LINKING EXISTING ON GROUND, ARRIVAL AND DEPARTURE OPERATIONS

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Abstract

LEONARDO, Linking Existing On Ground, Arrival and Departure Operations is a research project promoted by the European Commission, with the participation of companies from France (ADP, DNA and Air France), The Netherlands (NLR), Italy (Sicta) and Spain (Aena, Iberia, Indra, Ineco and Isdefe), together with Eurocontrol. The objective of Leonardo is 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. The integration of these decision supporting tools promotes the information sharing among airport stakeholders and makes it possible to provide the airlines, the airports and the air traffic service providers with early and reliable planning updates. In order to achieve these objectives, systems integrating the afore mentioned planning tools were developed and tested at Madrid-Barajas airport and at Paris-Charles de Gaulle airport.

The results of Leonardo experiments give evidence of the benefits achievable applying CDM procedures at the airport level. It has been demonstrated that the airport operator and the airlines improve the safety and the efficiency of their ground processes using ATC planning updates and that the ATC improve air traffic management thanks to the information provided by the airport and the airlines.

This paper begins with the description of the concept of CDM implemented and tested by Leonardo. Then, the paper 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 achieved.

Description of LEONARDO System, a CDM integrated System

LEONARDO Operational Concept

The main problem that LEONARDO intends to solve is the lack of coordination and efficiency in the context of Airport Arrival, Departure and Ground Operations, which leads to unacceptable amounts of delays and operating costs.

In particular, the areas on which the LEONARDO Project is focusing are the followings:

- Currently, there are existing tools to plan and manage arrivals, departures and ground operations at airports. However, most of these tools work in isolation. It means that each tool uses its own criteria to optimise part of the airport disregarding what is happening elsewhere at the airport.

  In this situation, only individual operations (i.e. arrivals, departures, stand operations, taxiing) are optimised. An integration of tools would make possible to improve the overall efficiency of the airport.

- The different actors involved in airport processes (e.g., air traffic controllers, airline and airport operation centers and handling companies) do not always have all of the information they need when they need it and with a suitable level of reliability. An increased exchange of information and co-operation between these actors could improve the management and planning of available resources.

In fact, the concerns described have one thing in common: all airport partners lack up-to-date global situational awareness due to inadequate information sharing or fragmented information flows. In this context, LEONARDO, starting from the Eurocontrol work on CDM [9] [10] [11] [13] and the results of the DAVINCI project [17] [18], it has developed an

Operational Concept which aims at integrating tools, actors and processes at the airport level.

LEONARDO Components

In order to put in place the Operational Concept proposed by LEONARDO, three system prototypes have been designed, developed and implemented based on a common model. Each prototype is suited to the specific context and operations of the corresponding site: Charles de Gaulle Airport, Madrid Barajas Airport and NLR ATC and Tower simulators.

LEONARDO system[1] is composed of the following:

1. Tools for planning arrival, departure and surface movement operations.
   - The Arrival Manager (AMAN) calculates the arrival sequence assigning a managed landing time (MLDT) to each flight.
   - The Departure Manager (DMAN) calculates the departure sequence assigning a managed take-off time (MTOT) to each flight.
   - Surface-movement Manager (SMAN) calculates estimated taxiing times for arriving and departing flights as a function of the stand and runway. It may also take into account the current traffic situation on ground.
2. Interfaces with external sources that provide real-time information about airport operations.
   - Flight plans and radar tracks are obtained from air traffic control systems.
   - Flight schedules, aircraft registrations, stand allocation and boarding status are received from the airport systems.
   - Actual times (ACARS 3OI) and delay messages are obtained from the airline.

   The interfaces with airport and airline sources at NLR were substituted by the GAST tool which simulated the planning operations at the airport (stand and gate allocation) as well as the turn around planning carried out by handlers and airlines.
3. The core of the system or CDM manager that processes the information received from the planning tools and the external sources.

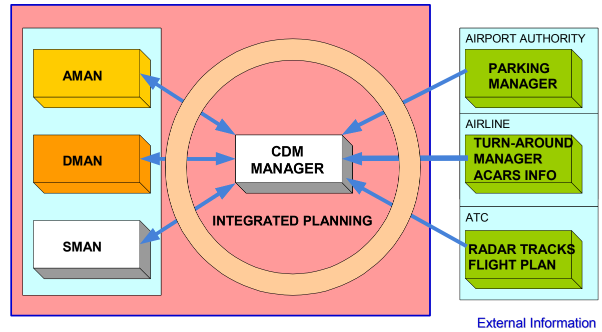

Figure 1. LEONARDO System

LEONARDO architecture

LEONARDO system has been integrated with the legacy systems at both airports without interfering with the daily operations.

The following scheme shows an example of the system architecture adopted at one of the sites. The yellow boxes represent workstations or PCs which constitute the LEONARDO system at Barajas airport. Four emplacements are involved: Air Control Center at Torrejón, Barajas Tower, Barajas airport offices and airline offices. The currently existing networks set by ATC (REDAN) and the airport (RECOA) have been used. At Iberia´s offices a new RECOA node has been installed to connect LEONARDO Human-Machine Interface (HMI).

The core of the system is installed at Barajas Tower where a new SITA network node was contracted in order to receive ACARS and delay messages forwarded by the airline.

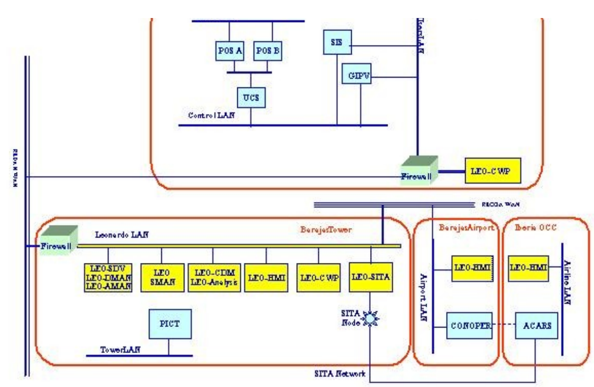

Figure 2. LEONARDO Architecture at Madrid Airport

[1] Whenever the LEONARDO system is mentioned, we are referring to the three prototypes developed within the LEONARDO project

LEONARDO Human Machine Interface (HMI)

The information provided by the system is displayed to the end users, i.e. air traffic controllers, airline and airport staff, through two HMIs.

Air traffic controllers have access to the departure and arrival sequences calculated by AMAN and DMAN through a Controller Working Position (LEO-CWP). Although at Paris Charles de Gaulle AMAN (MAESTRO) is operational, this is not the case for Madrid Barajas where a new CWP had to be implemented to include specifically developed prototypes for AMAN and DMAN.

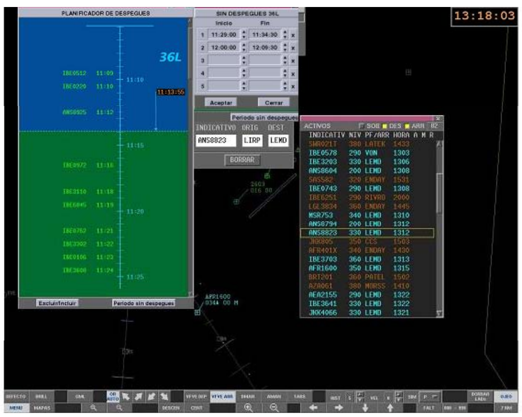

Figure 3. LEONARDO Controller Working Position at Madrid

Another type of terminal, LEO-HMI, provides the information that is at present scattered in different systems as well as the planning updates calculated by LEONARDO, alarms for regulated flights and comments on flight status. All this information is put together and shown in tabular form for each flight. Unlike LEO-CWP, this type of terminal does not allow the user to interact with the system, but data is updated in real time with ATC controller's manual inputs.

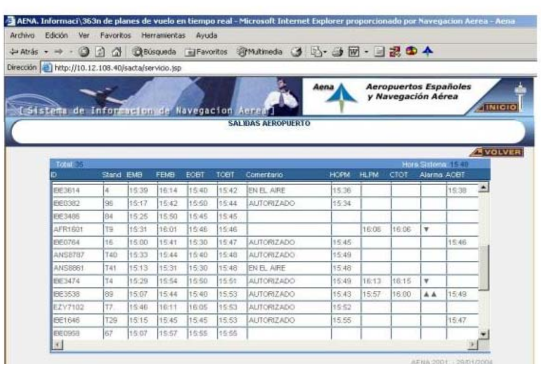

Figure 4. LEONARDO HMI at Madrid

Functionalities of LEONARDO System

1. Estimated Time of Arrival to the Stand (Managed In-Block Time: MIBT)

LEONARDO system provides an estimated time of arrival at the stand for each flight. This estimate has been called the Managed In-Block Time (MIBT)[2]. A more accurate knowledge of the MIBT far in advance serves to optimise stand management and help airlines to use their resources more efficiently.

AMAN proposes an arrival sequence as a result of an optimization process of the landing estimates provided by the ATC system. These estimates take into account the planned trajectory for the aircraft, its performance and radar updates. The objective is to create a continuous flow of incoming traffic by minimizing the total delay of the flights in the TMA whilst meeting the stipulated levels of safety [14].

As soon as LEONARDO system has received an optimum landing time (Managed Landing Time: MLDT) from AMAN, it calculates the estimated time of arrival at the stand (Managed In-Block Time: MIBT) using the estimated taxiing time provided by SMAN. When the flight lands, an ACARS message containing the actual landing time is received and the MIBT updated.

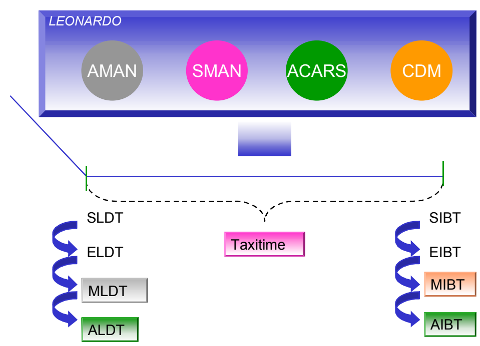

Figure 5. Calculation of MIBT

2. Estimated Time of Departure from the Stand (Target Off-Block Time: TOBT)

[2]This common terminology has been first derived from the CDM at Barcelona Airport project [12] and made compliant with the Eurocontrol Standards Acronyms and Definitions [16]. The Acronyms follows the standardisation rules based on 4 letters: The second and third letters defines the event (for instance, TO for Take-Off), the fourth letter defines the event type (Time event or Duration event) and the first letter nature of the event (for instance, A for Actual, E for estimate) [2].

For all departures, the system calculates the estimated off-block time (Target Off-Block Time: TOBT). This estimate takes into account flight plan updates, delays accumulated at the arrival and information on delays received directly from the airline.

Associated to this time there is a comment indicating the flight status. If a flight has been delayed, or if there has been a problem and the airline can only give a time at which it may provide new information, all users shall be able to quickly identify the situation thanks to the comments. Also, the airline operation center shall know the delivery of the start-up clearance in real time thanks to these comments.

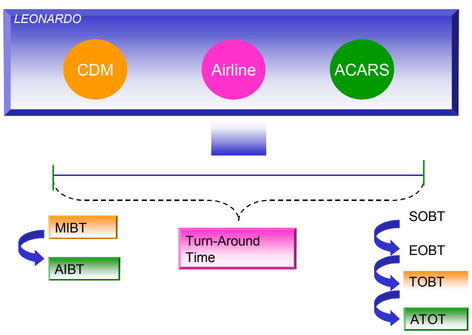

Figure 6. Calculation of TOBT

3. Estimated Time of Take-Off (Managed Take-Off Time: MTOT)

DMAN proposes an optimum take-off sequence that minimizes holding time to enter the runway. The criteria used to create the optimum sequence includes the separation minima that must be met between aircraft as a function of its departure route (SID), speed and wake vortex. Central Flow Management Unit (CFMU) regulations and the capacity restrictions imposed by the airport are taken as constraints [15].

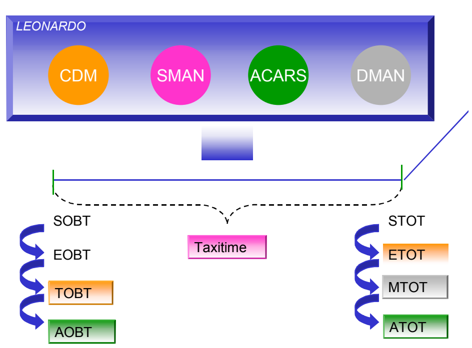

Figure 7. Calculation of MTOT

The tool also provides the optimum start-up time (Managed Start-Up Time: MSUT), which is the time at which the aircraft should receive its start-up clearance to take-off at the MTOT.

For aircraft that have not been cleared to start-up, an estimation of the take-off time (ETOT) is also provided based on the TOBT. The ETOT assumes that aircraft begin to move as soon as they are ready, i.e. at their TOBT, and take off in the same order in which they reach the head of the runway (natural sequence).

The controller may alter the sequence manually at any time, changing the managed take-off time or imposing periods of time without take-offs. Whenever an aircraft takes off or if start-up clearance is given to an aircraft, the tool recalculates the take-off sequence. Manual actions also trigger a recalculation of the sequence.

4. Alarms for regulated flights

For aircraft regulated by the Central Flow Management Unit (CFMU), the system helps the controller on the decision-making process of start-up clearance in terms of slot compliance. To this end, the system displays alarms depending on the delay or earliness with respect to the Calculated Take-off Time (CTOT).

The CTOT time window (CTOT-5', CTOT+10') is shifted to the off-blocks- time horizon to see how the TOBT, which is the best prediction of off-block time available, fits within this time frame.

Three main alarms are provided by the system:

- "Slot missed": The system estimates that it is not possible for the aircraft to reach the take-off runway in time to meet its CTOT. This alarm is calculated under the assumption that the aircraft has priority over the rest of the traffic.
- "Priority required": The system estimates that the aircraft can meet its CTOT if it is given priority over the rest of the aircraft.
- "Too early": The system estimates that the aircraft may be ready to take off before its CTOT. This alarm is calculated under the assumption that the aircraft does not have priority over the rest of the traffic.

5. CDMMA between AMAN, DMAN, Taxi Planner and Parking Manager / Airline Turn-around

This functionality involves the automation of the decision-making process through the multi-agent concept. It implements automated negotiation between actors by maintaining the man-in-the loop.

CDMMA negotiation is only active when some of the planning tools encounter unsolvable problems or when the collaborative sharing of flight information predict severe planning conflict between the AMAN, the Parking Manager and/or DMAN.

This functionality has only been implemented in the prototype developed by NLR. Since it was the most innovative aspect of Leonardo, it was found appropriate to test it first in a simulation environment prior to do it at real airports.

Description of Trials

The purpose of the trials was to evaluate the system at an operational level. Trial sessions were conducted at the three sites. Results were obtained by means of quantitative and qualitative data gathering methods in order to provide both objective and subjective data.

Paris Charles de Gaulle Airport and Madrid Barajas Airport

The trials were performed 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 evaluators use real information in a real operating environment, without interfering with airport operations.

LEONARDO system was installed at ATC Towers, Terminal Maneuvering Area (TMA) Control Centers, Airport Operations Centers and Airline Coordination Centers. Experienced air traffic controllers and staff from both airport and airline operations centers evaluated the utility of the information provided by the system. Prior to the trial sessions, all users received specific training. During the trials, evaluators were located near the real positions which they were "shadowing" so that they could have a clear view of the real situation. This made it possible for them to evaluate the system by comparing it with the real system.

CDMMA at NLR

The experiments for LEONARDO were run on the NLR ATC Simulator (NARSIM) and the NLR Tower Research Simulator (TRS). Real-time simulations enabled to test LEONARDO tools in an environment where traffic is affected by the decision-making process. The experiment was run using a part of the Schiphol layout as a basis. NLR personnel and Eurocontrol controllers participated at the CDMMA real time simulation. Each controller, gate planner, and pilot had an own specific working position.

Figure 8. NLR TRS

Results of Trials

Safety Benefits

Safety was analysed through the subjective perception of ATC Controllers. According to them, the airport CDM systems proposed by LEONARDO will not degrade the safety levels on ground. Moreover, it may contribute to improving operational safety in some specific situations: For example, ground controllers will have a better situation awareness thanks to the information on stands, Actual Landing Time ALDT, Actual In-block Time AIBT and Managed Landing Time MLDT, among others. This new perception could prevent complicated situations that may occur on taxi areas.

Capacity Benefits

Capacity was also evaluated from the perception of users on their workload and on the runway throughput. The results show that most controllers involved in the evaluation feel that the system would reduce the current number of co-ordinations and communication actions. In addition, the sharing of the CDM information will reduce the time used by the actors to make individual calculations, such as mental estimation of taxiing times.

Furthermore, during the real-time simulations, the Delivery Controller visual workload was evaluated using an eye tracking tool. Results concluded that a significant reduction in the Delivery Controller visual workload is achieved thanks to LEONARDO.

Efficiency Benefits

The objective for the trials was to provide a quantifiable measurement of the efficiency benefits of the CDM integrated system and procedures proposed by LEONARDO. In particular, the following benefits had been studied:

- Improvement of Flight predictability
- Improvement in the decision-making in the airline operations (e.g. handling operations):
- Improvement in the decision-making in the airport authority operations (e.g. stand management)
- Improvement in the decision-making in the ATC operations:
- Improvement of schedule compliance (e.g. CFMU regulation compliance).

1. Landing time Predictability

From the comparison with the information currently used by the individual actors, it can be said that the new estimations provided by the LEONARDO system are much more accurate. At Barajas airport it can be obtained about 42.51% of error decrease (from 03:57 to 02:14 min.) in the landing time estimate 20´ before landing and 45% of error decrease (from 02:51 to 01:32 min.) when the flight is landing. At Charles de Gaulle airport, the results show a 30.9% (from 05:24 to 03:06 min) and 3.9% (from 03:30 to 02:42 min) of error decrease respectively.

Critical situations, such as holdings, were studied in Paris CDG and it was detected that although predictions were less accurate, the improvement in reliability was higher. The differences between the estimations provided by the LEONARDO system and the currently existing estimations are about 35.2% of error decrease (from 09:42 to 04:00 min) 20´ before landing and 12.3% (from 04:42 to 02:36 min) of error decrease at the landing. The more the flights have to hold, the less the current estimations are accurate and the more significant the improvement provided by the LEONARDO CDM estimation is.

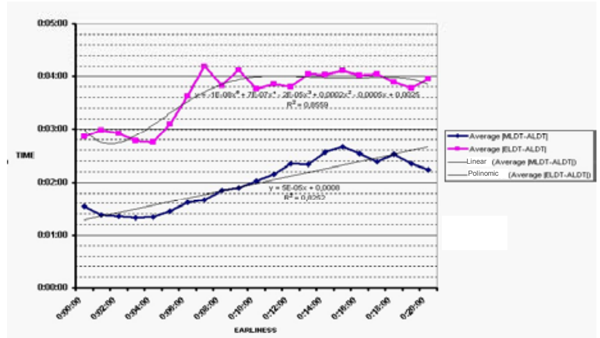

Figure 9. Example of landing predictability improvement at Madrid-Barajas

2. In-block time Predictability

Before a flight is on ground, the reliability of the in-block estimation depends on the reliability of both the landing time estimate and the taxi time estimate. Trials results show that in-block predictions are improved when using an AMAN and SMAN. The improvement on landing time and taxi time predictions obtained thanks to the introduction of automated tools leads to an improvement of the in-block time estimation. Once, the flight has landed, the reliability of the in-block time prediction depends only on the taxi time estimation.

Airlines and airport authorities are the most interested on the in-block time estimation. The improvement on the time estimate reliability depends on the accuracy of the current in-block estimate used by each actor. At Madrid Barajas the major improvement is for the airline (Iberia), 79.3%, while for the airport the improvement achieved is 3.7%. The accuracy provided is 01:05 minutes in absolute terms, versus the current accuracy of 01:09 minutes and 05:09 minutes for the airport and the airline respectively. These values are calculated when the flight is landing.

At Paris CDG the improvement was higher for the airport authority (ADP): about 45.3% of error decrease 30´ before in block and about 55.1% of error decrease 10´ before in block. The accuracy provided is 04:30 minutes versus the current accuracy of 09:42 minutes 30' before the in-block. 10' before the in-blocks, in-block accuracy changes to 03:06 minutes from the current 07:42 minutes.

The reason for these results is that currently Iberia and CDG airport authority estimate the in-block time without any supporting tool and introduce manually this estimate into their systems. With such a process, the accuracy of the estimations is highly dependent on the person who makes the calculation: his/her skills, experience and conditions. In these cases, LEONARDO will provide them an automatic mean to get more accurate time estimation than the one they currently have.

Holding conditions in TMA were also studied at Paris CDG. As well as for the landing time estimation, results have shown that the benefits are higher under these conditions (63.6% of error decrease for ADP, that is, from 09:18 minutes accuracy to 02:18 minutes 10´ before in block). The more the arrival flight has to hold the more the improvement in predictability is.

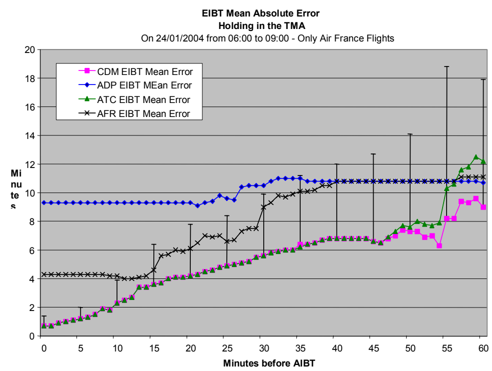

Figure 10. Example of in-block predictability improvement at Paris CDG with holding conditions in TMA

3. Off-Block Time Predictability

Regarding the departure predictability at stand the study focused on the off-block time estimate before the start-up clearance. An improvement on the off-block time predictability compared with the off-block estimate included in the flight plan (EOBT) was found. This was caused by the fact that the airline shares its information with the LEONARDO system.

At Charles de Gaulle, the improvement on the off-block estimate predictability is of 31.6% (from 25:00 min. accuracy to 14:18 min.), 20' before the off-block event, and of 50.7% (from 24:00 min. accuracy to 09:00 min.), at the off-blocks time. These values are obtained considering only those flights which were delayed. At Barajas, the average improvement in the estimate does not vary noticeably with time and it is about 19.71% (equivalent to a 01:35 min. accuracy improvement) when considering all delayed aircraft and about 50 % error decrease when considering only the impact of late arrivals in departure flights.

It should be highlighted how the better estimation of the in-block event due to the detection of arrival delays greatly improves the off-block predictability. This is shown in Figure 11 which represents the evolution of the TOBT error compared to the EOBT for departing flights which have arrived late.

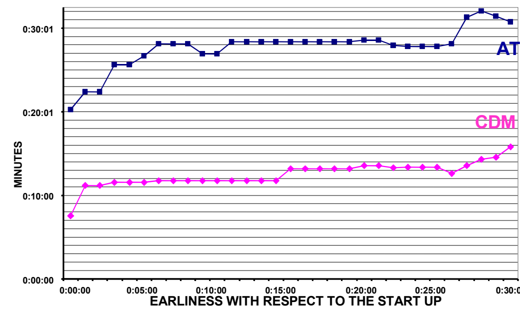

Figure 11. TOBT Mean Absolute Error at Madrid-Barajas for departing flights with late arrival

4. Take-Off Time Predictability

Take-off estimations are based on the estimations of the off-block time, the estimations of the taxi time and the organisation of the departure sequences. After the off-block event the estimation only depends on the two last factors.

The estimates provided by LEONARDO system are based on enhanced taxi time predictions. This result added to the better off-block time prediction leads to a better take-off time estimation. ATC is the most interested actor on this event.

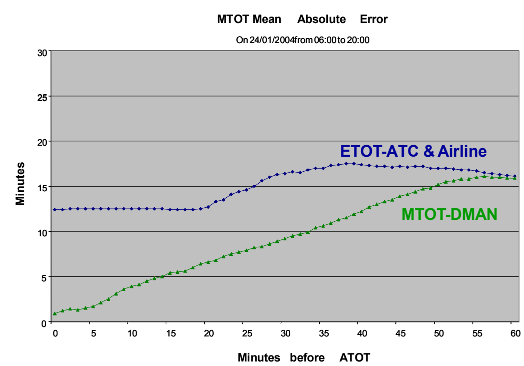

Figure 12. Example of take-off predictability improvement at Paris CDG

5. Slot Compliance Predictability (Alarms)

During trials, both airline evaluators and controllers felt that the CTOT compliance alarms are very useful and that the information that they provide is reliable. Thus, the alarms are good predictors of future situations with respect to CTOT compliance. Having this type of alarms would help airline operators and ATCos to optimise the ground operations management.

6. **Improvement in the decision-making in airlines operations**

Regarding the in-block event, the better estimation of the arrival at the stand allows the airline to perform changes in the order of its departures flights to ensure they depart on time. The better in-block time was also found to be useful for the airline to detect the delay of transit passengers. In the case of connecting flights, the arrival sequence and the detection of delay for arrivals help the airline to decide on whether to make the departing flight wait or to redistribute the passengers to later flights.

Regarding the take-off event, the airline can profit from the MTOT calculated by the DMAN to improve the decision making in the handling process of the departure flight. Currently, the airline has no access to what is happening on the taxiways. In addition, messages informing that an aircraft has been cleared to start up, assist the airline in its decision making process for regulated flights.

7. **Improvement in the decision-making in airport authority operations**

Airport's interest is focused on the in-block and off-block event, i.e. in the benefits derived from an improved prediction of these two time events.

Regarding the arrival predictability at stand (in-block time), the airport authority shall benefit from receiving the arrival prediction through the CDM system especially when the current estimation is mentally calculated and manually introduced in the system. In this case and under nominal conditions, predictability has shown to be improved from 8 minutes error to 3 minutes error at Paris. Thus, benefit could be even greater when nominal conditions are not met and there are unexpected delays (e.g. holding conditions in TMA). In both cases, Madrid and Paris, the obtained average estimation accuracy (± 3 min) seems to be sufficient for an effective planning of resources. This result is enforced by the real-time simulations, which have shown that stand changes can be made earlier in the process if reliable estimation is available.

Regarding the departure predictability at stand (off-block time), TOBT is a better estimation than current estimates. However, at Madrid Barajas airport, TOBT reliability was not enough for the airport operator. This lack of reliability was also shown at the real time simulation trials.

However, the information about the status of the aircraft, such as the "start-up cleared" comment used in Barajas trials, provides a clear indication of the aircraft readiness.

8. **Improvement in the decision-making in ATC operations**

Air traffic controllers expressed that their decision making processes would be noticeably improved with such a system in case the airport is congested.

With better off-block estimates and all the information provided by the airline regarding the flight status at stand, controllers are able to know if certain flights are going to delay their start-up clearance request. In addition, when the flight plan has not yet been updated, TOBT would provide an estimate of when the aircraft will call and be ready to depart. Furthermore, it could even be a reference to request the airline to update its flight plan.

Regarding regulated flights, LEONARDO alarms help the clearance delivery and the tower controllers to detect regulated flights that need priority in order to comply with their regulation. Moreover, alarms help also to detect aircraft that should request a new regulation since they cannot comply any longer with their CTOT.

Conclusions

The results of LEONARDO experiments give evidence of the benefits achievable applying CDM procedures at the airport level. It has been demonstrated that CDM is an important approach to make best use of available infrastructure (runways, taxiways, aprons, stands and gates, etc) and the scarce resources (both equipment and manpower) and that it is also an important support for Air Traffic and Airport slot compliance.

In addition, thanks to the CDM processes the individual planning improvements have a network effect and contribute to the improvement of the efficiency not only of the overall airport but also of the overall air traffic system: Better estimations of the in-block times make possible better estimations of the off-block times which imply, in its turn, better estimations of the take-off times.

Results have also demonstrated that the benefits from the implementation of a CDM system are more significant in disruption situations. According to the users, the more critical the situation is (delays, holding or bad weather) the more LEONARDO is useful.

In conclusion, the work achieved in LEONARDO brings technical solutions for information sharing, collaboration and negotiation among airport actors. Further CDM applications and more integrated systems will allow us to operate in a very safe and efficient environment while improving traffic flows at congested airports, reducing operating cost for airlines and benefiting the end user: the passenger.

Further information

General information at [1] and at the Web Site: http://leonardo.aena.es

Further details on the Operational Concept and System Functionalities at [2] and [3]

Further details on the Trials at [4] and [5]

Further details on the Results at [6], [7] and [8]

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