WMO Aeronautical Meteorology Scientific Conference 2017
6 - 10 November 2017
Centre International de Conférences - Météo-France - Toulouse - France

Session 2 – ***Integration, use cases, fitness for purpose and service delivery***
2.2 – **Terminal Area and Impact-based forecast**

Data-driven influence model of weather condition in airport operational performance

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1. INTRODUCTION

Adverse weather conditions are a major cause of flight delays and cancellations each year. In Europe, the influence of meteorology on airport operations is a matter of everyday experience, but it is still lacking of quantitative models supporting decision-making processes.

Airport operational performance is affected by different factors, including air navigation network delays or Air Traffic Control performance, but the performance under adverse meteorological conditions is one of the most challenging factors. These conditions vary from crosswinds to storms or accumulated snow, and the appearance of any of them causes delays, cancellations, which not only affect the airport performance but also airline schedules and every passenger.

This study determines the relationship between airport meteorological conditions and different airport operational performance metrics. The aim is to incorporate the meteorological information into the ATM decision-making process by means of an integrated meteorological indicator, based on actual or forecasted data, to qualify the actual or expected situation.

The process followed in this research starts with empirical values both for the thresholds of the different meteorological parameters and the impact those on the operation, which allows the definition of the integrated meteorological indicator itself. These thresholds are then modified in an iterative process based on genetic algorithms, improving the thresholds in order to achieve a better relation with the airport performance metrics. The positive results obtained with this innovative approach show great potential for operational usage within the airport domain.

2. MOTIVATION

Previous studies [1,2] have developed indicators for meteorological impact on airport operations. However, these studies are exclusively based on empirical decisions. The main goal of this study is to provide a data-driven model to assess weather impacting on airport operational performance. This model will derive in the definition of an integrated indicator. Thus, meteorological information can be introduced into the ATM decision-making process in the airport environment. By including airport metrics information into this decision-making loop, this study ensures that the specific characteristics of each airport are taken into account.

3. METHODOLOGY

The indicator is developed with different parameters and thresholds depending on the actual nominal conditions of each airport and validated according to those conditions.

The indicator itself is a specific value composed by different inputs coming from each of the categories that the METAR [3] is divided in: 1) wind conditions, 2) shear wind conditions, 3) visibility, 4) meteorological phenomena and 5) cloudiness. Each of these categories has different weights and the final value of the indicator will be the sum of each individual category value. A set of colours which is related to the meteorological risk is defined, and the different indicator and categories values are assigned to the ranges of colours.

3.1. WIND SPEED AND WIND SHEAR

The contribution to the final indicator corresponding to the wind conditions is taken from two different parts of the METAR: the wind speed and the wind shear.

Table 1. Summary of wind intensity and wind shear contribution to the indicator value

METAR Field	Threshold	Contribution
Wind Speed	< Minimum Threshold	0
	< Intermediate Threshold	0 to 4
	< Maximum Threshold	4 to 8
	> Maximum Threshold	8
Wind Gusts	Appearance	Gust Multiplier
Shear Wind	No appearance	0
	Partial	Partial Shear Wind Multiplier
	Total	Total Shear Wind Multiplier

The previous table summarizes the calculation of this contribution. For the wind speed three different thresholds are defined and then assigned a fixed value with linear proportionality between them. Wind intensities higher than the maximum threshold will always provide the maximum contribution value, and intensities lower than the minimum threshold will always provide the minimum contribution value.

All numerical values appearing in this table (and the ones incoming) have been set via expert judgment. Each value was set in order to best match the reality when the final indicator is assigned a colour. These contributions will be validated in further studies.

Wind gusts are an important part of the wind conditions category. When wind gusts are reflected on the METAR message, the wind intensity value will suffer a multiplicative effect (which will depend on the airport). If there is no appearance of wind gusts on the message this multiplicative value is set to 0. This will show higher danger on wind gusts with high intensities.

Another category is the shear wind condition of the airport. Although wind direction may account for the shear, the METAR has a specific code for partial (at least one runway) or full (all runways) shear winds. In the case this code does not appear, the shear category will be clear with a 0 value. In the case there is partial shear winds, there will be a multiplicative value dependent on the airport itself. For the cases where all runways are affected by shear winds, the multiplicative value is different from the partial one. This multiplicative value of the shear wind is then added to the wind magnitude together with the wind shear.

The total added value of these two categories to the final indicator is computed as:

$$\text{Wind Category} = \text{Intensity Value} * \text{Gust Multiplier} + \text{Shear Wind Value} * \text{Shear Wind Multiplier}$$

3.2. VISIBILITY

The same methodology applied to the wind conditions can be applied to the visibility.

Table 2. Summary of visibility contribution to the indicator value

METAR Field	Threshold	Contribution
Prevailing Visibility	< Minimum Threshold	6
	< Maximum Threshold	6 to 0
	> Maximum Threshold	0
RVR / Minimum Visibility	Appearance	RVR/MinVis Multiplier

Previous table summarises the different thresholds and contributions of the visibility effects. Prevailing visibility value itself contributes with two different thresholds with the same applicability conditions than the ones expressed for the wind.

The appearances of RVR or minimum visibility conditions apply a multiplier to the contribution of the predominant visibility value.

The total added value of this category to the final indicator is computed as:

$$\text{Visibility Category} = \text{Predominant Visibility Value} * \text{RVR/MinVis Multiplier}$$

3.3. METEOROLOGICAL PHENOMENA

In the METAR messages there are special codes devoted to the occurrence of different meteorological phenomena that are present at the airport and that affect aviation. There are two types of codes, one defining the type of phenomena and another one describing its intensity.

Table 3. Summary of meteorological phenomena contribution to the indicator value

METAR Phenomena	Contribution
Drizzle	DZ Value
Rain	RA Value
Hail	GR Value
Snow	SN Value
Mist	BR Value
Fog	FG Value
Bank	BC Multiplier
Shower	SH Multiplier
Storm	TS Multiplier

The types of phenomena considered are the following: drizzle (DZ), rain (RA), hail (GR), snow (SN), mist (BR) and fog (FG). The appearance of one phenomenon will have an added value to the category indicator. The value associated to each of the phenomenon is dependent on the airport.

The descriptors of the phenomenon that can appear are: bank (BC), shower (SH) and thunderstorm (TS). Commonly, banks are associated to fog, showers to rain and storms can appear together with rain, hail or snow. All three of them will have a multiplicative value to the value from the phenomenon itself. This multiplicative value will depend on the airport.

In the cases where more than one phenomenon appears, the values for each of them are added together.

The total added value of this category to the final indicator is computed as:

$$PhenomenaCategory = Phenomena\ Value * Descriptor\ Multipleir$$

3.4. CLOUDINESS

Table 4. Summary of cloudiness contribution to the indicator value

METAR Field	Threshold	Contribution
Cloud Height	< Minimum Threshold	0 – Maximum Cloud Height Contribution
Cloud Quantity	FEW	Cloud Quantity Multiplier* 0.5
	SCT	Cloud Quantity Multiplier* 1.5
	BKN	Cloud Quantity Multiplier* 2.5
	OVC	Cloud Quantity Multiplier* 4
Cumulonimbus	Appearance of CB/TCU	CB Multiplier

The previous table summarises the methodology to address cloudiness impact. First of all a threshold of cloud height is defined. Above this height the cloud formations are not considered. This is because the clouds are considered to be sufficiently high not to affect aircraft operations.

Then the cloudiness added value will get a linear inverse proportionality with another inferior threshold. Both the threshold and the value associated to it (and thus the proportionality itself) are dependent on the airport. This is to address the different nominal conditions of airports, in which one airport can be operating with clouds commonly and have specific procedures while other airports may not be that prepared.

To this value of the cloud height, the quantity of the clouds is included. This is performed through a multiplicative value depending on the quantity times an empiric value for each cloud quantity: 0.5 for few clouds (FEW), 1.5 for scattered clouds (SCT), 2.5 for broken clouds (BKN) and 4 for overcast clouds (OVC).

And finally, another multiplicative value is applied due to clouds with special affection to airport operations. These clouds include cumulonimbus or towering cumulusas they appear in the METAR (CB and TCU). The multiplicative value is the same for both cloud types and the magnitude is dependent on the airport.

The total added value of this category to the final indicator is computed as:

$$Cloudiness\ Category = Cloud\ Height\ Value * Cloud\ Quantity\ Multipliers * Cumulonimbus\ Multiplier$$

4. AIRPORT METRICS

All the thresholds and magnitudes defined in the previous section must be defined prior to the computation of the indicator value itself. Every of them are individual for each airport, accounting for the characteristics of the airport. With this intention, the thresholds and magnitudes are crossed with an airport metric known as Additional ASMA Time. The ASMA (Airport Sequencing and Metering Area) is an area defined as a circle 40NM around the airport.

The metric is a measurement on the additional time spent by an aircraft since the entrance to the ASMA until landing compared to a statistical time based on low demand periods of time (and in nominal weather conditions).

5. THRESHOLDS COMPUTATION

The validation performed to address the computation of these thresholds is based on genetic algorithms. Genetic algorithms are search algorithms based on natural selection and genetics features [4-6]. Their behaviour is based on the survivability of the strongest individual. In this specific application, the best individuals will be the thresholds providing the best results.

The genetic algorithm starts with an empiric population and starts performing different steps until reaching the best possible outcome. These steps may include the so-called tournaments (facing pair of results and discarding the worst) and mutating (test best obtained values mutating different thresholds to create a new population). The total number of iterations to be performed was set to free, so the algorithm stopped when all the individuals were equal to the best possible.

In the problem faced in this paper, the best outcome will be the best representation of the reality with respect to the ASMA metric. There were a total of 22 thresholds and contributions optimized in the study (underlined in the tables of previous sections). The algorithm used searches to adjust each point (with coordinates based on the indicator and the metric values) to an area indicating the best expected outcome. Locating a point inside an area will sum up a value depending on the area (1 for optimum area, 0.6 for intermediate areas and 0.2 for outside areas). These areas can be observed in Figure 1. To simplify the problem, both the value of the indicator and the Additional ASMA Time were normalized with their maximum and minimum values. The best individuals will be the ones whose total sum is higher.

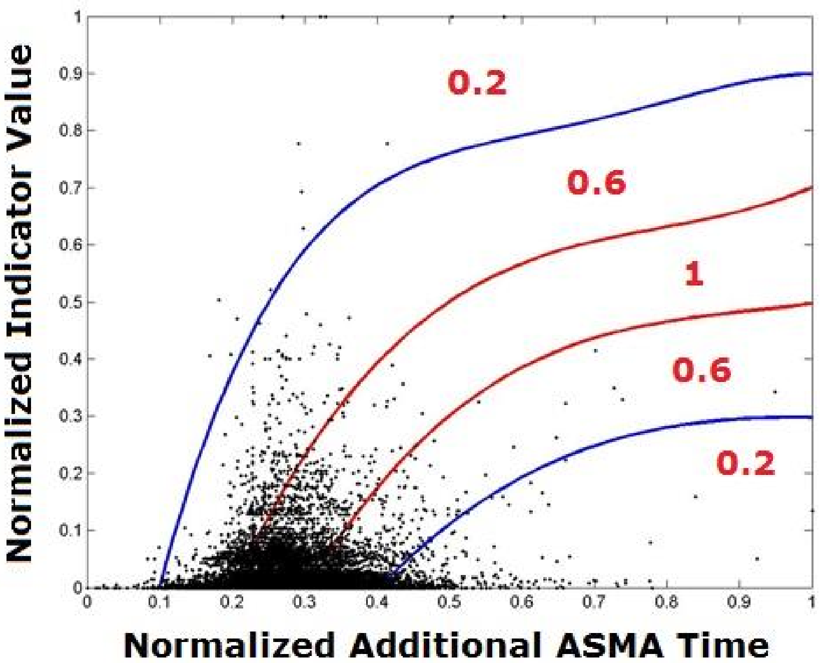

Figure 1. Area definition for the genetic algorithm optimization

6. INDICATOR COMPUTATION

Once the validation has provided the thresholds, the defined methodology is applied to each METAR message, obtaining the different values of the indicator.

Additionally to the indicator value itself, it has been defined different colours to locate this value and ease the definition of meteorology affection. A range of 6 colours is defined for the indicator value, while only 4 colours are defined for each of its categories (wind, wind shear, visibility, phenomena and cloudiness). The different thresholds of each colour are summarized in the following Table:

Table 5. Colour code for the indicator and its contributors

	Green	Cyan	Yellow	Orange	Red	Black
Indicator	0	>0	>2	>4	>8	>12
Wind Speed	0	-	>0	>4	>8	-
Wind Shear	0	-	1	-	2	-
Visibility	0	-	>0	>3	>6	-
Phenomena	0	-	>0	>3	>6	-
Cloudiness	0	-	>0	>3	>6	-

7. INDICATOR RESULTS

The first example reflects the indicator obtained for April 24th of 2014 at the airport of Madrid. The corresponding METAR for that moment is the following:

METAR LEMD 241800Z 27011KT 240V310 9999 FEW030CB BKN055 12/06 Q1016 NOSIG

This METAR message provides the following indicator results applying the thresholds and contributions from the three year validation:

Table 6. Example of indicator and contributions values for the provided METAR message

Indicator	
Wind Speed	
Wind Shear	
Visibility	
Phenomena	
Cloudiness	

Comprising the results for a whole day, the results are the following:

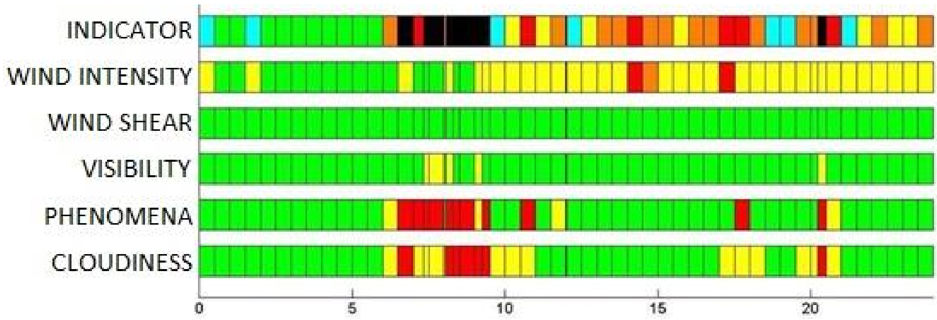

Figure 2. Indicator and contributions values example for a specific day. Each vertical division ccorresponds to a METAR/SPECI message

Figure 2 shows the indicator values obtained for April 12th of 2014 at the airport of Madrid. The indicator itself is shown in the bar at the top and the different components are shown below it. This visualization allows analysing which can be the causes of having bad meteorological conditions.

8. CONCLUSIONS

The proposed methodology allows the development of a meteorological airport indicator based on METAR messages. These messages are provided following actual conditions of the airport. The provision of a meteorological indicator to an Air Traffic Control Operator will help them check quickly the meteorological conditions of the airport without the need to decipher the METAR message and allowing them to perform better their tasks.

The methodology proposed by this study can be introduced into the ATM decision-making loop in the airport environment. Its added value is the introduction of non-empirical methodology with the use of a data-driven model. This model will be specific for each airport, providing specific meteorological assistance to the Air Traffic Controller decision-making process.

9. REFERENCES

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