Modelling Delay Propagation Trees for Scheduled Flights

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Abstract—**Reactionary delays have a large impact in the air transportation system both at operational and economical point of view. However, research efforts to understand their origin and propagation patterns in Europe have been limited. The TREE project (data-driven modeling of network-wide extension of the tree of reactionary delays in ECAC area) is focused on characterizing and forecasting the propagation of reactionary delays through the European Network. The best approach to tackle this problem passes through the use of Complex Systems theory. This theory analyzes systems formed by a large number of components interacting between them by means of networks and attempts at predicting their meso-scale and global behaviors. In this model, airports are taken as nodes and links between them are created by direct flights, with delays appearing as malfunctions in the daily planned schedule that can and do propagate over an important fraction of the network. An agent-based, data-driven approach is introduced, able to simulate the delay propagation process. The first results show a promising similarity with the real delay propagation patterns, being able to describe the cluster of congested airports and its evolution along the day.**

Keywords-Delays; Complexity Science; Big Data, Modelling, Simulation, Disruption Management; Network Performance;

I. INTRODUCTION

This paper presents the work that is being performed in the frame of SESAR WP-E TREE project, whose aim is to recreate the propagation of reactionary delays and understand the European Air Transport Network behavior. The project final objective is to introduce a model able to predict the delay evolution in the network and to analyze delay mitigation strategies by part of the network or airline managers.

Flight links related to flights using the same aircraft and/or crew and/or passengers are the skeleton through which delays are propagated. Following the tree of reactionary delays allows studying the impact of different local strategies into the delays propagation through the network. The modelling approach in TREE is an agent-based approach, with aircraft as basic units, and includes mechanisms for simulating slot reallocation and slot swapping strategies as alternatives prior to flight cancellation.

The rationale upon which the present work is built is defined by the latest expectations published by different organizations concerning traffic growth, airports capacity limitations and largest delay causes in Europe.

The Challenge of Growth (CoG) report issued by EUROCONTROL [1] in 2013 states that when confidence and economic growth return, air transport demand will start growing faster again, so Europe will face a significant airport capacity crunch, which will damage the continent's aviation system and connectivity. As a result of insufficient airport capacity, in the most-likely scenario, 12% of demand for air transport will not be accommodated by 2035. This means losing 1.9 million flights (120 million passengers, €230 billion in lost GDP) per year. This will be the consequence of a traffic grow and a highly capacity constrained Air Transportation System (ATS) in Europe due to the limited availability of resources on the ground and en-route. A good management of these resources determines the extent to which the airport can reach its full capacity potential.

Looking at the figures provided by the Central Office for Delay Analysis (CODA) in its CODA Digest 2011 and 2012 reports, reactionary or propagated delays are one of the largest delays causes in Europe. Among all the causes, airlines' management related causes are the ones with highest contribution to the total delay.

Regarding Airports' capacity constraints the CoG warns about the repercussions of the airports capacity crunch in 2035:

- Average delay per flight will rise from current levels of 1 min/flight to 5-6 min/flight.

- The cost for airlines and airports will be €40billion of lost revenues and €5 billion in congestion costs - per year.

These three aspects made interesting to analyse the behaviour of the reactionary delays in the European air transport network. The TREE model evaluates the daily planning performance and analyses the impact of perturbations in the network. Moreover, the model is able to simulate strategies applied by the airlines or the network manager for disruption management and analyses their impact in delay propagation mitigation. Metrics inspired in Complex Network theory are being considered to quantify the level of Air

Transport Network congestion. These performance metrics may have different levels of resolution, from airport based to network-wide.

II. BACKGROUND

There are two main lines of study of delay propagation in air transport: mathematical static studies and modelling and simulation attempts. For both lines, most literature is focused on USA data and network, even if the investigation is undertaking by European organizations and researchers.

Several studies analyzed static data to find cause-effect relations between air transport schedules and the reactionary delays distributions. The algorithmic optimization of airline schedules had the objective of have better delay propagation pattern. In [2] a model was developed for producing robust crew schedules. [3], [4] and [5] focused respectively on maintenance routing constraints, redistribution of existing slack in the planning process and multi-objective optimization. All these theoretical studies showed promising results in reducing propagated delays and improving the network robustness.

Propagation trees are another tool for tracking individual flight delays propagation through the network and studying the impact of airline schedules on delay propagation. Pioneering study [6] pointed out to the early reduction of primary delays. Other study ([7]) concludes that nearly 40% of the flights have no propagating effect.

Extensive data mining provided valuable results in [8], one of the few attempts to analyze European airline planning and traffic data. Results showed that 50% of delays in low-cost operations are reactionary delays, 40% for hub-and-spoke operators and 45% for point-to-point operations.

There have been several attempts to model delay spreading. The inherent complexity of the mechanisms motivate that different modelling techniques were proposed:

- Simulating the air traffic system as a network of queues [9] looking for estimate slack and flight time allowance needed to compensate for the root delays at airports and en-route.

- The stochastic nature of the air transport network performance is analyzed in [10] to develop a strategic departure delay prediction model for a single airport.

- Other studies focused on characterizing delay propagation patterns and influence parameters using a mesoscopic approach and including stochastic parameters to better reflect the inherent uncertainty of the air transport network performance.

This last strategy is the one chosen in the TREE project. Previous works in this field included [11], an approximation for analyzing the USA airport network as a stochastic and dynamic queuing model based on the Approximate Network Delays concept (AND-concept). The analytical macroscopic model computed the propagation of delays within a network of airports, based on scheduled itineraries of individual aircraft and a First Come First Served queuing system for each airport based. The metrics were local and of system-wide (propagated)

delays over a 24 hour period. The authors used a stochastic and dynamic queuing engine to estimate local delays and a network decomposition approach to propagate delays through the network. The model's results were sensitive to different parameters, such as the setting of the ''slacks'' in ground turnaround times and promising results were obtained in reproducing trends and behaviors that are observed in practice in the US system.

TREE project team members worked in [12] and [13] developing also an agent-based framework to give insights, in a cost-effective way, of how microlevel interactions in the air transport give place to emergent behavior from a network-wide perspective. The first study [12] introduced a model that reproduced the delay propagation patterns observed in the USA performance data. By monitoring the evolution of clusters of congested airports, the model proved to be successful in assessing the daily schedule ability to deal with disruptive events and to study the relevance of primary delay localization for the evolution of congestion in the network. The second study [13] proposed an application of the model to understand the system response to the introduction of large-scale disruptions and to assess strategies to handle the disturbances.

The model developed track the state of each aircraft as daily schedules were performed. At the beginning of each simulation run, passengers' connections between eligible flights pairs were established randomly, this is one of the differences with the European model, in TREE passenger connections are estimated from real data, taking into account each airport and each airline particularities.

Other difference refers airport capacities: in the US each airport had an hourly capacity given by an estimated parameter; aircraft exceeding this capacity were put on hold in a queue on a "First Come-First Served" basis, thus accumulating delay. In the EU model, published nominal capacities are used and as the European air transportation network has a slot policy, in TREE project the delayed flights don´t depart in a FCFS order, they have to be allocated in a new slot.

Other previous research works carried out by the project team members are the base for the knowledge of the European Network behavior. For example NeCo 2030 project [14] proposed a high level assessment of the behavior and stability of the highly congested European 2030 air transport network. The tool used was a macroscopic model conceived to capture the emergence of network properties such as performance degradation, behavior predictability, amplified impact of external events and geographical stability. The ability of the model to measure reactionary delays and their propagation was also explored.

This model was later on evolved and customized to analyze the impact in terms of network-wide performance and delay propagation of local departure prioritization strategies [15][15] and [16]. In this work, it was observed how First Come First Served provides better performance picture at global level than any of the studied departure prioritization criteria. As general conclusion, it was proved the suitability of the mesoscopic modelling framework for analyzing the multi-component air transport network and, in particular, for obtaining

straightforward performance results associated to specific prioritization rules applied to flights.

III. METHODOLOGY

A. TREE model description

TREE modelling approach consists in tracking the state of each aircraft and airport as the aircraft perform their daily rotations attempting to follow their schedule (Fig. 1). Limited airport capacities (the maximum numbers of aircraft movements which can take place in an hour) and flight connections (through aircraft, passengers and crew) are taken into account as delay propagation mechanisms.

Figure 1. Overall model flow diagram.

The model is data-driven since as many simulation inputs as possible are reconstructed from empirical data:

- Airports capacities: from the Demand Data Repository (DDR2) [17].

- Monthly passengers' connectivity patterns: the source is Sabre [18], a travel technology company and one of the largest global distribution systems providers.

- Flight schedules with the primary delays: provided by the Central Office for Delay Analysis (CODA) of EUROCONTROL [19].

At the beginning of each run simulation, the model builds the ECAC airports network and the network operational plan, linking the aircraft in their daily connections. While there are aircraft operating, the simulation processes the queue of events in chronological order, sorting flights by their scheduled departure time.

The model processes the flights (Fig. 2) in accordance with their state:

- If a flight has no delay, no measure is necessary, i.e. the flight will depart and land as scheduled.

- If one flight is delayed, but still able to depart and arrive within its currently assigned ATFM slots, delay needs to be propagated to the next leg in the aircraft's rotation and the passenger/crew connections (if any).

- If a flight is delayed (because of a primary or a reactionary delay) and lost its slots, the simulation tries to find a new suitable pair of slots (first through re-scheduling, then through slot swapping), which also may cause delay to be propagated. If these processes fail, the flight and all the successive legs in the same aircraft's rotation are cancelled.
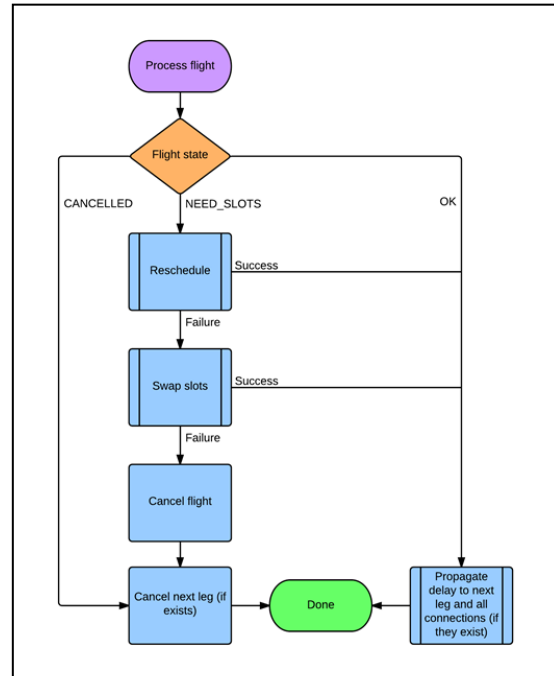

Figure 2. Main simulation loop.

At the end of each simulation run, the final state of each flight is the output, detailing if it was re-scheduled or cancelled, its amount of reactionary delay, and the flights to which it has propagated delay. From this, macroscopic quantities such as the daily distribution of delays or the temporal evolution of the cluster of congested airports are calculated.

B. Modelling the flights connectivity

1) Aircraft connectivity is the most basic kind of connectivity: for the model, if two flights, one arriving at and one departing from the same airport, are from the same airline and have the same tail number, it means that both flights will be operated by the same aircraft. This connectivity is determined by the flight schedules, so cannot be "turned off" in the simulations. In the model, if the arriving flight is delayed then there will be two options:

a) the actual arrival time plus the minimum service time is lower than the next flight's scheduled departure time. Then the delaye will be recoveered in the rotation and the second flight will depart on time.

b) the actual arrival time plus the minimun service time is higher than the next flight's scheduled departure time. Then the second flight will have to be delayed and look for a new slot at departure and arriving airports.

2) Passenger connectivity refers to those passengers that need to change aircraft to arrive to their destination. For this kind of connectivity, possible connections are established randomly at the beginning of each simulation run between eligible pairs of flights. The probabilities are estimated from the actual passenger conectivity data that include the monthly number of passengers and flights between any pair of airports for each airline, as well as the number of passengers who connect to further flights and to which destination they connect. The model takes the monthly percentage of passengers remaining at an airport or connecting to extra flights as the probabilities of a stochastic multinomial process.
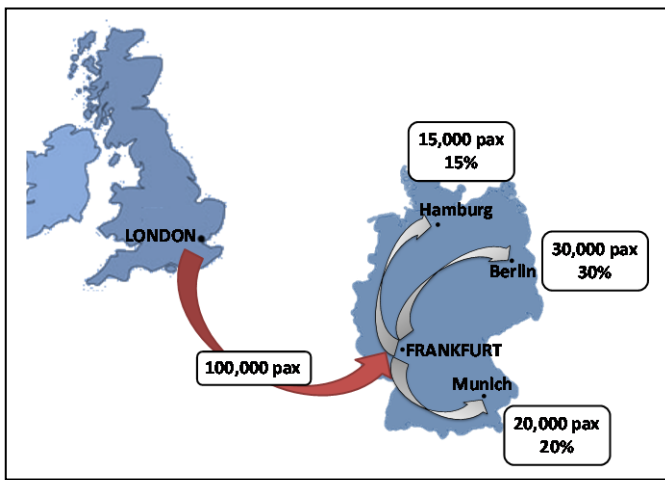

Figure 3.   Example: monthly passengers connectivity in a route.

As an example (Fig. 3), there is a flight from London to Frankfurt, and there are three flights departing from Frankfurt after the arrival of the first flight plus the minimum transfer time and before the maximum. With 15% probability a passenger from London will continue his travel to Hamburg, with 30% to Berlin, with 20% to Munich and the 45% of the passengers will finish their trip in Frankfurt.

The airlines do not always wait for all the connecting passengers. However, delays only propagate between flights when they do wait. To take this fact into account a parameter α between 0 and 1 is introduced in the model. α represents the average fraction of passengers that the companies wait for and must be calibrated in the simulations. The factor α multiplies the number of passengers connecting in the airport decreasing the connecting probabilities.

3) Crew connectivity is performed only in the hub airports of the different airlines. The crew connectivity is estimated by a parameter when two aircraft owned by the same airline comply with the passenger connectivity rules. The parameter γ is calibrated by comparing the model's output with empirical data.

C.   Re-scheduling

When processing a flight that has lost its slots, the simulation tries to find a new pair of slots in both the departure and the arrival airports. The flight has a "desired departure time" (Fig. 4):

Figure 4.   Desired departure time

The possible departure/arrival slots' pairs are those such that the departure slot begins at the desired departure time or later, but without exceeding the re-scheduling threshold time (3 hours) parameter. A slot will only be assigned if there is available capacity in both origin and destinations airports at the new assigned times.
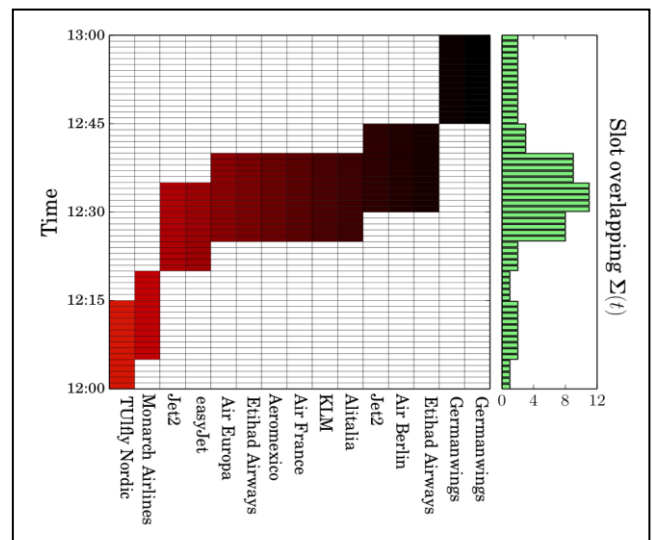

Figure 5.   Example of slot overlapping. Departure slots at PMI airport on the 14th of September 2014, data from Flightradar24.com

Each possible slot pair partially or totally overlaps with other slots used by other flights, e.g. in Fig. 5 it is seen that 6 flights from 6 different airlines share the 12:25-12:40 slot. The model would choose the earliest pair, dealing with the capacity constraints. At this point there are different possibilities:

- If in departing and arrival hours the demand is below capacity in both airports, the flight is assigned the pair of slots requested at the "desired departure/arrival time".

- If one or both airports are operating to the limits of capacity, the flight pass to the next hourly block until one slot with free capacity in both (departure and destination) airports is found. Then the earliest possible slot-pair (at the beginning of the hour) is assigned to the flight (Fig. 6).

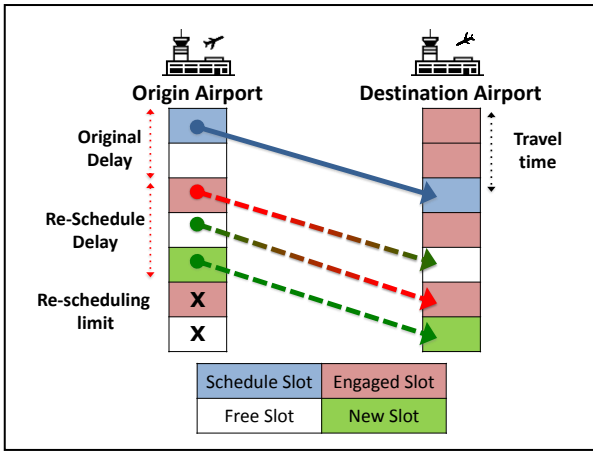In both cases, the flight's delay is updated to reflect its new departure time.

Figure 6. Re-scheduling

If no suitable pair of slots is found before the end of the day or within the "re-scheduling threshold time" from the flight's scheduled departure, re-scheduling fails and the next strategy, slot swapping, is tried.

D. Slot swapping

Through slot swapping, the simulation tries to avoid a flight **F** being further delayed or cancelled, at the expense of another flight **G** belonging to the same airline. If slot reallocation has failed for flight **F** because of a capacity shortage in the origin or the destination airport **G** will give up its departure or arrival slot to **F** and go through a new slot reallocation process.

The candidates for **G** will come from two lists formed by flights departing from the origin airport in the considered time window or arriving at the destination airport after the expected duration of the flight. In any case **G** must be "less important" than **F** (less daily movements at the airport different from **F** route).

The simulation examines the possible arrival/departure slot pairs that could be obtained by requesting a new slot in either origin or destination (Fig. 7). New slots acquired through swapping have the same restrictions that the re-scheduling ones.
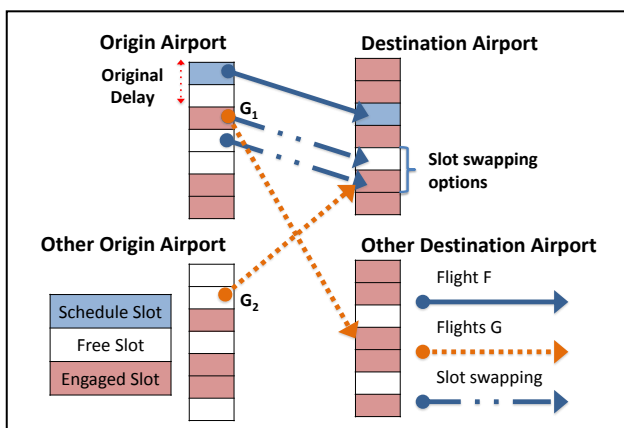

Figure 7. Slot Swapping

The pair with the earliest hour of departure is chosen, and if multiple pairs have the same departure hour, one is chosen randomly with probability inversely proportional to the importance of G. In case neither of the airports have available capacity, F will be cancelled.

E. Dealing with congestion

For the model, an airport is congested when requested demand is above capacity. Large congestion can be observed in days with no external factors and other days the congestions are caused by external perturbations: bad weather, strikes, technical problems.

At the beginning of each hour, the model checks all the airports to see if in any of them is congested. If it is, a regulation starts. The hour is divided into segments, and the flights are assigned to those segments. The flights that cannot be accommodated in one hour are passed to the next hour and so on until the excess demand is dealt with. For the assignment of the segment, the following priorities are applied (each flight is assigned to the segment closer to its departure time):

1. On-the-air flights have priority to land.

2. Flights that have been already penalized because of external perturbations.

3. Flights for which the conflict resolution procedure has been activated (explanation next paragraph).

4. All other flights, on a first-come-first-served basis.

Conflict resolution procedure: If multiple airports are regulated at the same time, there can be conflicts, e.g. both departure and arrival airports are regulated, and they want to re-schedule a flight at different times. If that happens, the flight will be re-schedule in the most penalizing slot, e.g. if departure airport wants to make the flight depart at 13:00 and arrival airport wants to make it depart at 13:30, the flight will depart at 13:30.

F. Most relevant model assumptions and simplifications

This is the list of relevant assumptions and simplifications that have been considered in the modelling approach, some of them may be removed in future developments of the project:

- Slots are always assigned or lost in pairs.

- It is not possible to recover delay en-route.

- A flight cannot affect other flights scheduled to depart before it.

- The minimum servicing time is a parameter and is the same for all aircraft.

- Minimum and maximum passengers transfer times are parameters, each with a single value for all flight pairs.

- Delayed flight will depart as soon as possible, i.e. in reallocated slots the departure is established at the first minute of the new slot although in normal on-time flights the slot goes from -5 to 10 minutes after the scheduled departure time.

- All the flights must wait for their connections, regardless of the impact on the airline.

- A fixed "re-scheduling threshold time" parameter has been defined and is equal across all flights.

- The model does not include aircraft re-routing.

- It is not possible to apply slot swapping at both departure and destination airport. Just one flight can be reallocated.

- An airport is congested if the average delay of flights departing from it in a certain period of time is larger than the average departure delay per delayed flight in 2013 in Europe (26.7 minutes [19]).

IV.   SIMULATION SCENARIOS

TREE model development is being staggered. Simulation strategy goes through different scenarios growing in complexity and establishing a baseline scenario to optimize the customizable parameters.

Thus, the overall simulation strategy involves three phases:

- *Phase I: Reproduction of Nominal Conditions*. The main goal is to assure the model's capability to recreate one day of operations in the European Air Transportation Network with no more conditions that the primary delays caused by the internal disturbances.

- *Phase II*: Reproduction of *extreme cases-scenarios*. The impact of three different types of external perturbations in the network behaviour is analysed in this phase:

   o *Bad Weather Conditions*: This is the first step to tackle the external perturbations and the approach is a reduction in affected airports capacity (further details are exposed in section A).

   o *Strikes*: Three types of scenarios are considered: *Air traffic controllers' strikes*, implemented reducing the capacity in the affected areas. *Airport staff's strikes*, modelled increasing the minimum turnaround time in the affected airports and *Pilots' strike*, implemented modifying the crew connectivity parameter.

   o *Technical Problems*: Two different scenarios are considered *Technical problems in the air control facility*, reducing the capacity of the affected airports and increasing the flight duration of the over-flights, and *Single aircraft technical problems* (on the runway or in the platform), modelled reducing the capacity of the airport.

- *Phase III: 'What-if' Case studies*. The model is able to evaluate an airline daily planning performance and analyse the impact of specific airlines or network manager strategies on the propagated delay mitigation. The challenge in this phase is to recreate the airlines disruption management strategies and consequences: in case of severe delays, airlines use to apply specific strategies to back on schedule as soon as possible (change aircraft, slot swapping, wait or not for connecting passengers, flights cancelation, etc.). The capture of Airlines' strategies has been based on Experts consultations. As a result of consultations, a set of confidential strategies/techniques have been gathered from airlines. These are the inputs for the model to reproduce realistic behaviours of the reactionary delays and their propagation across the network.

A.   *Modelling the extreme cases-scenarios*

Different kinds of external perturbations are taken into account to be modelled, each one with its peculiar feature. For simplicity, the following rules have been defined:

- Perturbations may only start at the beginning of an hour and last for periods of an hour.

- The model cannot react pre-emptively to the perturbation.

- The system has no knowledge on when the perturbation will end.

Most of the external factors have as a result a capacity reduction for the next hours. When this kind of perturbation event is processed, different states are possible:

- The reduced capacities are enough to support the movements that should take place in the following hour, then the operations proceed as usual.

- If the capacities are not enough, excess flights will be delayed until the next hour and will take the second priority level after the flying flights. The delayed flights are treated differently depending on whether they are supposed to arrive to or depart from the affected airport:

   o Urgent departing flights are given precedence over non-urgent flights and will be allowed to depart as soon as possible, taking into account the reduced capacity and the destination airport availability.

   o For arriving flights that have not departed yet at the beginning of the perturbation, the system cannot know if the perturbation will still be affecting the airport at the scheduled arrival time. That is why the model acts like the perturbation will last indefinitely, re-scheduling flights according to the capacity restriction.

This process continues until the perturbation is over, i.e. the capacity reduction has ended and the system has recovered (there are no urgent flights from previous hours).

The flights re-scheduled due to a capacity restriction also propagate their delay to their subsequent connections and are cancelled if they cannot be re-scheduled.

B. Potential benefits for airlines and NM

TREE modelling and simulation capabilities will allow airlines to evaluate different strategies for the day to day operation and also for extreme situations.

The model has been validated, testing it against historical data, adjusting the result to the real network performance as much as possible. The data treatment has been also discussed with CODA staff.

In February 2015, a demonstration session was held in Palma de Mallorca with the presence of ATM experts, Airlines representatives, Network Manager representatives, pilots and CODA staff. The objective was to go into very low level details of operations in the model and get the experts' reviews and impressions. In general they were satisfied and interested by the project and gave recommendations for more detailed future developments.

In January 2014 a workshop was developed to request information about the airlines strategies. The TREE project idea is to analyze a set of realistic airlines strategies and that's why first-hand information was so important.

The program has the capacity to compare two schedules for the same daily operations. Essentially, it is run with the same initial conditions for both and the outputs: total minutes of delay, delayed flights, affected airports, or any other global performance metric can be directly compared.

The model has been developed to allow changes with minimum modifications in the program structure, so it is possible to analyze the impact of different strategies easily. For example:

- Spare aircraft and/or crew
- Different waiting for connecting passengers policies
- Intra-alliance slot swapping
- Decreasing/improving service time
- Punctual up-to-the-capacity operation
- Change the aircraft/crew rotations
- Etc.

V. PRELIMINARY RESULTS

The first simulations are being running with the 20th of June 2013 flights schedule. This was a day with high average delays but without knowing external problems such as bad weather or strikes, just the primary delays from the CODA data.

The chosen day contains 19,969 flights in the ECAC area, the data cleansing process includes remove the flights with origin or destination outside of the ECAC area, beginning or ending in another day or belonging to rotations in which one or more legs are missing. Finally the model works with 15,721 flights with 1,490.3 hours of reactionary delays and 1,828.6 hours of primary delays. The results shown are obtained by averaging over 1,000 simulation runs.

Metrics are calculated for both empirical data and simulations results and compared. Fig. 8 and Fig.9, show examples of such comparisons: the distribution of delays and the total cumulative departure delay as a function of time along the day. As can be seen the empirical and the simulation results are quite similar.
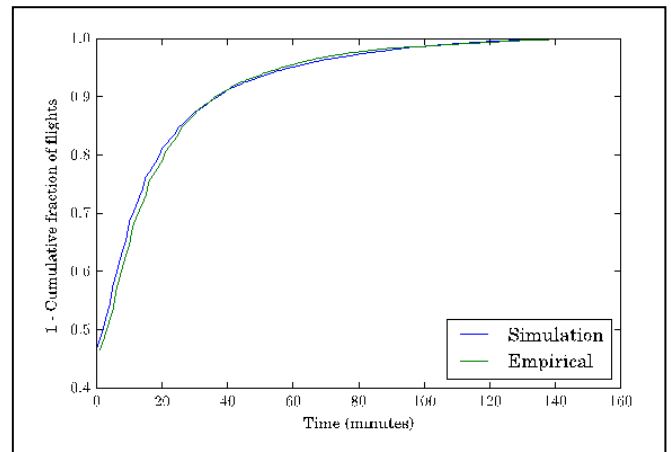

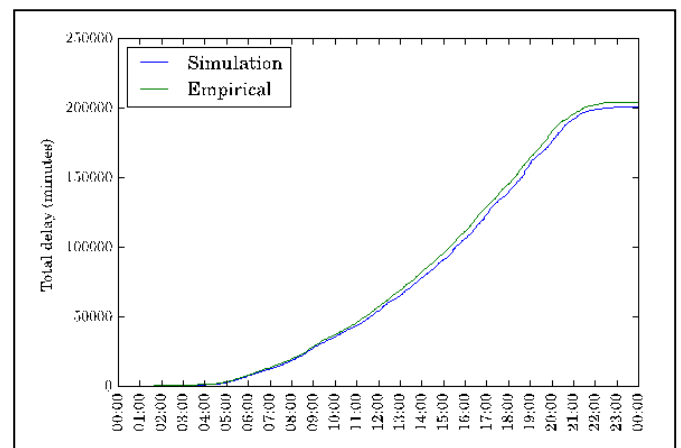Figure 8. Distribution of delays.

Figure 9. Cumulative distribution of reactionary delays.

The operations in the airports are connected by the flights that travel between them, a network is constructed with the daily flights. Then the delay in a cluster of connected airports showing congestions in similar or close time intervals can be seen as correlated and likely to come from a common source. The size of the largest connected cluster is used as a measure of the level of network-wide congestion.

Fig. 10 shows the temporal evolution, hour by hour, of the size of the largest cluster of congested airports. The qualitative features of the cluster's evolution, such as the position of the maximum and the asymmetric shape, are correctly reproduced by the model.
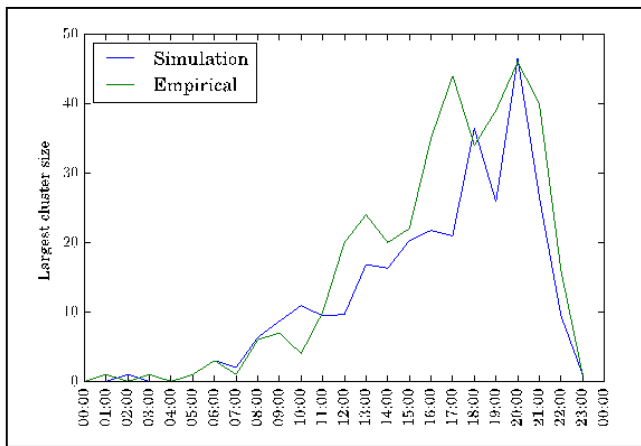
Figure 10. Temporal evolution of the cluster of congested airports.

Some preliminary simulations have been also performed in extreme situations, for example reducing London Heathrow nominal capacity up to 90% for two hours in the afternoon. The simulation indicators were compared with the ones obtained in nominal conditions (Fig. 11).
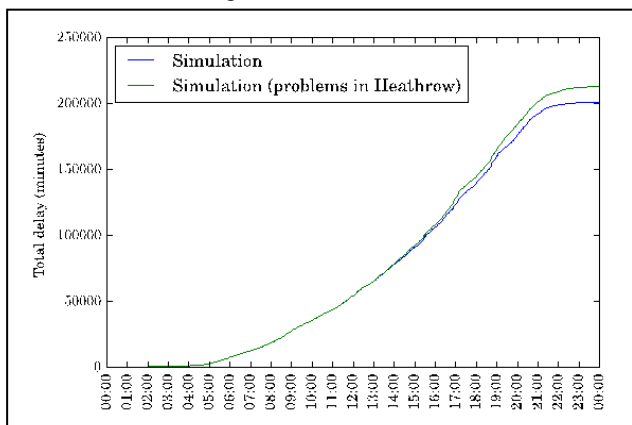

Figure 11. Impact of reducing the capacity of Heathrow Airport to 10% of its normal value between 2 Pm and 4 Pm.

The first simulations reproducing what-if cases have also been developed. As an example Fig. 12 represents a Lufthansa strategy of not waiting connecting passengers in case of delay.
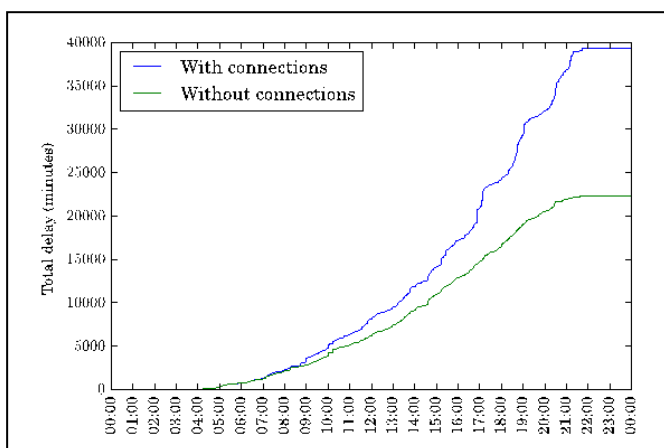

Figure 12. Impact of connections of total cumulative delay for Lufthansa.

VI. Conclusions

TREE project develops a model to simulate the propagation of reactionary delays in the ECAC area. The model reproduces aircraft links, passenger connectivity, crew rotations and airport congestion. As it is specifically developed for the European network, it includes mechanisms for slot reallocation and swapping in case of capacity contractions.

The model has produced the first results and they are being analyzed and validated. Preliminary works show a promising agreement with the actual delay propagation patterns of the CODA flight performance data.

The model improvement continues. Simulations will allow testing the model in different scenarios and also different actors will be able to test different strategies. This functionality will give highly valuable support in problem solving processes to the airlines and to the network and airport managers.

VII. Biographies

Isdefe's Team:

- **Carla Ciruelos** has a degree in Statistics (2004 UCM, Universidad Complutense de Madrid, winning prize to the best expedient of the promotion) and a degree in Marketing (2010 UOC, Universitat Oberta de Catalunya). She has worked in Isdefe since 2008, for the first 6 years in AENA (Spanish Airport Operator) analysing the airlines strategies, studying airlines opportunities in the Spanish airports and analysing passenger's behaviour. After that Carla moves to the Quality and Testing in Transport Unit where she is focused in the areas of ATM management, data mining, modelling and requirements. She has participated in European funded research projects such as NEWO, GAMMA or CATER among others.

- **Andrés Arranz** has been working for ISDEFE during his entire professional life (15 years) in the ATM and Airport domains. The last three-years Andrés has been supporting ENAIRE (former AENA) in its participation in SESAR project and has taken part in various WP-E SESAR projects as ISDEFE technical expert such as ADAHR, NEWO or TREE

- **Sara Peces** has a degree in Physics (2002 UAM, Universidad Autónoma de Madrid). She has worked since 2006 in Isdefe in the field of ATM R&D. She is focused in the areas of concept/process modelling, concept development, workload and capacity assessments, validation and simulation. She has participated in national and European funded research projects such as MICA programme, iFLY, CRICTISIM, XP-DITE, ACROSS among others. Previous work in Indra (2004-2006) as a functional and testing analyst, responsible for business analysis, needs assessments, software/system requirements and testing plans and procedures for Pitot project, Simulating ATC Platform for ATM decision making.

- **Izaro Etxebarria** holds an Industrial Engineering degree (MSc) from the Escuela Superior de Ingenieros

de DEusto (University of Deusto, Bilbao, Spain). With almost 10 years of experience in European R&D programs her work at Isdefe has been focused on ATM field. Air Traffic Management R&D Team Coordinator at 'Quality and Testing in Transport' Unit at Isdefe, her participation in different R&D programs has been focused on the leadership of validation activities (ground and airborne operations), contribution to operational requirements engineering tasks, participation in airspace modelling activities and projects & contracts management activities. Currently she is the SESAR WP-E TREE project leader.

IFISC's Team:

- **Bruno Campanelli** has a Bachelor's Degree and a Master's Degree (with honors) in physics, both obtained at the University of Rome "la Sapienza". He is now enrolled in the Physics PhD program funded by the Government of the Balearic Islands through the CAIB, at the Institute for Complex Systems and Interdisciplinary Physics (IFISC) in Palma de Mallorca, where he is studying the properties of transport networks.

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