



D4.5 A data-driven approach for dynamic and adaptive trajectory prediction

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Abstract

This is the final technical report of *A Data-driven approach for dynamic and Adaptive trajectory Prediction (DIAPasON)* project, which was awarded funding through the Engage KTN's first Call for catalyst funding.

Founding Members



SESAR Engage KTN – catalyst fund project final technical report

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Authors:	Jose Manuel CORDERO / CRIDA
	Icía GARCÍA-OVIES / CRIDA
	Enrique IGLESIAS / CRIDA
	Carlo DAMBRA / ZENABYTE
	Luca ONETO / ZENABYTE
	Irene BUSELLI / ZENABYTE
	Carlo ABATE / DEEPBLUE
	Simone POZZI / DEEPBLUE

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1. Abstract and executive summary

1.1 Abstract

The DIAPasON project focuses on the need of the ATM system to develop tools and methodologies which are able to support traffic and trajectory management functions. For these activities, trajectory and traffic prediction is key, in particular within the context of Trajectory-Based Operations (TBO). While previous research exists addressing these matters, DIAPasON presents a different approach. In particular, the project aims at analysing patterns of flight plan evolution for individual flights, and extract patterns and feature which can be applied in a wide number of operational contexts where this information is available. The main result of the project is the development of a methodology for trajectory prediction and traffic forecasting in a pre-tactical phase (from a few days to a few hours before the operations, when a only limited number of flight plans are available). This can be adjusted to different time scales (planning horizons), considering the level of predictability of each of them and the specific use case to where it should be applied. These results have been explored with support of operational staff to maximise the benefits in the pre-tactical phase.

1.2 Executive summary

To face the increasing air traffic demand, the future Air Traffic Management (ATM) system will rely on the Trajectory Based Operations (TBO) approach, which will require aircraft to follow an assigned 4D-trajectory (time-constrained trajectory) with high precision. TBO involves separating aircraft via strategic (long-term) trajectory definition, rather than the currently practiced tactical (short-term) conflict resolution. The main goal is to increase air traffic capacity by reducing the controllers' workload. Nevertheless, real time measures (over the trajectory) will be required to improve reliability, react to unplanned conditions and thus maintain the expected capacity.

The 4D-trajectory concept is based on the integration of time into the 3D aircraft trajectory, defining each point by position (latitude, longitude and flight level) and time. In the same way that there are restrictions associated with flight levels, the future operational framework foresees restrictions regarding time. It aims to ensure the flight is on a practically unrestricted, optimum trajectory for as long as possible in exchange for the aircraft being obliged to meet very accurately an arrival time over a designated point. In the context of TBO, Airspace Users (AUs) will agree a preferred trajectory with Air Navigation Service Providers (ANSPs) and airport operators (AOs). Aircraft and ground systems will exchange information regarding the trajectory and the expected airspace capacity, in order to foresee the ability to meet the assigned Controlled Time of Arrival (CTA).

The benefits of the 4D-trajectory approach on the ATM framework are: (a) improvement of air traffic operations reliability by increasing the overall traffic predictability; (b) optimal operations for airlines (aircraft using preferred routes and levels); (c) better service provided (due to ground-ground and air-ground interoperability) and fewer trajectory distortions; (d) potential absorption of delays; (e) enhanced safety with less controller workload (fewer conflicts, strategic management, information rich environment with data in advance); (f) reduction of costs (e.g. fuel and/or time); (g) increased airspace capacity; and (h) reduction of the environmental impact through reduction of emissions and noise. To exploit these benefits accurate and reliable trajectory prediction (TP) is required. Enhanced traffic forecasts (which integrate uncertainty assessment and include different sources of relevant flight information) may enable improved demand-capacity balancing and conflict detection and resolution (CD&R) models. Moreover, new methodological approaches, as the exploitation of historical data by means of machine learning techniques is expected to boost TP performance.

In this context, the DIAPasON project has been able to develop a methodology framework for TP and traffic forecasting in a pre-tactical phase (from a few days to a few hours before the operations, when only a limited number of flight plans are available). This has been adjusted to different time scales (planning horizons) supporting different operational scenarios, taking into account the level of predictability of each of them according to the available data. This step has resulted in an individual flight plan predictive model which considers patterns in historical data to provide a pre-tactical prediction and incorporate “uncertainty” to Trajectory Prediction (as a probabilistic approach), incorporating also the possibility to self-calibrate with updated tactical data.

This way, the project has not just obtained a specific implementation but a data-driven, dynamic and adaptive TP framework, suitable for further implementations. It is data-driven as the main project outcomes will be based on data analysis and interpretation, dynamic as can be adjusted to different planning horizons and adaptive as it can be enhanced iteratively with new tactical data. A fourth research objective of the project is for the TP framework to adapt to different Airspace Users’ characteristics and strategies. AUs will exhibit different strategies, as far as flight intentions and execution are concerned. The project has analysed and unravelled policies and features to apply the best TP for each AU according to observations.

DIAPasON has validated the TP framework in a case study, including interviews to operational staff to understand the best way to apply such features. The proposed method aims to anticipate the needs of the ATM system; main applications of the model are related to reduction of complexity, demand-capacity balancing, conflict resolution, separation management, ANSP resource allocation.

The DIAPasON project has been structured as an extension of the work achieved in previous studies and has also reached the targeted TRL4 maturity level (self-assessment). The main results of the project are the specific implementation with Spanish data (the project exploring ECAC area capabilities as well with existing datasets), the TP methodological framework and the mock-up comprising operational staff feedback.

2. Overview of catalyst project

2.1 Operational/technical context

As illustrated by Engage’s thematic challenge #2 (<https://engagektn.com/thematic-challenges/>), accurate and reliable trajectory prediction (TP) is a fundamental requirement to support trajectory-based operations (TBOs). Particularly, the mismatch between planned and flown trajectories (caused by operational uncertainties from airports, Air Traffic Control interventions, Airspace Users behaviour and changes in flight plan data) act as a driver for shortcomings in flow and capacity management (e.g. congestion and suboptimal decision making) and as a precursor for potential safety conflicts. Therefore, enhanced traffic forecasts (which integrate uncertainty assessment and include different sources of relevant flight information) may enable improved demand-capacity balancing and conflict detection and resolution (CD&R) models. Moreover, new methodological approaches, as the exploitation of historical data by means of machine-learning techniques is expected to boost TP performance.

2.2 Project scope and objectives

Traffic prediction is a key element in Air Traffic Management (ATM), as it plays a fundamental role in adjusting capacity and available resources to current demand, as well as in helping detect and solve potential conflicts [1]. Moreover, the future implementation of the Trajectory Based Operations (TBO) concept will impose on aircraft the compliance of very accurately arrival times over designated points [2] [3]. In this sense, an improvement in TP aims at enabling an efficient management of the expected increase in air traffic strategically, with tactical interventions only as a last resort. To achieve this

objective, the ATM system needs tools to support traffic and trajectory management functions, such as strategic planning, trajectory negotiation and collaborative de-confliction. In all of these tasks, trajectory and traffic prediction represents a cornerstone[4].

The problem of achieving an accurate and reliable trajectory and traffic prediction has been tackled through different methodologies, with different levels of complexity [5][6][7][8][9]. There are two main aspects to consider when assessing the most appropriate forecasting methodology:

- Time-horizon. Depending on the timescale (anticipation before the day of operations), the level of uncertainty associated to the prediction will be different.
- Input data. Both the source and the quality of the input data (completeness, validity, accuracy, consistency, availability and timeliness) are key characteristics when assessing the viability of the prediction.

The main target of the project is the development of a methodology for TP and traffic forecasting in a pre-tactical phase (from a few days to a few hours before the operations, when a only limited number of flight plans are available). This can be adjusted to different time scales (planning horizons), considering the level of predictability of each of them and the specific use case to where it should be applied. This initial step delivers a model that considers advanced tactical data to validate/enhance the previous pre-tactical prediction and incorporate "uncertainty" to Trajectory Prediction (as a probabilistic approach).

In this way the project has obtained a data-driven, dynamic and adaptive TP framework. Data-driven as the main project outcomes is be based on data analysis and interpretation, dynamic as can be adjusted to different planning horizons and adaptive as it allows iterative enhancement with new tactical data.

Another objective of the project was, for the TP framework, to adapt to different Airspace Users' characteristics and strategies. Our previous works showed that different AUs exhibit different strategies, as far as flight intentions and execution are concerned, affecting predictability, even at route level in some cases (SESAR P04.07.07, in EXE-04.07.07-VP-006 run in Barcelona ACC; statistical analyses carried out as part of the SESAR WPE project ELSA) [10][11]. The implication is that different methodologies need to be used to develop the best TP for each AU.

2.3 Research carried out

2.3.1 State-of-the-art

A summary of the state of the art is provided in order to provide a view on what has been done in this part of the research. Note: Some sample references are included as footnote.

The works developed around organization of airspace are globally focused in achieving an “ideal” airspace configuration, for this matter, dynamic sectorisation is considered with the corresponding problem of Demand-Capacity balancing. In a more in-depth analysis of the demand, the research is fixed in clustering techniques, improving the scope as well as the analysis of the data already available. Then, the trajectory prediction is enlarged by considering other type of data apart from the temporal and spatial, designated as contextual data.

From the point of view of clustering, several approaches can be stated. Clusters are formed from similar trajectories; this similarity trait requires an extensive analysis of origin/destination pairs, take-off patterns, weather deviations and any other type of data [9]. Considering a different approach, the clusters are formed taking into account the relevant part of the trajectories, relevance is understood as a changing variable where markers to each of the route waypoints are assigned and added or discarded for each analysis [12]. Contextual data can be chosen to cluster by relevance. Following this line, temporal characterization is thought to be of high importance [13], enabling the identification of salient traffic and temporal persistent flows. Temporal clustering has been implemented [14] using a k-means algorithm, for the classification of arrivals and departures for Multi-Airport Systems. The final objective is to obtain a route that can be representative for each cluster, lowering the computational requirements.

In terms of the data available for clustering, Flight Plans are the most important resource and they are extremely dependent on the airline, consequently analysis of the behaviour of the airline have been developed [15] obtaining patterns that can be posteriorly used for a more accurate prediction. This trait is measured with three indices: predictability, reliability and accuracy.

For further determination of the spatial-temporal state of the aircraft a variety of trajectory prediction methodologies have been developed that do not require any specific data of the performance of the aircraft, they do require aircraft state data, flight information, historical data or flight information from aircraft messaging. Environmental conditions are included in analysis [16]. In recent studies the analysis and prediction are developed using Machine Learning techniques. Furthermore, in some reference [17] the trajectory (route terminology employed in the paper) is obtained from weighting a series of factors; concretely two groups of factors are considered: reaction (constraints to the route) and planned (changes in the route utilization). These factors are obtained using a regression model. In recent studies the analysis and prediction are developed using Machine Learning techniques [9], the Hidden Markov Model is considered among several options.

An accuracy analysis is consistently associated to the trajectory prediction methods. The confidence level of the output is dependent on the quality of information extracted and varies depending on the phase of flight due to the difficulty of prediction for each of the phases [18], while in other studies [19] a statistical model is used based on empirical observations and a Monte Carlo simulation is conducted. Other studies involve the use of a Distributional Robust Optimization formulation [14], the uncertainty of the prediction is based on the drawing of information from different uncertain parameters by using probabilistic operations. To set the method in place, data is used from the Time Based Flow Management system obtaining this way the calibration.

For the demand-capacity balance instead of considering individual flights the approach is to consider a flow allowing independent flow routes, this is the Eulerian-Lagrangian [20] model where the optimization is solved using a Model Predictive Controller Technique minimizing the air and ground delay. Contrarily if individual flights are taken into account (which is typical for conflict resolution),

interacting trajectories can be localized and modified in order to solve this problem, for this purpose collaborative reinforcement learning methods have been explored [21]. For the sector configuration it is feasible to be obtained through a Branch and Bound algorithm choosing between the combinations available [22].

2.3.2 Predictive model: High-resolution scenario analysis

The high resolution analysis corresponds to operational data from Spanish Airspace extracted from operational ATC platform (SACTA), including highly reliable data such as surveillance or every flight plan update.

In this initial phase of the analysis, a sample of relatively frequent flights (of relatively frequent airlines) in **January, March and August 2018** is selected. Callsigns flying less than 10 times in a month and airlines with less than 200 flights in a month are discarded. These numbers are set accordingly to cumulative graphs.

Using this dataset, a clustering process is applied. The main “dissimilarity measure” used in the analysis is:

$$d = 1 - (\text{common wp} / \text{max wp}), \text{ where:}$$

- **common wp:** number of waypoints appearing in both the first and the last Flight Plan of each FPkey (last intended as **last before estimated off-block time**);
- **max wp:** maximum between the number of waypoints appearing in the first Flight Plan and the number of waypoints appearing in the last Flight Plan.

The histogram in Figure 1 represents the distribution of d in the different months. It is clear that 0 is the most common value and that the frequency of greater values rapidly decreases as the value increases: in particular, more than **70% of the Flight Plans do not show any difference** in the first and the last path declared and that, in general, only 10% of the Flight Plans shares less than the 50% of waypoints between the first and last record before off-block time.

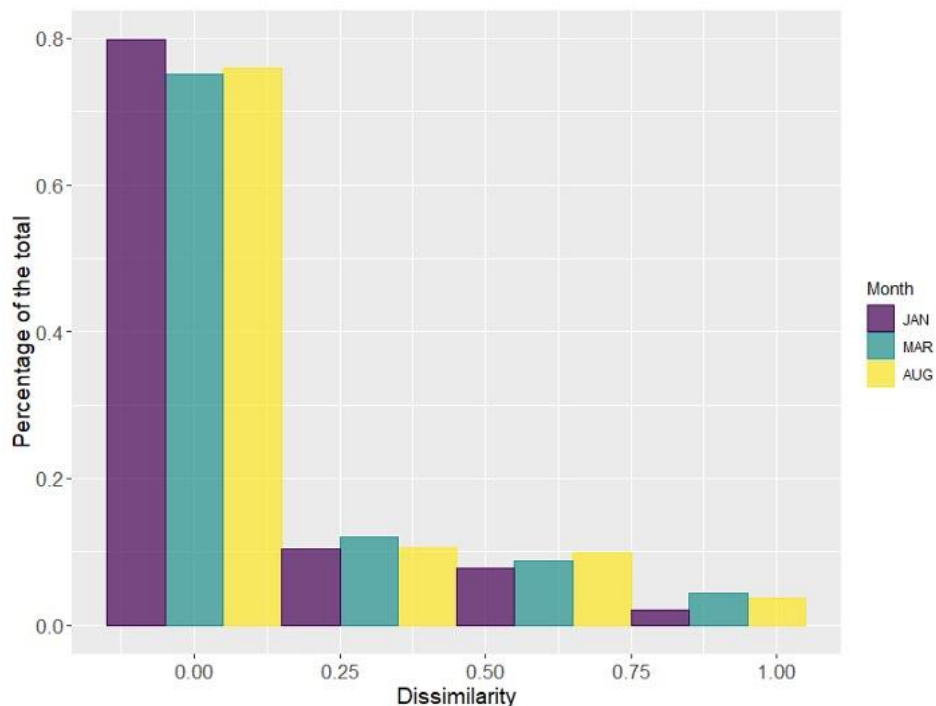


Figure 1: Histogram of the distribution of d in the different months analysed.

Furthermore, differences between months do not seem to be really relevant from this perspective. March and August behave almost identically, while in January there seem to be slightly smaller values of d .

The variable immediately associated to this d is a **DeltaT** variable defined as the **difference between the expected off-block time of a flight and the record time of its first flight plan**, in order to understand at what level of anticipation (before the beginning of departure operations) the flight plan was emitted.

As can be seen in Figure 2 (Dt is expressed in hours, and the categories are chosen as almost homogenous in size), d seems slightly or not dependent on the level of anticipation with which the flight plan is registered. In fact, while the first histogram (less than 2 hours before EOBT) is different from the others, there is apparently no pattern in the following ones. The fact that the “<2” section is composed essentially of observation with $d=0$ can be also because in many cases the first and last flight plan coincide. However, the graph remains meaningful as it shows that flight plans recorded in that time slot are almost surely reliable.

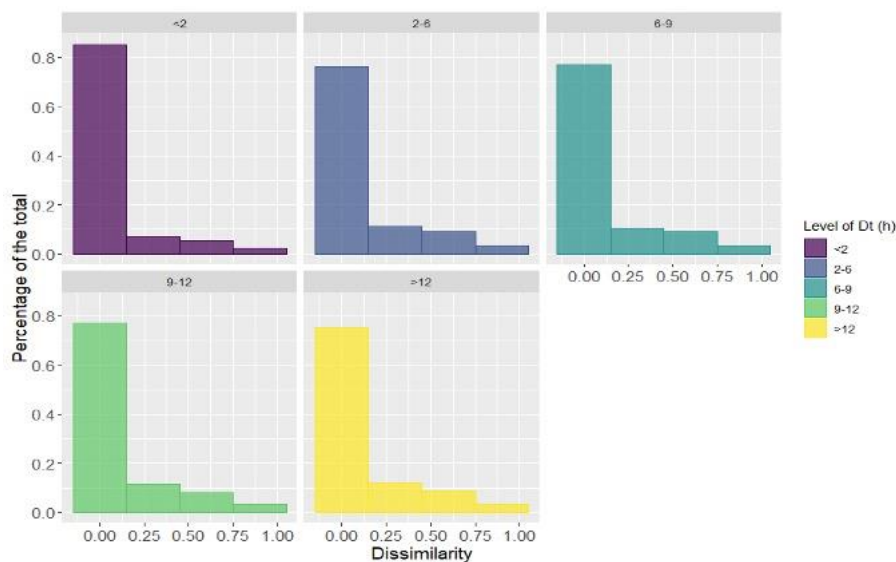


Figure 2: Representation of DeltaT (Dt) for different anticipations in the reception of the flight plan.

Another variable which seems not linked to the dissimilarity is the **involvement in weather phenomena**. The same comparison was performed distinguishing different weather conditions, in all the three months, leading to the same conclusions. Furthermore, no stable pattern is found also for aircraft type.

The distribution of d is also analysed for airlines, airports and routes. To associate a representative value of d to a group of flights, one possible choice is to use the average value of the variable in the group. The distribution of d is very asymmetrical and consequently the average is mainly determined by the highest values, possibly leading to a non-representative estimation. Because the median is 0 for every airline and airport (in fact, the 70% percentile of d is 0 for almost every subgroup), a possible choice is to consider another quantile; the most effective in discriminating the airlines and airports is found to be the 80% percentile.

The following graphs represent airlines in three groups (European Legacy, European Low Cost and Non-European). These graphs report the 80% percentile essentially for two reasons:

- This value is assumed by d , while this is not true for the mean.
- It has an “operational” meaning being x the quantile, it can be said that the 80% of data relative to the group assumes values smaller than x .

Furthermore, in Figure 3, Figure 4 and Figure 5, the size of every group is indicated. Please be aware that these numbers indicate the occurrences in the selected samples (so, for example, infrequent flights are discarded) so they are just approximations of the real number of flights.

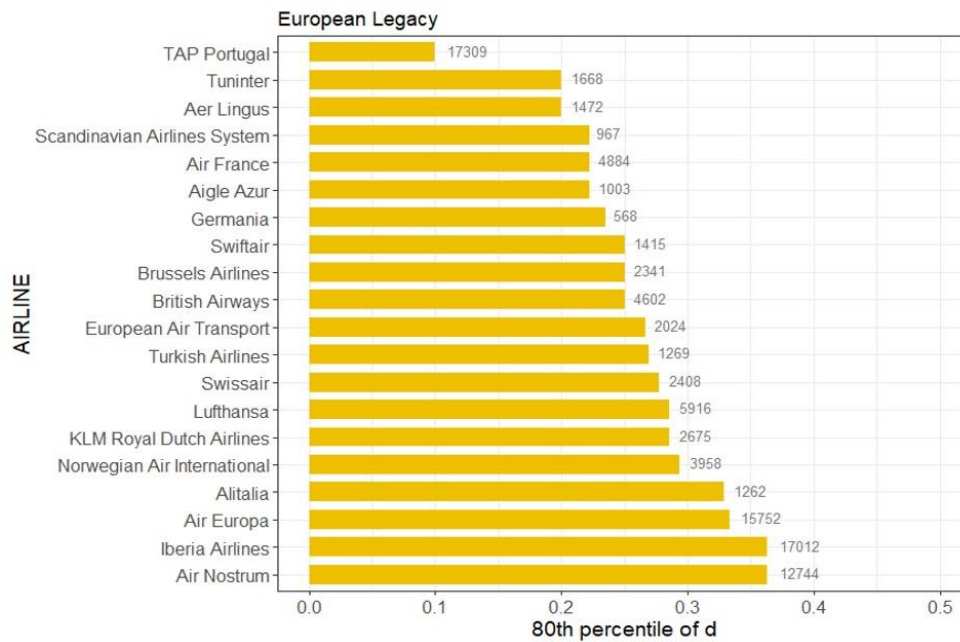


Figure 3: Representation of the 80th percentile for the Group of “European Legacy” airlines.

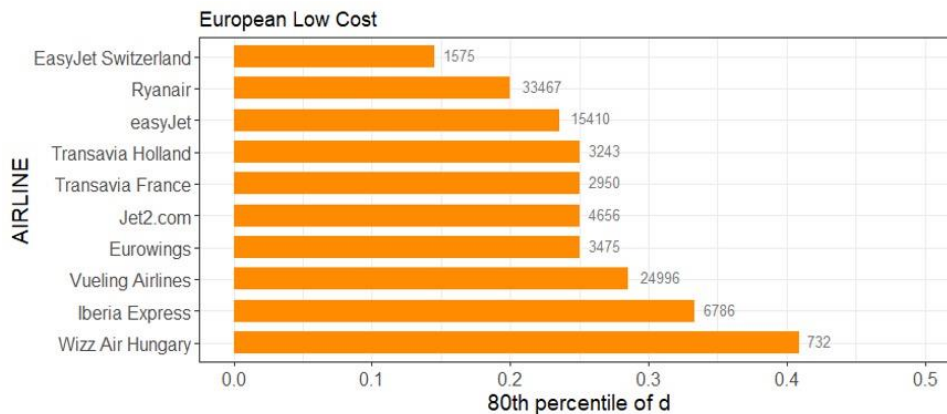


Figure 4: Representation of the 80th percentile for the Group of “European Low Cost” airlines.

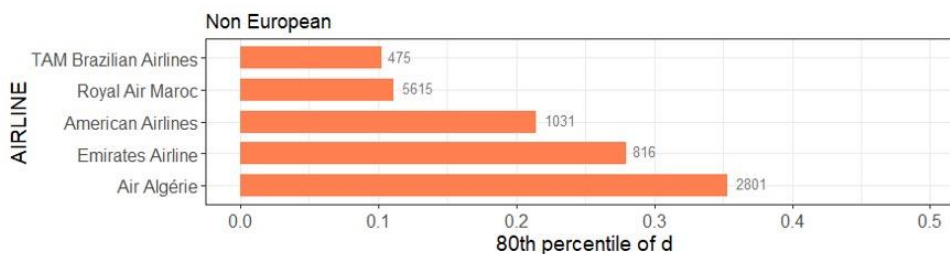


Figure 5: Representation of the 80th percentile for the Group of “Non-European” airlines.

Looking at the graphs above, there seems not to be great differences between the three groups (legacy, low cost, non-EU airlines); the major differences are, in fact, within each group.

The role of airports, instead, seems more decisive: departures from non-EU airports show lower values of d and departures **from Madrid** show much “less reliable” behaviours than the other **frequent** airports.

Arrivals, on the other hand, behave differently: non-EU airports show more variable values of d and often also higher values. This distribution is also reflected in the ranking of routes (e.g., flights departing from Madrid have higher d -values than flights arriving in Madrid).

Moreover, the Reliability time has been analysed. It is possible to estimate, for each flight number but also for each airline, the average time in which the flight plan became identical to the last one, plus a Confidence Interval based on the variance and size of data relative to that airline.

Figure 6 and Figure 7 are representative of the idea: the **point is the average “reliable time” (sample mean)**, and the black line is the **95% probability interval of the mean**.

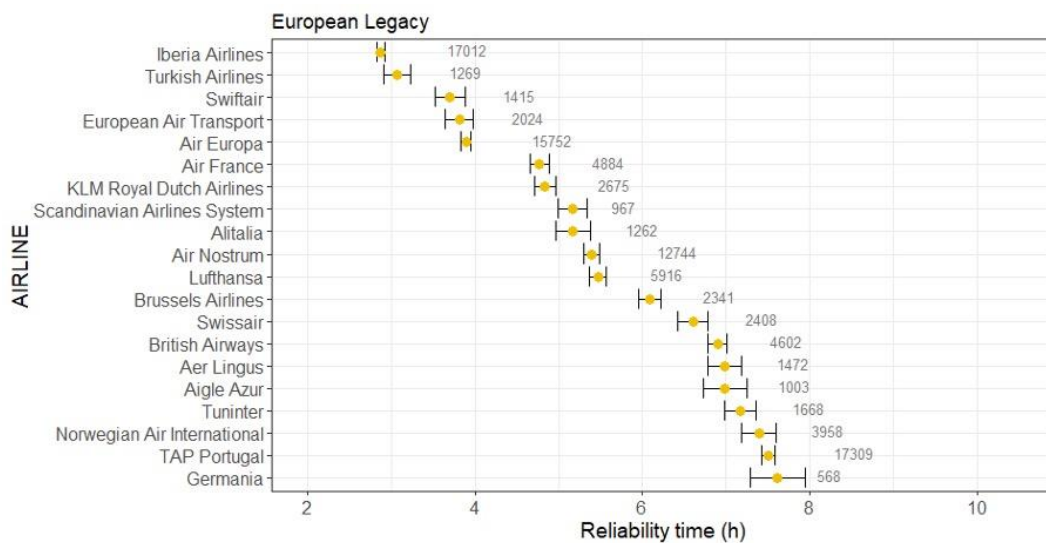


Figure 6: Reliability time for European Legacy Airlines.

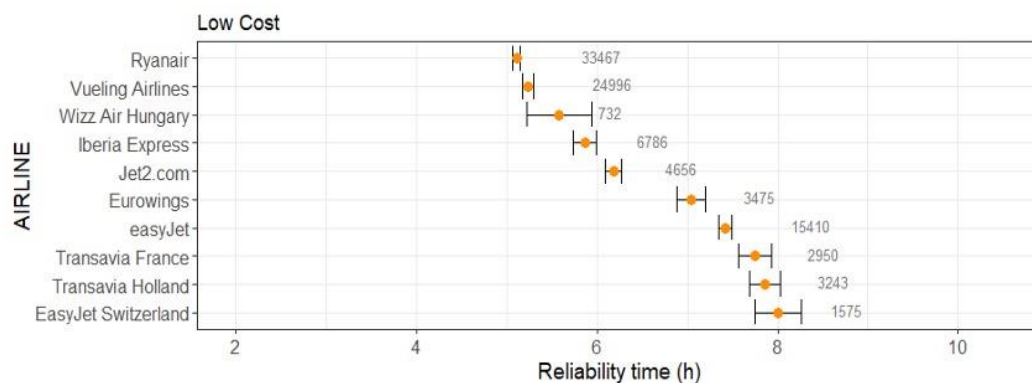


Figure 7: Reliability time for Low Cost Airlines.

Since the previous analysis indicates that the reliability of a flight plan depends essentially on the “intrinsic” properties of the flight and in some cases on the season, while the “contingencies” (e.g., weather, hour of the day, day of the week) play no or little role, the prediction presented here is only based on historical data; furthermore, this approach emphasizes the role of the companies’ strategic reasoning.

The prediction is performed for different Δt 's (where Δt is the difference between current time and off-block time): 8h, 4h, 2h, 1h.

For each Δt , the predictive methodology is the following:

- the current flight plan is compared with all the historical flight plans of the same flight (in this context, flight = *callsign*) at the same Δt , selecting all the past *single flight*'s whose trajectories coincide with the current one.
- if the current flight plan is not the first one recorded that day, also the previous flight plans are compared with the corresponding past ones, discarding from the previously selected *single flights* all the ones that do not match.
- for all the selected *single flights*, the last-before-off-block-time planned trajectory is retrieved.
- the predicted trajectory is the most frequent one in this set.

In this case, this methodology is applied on two sets of data, different from the one used in first place for the dissimilarity measure:

- data from February 1st to May 31st, 2018 (in the following, denoted as **spring**)
- data from June 1st to September 30th, 2018 (in the following, denoted as **summer**)

and only to flights: classified as "Regular", flying at least 3 times a week, pertaining to the most frequent airlines, and with average levels of Δt sufficiently high.

To estimate the real usefulness of the prediction, its accuracy is compared with the one of the "default" prediction (i.e., the last trajectory is predicted to be the current one). **Accuracy** is the percentage of trajectories which are correctly predicted for each flight (see Table 1 and Table 2).

SPRING	8h	4h	2h	1h
average <i>default</i> accuracy	76%	75%	82%	86%
average <i>prediction</i> accuracy	82%	82%	85%	87%

Table 1: Average Default and Predicted Accuracy in the different time horizons for the spring dataset analysed.

In spring the prediction is able, on average, to **anticipate at $\Delta t = 8$ the accuracy that the default prediction has at time $\Delta t = 2$** , so it reaches the same level of certainty 6 hours before.

SUMMER	8h	4h	2h	1h
average <i>default</i> accuracy	88%	76%	83%	88%
average <i>prediction</i> accuracy	92%	85%	87%	90%

Table 2: Average Default and Predicted Accuracy in the different time horizons for the summer dataset analysed.

It is important to remark the fact that the smallest accuracies appear in $\Delta t = 4$ and not in $\Delta t = 8$ can probably be explained with the fact that not all the flights considered record flight plans with the anticipation of $\Delta t = 8$ every day, so the values are computed on slightly different samples (and it can be reasonable to suppose that the sample relative to $\Delta t = 8$ is somehow more "reliable"). For this reason, $\Delta t = 8$ in these tables can be considered as a world apart.

Relative improvement in accuracy is computed for each callsign as follows:

$$(\text{callsign } \mathbf{prediction} \text{ accuracy} - \text{callsign } \mathbf{default} \text{ accuracy}) / \text{callsign } \mathbf{default} \text{ accuracy}$$

As could be expected, the relative improvement in accuracy is greater for and $\Delta t = 4$ than for the smallest Δt 's, in both the seasons.

SPRING	8h	4h	2h	1h
average <i>relative improvement</i>	23%	29%	10%	6%

Table 3: Average Relative Improvement in the different time horizons for the spring dataset analysed.

SUMMER	8h	4h	2h	1h
average <i>relative improvement</i>	13%	59%	23%	13%

Table 4: Average Relative Improvement in the different time horizons for the summer dataset analysed.

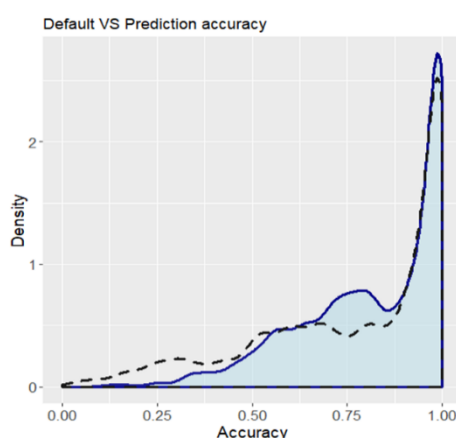


Figure 8: Comparison between default and predicted accuracy.

In Figure 8, *prediction accuracy* (in blue) and *default accuracy* (dashed line) at $\Delta t = 8h$ in **spring** are represented (this representation is consistent with other Δt 's and *seasons*). In view of this, three main considerations arise:

- the distribution of *prediction* accuracy is concentrated on highest values in general.
- the *prediction* accuracy has a negligible percentage of values lower of 0.5, so the biggest difference with the *default* accuracy is with regards to the lowest values.
- if values greater than 90% are concerned, the two densities appear almost overlapped.

So, the main conclusion seems to be that this *prediction* is particularly useful in enhancing accuracy for “very unpredictable” flights, while for very regular flights the *default choice* and the *prediction* are almost always the same.

This conclusion is confirmed by the correlation between the default accuracy and the relative increase due to the prediction, clearly represented in Figure 9 ($\Delta t = 4h$):

In the following, results about *relative improvement* are often reported only for $\Delta t = 4h$. The reason is that this Δt is computed on a larger sample than $\Delta t = 8h$, and at the same time the differences in relative improvement are more visible than for $\Delta t = 2h$ and $1h$.

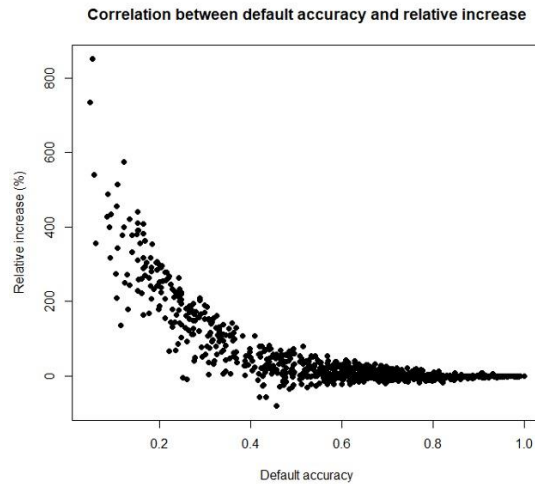


Figure 9: Correlation between default accuracy and relative improvement for the $\Delta t = 4h$ time horizon.

From Figure 9, it is also possible to understand the global distribution of the relative increase: **the most frequent value is 0** and, though there are some (very few) negative values (which means, cases in which the default prediction would suggest the right trajectory while our prediction fails), the general mean is “pushed up” by the many high values. The **maximum is around 800%**, which means there are flights for which the accuracy of our prediction is 8 times greater than the default (e.g., 0.1 of default accuracy and 0.8 of prediction accuracy).

Now, we have a look at how the **prediction accuracy** is distributed with regards to airlines. These graphs are referred to **spring**; summer graphs are not reported since there are no meaningful differences. For the comparison to be meaningful, $\Delta t = 8h$ was not represented, for the previously explained reasons.

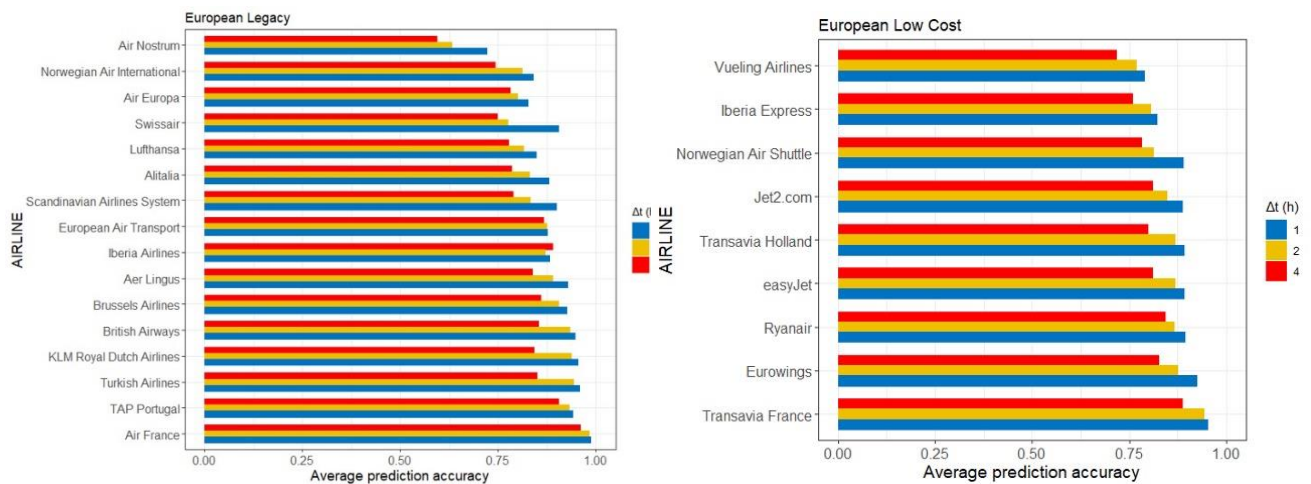


Figure 10 and 11: Average prediction accuracy for European Legacy and Low-Cost airlines.

Three main considerations arise:

- In most of the airlines the prediction accuracy increases as Δt decreases.
- There are some slight differences between airlines, but basically the prediction reaches a similar level of accuracy in for all the airlines, apparently without any bias.
- The level of accuracy is, on average, over 80% for the great majority of airlines.

What is probably of major interest is to evaluate the **average relative improvement in accuracy for each airline**. In fact, this value is informative: if it is high, it means that **the unpredictability of that airline is “systematic enough” to become predictable**, and so it is likely to be part of a strategy.

Graphs are relative to $\Delta t = 4h$, **both seasons**. The number of flights involved in the analysis is reported next to each bar. The horizontal axes have different scales in the two seasons since the relative improvement in summer has highest values. European airlines show a clear behaviour: Air Europa, Alitalia and Air Nostrum (legacy) and Vueling, Ryanair and Iberia Express (low cost) have significantly higher values than the others, in both the seasons. Also, the companies with the smallest values are consistent in the two seasons. The aforementioned airlines show the same behaviour also when we compare them with other airlines traveling on the same routes, as represented in Figure 11:

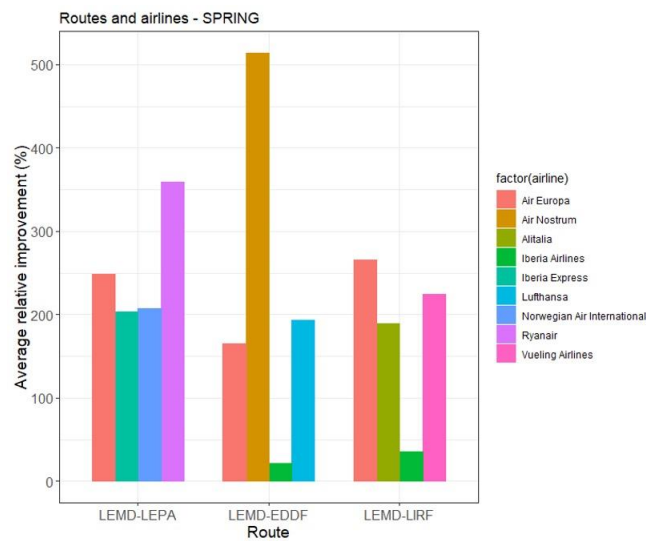


Figure 11: Comparison between airlines flying the same route in the spring period analysed.

By means of the previously described predictive model, it is possible to estimate the probability of change of every flight (given that the flight is a regular and frequent one).

The following graph (Figure 12: Average probability of change of Lufthansa for $\Delta t = 4h$ for different routes during the diurnal shift. is relative to the **diurnal shift** and it is referred to $\Delta t = 4h$. Callsigns with average probability of change less than 0.01 are not shown.

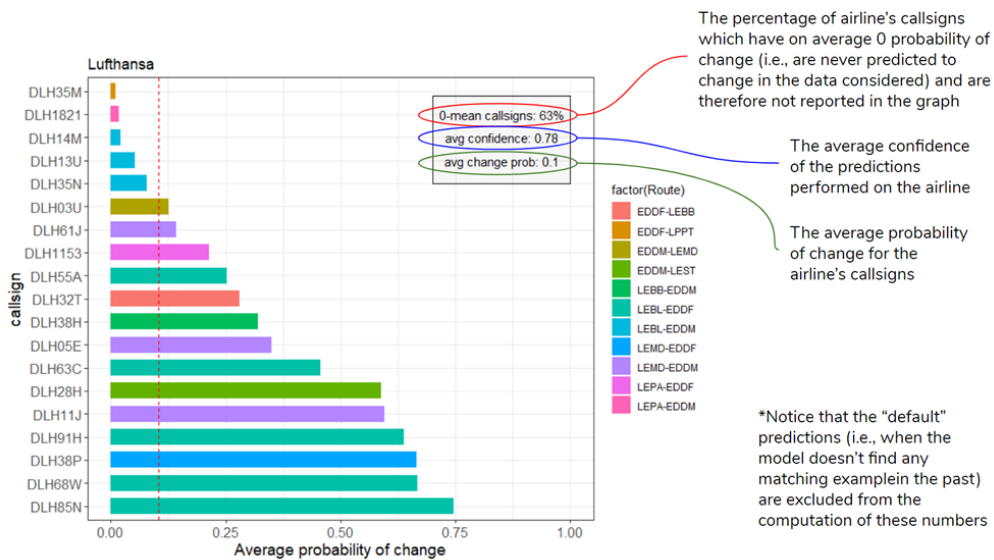


Figure 12: Average probability of change of Lufthansa for $\Delta t = 4h$ for different routes during the diurnal shift.

Furthermore, the probability of change is not independent of the route; in Figure 13 and Figure 14, it is clear that the same airlines can behave in quite different ways on different routes, while on the same route, different airlines tend to behave in similar ways.

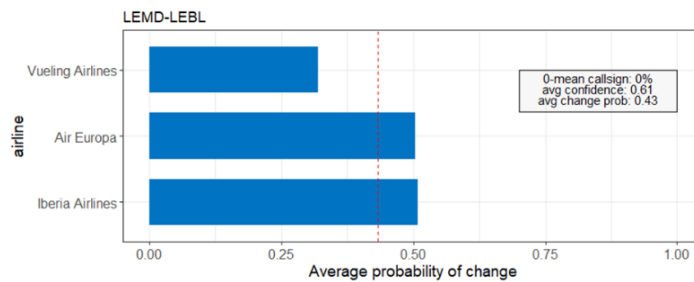


Figure 13: Average probability of change in the route LEMD-LEBL for the airlines: Vueling, Air Europa and Iberia.

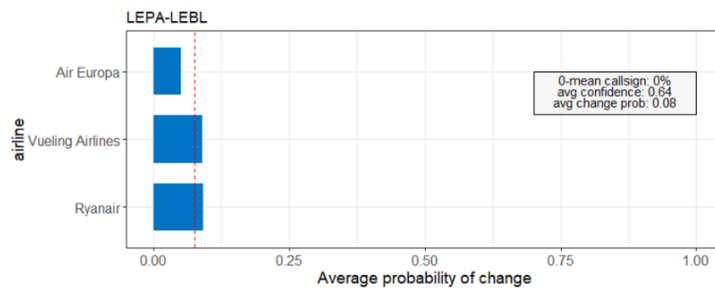


Figure 14: Average probability of change in the route LEPA-LEBL for the airlines: Vueling, Air Europa and Ryanair.

Another observation that deeper analyses suggest is that flights departing from some airports (especially the biggest ones) seem to have higher probability of change, e.g. LEMD.

2.3.3 Predictive model: Low-resolution scenario analysis

This scenario is referred to ECAC area, trying to apply similar analysis. It is to be noted that the European-wide data source (DDR – Demand Data Repository) is a determinant factor in what can be applied. The project has tried to illustrate the result all applying a similar approach to this scenario, for reference. In order to render the low-resolution analysis comparable with the high-resolution one, we needed to find the correspondent definition of waypoints; to do so, we compared the trajectory description of

DDR with the one in the data from the first scenario, whenever the same flights are involved (i.e., flights whose entire trajectory pertains to Spanish airspace).

Here is an example from the 1st of June 2018, a flight from Madrid to Valencia:

- high-res (spatial) trajectory description:
MD14L; MD050; MD035; NANDO; MINGU; ABOSI; CLS; OPERA; VLCT
- low-res trajectory description:
20180601142400:LEMD:NANDO1U:20:0:A:402820N0033339W::Y
20180601142415::DCT:25:1:V:402759N0033304W:14:Y
20180601142443::DCT:35:4:V:402657N0033121W:57:Y
20180601142513:*MD50:NANDO1U:48:7:D:402554N0032937W::Y
20180601142517::DCT:50:8:V:402538N0032900W:6:Y
20180601142600::DCT:70:13:V:402415N0032558W:38:Y
20180601142645::DCT:90:19:V:402237N0032219W:75:Y
20180601142709:*MD35:NANDO1U:100:23:D:402131N0031953W::Y
20180601142820::DCT:130:35:V:401902N0031206W:11:Y
....

This kind of behaviour is rather systematic, so to apply the model to the new scenario we used as waypoints the information in the second field of the variable. The low-resolution model was built by mimicking the high-resolution one, with the necessary adaptations. In fact, since in this scenario we only have one flight plan per day, the predicted trajectory is the most probable one given the flight plan of the day before.

The model, as in the high-resolution case, has two main functionalities: predict if the trajectory will change and predict the final trajectory (and its probability). The following results are relative to about 8000 flights (i.e., the ones flying every day) in June 2018.

The model was tested on the last week of the month; for each test day, all the preceding ones are used as training set. This assessment methodology is slightly different from the one adopted in the high-res scenario since in this case the order of days is absolutely not negligible.

For each flight, the predictive accuracy of the model was computed. The performance on low-resolution scenario is - quite predictably - lower than the high-resolution one. The main reason for this is the probability of change:

- In the high-res scenario, we compared the last-before-eobt trajectory with the flight plan recorded 2h/4h/8h before, and in the vast majority of cases the input trajectory was already reliable, with a probability of change on average around 20%;
- In this low-res scenario, we compare today's trajectory with yesterday's one, and **the probability of change is on average 55%**.

Furthermore, this change rate (and therefore also the accuracy of the model) is distributed in quite an uneven fashion. Figure 15 shows the distribution of airlines' change rate, from which there are a huge amount of extreme values.

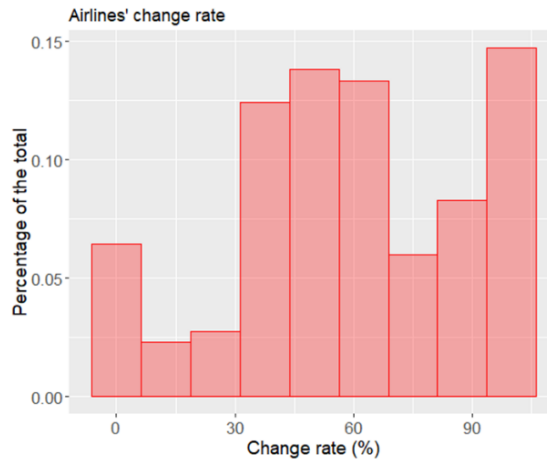


Figure 15: Airline's change rate.

For this reason, the **median accuracy** is considered, instead of the average one, since is more robust to extreme values:

- Median accuracy per flight of the model: **67%**
- Median accuracy per flight without the model: 33%

As in the high-resolution case, we can retrieve some interesting information on airlines by looking at the distribution of the **average relative improvement per airline**. The **median value is around 500%** (e.g., if the probability of correctly predicting tomorrow's trajectories for an airline just trusting today's trajectories is 15%, on median thanks to the model it will be 75%). Also, in this case, values are actually very spread, and a central value cannot be representative.

Figure 16 shows the average relative improvement of some airlines. In general, all the values range between 0 and 3. Notice the x-axis is not expressed in percentage (e.g., 3 is 300%).

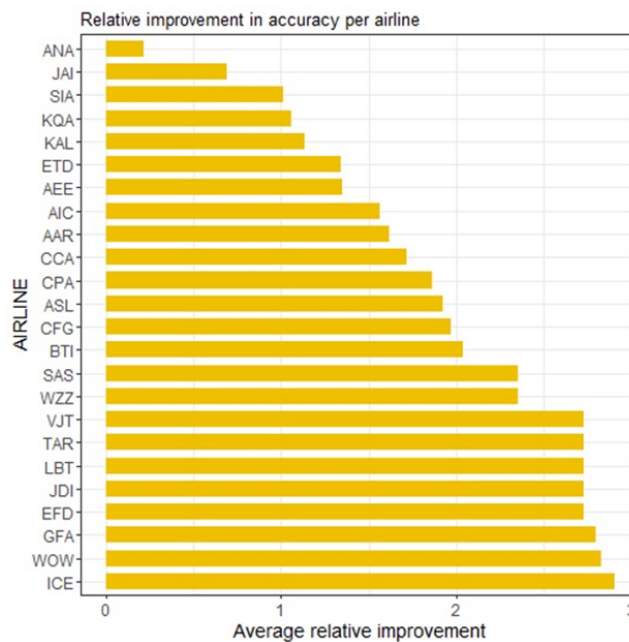


Figure 16: Average relative improvement of some airlines.

2.3.3. Use case application/mock-up tool

The DIAPasON model generates, for each individual scheduled flight of a given day, the prediction of the most likely flight plan (FP) submitted by the airspace user (AU) hours before the expected off-block time. The purpose of this model, when applied to one operational use case, is to provide the Network Manager (NM) and Air Navigation Service Providers (ANSPs) with additional information about the upcoming flights and a prediction of the demand of airspace that improves the current methods based on the FPs issued by the AUs and on historical data.

To validate the use case and expected benefits of the DIAPasON model, we interviewed potential target users, developed a static mock-up to demonstrate how the *DIAPasON tool* could be integrated in the current workflow, and eventually collected target users' feedback on the developed mock-up. This is considered an essential step to reach target maturity.

The process is summarised as follows:

1. Interviews to target users
2. Definition of user needs and requirements
3. Redesign of strategic planning, enhanced by DIAPasON
4. Design of HMI mock-up
5. Analysis of data to be visualised into the HMI mock-up (*will be reflected in results section*)
6. Feedback from target users (*will be reflected in results section*)

STEP 1 – INTERVIEWS TO TARGET USERS

Three semi-structured interviews with:

- *[name removed]*, EUROCONTROL, *[position in company removed]*. Date: 28/04/2020.
- *[name removed]*, ENAV, *[position in company removed]*. Date: 07/05/2020.
- *[name removed]*, ENAIRE, *[position in company removed]*. Date: 13/05/2020.

Questions used for the interview:

1. *What activities does your Organisation perform in the pre-tactical phase?*
2. *What is your role? Which tasks do you perform in the pre-tactical phase? Who do you interact/communicate with in your organization and outside?*
3. *What kind of information does your Organisation use at pre-tactical level (1 – 6 days before operation) to forecast the air traffic and plan your response/resources/etc?*
4. *Can you describe the typical set of decisions that you make regarding flights from 6 days before to 24 hours before?*
5. *Is weather forecast data taken into account in planning? Does it impact the planning, and if so, how?*
6. *Can you describe the typical decisions that you make regarding flights in the 24 hours before the flight, until its execution?*
7. *Can you identify the most urgent pain points of the current planning activities performed by your Organisation? Can you describe a critical scenario, i.e. an example of a problem you dealt with?*
8. *If you could write a "wish list", how would you improve the current planning activities? Is there any information that you would find beneficial to improve the planning process?*
 - 8a. *Why do you think this additional information would be beneficial?*
 - 8b. *To whom in particular would this additional information be beneficial? (e.g. the network manager, the ANSP flow management, the OPS room supervisors, the ATCOs, the airline Control centre, pilots, passengers ...)*
 - 8c. *Why this information is not currently used?*

Process Timeline

	Time before expected time of operations				
	>1 month	1 month	1 week - 1 day	24 - 2 hours	2 hours
Airline	Slots and routes for the up-coming season are planned and communicated to ANSP/NM		Early plans are made based on RAD and expected passengers and weather info in case of special bad weather events (hurricanes, etc)	FPs are made based on weather forecast, RAD, and actual number of passengers, weight, etc. FPs are submitted to the NM. Especially in summer, the earlier the better, or there is the chance to lose the slot. FPs are updated in case the NM informs of regulations or possible delays >15'.	Any change to the FP is a reaction to local problems (accidents, airport limitations, bad weather) or regulations from NM.
NM	Publishes the RAD which collects all restrictions put in place by National ANSPs. Predictions on traffic growth at short-/medium-/ long-term are made using single flight data trends.	Sectorization and capacity for the upcoming 4 weeks are collect-ed from ANSPs	Simulation of day X traffic based on single flight of day X-7. PREDICT system compares predicted traffic to capacity declared by ANSP. Potentially critical sectors/units are identified. RAD is updated if necessary.	Upon FP availability, traffic simulation is refined. PREDICT matches FP with single flight of day X-7 and forecasts most likely route. If traffic is predicted to exceed available capacity, strategy is agreed with ANSPs. Eventually, FPs are rejected. In case of uncertainty, Airlines are informed of possible delays and re-routing is recommended.	Coordinates the traffic and compares FPs with info from ANSPs. Eventually, flights are delayed to avoid overfilling ACCs.
ANSP	Put in place general airspace restrictions for the upcoming season and communicates them to NM. Airspace fees are set.	Based on RAD and airlines early planning, sectorization & capacity are established. Rostering is decided.	Weekly, staffing in control room and standbys is decided. Strategies to ease traffic in potentially-critical sectors are agreed with NM. Eventually, new regulations are put in place.	With ECTL's STATFOR (or similar internal tools), traffic predictions are compared with capacity. If capacity is exceeded, regulations are put in place and communicated to NM. Info on weather is taken into account to reduce capacity in sectors if special conditions occur (storm, large convective regions, ice, etc.)	Except for short flights (< 2h), it is too late to require a new FP. If an ACC is close to overflow, it has to decide whether it will 'resist' or a regulation is required.

STEP 2 – DEFINITION OF USER NEEDS AND REQUIREMENTS

View from NM's perspective

1. Key values and high level objectives:

- a. Coordinate work of all ANSPs/ACC units
- b. Facilitate flow by allowing (where possible) flexibility of the sector configurations, keeping the regulations at minimum, and simplifying interaction between airlines and ANSPs
- c. Avoid bottlenecks such as sectors that are recurrently overfilled and sub-optimal use of space because of lack of coordination among units or between units and airlines.

2. Critical tasks and pain points in the current system:

- a. The NM needs to predict the air traffic of the upcoming day. The better the prediction, the more seamless the flow will be, and the fewer problems/delays will occur. These predictions are normally computed combining the data on:
 - (1) the air traffic the same day of the past year,
 - (2) the same day of the past week (i.e. day X-7), and
 - (3) the expected traffic growth extrapolated from longer-term trends.Special days, (important sport events, 1st of August in ACCs of typical summer holiday destinations, etc) are taken into account differently because the traffic is expected to be particularly intense in those circumstances.
- b. FPs are often sent too close to operations, when NM has no time to react. Also,
 - 8% of flights are private flights, FP are sent at any time,
 - 10% of flights are military flights, FP are sent at any time.Using the past flights, the accuracy of predictions is ~80%
- c. Wrong predictions can imply wrong allocation of resources, that is some sectors would need to be split and cannot, because there is not enough staff. This problem can only be addressed by imposing regulations to reduce the load on specific sectors, and consequently delays. In the holiday season, or in presence of bad weather, this problem is exacerbated.
- d. Each Country/ANSP uses its own weather forecast services, which may vary significantly. This may generate conflicting decisions in neighbouring ACCs about the allocation of staff and/or the opening/closing of sectors and/or ask the airlines to cancel part of their planned traffic. Only recently the EUMETNET service has been put in place to produce harmonised forecasts for a region that currently includes almost all UK, France, Spain, Germany, Portugal, and Northern Italy.
- e. Bad planning causes traffic overload on ACCs which, eventually combined with bad weather conditions, creates situations of great stress on controllers and ATCOs and potential safety issues.

3. Needs and requirements:

- a. All Airspace Users (AUs) send their FPs at least 5h before EOBT.
At present this does not happen for a variety of reasons, including a structural one: to optimise their flight, Airlines need to know the total weight of the aircraft (i.e. the total number of passengers, luggage, etc). This impacts on the trim of the aircraft, on the optimal FL which also depend on the wind and weather conditions.
- b. ANSPs, Computerised Flight Plan Service Providers (CFSPs), AUs, etc should be connected with the NM to share information (not only to download NM's data)
- c. Better traffic predictions (>90%)
Points (a) and (b) are meant as intermediate steps to (c). Ideally, the NM would want to know the FP one day in advance for a better planning. However, this will be impossible

for the reasons mentioned above. 5h in advance is a compromise between the needs of the AUs and those of the NM and ANSPs. In particular, knowing the FL (which is one of the most uncertain parameters of the FP) is fundamental in ATM especially to determine the vertical profile at the entrance/exit of sectors. Currently, this information is generally not available until 2h before EOBT.

Point (b) would help have more informed decisions about how all actors will react to different situations. This would be beneficial at pre-tactical and contingency levels.

Point (c) would be beneficial for all actors: ATFM, ATC, NM and AUs. Better air traffic forecast enables better planning, which as a consequence implies a reduction of the ATCOs workload, a better use of airspace, and less delays for AUs.

View from ANSP's perspective

1. Key values and high-level objectives:

- a. Guarantee safety of flights
- b. Facilitate the flow by giving information and instruction to AUs when needed.

2. Critical tasks and pain points in the current system:

- a. The decisions on the configuration and staffing are crucial and are taken 1 month to 1 week before operations, when mostly statistical information on past flights are available.
- b. ECTL's STATFOR provides low and high traffic scenarios for the entire ECAC airspace down to the individual ACC. In some specific ACCs (in normal non-Covid19 conditions) even the high-traffic scenario might be surpassed by the traffic, so at National/local level the experience of the ATCOs is crucial to choose which scenario to believe.
- c. ACCs behave as independent units. At National level there is some coordination, but at international level there are only limited interactions. The National NM units coordinate actions with the NM on a weekly basis and coordinate the operations with the ACCs, but in general ACCs of different countries do not interact. This is a limitation, as a traffic overload in a unit in Germany might cause that unit to put a regulation, which in turn causes AUs to change their FPs to choose different routes and avoid delays, thus impacting other units in Italy, or France, Spain, etc.
- d. Uncertainty on the weather conditions only exacerbates the above problems.

3. Needs and requirements:

- a. Increased communications across ACCs to have a better understanding of the impact of certain actions (such as putting in place a regulation) on other (not-necessarily neighbouring) ACCs over Europe.
- b. A tool to find recurrent patterns in how different ACC units react to given situations and to coordinate the reactions. As yet, this is left to the experience of the individual ATCO. For example, a regulation set under certain conditions of traffic in London ACC causes, 2-3 hour later, other ACCs in Spain/France/etc. to overload and hence a second 'wave' of regulations, as every ACC acts independently. Knowing in advance these patterns would help coordinate responses. The opposite example is that, in certain conditions, the experience tells that even if the traffic is close to 100% capacity, other ACCs will 'fold' first and the flow will never reach the limit.
- c. A system to calculate the best sectorization for a given traffic forecast. At present this does not exist, but it would help ATM to optimise the planning of the airspace.
- d. A system to identify the flight(s) that contributes the most to the complexity of the system in case of overflow. This helps the ATCOs in setting regulations that minimise the impact on AUs, removing/delaying from the flow only the flight(s) that have the higher 'weight'.

STEP 3 – REDESIGN OF STRATEGIC PLANNING, ENHANCED BY DIAPasON

The scheme in Figure 17 represents how the planning process of the NM could be modified to include the information generated by DIAPasON.

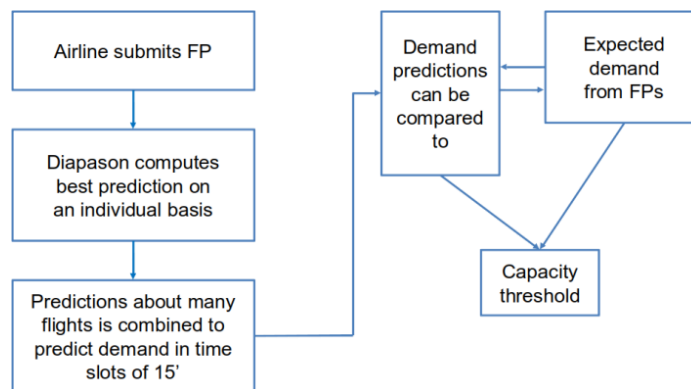


Figure 17: Schematic of the way DIAPasON predictions could be integrated in the planning process at NM level.

Every time an airline submits a FP hours before the EOBT, DIAPasON computes the best prediction of what the final FP will be. While each prediction could be useful also on its own individually, the target users expressed a need of aggregate information, about all flights predicted to cross specific airspace sectors within a certain time interval. This prediction corresponds to the overall demand of traffic as a function of time in every given sector.

As soon as FPs become available, the *predicted* demand computed with the DIAPasON model can be compared to the *expected* demand calculated from the airline FPs. Both demands are to be compared with the capacity of the sectors at any given time of the day. The objective of the planning is to always keep the demand below the capacity threshold.

The DIAPasON benefit occurs when the predicted and expected demands differ, and essentially when one of the two exceeds the capacity threshold. In this situation, the planner must choose between the DIAPasON prediction and the expectation based on the FPs.

At this stage, the HMI mock-up is designed to display the flights exceeding the capacity threshold and for which there is a discrepancy between the DIAPasON prediction and the *expected* FP.

As the DIAPasON prediction comes with an indication of the prediction quality (in percentage), a different design option would be to decide a threshold over which only this prediction is considered.

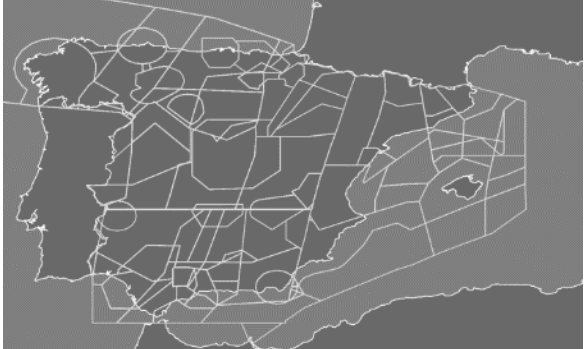

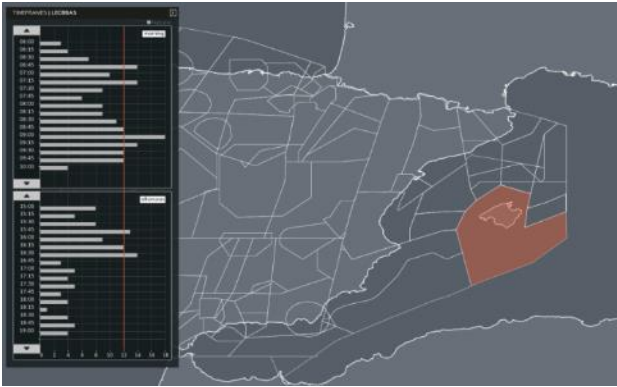
STEP 4 – DESIGN OF HMI MOCK-UP

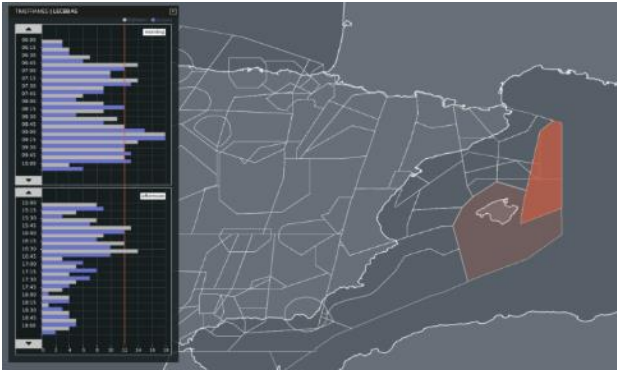


To give a demonstration of how the DIAPasON model can be integrated in the tools for planning that are already in use at the pre-tactical level, we developed a static HMI mock-up, which was used to collect feedback from target users (included in results section). The mock-up is meant to capture the DIAPasON benefit to current planning processes, focusing on the role a *DIAPasON tool* might play. The look & feel simulates an interactive tool and it was implemented using an off-the-shelf prototyping software (i.e. Figma).

To design the role and the mock-up look & feel, we first designed a storyboard, describing:

- User input
- System reaction
- HMI sketch
- Graphical and data elements to be produced in step 5

The final storyboard describing the HMI mock-up is reproduced in Table 5.

Step	Description	Visualisation
1	<p>The system shows: a general overview onto the area of Spain and Portugal airspace; the map shows a geographical reference complemented with airspace details thanks to the visualisation of air sectors.</p>	
2	<p>The system shows: the general overview map shows a highlight onto a specific air sector, as soon as the capacity of the sector is reached. The highlight consists of an easy detectable colour connotation, which also conveys the meaning of critical issues going on.</p> <p>The user performs the action of clicking onto the coloured air sector, exceeding its capacity.</p>	
3	<p>The system shows: The coloured sector is still shown on the map. On a bottom panel, the capacity of the air sector is shown on a timeline through its temporal distribution throughout the day. The visualisation consists of a bar chart, in which each bar represents an interval of 15 min. A timeframe of a few hours is shown simultaneously on the screen, completed with capacity threshold and overloads when happening. The timeline is meant to show 2 or 3 critical timeframes which typically occur in the morning (6-10 am), and in the afternoon (15-19 pm).</p> <p>The user performs the action of activating the DIAPasON predicting software</p>	

4	<p>The system shows: The coloured sector is still shown on the map. On the bottom panel, besides the “actual” timeline, a new timeline appears showing the DIAPasON “expected” capacity temporal distribution. The visualisation is in every element comparable with the one described at step 3.</p> <p>The user performs the action of comparing the “actual” timeline, with the DIAPasON “expected” timeline. If the user notices a deviation between the two, he/she clicks on the corresponding bar chart to access detailed information.</p>	
5	<p>The user performs the action: thanks to the DIAPasON prediction the user can visually notice that the air sector which was meant to be the most critical in the “actual” situation, is no longer critical in the DIAPasON “expected” situation; while a second air sector emerges and is highlighted as critical.</p>	
6	<p>The system shows: the coloured sector is still shown on the map. On the bottom panel the two capacity timelines, with “actual” and “expected” data are shown, with a highlight around the selected interval. A second panel displays a list of all the flights present in the selected air sector, for the selected time interval. In evidence the flights for which there is a difference between the “actual” and the “expected” situation.</p> <p>The user performs the action of selecting the flight with the highlighted deviation, by clicking the flight card from the list.</p>	

7	<p>The system shows: with the flight selected, the system displays the most probable flight plans for the selected flight.</p> <p>The user performs the action of clicking on a single flight plan (visualised trajectory) in order to get the relevant information such as probability of the forecast, reliability time, sector's capacity.</p>	
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Table 5: Description of the process used in the HMI mock-up to deliver the output generated by the DIAPasON model and the actions the user can perform

2.4 Results

2.4.1 Use case application/mock-up tool results

Continuing the research section above, steps 5 and 6 reflect the results obtained:

STEP 5 – ANALYSIS OF DATA TO BE VISUALISED INTO THE HMI MOCK-UP

We took 6 months of data from 01/02/2018 until 30/09/2018, which include 26369 individual flights, with focus on the flights connecting the two main Spanish airports, LEMD and LEBL, with a limited number of European airports, LPPT, LFPG, EGLL, and LIRF. To understand the extent to which the DIAPasON prediction differs from the FP data 4-8 hours before EOBT, we plotted the trajectories on maps, as illustrated in the following Figure 18.

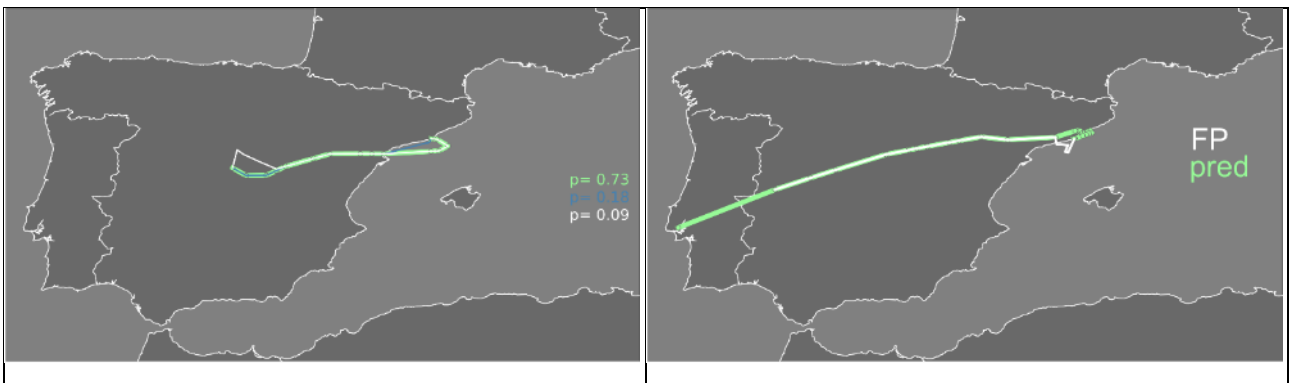


Figure 18: (left) flight #2328616 MAD - BCN on 20/06/2018 with 3 alternative predictions from the DIAPasON model with decreasing likelihood of being accurate. (right) submitted FP for flight #2326321 BCN - LIS on 02/02/2018 (white line with open circles) and corresponding predicted trajectory (green).

This illustrates how, compared to the FP submitted by the AUs 8 and 4 hours before EOBT, respectively, the DIAPasON prediction at the same time points leads to a more accurate estimate of the last FP before operations. Figure 18 also depicts a problem encountered in the majority of the trajectories selected at this stage: in particular, despite being more accurate, the predictions of DIAPasON differ from the FP only in the regions immediately surrounding the TMAs, while the two coincide in most of the en-route phase. This difference is only of limited benefit for the target users, as it might be related to local needs emerged at contingency level (an issue on a runway, a change in local weather conditions, etc.), and therefore as a follow up we choose a different approach to select the flights to visualise on the map.

In our revised approach, we focus on one week dataset (25 – 31 May 2018) and we select only flights that exhibit significant differences in the en-route waypoints Figure 19 and Figure 20 below show some of the results obtained with this selection criterion. For these flights, the DIAPasON model may enable a better demand prediction in en-route sectors.



Figure 19: FP (white) and DIAPasON prediction (blue) 4 hours before EOBT for flight #3229838 LIRF – LEBL.



Figure 20: Same as Fig. 3 for flight #3229078 LEMD – LEMH.

The next step to develop the HMI mock-up is to visualise the map of the Spanish en-route sectors of the Madrid, Barcelona and Sevilla ACCs. For these sectors, we study the occupancy demand and capacity as a function of time. In particular, we highlight in red the suffering sectors in which either the expected occupancy calculated with the FPs or the DIAPasON-predicted occupancy (or both) exceed the declared threshold capacity of that sector at a given time. By selecting one such a sector, the user access to additional information, namely:

- The expected occupancy as a function of time compared to maximum capacity.
- The predicted occupancy as a function of time compared to maximum capacity.
- The list of flights expected to cross the sector in the time interval in which the demand exceeds the capacity.
- For these flights, the comparison of the trajectories in the FP and in the predictions, with their associated probability.

These data are meant to support the decision process of the target users at pre-tactical level as follows:

- By drawing attention on sectors that will be under stress in the course of the day.
- By enabling a more accurate estimate of the sectors' occupancy than that obtained from the FPs.
- By showing how the sectors under stress may vary in the forecasts based on FPs and DIAPasON.

- By displaying the expected and predicted trajectories of flights that might overflow sectors close to the capacity limit.

STEP 6 – FEEDBACK FROM TARGET USERS

A second round of interviews has been conducted among target users to obtain their feedback on the HMI mock-up (in terms of functionality), on the DIAPasON model, and on the way the information generated by the DIAPasON model could be integrated in the existing tools currently adopted by air traffic controllers and the NM.

During the interviews, the HMI mock-up was presented to the target users and subsequently the following questions were asked to guide the discussion

- *What are your first impressions?*
- *What do you like/find useful in this tool?*
- *Would you change or add anything to the tool?*

In general, the response was very positive. In the context of the development of an innovative tool to support the decision process at a pre-tactical level, the most relevant elements the interviewees appreciated include, among others:

- The graphical layout of the interface which resembles other tools currently adopted by EUROCONTROL and ANSPs.
- The way the information is delivered was perceived as very clear.
- The actions that were mimicked in the HMI mock-up (such as the selection and visualisation of critical sectors or critical time intervals, the visualisation of individual flights, etc.) were perceived as intuitive to understand and to perform.
- The histograms with the aggregated data about the evolution of the sector occupancy in time were perceived as clear. The interviewees were very familiar with this way of conveying the information and they consider it fundamental to have a thorough view of how the demand of airspace will evolve in each sector. The possibility to directly compare between the expected and predicted air traffic load was considered very useful.
- The panel with the additional information about the reliability time of the airlines, i.e. the threshold in time after which, on average, a given airline is unlikely to change the FP, was found innovative and insightful.

The interviewed target users provided thorough advice on possible aspects to consider and explore in the further development of the tool:

- Attention should be paid to the possible reasons that trigger a change in FP: this could be related to the weather conditions, temporary needs of the company, regulations, and so on. The case of imposed regulations should be studied separately, as they force AUs to take a decision that normally they would not make. Therefore it is interesting to isolate the situations in which the AUs actively take a decision from the cases in which they are subjected to a decision taken at ATM level.
- A useful information to include is the dynamical evolution of the sectorisation. This information would provide the users with elements to evaluate if the currently planned sectorisation is the best possible or if it is possible to adapt it to the forecasted traffic, for example merging two sectors that are both predicted with a limited load. It would be useful for the controller to visualise the consequences of this decision, namely by how much the traffic would increase on the merged sector, for how long the new configuration could be sustainable, etc.

- Target users consider useful to have the possibility to dynamically change the size of the time window at which to look at when studying the overall traffic load on a specific sector over time. In particular, at ATCO level it is common to visualise 20-minutes or 60-minutes slots. Sometimes, in particularly trafficked situations, it could be useful to visualise shorter time slots of 5-10 minutes.
- The interviewees confirmed that the tool is most useful in predicting variations in the en-route phase of the flights. This is because variations in the TMA are most often connected to local needs at airport level and consequently lack the regularity that is necessary to have reliable predictions.
- The future tool could integrate data-based advice to the users on how to react to a foreseen critical situation, for example by showing and comparing the impact of different decisions, such as: imposing a regulation on one or several flights, opening a new sector, collapsing two sectors, etc.
- The future tool should include the vertical dimension, which is considered a fundamental information to optimise the air space management.
- An intriguing development of the tool to improve its efficacy at airport/TMA level is to include the temporal dimension and a precise timing of the arrivals. This could help avoid congestion at airport level.

2.4.3 Predictive Model results

Finalizing the results section, a summary of the validation performed to the predictive model is presented. The objective of this section is to show the differences in occupancy counts per sectors between the real data in the planning phase and the output provided by DIAPasON.

It is important to note that for the validation of the model presented in this section, the time and altitude were estimated (so that we had a 4D trajectory), while in the results presented in section 2.3.2, it was only considered the 2D prediction of the waypoints.

The first step was to extract the information from the Network Manager in order to obtain the number of occupancy counts based on the information of the flight plan just before the EOBT (Estimated Off-Block Time) of the flight. The second step was to extract the output from DIAPasON using the same time windows, that is, fifteen minutes width sliding fifteen minutes, as showed in Figure 21.

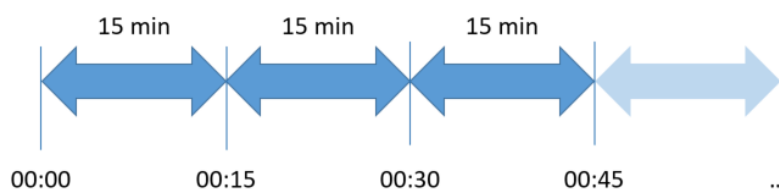


Figure 21. Distribution of times windows.

The third step was to compare the real data, flight plan before EOBT, with the computation of occupancy counts extracted from the algorithm. It is key to highlight that DIAPasOn provides two different outputs: data that are just what would be predicted if the flight plans were completely reliable (and so the knowledge from the week before), and data with the prediction model of DIAPasON. Both cases are provided in two different timestamps: eight and four hours before EOBT.

The aforementioned comparison was carried out for six different days from summer and winter season of 2018: 18th, 20th and 23rd of June, and 19th, 21st and 24th of November (Monday, Wednesday and Saturday), and for two different sectors: LECMTLL and LECMASU. A summary of the results are presented in Figure 22, Figure 23, Figure 24, Figure 25 and Figure 26 , where the light blue line is the real data, “fp” stands for flight plan (trusting in the reliability of the flight plan), “pred” corresponds to the output with the DIAPasON model, and DT4 and DT8 are the two different timestamps described.

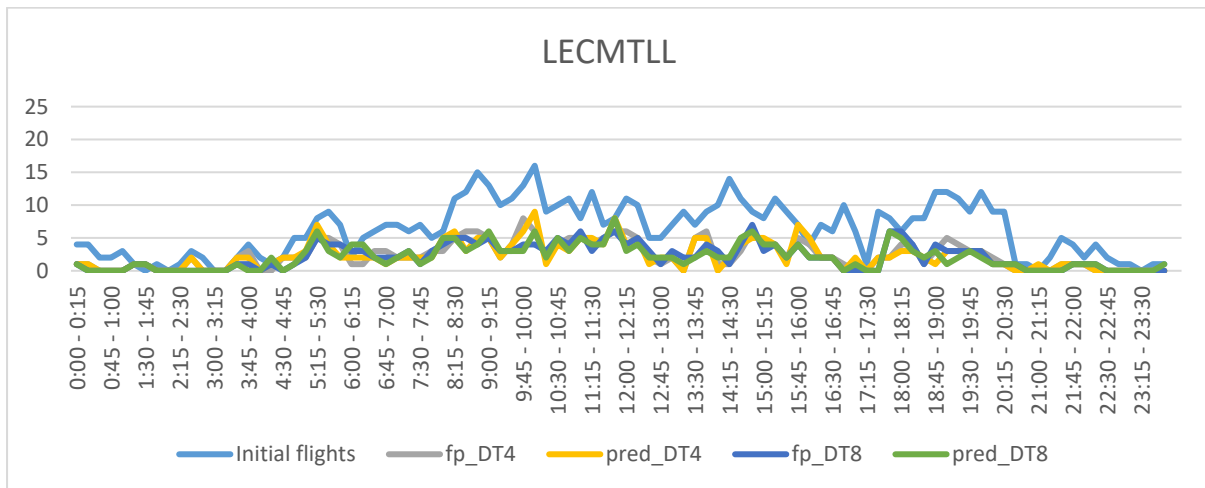


Figure 22. Comparison for 18th of June in LECMTLL sector.

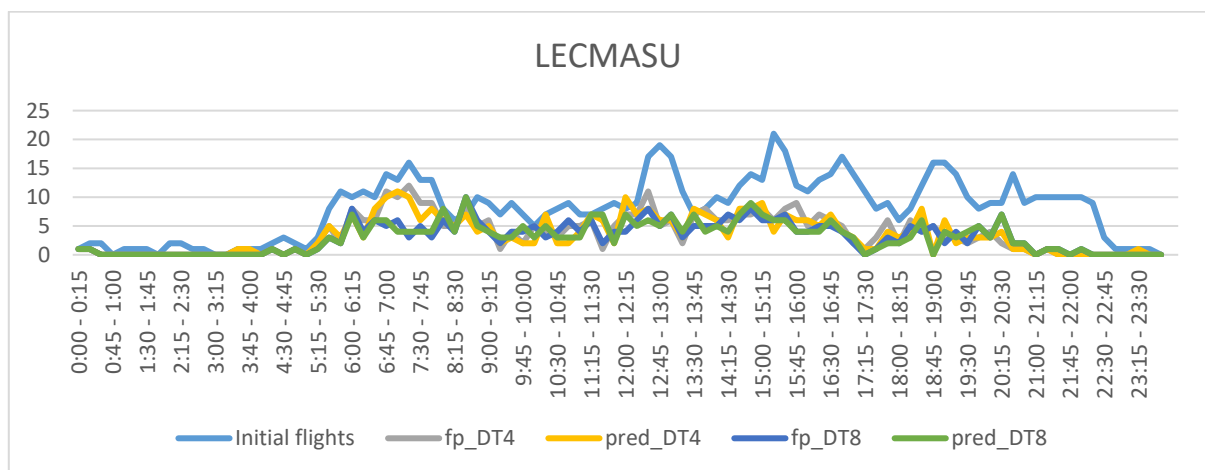


Figure 23. Comparison for 18th of June in LECMASU sector.

Figure 22 and Figure 23 show the comparison between the reality and the forecast for 18th of June 2018 and for two different sectors: LECMTLL and LECMASU. In both cases, the trend of the occupancy counts is captured by the forecast, but it is interesting to underline that the behaviour of the prediction is better in the case of LECMASU than LECMTLL which is a sector with most of the flights in evolution, instead of in en-route phase, more typical for LECAMSU sector. Moreover, zooming in to a specific period, as seen in Figure 24 , it can be said that, in general, the prediction 4 hours before the EOBT is better than the one 8 hours before.

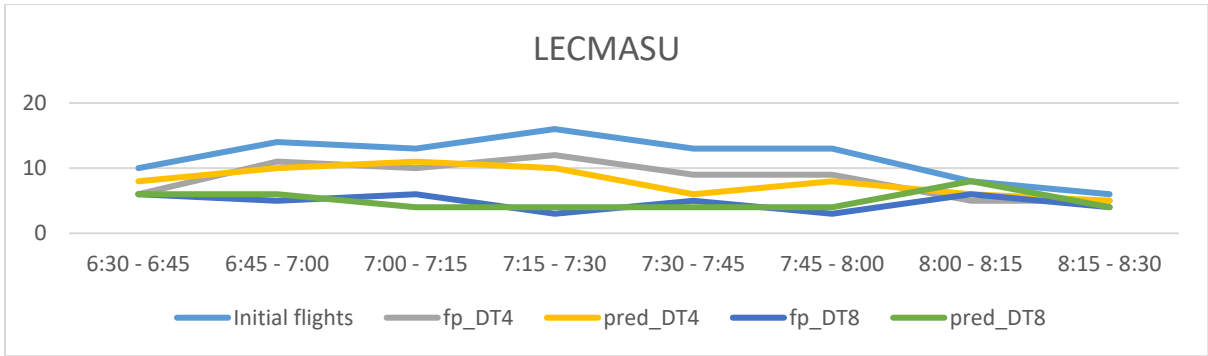


Figure 24. Comparison between DT4 and DT8.

Regarding the day of the week, there are no important differences, and the trend of the occupancy counts is also captured, as it can be seen in Figure 25.

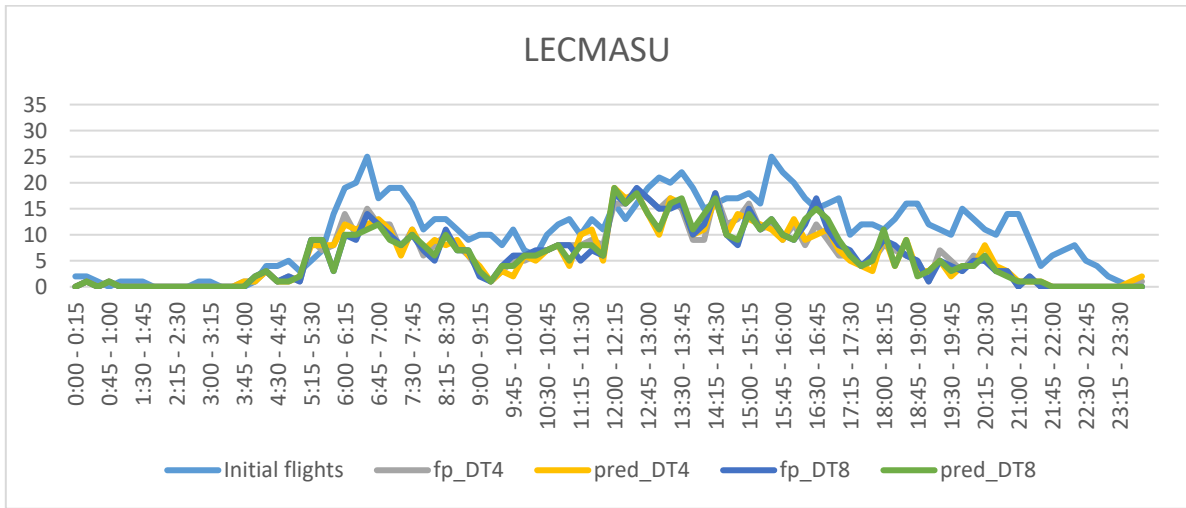


Figure 25. Comparison for 23rd of June in LECMASU sector.

However, for winter season the difference between forecast and reality is higher than in summer season, as it can be seen in Figure 26, which can be explained by the uncertainty induced by bad weather.

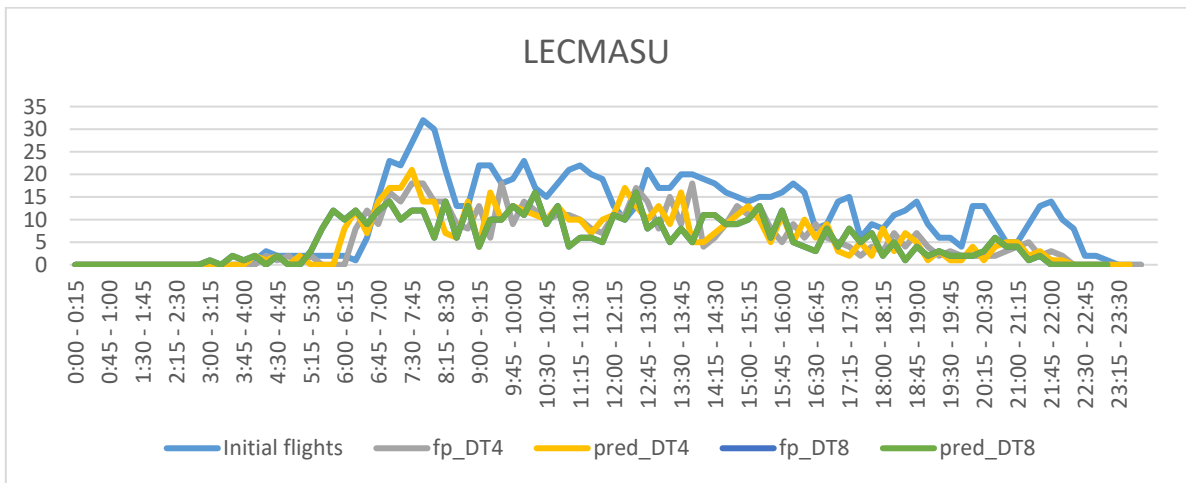


Figure 26. Comparison for 24th of November in LECMASU sector.

3. Conclusions, next steps and lessons learned

3.1 Conclusions

DIAPasON aimed at developing a methodology for Trajectory Prediction and traffic forecasting in a pre-tactical time horizon (covering from one to six days prior to operation), period in which few flight plan are available.

As a result of the work conducted, the project has obtained a **Trajectory Prediction framework** with the following characteristics:

- **Data-driven**, as the methodology is based on data analysis and its interpretation.
- **Dynamic**, as it can be adjusted to different planning horizons.
- **Adaptive**, as it the methodology can be enhanced through the inclusion of new tactical data.
- **Airspace User oriented**, as the framework is adapted to the characteristics and strategies of different AUs.

Both the **actual specific implementation based on operational Spanish data** and the overall **methodological framework** allowing extension to any similar context of operations are considered sufficiently usable and having reached the **targeted TRL4** maturity. In particular, the implementation for Spanish data is considered a **candidate for inclusion in operational decision-making support tools**.

The Trajectory Prediction Framework has been developed in both a high resolution and low-resolution scenario:

- For the **high-resolution scenario**, a predictive model was developed using actual high-quality operational data from the Spanish ANSP, ENAIRE.

Results of the **predictive model** derived in the project were analysed in **different time horizons** to conclude that the **lowest accuracy is found in $\Delta t = 4$ and not in $\Delta t = 8$** . This can probably be explained with the fact that not all the considered flights submit flight plans with the anticipation of $\Delta t = 8$ every day, so the prediction accuracies for different Δt are computed on slightly different samples. The main outcome is that **the model significantly enhances the prediction accuracy for “very variable” flights, while for very regular flights the default choice and the prediction are usually the same**.

The **prediction accuracy** of the model was also **computed for different airlines**, concluding that in most of the airlines the prediction accuracy increases as Δt decreases, being similar for mainly are airlines and over 80% in most of the cases.

- For the **low-resolution scenario**, the predictive model was developed using **DDR data** instead, to cover the ECAC area. In order to make this scenario comparable to the high-resolution one, the correspondence between both sources of data was identified. **The model, as in the high-resolution case, has two main functionalities: predict if the trajectory will change, predict the final trajectory (and its probability)**. The **performance** on low-resolution scenario is - quite predictably - **lower than the high-resolution one**.

On the other hand, digging on the usability and feedback from operational TP end users, the purpose of this DIAPasON predictive model is to provide the NM and ANSPs with additional information about the upcoming flights and a prediction of the demand of airspace that improves the current methods based on the FPs issued by the AUs and on historical data. For this reason a **series of interviews** with potential target users were conducted and a **static mock-up** to demonstrate how the *DIAPasON tool* could be integrated in the current workflow was developed. The most relevant elements the interviewees appreciated include, among others:

- The graphical layout of the interface
- The way the information is delivered was perceived as very clear.
- The actions that were mimicked in the HMI mock-up were perceived as intuitive to understand and to perform.
- The histograms with the aggregated data about the evolution of the sector occupancy in time were perceived as clear.
- The panel with the additional information was found innovative and insightful.

3.2 Next steps

To continue with the work already done in DIAPasON, two main aspects need be addressed:

- A refinement of the predictive model itself to obtain better accuracy in the low resolution scenario, though the use of more reliable data sources to cover ECAC area.
- A refinement of the tool to present the results of the predictive model. In this sense, target users interviewed, proposed the following:
 - Attention should be paid to the possible reasons that trigger a change in FP.
 - A useful information to include is the dynamical evolution of the sectorisation.
 - Target users consider useful to have the possibility to dynamically change the size of the time window at which to look at when studying the overall traffic load on a specific sector over time.
 - The interviewees confirmed that the tool is most useful in predicting variations in the en-route phase of the flights.
 - The future tool could integrate data-based advice to the users on how to react to a foreseen critical situation.
 - The future tool should include the vertical dimension, which is considered a fundamental information to optimise the air space management.
 - An intriguing development of the tool to improve its efficacy at airport/TMA level is to include the temporal dimension and a precise timing of the arrivals.

3.3 Lessons learned

The first lesson learned in DIAPasON project is related to the use of DDR data to perform data-driven analysis based on flight plan information, as this source of information has shown to not be useful in this purpose given the lack of data on the flight plan updates. For this reason, for further works on this field, different sources of information at ECAC level should be used to obtain more accurate results. The project was able to demonstrate the difference between a high-quality dataset such as operational.

However, initial expectations were that, even only in the high-resolution scenario, predictions of flight plan behaviour (planned trajectories) would imply a larger accuracy when apply to an actual scenario, such as those described in the results section. The potential of such information is observed in a non-constant way, despite a very wide set of factors for predictability was addressed. This implies that this approach for TP is not applicable to all cases as implemented in DIAPasON. The use case needs to be carefully chosen to extract a maximum benefit (i.e., specific time advance, or specific shifts to be applied). The possibility to consider not just individual flights factors but repeated patterns in aggregated demand is considered to be a potential enhancement, as it would incorporate “hidden” policies or behaviours of interest for global TP/demand forecast.

An additional lesson, not unknown but definitively highlighted in the project, is how positive the input from operational staff is when applying methodologies to actual operations. The operational staff guidance and vision brings a lot of practical value to projects with a certain maturity level, such as DIAPasON.

4. References

4.1 Project outputs

N/A (no deliverables produced) – key results were described in internal working documents, comprised in the present technical report.

4.2 Other

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