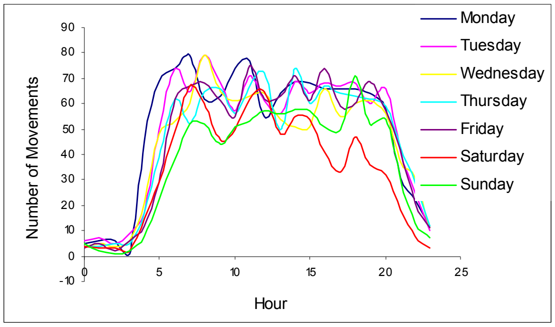

Figure 2. Traffic distribution in along the week.
Source: controllers from TWR recording Madrid-

As a conclusion, the following figure illustrates how these factors affect taxiing time distribution at Madrid-Barajas airport. It represents the dispersion of departure taxiing times along the day for a sample of 1545 flights in July 2003.

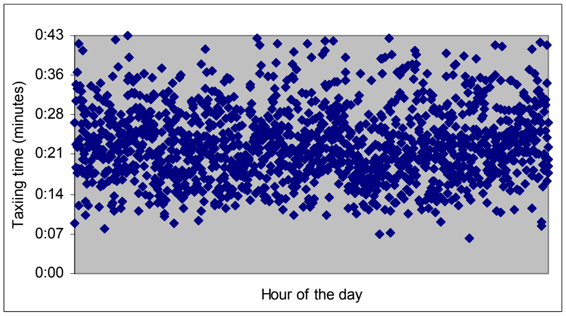

Figure 3. Taxiing Time dispersion at Madrid

Regarding the importance of realistic taxi time estimations at Madrid-Barajas airport, it is essential to remember that the new Madrid-Barajas airport with 2 pairs of parallel runways will be fully in operation by the end of the year 2005. The simulation studies carried out for this new scenario, demonstrate that the variability of taxiing times will even increase. Taxiing times for departures will probably vary between 5 and 20 minutes depending on the runway and the stand. In the case of arrivals, taxiing times will fluctuate between 3 and 15 minutes. Moreover, since the possible combinations of stand and runway greatly increase, the dispersion of the taxiing times will also increase.

It means that if we want to full benefit from the new Madrid-Barajas airport, the realistic estimation of taxiing times will become a major issue.

Statistical values of taxiing times as a function of the stand and the runway.

As it has been previously introduced, one of the solutions tested was to use statistical values of taxiing times as a function of the stand and the runway. The objective was to evaluate how realistic and useful was the use of such statistical values in comparison to a dynamic airport model which considered real congestion.

In order to calculate these statistical values, Aena launched a measurement campaign on July the 16th, 17th, 21st, 22nd, 23rd, 24th and 28th of 2003 at Barajas Airport in order to collect data of the current flight operations at the airport to validate and tune the LEONARDO system.

Data were collected at Barajas Airport in the following conditions:

- During daylight periods.
- The Airport operating in North Configuration: RWY 33 and RWY 36L/R are preferential in weather conditions when tail wind component is less than 10 knots provided the runway surface is dry or wet with braking action good:
    - Arrivals: RWY 33.
    - Departures: RWY 36L.
- In meteorological conditions characteristic of summer season at Madrid, thus with:
    - Good visibility.
    - No precipitations.

The sample contained 1800 departing flights and 1200 arriving flights whose taxiing times were analysed to determine differences depending on the stand. In addition, possible differences depending on the traffic volume and period of the time were also analysed. However the size of the sample was not sufficient for such an assessment and it was impossible to find a clear tendency.

Regarding the taxiing time analysis depending on the stand, it is important to highlight that for such analysis, the stands were grouped. There are more than 150 stands at Madrid-Barajas airport and it was not practical and useful to work with such a huge number of different taxiing times. The stands were grouped taking into account their location (proximity) and the taxiing procedure of the aircraft from the stand to the runway or vice versa (operational procedures). The following figure illustrates the Barajas parking area and the groups considered for the analysis.

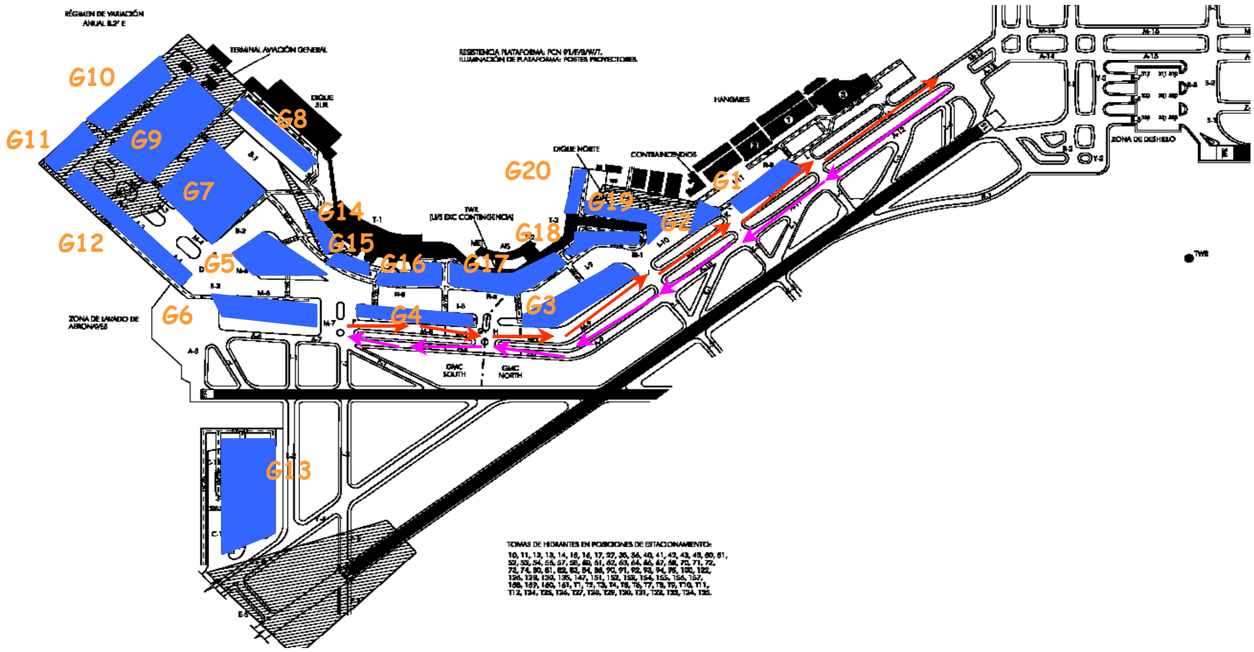

Figure 4. Groups of stands at Barajas Parking Area

Dynamic Taxi Planner

The taxi planner prototype implemented in Leonardo consists of a mathematical model that optimises aircraft ground movement at an airport. It assigns the optimum taxi route to each aircraft according to the most efficient operational configuration taking into account the current and predicted traffic situation. In addition, it calculates the taxi duration for each aircraft.

This prototype was developed in collaboration with the Polytechnic University of Madrid in Aeronautics. It was not foreseen to become an operational tool, but it was developed aiming at the following two objectives:

- On the one hand to be integrated in LEONARDO at Madrid-Barajas airport as an experimental tool, providing an independent and alternative module for the trials instead the static tables containing statistical data. The objective was to study if such a tool could predict more accurately the taxi duration taking into consideration the actual traffic congestion.
- On the other hand to explore the applicability of the mathematical techniques based on flow optimisation in networks for the ground traffic management.

1. Airport model and traffic data

The taxi planner models the tarmac as a network of nodes and links, from runway exits/entries to stands. Nodes represent stands, runway exits or entries, holding points and crossings, whereas links represent taxiways. Both nodes and links can be fictitious items used to model queues, delays, congestion, etc.

On the other hand, the model considers the traffic flow in an aggregated way for the calculation of the congestion of the whole network and the congestion of each individual taxiway. However, each aircraft keeps its individuality along the network for the calculation of the output parameters.

Traffic data is received from the Spanish Air Traffic Control System (SACTA) through real flight plans. It means that the tool is periodically fed with real data -actual or updated forecasts-. The calculations are not triggered by events but the user defines the period between two consecutive computations. Every time the computation is repeated, all the inputs are updated. This re-planning period is a configurable parameter as well as the planning horizon.

2. Taxi planning as a multicommodity network flow in a time-space network

The problem is defined by a time space network, which is defined in base an airport space graph, G(N,A), where the nodes, N and links, A, are choose to represent the conflicts between aircrafts and the congestion generated when several flights try to use the limited resource capacity of the airports. Each link, (i,j), is described by its pair: origin and destination nodes, $(i,j), \forall i,j \in N$.

The time space network is defined replicating temporarily the previous space network, using periods of time to divide the considered planning period, PP. The period set is $T = \{0,1,..,|T|\}$. The time space graph, G* (N*,A*), is defined by the replicated node set, N*, and the space-temporal links, A*. The taxi planning time in minutes is called the tTP, which is calculated as follows:

$$t_{TP} = \frac{t_P |T|}{60}$$

The tP is the uniform time duration, used to define each period.

The variables are referred to the space-temporal links, $\{(i,t),(j,t'), \forall i,j \in N, \forall t,t' \in T\}$, but taking account that for each link the time, tij, used by any flight to move for each link depend on its velocity which is considered fixed in average value.

Each flight, w, is defined by an origin node, o(w), a destination node, d(w), and an origin time, t(w).

The variables used to define the model are:

E_{it}^{w}= 0/1 , if the aircraft "*w*" no/yes wait in node "*i*" at the period "*t*".

X_{ijt}^{w}= 0/1 , if the aircraft "*w*" no/yes is routed from the node "*i*" to the node "*j*" at period "*t*".

The taxi planner minimizes the objective function, F, defined by the periods spent to route all the aircrafts:

$$F(X,E) = \sum_{w \in W} \sum_{t \geq t(w)} \lambda^{w} \left(\sum_{ij \in A} t_{ij} X_{ij,t}^{w} + \sum_{i \in N^{W}} E_{i,t}^{w} \right) + \sum_{w \in W} \sum_{i \in N} r_{i}^{w} E_{i,|T|}^{w}$$

where λ^{w} is the priority that the aircraft "w" reduce its route time, NW is the wait node set, W is the aircraft set and r_i^w is the estimated time necessary for the aircraft "w" to arrive at its destination from the node "i", that is the node used at the final of PP. r_i^w is obtained using a shortest path algorithm.

The taxi planning feasible set is defined by the multicommodity flow conservation and flow capacity constraints.

The flow conservation at node constraints are:

$$E_{it}^{w} + \sum_{j \in T^{*}(i)} X_{(j,i),t-t_{ji}+1}^{w} = E_{i,t+1}^{w} + \sum_{j \in F^{*}(i)} X_{(i,j),t+1}^{w}, \forall t, \forall w, \forall i$$

, where the sets "From, F*", and "To, T*" are defined as:

$$F^{*}(i) = \{ j \,|\, (i,j) \in A^{*} \},$$

$$T^{*}(i) = \{ j \,|\, (j,i) \in A^{*} \}, \forall i \in N^{*}$$

The flow node conservation constraints need to take into account the aircraft at origin node, o(w). The aircraft "w" may wait or move at (o(w),t(w)):

$$E_{o(w),t(w)}^{w} + \sum_{j \in F^{*}(o(w))} X_{o(w),j,t(w)}^{w} = 1, \forall w \in W$$

The same at $t = |T|$, the flights must be end waiting in some node (include the air node, if the aircraft can take off during the PP).

$$\sum_{i \in N} E_{i,|T|}^{w} = 1, \forall w \in W$$

The flow capacity constraints at nodes "i" are defined as follow:

- Wait node, NW, capacity:

$$\sum_{w} e_{w} \; E_{it}^{w} \leq capn_{i}, \quad \forall t, \forall i \in N^{W}$$

where capni is the capacity (in surface units) of the node "i", and "ew" is the surface needed for the aircraft "w".

- Ordinary, NO and exit runway, NER node capacities: The aircrafts cannot wait in these nodes.

$$E_{it}^{w} = 0, \quad \forall t < |T|, \forall i \in N^{O} \cup N^{ER}$$

Parking, NP and access runway, NAR node capacities are of value 1:

$$\sum_{w} E_{it}^{w} \leq 1, \quad \forall t, \forall i \in N^{P} \cup N^{AR}$$

Other constraints may be defined to characterize different conflicts and congestion effects, such as link flow, logical, and boundary constraints.

3. Methodology

The taxi planner is a multicommodity network flow model with binary variables and side constraints, and it may be solved using methods of Binary Programming such as the methods of Branch and Bound, and Fix and Relax.

The method more often used to solve integer problems without special structures is the method of Branch-and-Bound (B&B). Another method with capacity to explore the hierarchical structures of the model is the Fix and Relax method (F&R).

Several test were done to compare results with respect to the use of B&B or F&R. F&R obtains between 10% and 40% better results than B&B, which is normal given that F&R can explore the hierarchical structure of TP[11].

Experiment results

Trials at Madrid-Barajas airport were conducted between Monday 2nd February and Thursday 26th February 2004 in what is known as "shadow mode". Shadow mode is a validation technique in which the system being validated operates in parallel with the real system. The only exchange of information between the two systems is that the real system feeds the shadow-mode system. The advantage of shadow mode is that the users/evaluators use real information in a real operating environment, without interfering with airport operations.

During the LEONARDO trials performed at Madrid-Barajas airport, evaluators were allocated at five different positions:

- Barajas North TWR position.
- Barajas South TWR position.
- Iberia Network Control Centre position.
- Iberia Co-ordination Centre position.
- Airport Operational Center (CEOPS).

Regarding data obtained in the trials, actual data as well as the estimations provided by the system were recorded for analysis. Next sections present the assessment done on taxiing times predictability. This analysis is done based on data obtained for more than 600 departing flights and more than 400 arriving flights. In order to complement the analysis, the qualitative appraisal of users is also included [9].

Taxi-in Predictability – Statistical Analysis

To analyze the reliability of taxiing times for the arrivals used by the LEONARDO prototype, a parameter called the EGIP Error has been defined. This parameter is the difference in absolute value between the taxiing time for arrivals estimated by LEONARDO (EGIP) and the actual taxiing time used by arrivals at Madrid/Barajas Airport (AIBT-ALDT).

For the two different taxiing estimates provided by LEONARDO, both the average EGIP Error times and the dispersion of the values from the average have been analyzed. Since the dynamic taxiing-time calculation model recalculates the estimated taxiing time depending on the situation at the airport, the evolution of the EGIP error over time will also be analyzed for the period between the AIBT and 30 minutes before the AIBT. This parameter has been called "Earliness".

1. Average Error of the Taxiing Time for Arrivals (EGIP)

A comparative table is provided below with the average EGIP Errors (in minutes) obtained during the trials. The values for each group of stands will be presented separately so that the reliability of the estimates is a function of the allocated stand.

The average error is obtained for both estimations, when using static tables and when using the dynamic taxiing-time model. The most accurate estimation of them has been shaded for each group of stands.

Group of Stands	Error from Tables	Average Error with dyn. model
G1	1:04	1:46
G14	1:44	1:22
G17	1:26	1:24
G18	00:47	1:04
G19	1:22	1:18
G3	00:47	1:36
G6	1:27	2:49
G9	1:08	1:31
TOTAL	1:07	1:24

Table -1 EGIP Error

Based on the data presented, the following conclusions can be reached:

- Taking into account that the average taxiing time obtained during the trials was 4:42 minutes, an average deviation of 24% from this time is obtained if the statistical values are used. When using the dynamic taxiing-time model, this deviation increases to 30%.
- Using only statistical values, the groups of stands with the most reliable estimates are G18 and G3, with an Error of 0:47 minutes. The average taxiing times for these stands are 3:51 minutes and 4:24 minutes, respectively, so the deviation obtained is of 20% and 18% with respect to the actual taxiing time. When the dynamic taxiing-time model is used, G18 is again the group of stands with the most reliable estimates, with an error of 1:04 minute (a 28% deviation from the actual taxiing time).

  A reason for this result could be that G18 stands are used by a great number of aircraft (around

20% of the traffic sample were parked at stands belonging to this group). The more data we have the better analysis we can perform and we obtain more significant results.

- Regarding the error in absolute value, when the statistical values are used, the group G14 has the largest one and when the dynamic taxiing-time model is used G6 is the group with the worst estimate (error of 2:49 minutes), which is a deviation of 44%. Both groups have a small sample which is not sufficient to consider these results as representative.

Based on these data, it can be concluded that, on average, the taxiing estimates for arrivals provided by the dynamic taxiing-time model are not more reliable than the statistical values calculated from real data.

2. Dispersion of the Average Arrival Taxiing-Time Error (EGIP)

The following figures are graphs that compare the dispersion of EGIP Error for each group of stands. The graphs represent the error interval in which the error of EGIP would be located for the 80% of the flights (normal distribution) as a function of the allocated group of stands. It is presented as % of the EGIP.

The first graph corresponds to the taxiing estimations provided by the dynamic taxiing-time model and the next one to the statistical taxiing times.

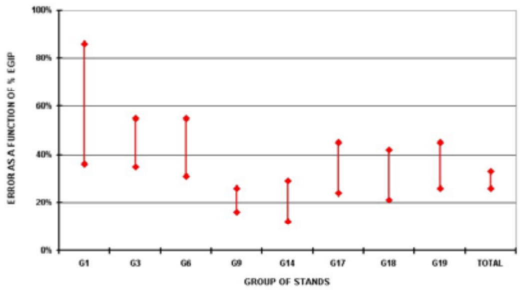

Figure 5 Error as a Function of % EGIP (Dynamic Model)

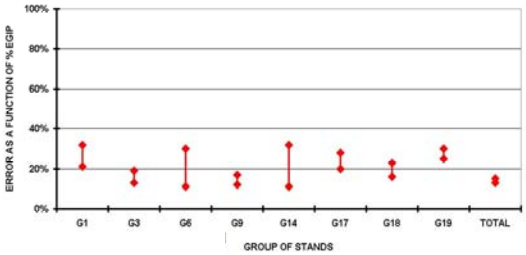

Figure 6 Error as a Function of % EGIP (Static Table)

A comparison of these graphs leads to the following conclusions:

- For the tables, groups G1, G3 and G18 give the best results, as regards both the average and the dispersion.
- The groups with the worst estimates, such as G6 and G14, have the greatest dispersion of EGIP error.
- Comparing these graphs, it can be seen that the dispersion is greater using the dynamic taxiing-time model for every group of stands except G14, which is the group that had the worst results for the average error using the statistical values.

Finally, it can be concluded that, for both the statistical values and the dynamic taxiing-time model, the groups of stands with the lowest average error are the ones that also have the least dispersion.

3. Evolution of the Error over Time when using the dynamic taxiing-time model

The following table shows the trend of the error obtained using the dynamic taxiing-time model as AIBT approaches. The trend is linear, but it can be seen that the error increases as AIBT approaches.

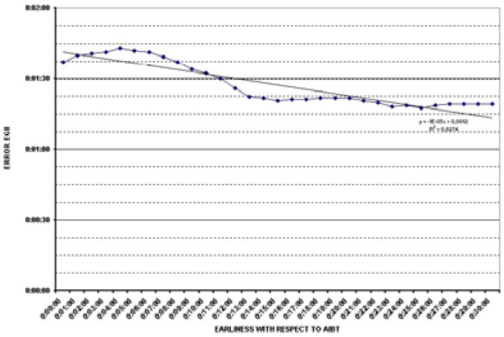

Figure 7 EGIP Error over time

In the light of the results, it is recommended to review the dynamic model for calculating taxiing times in detail for arrivals as a function of the expected traffic and validate the changes made for each group of stands.

Taxi-in Predictability – Qualitative Appraisal

1. Qualitative Appraisal from the Airline Point of View

The Iberia evaluators feel that even if standing alone, taxiing times provide no useful information for the airline, having good estimated taxiing times for landing flights could assist them in distributing handling teams because they are essential to calculate accurate in-block time estimates. Iberia people highlight the importance of accurate taxiing estimates when the airport operates in South Operational Configuration, because in such cases currently available taxiing time estimates have great variations with respect to the actual times.

Comparing the estimates with their own experience, airline operators feel that the taxiing times for landing flights are closer to the actual times when statistical times are used instead of when they are calculated using the dynamic taxiing-time model tool. Besides, the variations in taxiing times calculated with the dynamic taxiing-time model are inadmissible for airline operators.

It is an added value for the airline the fact that the system is directly connected to the airport system and updates taxiing estimates whenever there is any variation in the stand assignment. Throughout the sessions it was verified that in most cases, when there was a change in stand assignment, the LEONARDO prototype had this information before the airlines (communicated by radio from the airport operations centre).

2. Qualitative Appraisal from the Airport Point of View

The operator and the supervisors involved in the evaluation felt that the reliability of the estimation of in-blocks time (which highly depends on the taxiing time reliability) is comparable to or higher than the reliability of the estimations made by the operators of Airport Operations Center with large experience.

It is important to mention that the airport operator, once the aircraft is landed, estimates on his own the in-block time for each aircraft and that he/she manually introduces this estimation in the Airport Operations Control System (CONOPER). The estimation of the taxiing time is based on the experience of the operator given an allocated stand and runway. This procedure reduces the consistency of the estimates because they depend on the experience and skills of the operator. During Leonardo trials it was demonstrated that it is possible to predict automatically taxiing times earlier and at least with a similar level of accuracy.

Taxi-out Predictability – Statistical Analysis

The purpose of this analysis is to determine the reliability of taxiing times for the departures calculated by the LEONARDO prototype. In order to do so, a parameter that has been called the EGOP Error is defined. This parameter is the difference in absolute value between the taxiing time for departures estimated by LEONARDO (EGOP) and the actual taxiing time used by departures at Madrid/Barajas Airport (ATOT-AOBT).

For the two different taxiing estimates provided by LEONARDO, both the average EGOP Error times and the dispersion of the values from the average will be analyzed. Since the dynamic taxiing-time calculation model recalculates the estimated taxiing time depending on the situation at the airport, the evolution of the EGOP error over time will also be analyzed for the period between the ATOT and 50 minutes before the ATOT. This parameter has been called "Earliness".

1. Average Error of the Taxiing Time for Departures (EGOP)

The following table compares the average EGOP errors in minutes obtained during the trials. The values for each group of stands are presented separately, enabling a comparison of the reliability of the estimate depending on the stand that has been assigned to the aircraft. The most reliable estimated EGOP for each group of stands has been shadowed.

Group of Stands	Average Error Using Tables	Average Error Using dyn. model
G1	5:10	4:07
G3	3:24	5:17
G8	4:57	6:41
G9	3:32	5:22
G10	3:30	1:49
G14	4:27	6:07
G17	4:00	3:46
G18	3:41	5:18
G19	3:37	5:40
TOTAL	3:46	5:11

Table 2 EGOP Error

The following conclusions can be reached from the data presented in the table:

- Taking into account that the average actual taxiing time[2] obtained during the trials is 18:26 minutes, a deviation of 20% from this average time is obtained when using the tables. Using the dynamic taxiing-time model, the deviation increases to 28%.

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[2] This average taxiing time is calculated with all flights regardless the allocated stand.

- The G3 group has the most reliable estimates when using tables, with an EGOP Error of 3:24 minutes which represents a deviation of 24% from the actual taxiing time(the average actual taxiing time for these stands is 13:57 minutes). When using the dynamic taxiing-time model, the G10 group has the most reliable estimate, with an EGOP Error of 1:49 minutes which represents a deviation of 8% from the average actual taxiing time (22:30 minutes).
- When using tables, the G1 group has the worst estimate in absolute value, with an EGOP Error of 5:10 minutes (a deviation of 39% from the average actual taxiing time, which is 13:12 minutes). Using the dynamic taxiing-time model, the G8 group has the worst estimate (average error 6:41 minutes), giving rise to a deviation of 25%.

  In this case, as it happened in the analysis of taxiing times for arrivals, both groups have a small sample which is not sufficient to consider these results representative.

Based on these data, it can be concluded that the percent of deviation of the estimates from the actual taxiing time varies greatly depending on the group of stands, when using both tables (24%-39%) and the dynamic taxiing-time model (8%-25%).

2. Dispersion of the Average Error in Departure Taxiing Times (EGOP)

The following graphs compare the dispersion of EGOP Error for each group of stands. The graphs represent the Error interval in which the error of EGOP would be located for the 80% of the flights (normal distribution) as a function of the allocated group of stands, presented as % of the EGOP.

The first graph corresponds to the taxiing estimations obtained from the statistical analysis and the next graph corresponds to the taxiing estimations provided by the dynamic model.

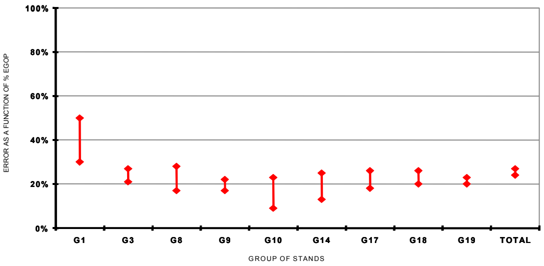

Figure 8 Error as a Function of % EGOP (Static Table)

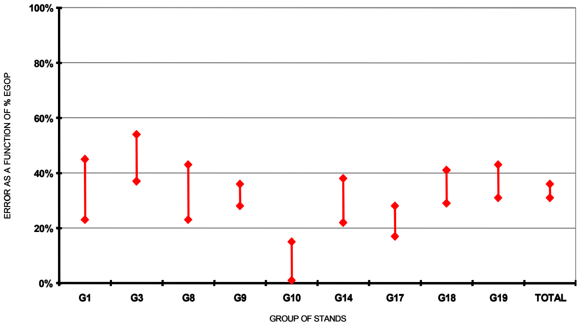

Figure 9. Error as a Function or % EGOP (Dynamic Model)

Comparing the graphs, the following conclusions can be reached:

- When using tables, the G3, G9 y G19 groups have the lowest dispersion of EGOP Error in their estimates, making these groups the ones with the best results for both the average and dispersion.
- The G1 group, with the worst estimate using tables, and the G8 group, with the worst estimate using the dynamic taxiing-time model, are those with the greatest dispersion of error values.

Finally, it can be concluded that, the dispersion is higher using the dynamic taxiing-time model, for any group of stands.

3. Evolution over Time of the Error using the dynamic taxiing-time model

The following graph shows the trend of the EGOP Error obtained using the dynamic taxiing-time model, as it approaches ATOT. The trend is linear and shows a slight decrease in EGOP Error as take-off approaches.

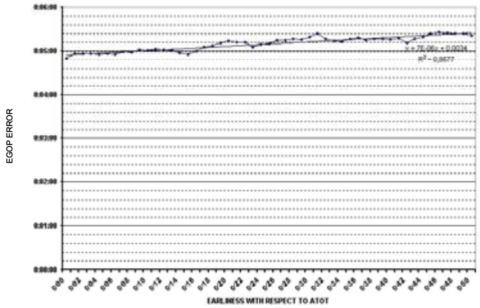

Figure 10 EGOP Error over time

Taxi-out Predictability – Qualitative Appraisal

1. **Qualitative Appraisal from the Airline Point of View**

The Iberia evaluators feel that having good taxiing time estimates for take-offs is useful in order to estimate if regulated aircraft can comply with their CTOTs and to calculate departure estimates. In addition, Network Control could use this taxiing time estimate to calculate the fuel aircraft need for the taxiing. Current fuel estimates are calculated without taking into account the stand at which the aircraft is located or the level of congestion at the airport.

During trials, the airlines operators had the feeling that the taxiing times for take-offs are closer to the actual times when statistical times were used. Moreover, the variation in taxiing times calculated using the dynamic taxiing-time model, is inadmissible for airline operators.

2. **Qualitative Appraisal from the ATC Point of View.**

Most of the controllers involved in the evaluation feel that having good estimates of taxiing times is useful and will enable a better prediction of aircraft behaviour.

Controllers found very useful taxiing times in the case of aircraft regulated by the Central Flow Management Unit (CFMU), to help them on the decision-making process of start-up clearance in terms of slot compliance.

Conclusions

Major European airports with complex architectures of taxiways have currently difficulties for predicting taxiing times. This results in great difficulties to respect CFMU slots. A better prediction of the Off-Block Time and the taxi-time would make it easier for the ATC to cope with the slots. Furthermore, airlines and airport could also benefit from realistic estimations of taxiing times.

Trials carried out at Madrid-Barajas within the Leonardo project demonstrate that we are able to estimate taxiing times much more realistically than we do it today. Solutions as simple as performing a statistical analysis gives direct benefits. The added value of using a dynamic taxiing-time model is still to be validated. In this latter case, the airport model is crucial and it must be carefully validated. In addition, the introduction of additional real data coming from surface radar would highly increase the reliability of the tool.

Finally, as a lesson learnt from these experiments, we would recommend to carefully considering the size of the sample needed for analyzing taxiing times as a function of the stand. Depending on the airport layout and operational procedures this size could be quite significant. In the case of the trials carried out at Madrid-Barajas airport, in some cases, the size of the samples were not enough to extract representative conclusions.

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