EXTREME WEATHER EVENTS AND THE EUROPEAN AVIATION INDUSTRY – AN ECONOMIC PERSPECTIVE

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ABSTRACT

This paper presents a calculation concerning the economic impacts of extreme weather events for the European aviation industry. These impacts were calculated for current situation and for future situation in 2040. Future calculations were based on climate change scenarios in terms of changes in probabilities for extreme weather events occurrence. Official figures for the value of time in the aviation industry and data from airport flight schedule as well as type of fleet were used to calculate the costs for major European airports. The airports selected also represent different climate zones, where current and future phenomena and frequency are diverging. Findings show that aviation industry is concerned with time costs affecting passengers, and costs of cancellations of flights on operators. Additionally this paper goes beyond the calculation of weather related costs to both the society and operators and discusses the importance of understanding the magnitude of these costs in terms of improving resilience and a more seamless travel in the future. Furthermore, it offers an overview of selected extreme weather phenomena and their consequences to the aviation industry.

Keywords: Extreme weather phenomena, time costs, socio-economic analysis, aviation industry

INTRODUCTION

Recent weather-related events in Europe have provoked discussion on how to measure the economic impact of extreme weather or natural disasters on aviation industry. Of all transport modes, particularly aviation industry has shown vulnerability in the face of the extreme weather phenomena, resulting in challenges in maintaining standards in service delivery. This was the case, for instance, at the London Heathrow and Paris Charles de Gaulle airports in December 2010, which had to close down due to heavy snow. There are several possible causes for significant delays and even closures for airports, even if no other transport mode is affected by the same weather conditions.

In the recent European Union Framework Programme (EU FP7) funded project “Extreme weather impacts on European networks of transport (EWENT, 2010-12)”, the impacts of extreme weather events for European transport system were looked at in detail. The situation of European aviation industry was analysed at present, as well as for 2040 and 2070. 2040 and 2070 estimates of bad weather occurrence were done using the chances in probabilities for extreme weather events between present and future. (Vajda et al. 2011).

Economic impacts of extreme weather on aviation industry can be classified into time costs for passengers (also referred to as social costs), cancellation costs for operators and maintenance costs for airport authorities and operators. In this paper we focus on the estimation of the economic consequences for the operators and the social costs resulting from delays and cancellations caused by extreme weather events as having been first assessed in the EWENT project. For aviation industry, this marks the first attempt to monetize the costs of such phenomena at the European level. Obviously, such pioneering research is not without its challenges, and the estimates need to be reviewed with caution of data used.

This paper is organized as follows: In the following chapter we present the data, followed by the presentation of methodology used in the analyses of costs to operators and to passengers. The results from analyses are presented in the following chapter and the final chapter provides conclusions and a way forward.

DATA

Aviation industry data

The starting point of analyses is the airport movements data, obtained from EUROCONTROL´s DDR database. Detailed analysis on daily flight movements have been carried out in this paper for three hub airports over Europe being located in three of the five climate areas according to Figure 1: Pairs Charles de Gaulle, Vienna Schwechat and Madrid Barajas. Apart from the three detailed studied airports in this paper, there were some more analyses done by Kreuz and Nokkala (2012) focussing on the hub airports London Heathrow, Amsterdam and Zurich. These analyses were extended to cover a group of 25 airports in various climates zones (see Figure 1) (Nokkala et al. 2012). The selected airports represent roughly 70 per cent of the total departures in Europe based on analysis done by EUROCONTROL (2011a), which gives a good estimate of the impacts at the European level. The preferred usage of narrow body jets for inner European routes results in "snowball" effects at the European level in terms of delays and cancellations. Similarly, for wide body jets the impacts are faced by the aviation industry globally, as airlines affected by extreme weather conditions at European airports contain also non-European companies, and vice versa.

Using flight data from OAG database (2012) specific fleet mix i.e. percentage of wide body compared to narrow body aircraft is elaborated. According to OAG database and EUROCONTROL (2007), the amount of light jets at these hub airports is negligible. Thus, they were not included in the calculations.

For the cost data, aviation industry is a unique case in the transport sector, as official industry values used in the analyses are provided (EUROCONTROL 2011b). These values are the same for all the airports analysed, which is different from other transport modes, where socio-economic calculations done at country level for other transport modes usually use figures determined nationally. Values used were 23€ per hour for leisure and 47€ per hour for business related purposes at present. For 2040, values of 63€ per hour (business) and 26€ per hour (leisure) were used in the calculations. The values were adjusted for future to represent the increase in cost of living, and could be substantially higher as well, which would result in greater costs in the future. The proportion of business and leisure travellers was set equal at 50% each (EUROCONTROL 2011b).

In terms of the number of passengers, the average seat capacity for wide body jets is 300 and 120 for narrow body jets (Civil Aviation Safety Authority 2010). An overview of the airports related key data used in both operator's costs as well as social costs calculations are given in following Table 1.

Table 1: Overview of aviation industry data (OAG data)

	CDG	**MAD**	**VIE**
Ø MOV/d (2012)	1.512	1.244	788
Ø dep/d (2012)	756	622	394
Proportion widebody/narrowbody	0,28/0,72	0,15/0,85	0,13/0,87

Based on the traffic data mentioned above the "conversation of customers" proposed by Little and Graves (2008) is assumed and offers a valid basis for the equality between the amount of departures and arrivals over a period of time (e.g. one year). This approach might be supported by a rather balanced flight plan at hub airports compared to airports with high amount of seasonal tourist flights leading to great variances in terms of flights per day over a year.

Weather data

In order to be able to analyse the impact of extreme weather, the occurrence of phenomena and their associated impacts were reviewed. The financial consequences were calculated for present situation and estimated future climate change scenarios, given the chances in probabilities for extreme weather events occurrence. Using the results of EWENT project (Vajda et al. 2011, Mühlhausen et al. 2011), the climatological data were linked to industry-specific impacts by climate zones.

Furthermore, for the extreme weather phenomena the threshold values and their impact on aviation industry were defined (Leviäkangas et al. 2011). The most important weather phenomena concerning the performance of the aviation were identified as heavy winds and cold temperatures amongst others. Annex 1 summarizes the thresholds and impacts for these phenomena for aviation industry. The thresholds show that same phenomena can have different impacts depending on threshold reached and climate zone in which the phenomena occur. As an example, heavy snowfall as experienced by London Heathrow and Paris Charles de Gaulle at the end of 2010 forced both airports to close down, whereas Scandinavian airports continue to operate under similar conditions with virtually no interruptions.

As there are large differences in the probabilities and intensity of extremes affecting transport systems across Europe, five climate zones were treated separately in the analyses. These climate zones including a selection of the five most important airports in terms of movements per climate zone are shown in Figure 1. Airports with the greatest amount of movements per time period (London Heathrow in the Maritime, Copenhagen in the Scandinavian, Amsterdam in the Temperate, Munich in the Alpine and Rome Fiumicino in the Mediterranean zone) are highlighted in each climate zone as can be seen in Figure 1.

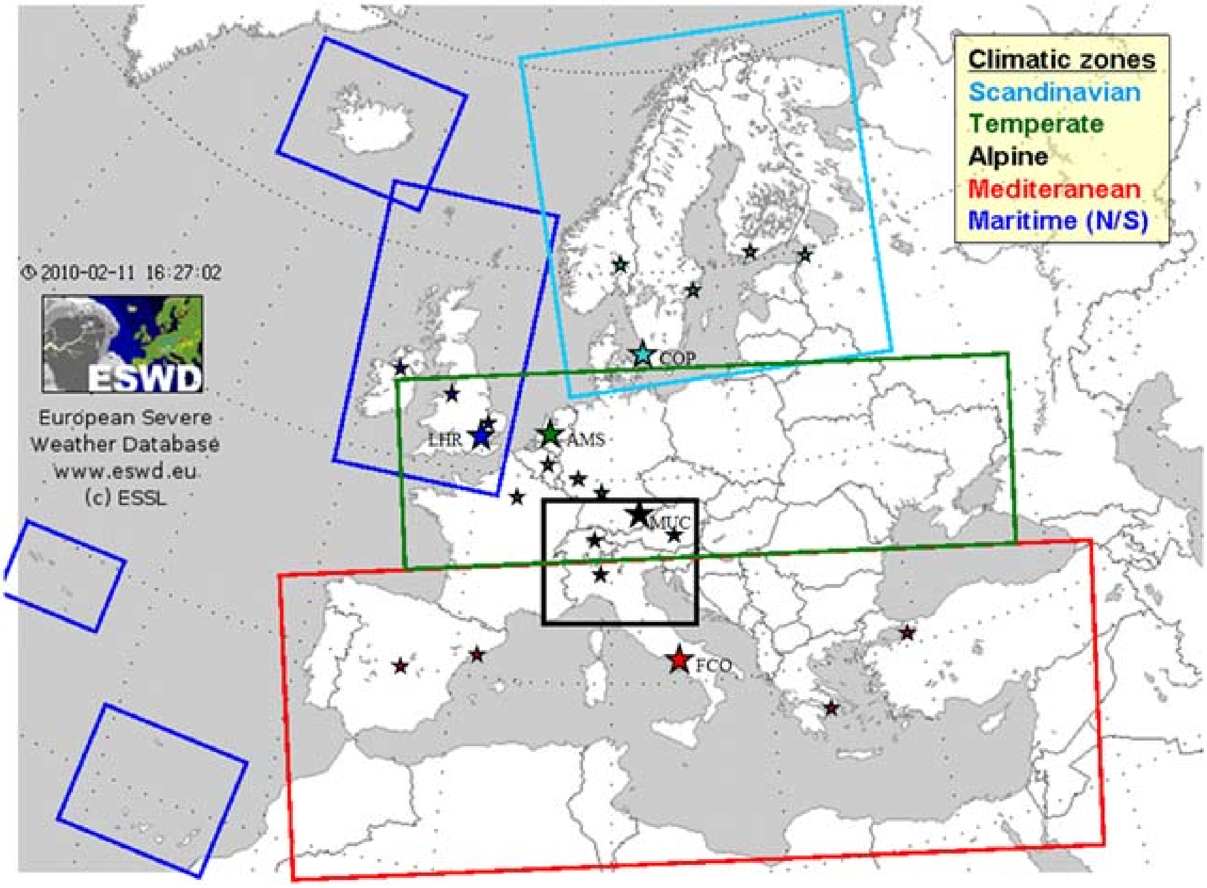

Figure 1 - Definition of climate zones over Europe (Mühlhausen et al. 2011)

Using extreme weather phenomena data (see Table 2) and ATM Airport Performance (ATMAP) data (EUROCONTROL 2009), the number of days with extreme weather is assessed. In the case of an airport being affected by more than one phenomenon at a given time, only the most significant one is used. This will prevent calculation of excess number of days with impacts on the particular airport, resulting in a more cautious estimation of the impacts.

Table 2: Severe weather phenomena changes in % from 1971-2000 to 2011-2040 (multi-model mean) (Vajda et al. 2011)

	Wind Gusts			Cold Waves			Heat Waves		
	17m/s	25m/s	32m/s	≤0°C	≤7°C	≤20°C	≥25°C	≥32°C	≥43°C
CDG	-0,1	0	0	-5,5	-0,8	0	7	0,8	0
MAD	0	0	0	-1,7	0	0	15,4	15,6	0,4
VIE	-0,1	0	0	-8,2	-2,4	0	10,4	2,9	0

As can be seen in this Table 2 wind gusts as well as cold waves are expected to decrease in period 2011-2044 compared to the one from 1971-2000 by values of up to roughly 8%. Besides these two already mentioned weather phenomena of greatest importance, changes in heat waves are estimated to act opposite and carry on some positive effects on the aviation industry. The impacts of the assumed increasing frequency of heat waves in future on the aviation sector will be discussed in the final chapter on conclusions in order to show the impact of climate change.

METHODOLOGY

Social costs

Social costs refer to the passengers' experienced delay from delayed or cancelled flights, measured through the value of time (VOT). In the economic literature, the actual idea of a value being attached to the time assigned to any activity goes back to Becker's theory (Becker, 1965) of the allocation of time. There, he postulated that individual satisfaction did not come from goods consumed directly, but from the "final commodities" that use market goods and time as inputs. What Becker had overlooked was that time at work could in fact be pleasant or unpleasant as well. In other words, working time could influence utility, in this case the level of satisfaction resulting from work, directly. If this influence was negative, then the value of work would be less than the wage rate and the opposite would happen if work were pleasurable. This was pointed out by Johnson (1966), Oort (1969) as well as by Evans (1972). Referring to present distinction in leisure and business travellers, it was DeSerpa (1971) who first include a set of minimum time requirements for each activity explicitly (analytically). Within this framework, he defined the value of time as a resource as the value of extending the time period, equivalent to the ratio between the marginal utility of (total) time and the marginal utility of income.

Calculation of time losses was done as follows:

$$\frac{\text{Ø}\,PAX}{JET_{W,N} \times d} \times P_{T_{B,L}} \times VOT_{SC_{B,L}} \times T_F \times W_{SC} \qquad \text{(1), where:}$$

$\frac{\text{Ø}\,PAX}{JET_{W,N} \times d}$	= average passengers per jet and day (wide body/narrow body)
$P_{T_{B,L}}$	= proportion of leisure to business travellers
$VOT_{SC_{B,L}}$	= value of time for business or leisure travellers in the respective scenario
T_F	= time factor for sensitivity analyses
W_{SC}	= amount of extreme weather days in the respective scenario

The average number of passengers per jet is represented by the number of seats offered and a passenger load factor. This factor is defined as the percentage of seats filled by fare-paying passengers and is set at value of 70% for narrow bodies and 83% for wide bodies (EUROCONTROL 2011b).

Operator costs

Operator costs, resulting from the flight cancellation, are the industry's cost of extreme weather events. Using the industry values for wide body and narrow body aircraft, and combining those with airport-specific fleet mix data, the calculation of operator costs of cancelled flights was carried out. The formula used in the calculation is:

$$\frac{MOV_{W,N}}{d} \times W_{SC} \times C_P \times C_{C_{W,N}} \qquad \text{(2), where:}$$

$\frac{MOV_{W,N}}{d}$	= average amount of movements per day (wide body/narrow body)
W_{SC}	= amount of extreme weather days in the respective scenario
C_P	= percentage of cancelled jets
$C_{C_{W,N}}$	= cancellation costs (wide body/narrow body)

Sensitivity analyses

For passenger time costs, the uncertainty is associated with the average length of the delay, when calculated for a given day as an average for all the passengers.

As not all weather phenomena lead to a complete cancellation of all planned movements, a sensitivity analysis was performed to determine to the amount of additional costs. Beginning with an average value of 10% cancellation, the development of operator's daily costs was carried out. In this approach a uniform distribution of movements at the selected airports per day is assumed. This issue will be picked up and discussed in the final section of this paper.

In similar fashion to the calculation approach to the operator´s cost calculation, changes in the amount of financial burden to the society are gained by shifting the time cost factor in the course of sensitivity analysis.

Weather-related data used to calculate operator costs were obtained from annual statistics showing the number of days with bad weather on selected European airports. From the society's point of view, the economic loss is the loss of productivity as a consequence of the time spent waiting (Mackie et al, 2001). Travellers willing to pay for the time savings are in inverse relation to the cost of increased travel time. In the aviation industry the figures are defined universally, making a study of the impact at the European level easier than in other transport modes, where national values based on various calculations methods are used. The fact that the value of time is greater than that observed in road transport in EU member states suggests that those using aviation as means of transport place a higher value to their travel time and, thus, have higher average earnings. The standard argument for calculating the value of time losses or gains is that through time use in productive activities and individual can contribute to total productivity (e.g. higher contribution to the society and economy measured in the Gross Domestic Product, GPD) and when excluded from doing so the costs are borne by society.

RESULTS

Social costs for travellers

Costs borne by society in case of extreme weather events for the present situation are given in following Table 3. Calculation is based on formula (1).

Table 3: Time costs at present (in €)

		CDG		MAD		VIE	
	rate of aircraft affected	15min	45min	15min	45min	15min	45min
grand total for respective weather scenario	0.1	1.205.251	2.169.451	828.177	1.490.718	509.385	916.893
	0.25	3.013.126	5.423.627	2.070.441	3.726.795	1.273.463	2.292.233

As the duration of extreme weather events varies, social costs at average delay levels of 15min as well as 45min for passengers were calculated. Furthermore, values were given for different rates of aircraft being affected by these weather related disruptions. In terms of e.g. a rate of 0.1 (as indicated in Table 3) 10% of the average movements per day are affected. Depending on the input parameters in formula (1), grand total for the respective weather scenario shown in Table 3 was elaborated. Concerning the weather phenomena used for the calculation, only the most prevailing phenomenon detected at the respective airports was used in order to prevent calculation of excess number of days with impacts on the particular airport.

In similar fashion to the approach in the 2012 scenario values for the future scenario for 2040 (see Table 4) were devised. Nevertheless, some major key input figures were changed as follows in order to draw a more realistic picture.

In accordance to the severe weather phenomena changes shown in Table 2 the number of days with extreme impact of the prevailing weather phenomenon at each of the selected airport was updated (see Table 2). Furthermore, VOT for both business as well as leisure travellers was changed as explained above (part aviation industry data) because VOT is supposed to increase from present to 2040 relying on analyses done by EUROCONTROL (2011b). As changes in the number of movements at these airports can be hardly foreseen, time costs in the future scenario were calculated on basis of both traffic volumes from present time (“traffic 2012”) and predicted traffic volume for future times (“future traffic forecast”). This gives a good estimate of the changes in time costs depending on the traffic volumes calculations base on.

In Table 4 scenario "traffic 2012" represents no differences in terms of the amount of movements per day compared to present time. Scenario "future traffic forecast" implies an assumed increase of 1% per year in terms of movements at the selected airports which is a conservative assumption especially in the context of intentions of expanding capacities at airports. In this case even higher average movements per time unit and in consequence higher time costs for passengers can be expected in future.

Table 4: Time costs in the future scenario (in €)

			CDG		**MAD**		**VIE**	
	rate of aircraft affected		15min	45min	15min	45min	15min	45min
grand total for respective weather scenario	0,1	traffic 2012	1.532.390	2.758.302	1.052.967	1.895.341	555.126	999.226
		future traffic forecast	2.024.733	3.644.519	1.391.276	2.504.297	733.483	1.320.269
	0,25	traffic 2012	3.830.975	6.895.755	2.632.418	4.738.353	1.387.814	2.498.066
		future traffic forecast	5.061.833	9.111.299	3.478.191	6.260.743	1.833.706	3.300.672

Grand total for the respective weather scenario was developed the same way as described in the 2012 scenario. With respect to the mean values of changes of severe weather phenomena shown in Table 2 and the estimates given in Table 4, the variation in the amount of the social costs are primarily caused by the assumed higher traffic volumes as well as the higher VOT. Changes in extreme weather are a minor explanatory factor compared to traffic volume changes.

Operators' cost results

Operators' costs at present time are shown the Table 5. Estimates were calculated using formula (2).

Table 5: Operators' Costs in the 2012 scenario (in €)

		CDG	**MAD**	**VIE**
	cancellation rate	traffic 2012	traffic 2012	traffic 2012
grand total for respective weather scenario	0,1	36.244.796	22.802.733	13.779.584
	0,25	90.611.990	57.006.833	34.448.960

Costs to operators caused by extreme weather events are highest in Paris Charles de Gaulle and lowest in Vienna Schwechat in the data set. This is due to the number of average

movements per day as well as the proportion between wide bodies and narrow bodies at the selected airports (see Table 5).
As extreme weather phenomena vary in their magnitude of impact on the specific airport, calculations were done for 10% as well as 25% of cancellations of the average number of movements per day. The grand total for the respective scenario implies the amount of wide bodies and narrow bodies affected by the major weather phenomenon in terms of days per time detected at this particular airport.

For the future scenario 2040 the operators costs are shown in Table 6 for both cancellation rates used in the analyses.

Table 6: Operators' Costs in the future scenario (in €)

		CDG	**MAD**	**VIE**
	cancellation rate	future traffic forecast	future traffic forecast	future traffic forecast
grand total for respective weather scenario	0,1	47.889.922	30.129.046	15.605.863
	0,25	119.724.804	75.322.614	39.014.657

Analogically to the social costs in the future scenario the volumes of traffic as well as weather data were changed for the future scenario compared to present one taken into account the values shown in Table 2. All other parameters, including the costs of cancellation for wide body and narrow body aircraft, were kept the same as both valid values for cancelling flights for the year 2040 (future scenario) are lacking. As a result, differences in the values are primarily outcome of the increase in the amount of movements per day when the results of the 2012 scenario are compared with the 2040 future scenario. With regard to the values in Table 2 the impact of the severe weather phenomena changes on the amount of operators' costs shown in Table 6 is negligible compared to the increase in traffic volumes. Furthermore, negative values for wind gusts and cold waves (as shown in Table 2) might have a cost reducing impact on the grand total as flight operations are less disrupted in consequence.

As mentioned in the text there were some more analyses done by Kreuz and Nokkala (2012) focussing on the hub airports London Heathrow, Amsterdam and Zurich. Having analysed six airports with comparable size in terms of movements per hour and traffic mix in terms of wide body and narrow body covering all of the defined climate zones results give a clear representation of the European context.

Taken into account all of these more detailed studied six airports, operators' as well as time costs are highest in London Heathrow due to the amount of movements per time unit (239.280 departures per year in 2009) and the proportion of wide body (31%) to narrow body aircraft (69%). Based on the evidence from these six in-depth studies, the massive loss at the European level encountered from extreme weather phenomena can be emphasized whereby operators´ costs are less in the volume than the social costs borne by the passengers and the European Community. Results of EWENT D4 (Nokkala et al. 2012) underline these assessments and moreover, offer a Europe-wide impact of extreme weather events on a total of 25 airports covering different climate zones as shown in Figure 1.

CONCLUSIONS AND FURTHER RESEARCH NEEDS

This paper addresses the magnitude of extreme weather-related challenges the aviation industry faces in Europe. In doing so, this paper represents a first of its kind approach in Europe covering both operator costs and passenger's time costs. However, the consequences are global as the delays and cancellations of heavy jets will have consequences on global aviation and affect non-European operators as well. The methodology applied allows studying the impacts in the light of prevailing uncertainty by adding a sensitivity analysis dimension. By placing a price tag on the events, it is now possible to do further cost-benefit analyses of the investments that would improve the resilience of the airports and, consequently, of the operators with respect to impacts of extreme weather. As focus is not only laid on present situation, scenario of impacts in the year 2040 was also created, taking into consideration the climate change agenda. Although some weather phenomena become less frequent, the costs are increasing as the value of time of passengers will increase. This will be the situation if no additional measures are taken to mitigate the impacts.

Results of the study also show that the aviation industry suffers significant losses from the cancellations of flights in the cases such as the volcanic ash cloud or closure of a major airport due to conditions beyond the industry control. Frequent occurrence of such events will impact the profitability of airlines and creates financial liabilities.

What is lacking at present is data from airports that would allow calculating the cancellations and average delays in a more systematic way, despite the fact that most likely such information exists. This research can provoke the provision of such data for future calculations for the airports resilience and to offer better performance statistics of the industry. Furthermore, it should be noted that probabilities for heat waves increase over the next decades. This is assumed to have a positive effect on the aviation industry as the approach speed will increase leading to less capacity problems, especially at those airports operating close to their limit. Focussing on the probabilities for changes in cold waves, a decreasing amount of days with temperatures less than 0°C may result in less de-icing activities at airports and therefore, in smoother operations compared to nowadays.

In this paper parameters such as cancellations costs, seats per wide body and narrow body aircraft on average as well as the fleet mix at airports (i.e. proportion between narrow body and wide body aircraft) were kept the same in today´s as well as future scenario. Broadening the focus by including e.g. aircraft manufacturer´s view on future Europe´s and as well global fleet mix is another set screw for optimization and achieving higher degree of realism. An increasing use of aircraft types like Airbus A380 that offers a significantly higher amount of seats than regular recent aircraft of type B747 or Airbus A340 will have strong potential to boost the values.

In total, the effects of climate change for aviation industry can be hardly foreseen, as there are many contradicting effects, which can offset one another. Besides these weather-related issues there are some more challenges to be faced in future analyses. Combining weather related forecasts with economic assessments leads to the following challenge: In the calculation process a rectangular distribution of flights over the period of one day is assumed. Statistics of hub airport show peak hours in the morning, at lunch time and in the afternoon with less demand in the time between though. A more sophisticated mathematical model could sharpen the analyses. Also the consideration of substitution opportunities with other modes of transport due to bad weather events affecting aviation will be become relevant subject for study. An increased availability of the information regarding the potential impacts of extreme combined with a higher cooperation amongst the different modes could increase the availability of travel choices. Multimodal traveller services could assist in mitigation of impacts, when the passenger could choose to use other mode of transport in the case of likely delay or cancellation. These multimodal considerations are the key strategy to increase the resilience and reduce the massive loss at the European level encountered from extreme weather phenomena at present time.

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ANNEX – SELECTED EXTREME WEATHER PHENOMENA AND THEIR CONSEQUENCES TO AVIATION INDUSTRY (LEVIÄKANGAS ET AL. 2011)

Low temperature – daily mean temperature				
Thresholds	Impacts	Consequences to infrastructure	Consequences to operations/services	Relevant climatic zones
$\leq$ 0 ^{o}C	This is an important threshold related to slipperiness (ice formation, form of precipitation: rain/sleet/snowfall). The temperature itself is rather a modifier of hazardous conditions for transportation than a main cause. Low temperature combined with precipitation and wind can have a disruptive affect on traffic. Occurrence of freezing drizzle, increased frequencies of freeze-thaw cycles.	Premature deterioration of runway pavements	De-Icing procedures are in place for any aircraft, i.e. increase of the turnaround-time, resulting in delays	Scandinavian, Temperate, Alpine, Maritime

≤ -7 °C	The effect of salting for ice removal decreases in low temperatures. So, even relatively small amounts of snowfall can cause slippery conditions on runways, taxiways and apron.	Premature deterioration of runway pavements	De-Icing procedures are in place for any aircraft, i.e. increase of the turnaround-time, resulting in delays	Scandinavian, Temperate, Alpine, Maritime
≤ -20 °C	Dangerous wind chill conditions occur when moderate winds prevail	Premature deterioration of runway pavements	Public transport may encounter breaks due to supply problems. Limitations for the transport personnel working outdoor.	Scandinavian, (Temperate), Alpine, (Maritime)
Wind				
Thresholds	Impacts	Consequences to infrastructure	Consequences to operations/services	Relevant climatic zones
Head wind Vhead<Vmin	Reduced ground speed		Delay	All zones
Tail wind 10 kt for 4 km RWY	Reduced lift / Moderate take-off, landing		Reduced runway capacity, ground strike, too fast	All zones
Cross wind/gust a/c dependent	Stabilization of a/c / Moderate in landing		Reduced runway capacity, go-around, ground strike	All zones
Low visibility				
Thresholds	Impacts	Consequences to infrastructure	Consequences to operations/services	Relevant climatic zones
CAT I : decision height (DH) >= 60 m, runway visual	Separation between aircraft increased		Delay	All zones

range (RVR) >= 550 m				
CAT II : 30 <= DH <= 60 m; RVR >= 300 m	Separation further increased		Delay Missed connections Loss of situational awareness	All zones
CAT III a : 15 <= DH <= 30 m; RVR >= 200 m	Separation further increased		Strong Delay Cancellations Diversion Missed connections Loss of situational awareness	All zones
CAT III b : DH < 15 m; 75 <= RVR < 200 m	Separation further increased		Strong Delay Cancellations Diversion Missed connections Loss of situational awareness	All zones
CAT III c : DH = 0m; RVR = 0 m	Stop of operations		Airport closed Strong Delay Cancellations Diversion Missed connections Loss of situational awareness	All zones