Guidebook for Enhancing Resilience of European Air Traffic in Extreme Weather Events
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List of Abbreviations

AEA: Association of European Airlines
ANSP: Air Navigation Service Provider
ATFM: Air traffic flow management
ATM: Air traffic management
ATMAP: ATM Airport Performance
EASA: European Aviation Safety Agency
IATA: International Air Transport Association
METAR: format for reporting weather information
SES: Single European Sky
SESAR: Single European Sky ATM Research
The MOWE-IT project: The goal of the MOWE-IT project is to identify existing best practices to develop methodologies to assist transport operators, authorities and transport system users to mitigate the impact of natural disasters and extreme weather events, but also other less extreme but adverse events and hazards on transport system performance. The project is funded by the European Commission’s 7th RTD framework programme between October 2012 and September 2014. MOWE-IT is co-ordinated by the Technical Research Centre Finland (VTT) and involves 12 European research institutes and companies. The MOWE-IT project has a website (www.mowe-it.eu) which has more information regarding the project and also contains a significant database for publications relevant to the subject. We encourage you to visit the website and also contribute to discussions and information sharing.

This guidebook addresses recent knowledge and good practices on the risk of adverse weather events for passenger as well as air cargo services. It offers best practice guidance on how passengers may react and how companies should be prepared. It describes what kind of information can be used as support and how information networks and information sharing technologies between the different means of transportation may lead to higher customer satisfaction. This guidebook shall help to optimise the use of financial and environmental resources and lead to higher resilience towards induced negative effects in the global air traffic system.

This guidebook is written for use by policy-makers, public authorities and transport professionals. It addresses airline operators, ANSPs, airport operators, and travel agencies. The needs and expectations of passengers are addressed in order to increase awareness of stakeholders.

1. Major Threats to Aviation

Various adverse weather events occurring over the European continent have a potential to impact the European aviation system. Due to locally varying conditions these events are more frequent in some regions than in others. However, their potential to impact the aviation system depends also on the awareness of the aviation authorities. Due to a changing climate it has to be expected that the patterns of adverse weather change to some degree. With this note we intend to provide a short overview of the most important weather types and their characteristics.

The characteristics of the selected weather types were analysed within the framework of the FP-7 EWENT project (Leviäkangas et.al., 2011). Additional analyses of the European thunderstorm activity have been carried out within the MOWE-IT project.

The most important types of adverse weather for aviation are listed in Table 1.1, including information on their geographical and seasonal relevance; the expected changes until the 2050s (and 2020s, if significantly different); typical duration and warning times and their impact on aviation transportation networks. It has to be noted that regional climate models cannot reproduce all types of weather events with the same accuracy and that results partially disagree between the models.
Table 1: The most important types of adverse weather events by geographical and seasonal relevance, changes until the 2050s (2041–2070), duration and warning time and main impacts.

<table>
<thead>
<tr>
<th>Type of adverse weather event</th>
<th>Geographical and seasonal relevance</th>
<th>Likely changes until the 2050s</th>
<th>Duration and warning time</th>
<th>Impact on aviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heat waves</strong></td>
<td>Most frequent and extreme in southern Europe, especially Iberian Peninsula, Greece and Turkish; Common in central and eastern Europe; Summertime event</td>
<td>Significant increase in the probability of hot days across Europe, especially in currently hot regions</td>
<td>Depending on the region – from days to several weeks; Several days of warning time</td>
<td>Damage of runway pavement; Forest fires reducing visibility;</td>
</tr>
<tr>
<td><strong>Cold waves</strong></td>
<td>Most frequent and extreme in Scandinavia and alpine regions; Decrease toward south; Winter event</td>
<td>General decrease all over Europe, especially in currently most affected areas</td>
<td>Depending on the region – from days to several weeks; Several days of warning time</td>
<td>Reduced runway friction; Runway maintenance; Deterioration of pavement; Technical failure of vehicles and infrastructure; Icing of aircraft</td>
</tr>
<tr>
<td><strong>Heavy precipitation (large-scale systems)</strong></td>
<td>Most frequent in southwestern Norway, Alps, Gulf of Genoa and British Isles; All-year event with strongest events mostly during winter</td>
<td>Slight mean increase for most regions; Slight decrease in some Mediterranean areas; Climate models disagree to some extent</td>
<td>Duration of several hours to days; Warming time of days</td>
<td>Reduced visibility and runway friction; Snowdrift; Runway maintenance; Icing of aircraft; Ground operations affected</td>
</tr>
<tr>
<td><strong>Snowfall</strong></td>
<td>Most frequent in northern Europe, alpine regions, eastern Europe; Relevant also for southern Europe; Winter event</td>
<td>Overall decrease in snowfall events over Europe strongest in northern Europe; More frequent strong events over the Scandes and parts of southern Europe</td>
<td>Duration between hours and several days; Warming time of days</td>
<td>Reduced visibility and surface friction; Obstacles on the runways; Reduced visibility; Icing of aircraft; Ground operations affected</td>
</tr>
<tr>
<td><strong>Large-scale storms and wind</strong></td>
<td>Most affected areas are the British Isles, Iceland and the western coastal areas; Relevant for the whole continent; Strongest events occurring during winter months</td>
<td>Slight increase in most western, central and southern European regions for the 2020s, decrease over the inland Iberian Peninsula and eastern Europe; General decrease for the 2050s; Climate models disagree to some extent</td>
<td>Duration of several hours up to days; Warming times of days</td>
<td>Enhanced turbulence with strong wind gusts; Obstacles on the runways; Reduced visibility; Icing of aircraft; Obstacles on the runways; Reduced visibility; Icing of aircraft; Ground operations affected; Safety regulations (wind threshold may lead to runway closure)</td>
</tr>
<tr>
<td><strong>Thunderstorms (strong wind gusts, lightning, intense precipitation, hail)</strong></td>
<td>Most frequently over the Mediterranean region, the Balkan and east-central European; Relevant for the whole continent; Summer event</td>
<td>Slight general increase over Europe; Difficult to capture with currently available climate models</td>
<td>Duration of tens of minutes to a few hours; Warming times of hours to a day depending on the spatial precision</td>
<td>Reduced visibility and surface friction; Obstacles on runways; Reduced visibility; Icing of aircraft; Ground operations affected; Safety regulations (wind threshold may lead to runway closure)</td>
</tr>
<tr>
<td><strong>Blizzards (strong wind gusts, intense snowfall)</strong></td>
<td>Predominantly in the Alps and northern Europe; Most affected areas are the western coast of Norway and Iceland; Winter event</td>
<td>Slight general decrease in the currently affected areas; Difficult to capture with the currently available climate models</td>
<td>Duration between hours and a day or more; Warming times of about one day; Generally difficult to forecast</td>
<td>Reduced visibility and surface friction; Obstacles on runways; Reduced visibility; Icing of aircraft; Ground operations affected; Safety regulations (wind threshold may lead to runway closure)</td>
</tr>
<tr>
<td><strong>Fog</strong></td>
<td>Mainly local event; Rather relevant in moderate and cold regions; Rare in the Mediterranean region; More common in late autumn and winter</td>
<td>General increase as observed in the last decade; Difficult to capture with the currently available climate models</td>
<td>Duration of several hours; Warming times of about a day (regional warnings); Local forecasts challenging</td>
<td>Reduced visibility</td>
</tr>
</tbody>
</table>
Purely temperature related events (heat and cold waves) are reproduced fairly well, while dynamic events (winds and precipitation) are more challenging. Small-scale events such as thunderstorms, blizzards and fog cannot be fully resolved by current models, thus the current frequencies and potential future changes have to be retrieved using indirect methods, implying additional uncertainties. The listed impacts represent the direct, weather induced, consequences, which in turn have the potential to cause delays, increased accident rates and temporary closures of airports.

A qualitative analysis of weather related events has been carried out based on recent reports and data collected by the Association of European Airlines (AEA) from January 2007 until March 2009. (AEA, 2008). In line with table 1, the impact of these weather events is explained based on some examples:

- Weather events, such as fog, wind, rain and others primarily cause disturbances at congested international and European hub airports. As a consequence of such weather events separation of aircraft has to be increased and, in case of heavy rain falls, runway conditions as well as braking power are decreased, leading to reduced runway capacity and different forms of delays or even cancellations. Changes in the runway traffic assignments or runway closures when tail wind components are exceeded result from these events. The specific restraints depend on an airports runway layout.

  At London Heathrow International Airport approximately 700 flights within three days were cancelled during Christmas time 2006 due to foggy conditions. Some of the 40,000 passengers were rebooked on flights from not affected airports or on other modes of transport (busses, trains). In many cases, severe disturbances occur due to “overlapping effects” of different types of weather events, causing disruptions in operations. At Munich International Airport low visibility combined with freezing fog and an inversion led to 232 aircraft being delayed and 24 being cancelled in December 2007.

- Long-lasting weather events such as snow fall or freezing conditions may lead to great disturbances at any airport including its complete shutdown. Snow clearance is coordinated among airline operators, meteorology, air traffic system services, and airport administration. In case of an airport with multiple runways, snow removal is usually carried out consecutively for the runways. The goal is to keep at least one runway usable and avoid up to a certain amount of snow a complete closure of the airport. Nevertheless, the available runway capacity is reduced.

  Freezing conditions at Frankfurt International Airport led on a first step to massive delays for departing aircraft due to de-icing procedures and afterwards to a complete shutdown of the airport from 10:45pm for four hours (December 21st 2009). In total, 90 movements were cancelled with approximately 8000 passengers being stranded.

- Heavy storms (reaching even hurricane strength) over a period of several days may cause disturbances affecting numerous airport related functional areas. Due to storms such as “Kyrill” (January 1st of 2007) or “Emma” (March 1st 2008) some European hub airports were suffering from delays, cancellations, and daily punctuality values below 30%.
Concerning events with heavy snow fall, the airports’ preparedness to react on these events are of great importance. Vienna Schwechat International Airport was hit by 40 cm of snow on January 17th 2013 leading to single runway operations from 11am to 8pm and a cancellation rate of approximately 65% of all scheduled flights for this day. Madrid Barajas International Airport was closed on January 9th 2009 due to snow fall with a recovery time of several days to return to regular operations. Even after weather conditions have completely improved, airport operations may be performed in a reduced mode only for some additional time.

- Weather events such as strong winds and turbulence at high altitudes or large thunderstorms may lead to re-routings (information provided by EUROCONTROL Area Control Center) and longer travel times.

Large-scale weather related disruptions are of great importance for the aviation industry as the problems occurring at hub airports may even have an impact on airports that have not been directly affected by these weather events so far. The number and size (in terms of passengers as well as physical aircraft size) of redirected aircraft will have an impact on alternate airports. Especially the airline network over central Europe with its high density of important international hub airports seems to be prone to large-scale weather related events in particular.

2. Aviation Management and Weather Data

The impact of adverse weather events for European aviation is usually measured in flight cancellations and delays. Incidents and accidents are counted but rare (compare “Transport accident statistics” provided by Eurostat), due to the high safety standards of the aviation sector. From a safety perspective, the most sensitive flight phases regarding weather conditions are the arrival and departure procedures. Adverse conditions may make procedures infeasible leading to delays or cancellations of flights. In addition, the infrastructure provided at airports has a high potential to be impacted by adverse weather events. In this case, part of the equipment or infrastructure is usually unavailable during a certain time period leading from handling delays up to flight cancellations. Thereby, the vulnerability of an airport or sector depends on the geographical location and extent of the event as well as the degree of capacity utilization at the affected airport or sector and the preparedness of the stakeholders.

2.1 Aviation Weather Influence Assessment

As documented by the monthly reports of the European Organisation for the Safety of Air Navigation EUROCONTROL, weather is among the main contributors for delay depending on the time of the year. The European Aviation Safety Agency (EASA) registers weather as contributing but not as causal factor for incidents or accidents. The reason for these facts can be explained by the high safety standards in aviation, which come immediately into action when weather events with hazard potential appear. As a safety response to weather events changes in operational procedures are initiated, which finally lead to delays or even cancellations.

To assess the impact of adverse weather events on the European aviation network, important parameters are – besides duration, type, and intensity of weather events – related to the affected sectors and airports. Bottlenecks of the recent ATM system are especially congested airports operating on or beyond their airside capacity limit. This can be seen at the international and European hub airports rather than at secondary ones. Even minor weather events can lead to
disruptions in the flight plan. Adverse weather events at these congested airports will result in limitations of the airside capacity, delays, or re-routings due to increased separation minima and decreased runway conditions. In this context, the SESAR (Single European Sky ATM Research) program of the European Commission aims to provide better technology and harmonise procedures in order to meet future capacity and air safety needs. Although increasing resilience was not the main idea of SESAR, some of the developed technologies and procedures intend to keep capacity as high as possible in usually disruptive conditions.

From our point of view, special attention has to be given to adverse weather events that threaten the European aviation system such as long-lasting snowfall, freezing rain, or thunderstorms. All airports, independent of their size, can be hit by these events that may both disrupt connections to other modes of transport and lead to a partial or complete shutdown of an airport. An important factor is the areal extent of adverse weather events. Central European airspace seems to be vulnerable against large-scale weather events in particular. A first step towards a higher resilience of airports and the air traffic network is the understanding of the particular influence of weather events and the propagation of disruptions within the air traffic network.

Concerning the assessment of an airport’s performance during adverse weather events, a first step includes an analysis of scheduled and actual take-offs and landings in terms of their punctuality. Thus, information on the severity of disruptions beyond their impact on just one single airport can be achieved. These analyses are complemented using statistics on the amount of daily movements at defined airports, re-routings as well as flight cancellations and weather event evaluations, e.g. based on METAR messages according to the ATMAP algorithm, (Eurocontrol, 2010). In addition, ATM stakeholders should be encouraged to document measures that are taken and the status the system is inhered (system failures, runway conditions, long-lasting effects). Such an analysis plays a role towards a better estimation of harmful events and the evaluation of the potential of local forecasts. The question if and how an airport can return to a defined minimum state after adverse weather events is one of the great research needs in future work. Thereby, cancellation analysis shall include flights that have been added to the originally scheduled flight plan especially in the recovery phase after an event.

Weather information systems including local forecasts are state of the art for major airports. In order to increase performance and reduce recovery times, there is a huge on-going effort to improve local weather forecasts for small-scale events such as thunderstorms; two examples are WxFUSION (Forster et.al., 2008) or the Vaisala Airport Lightning Information System (Murphy et.al., 2008).

Besides these directly to weather events related impacts, there are a number of rules and regulations that compromise the evolvement of solutions with good results for the European economy as a whole. It has to be looked at the conditions for compensation of passengers, the distribution of flight fees among air navigation service providers, and cooperation among stakeholder alliances. Stakeholders try to optimise their own economic result first. Current regulations and payment rules foster stakeholder centric behaviour.
2.2 Response Strategies

The response on disruptions depends on the impact of (adverse) weather events. Due to the high safety standards in aviation, several response strategies have been established depending on the demand and supply ratio as well as the type, duration and intensity of the disruptions. Among the most often applied measures due to weather are interventions of air traffic controllers on the traffic situation without any adverse consequences on the performance, e.g. changing the dedicated runway operations due to shifts in the wind direction. This may lead to a temporary peak in the traffic demand with the overall demand being on a low level. Changes in the runway usage, e.g. prioritization of arrivals on a certain runway during fog conditions are also standard procedures. These changes may lead to reduced runway capacities. Runway capacity is either reduced if weather conditions (wind, visibility) degrade or even turned to “zero rates” (temporary shutdown of a runway). In case of thunderstorms the complete runway system might be temporarily closed.

Deviation from the optimised standard procedures may result in more traffic demand than procedures allow. In case of demand exceeding supply delay (ATFM, holdings) results in different characteristics – beginning from temporarily in- and outbound delay or start-up delay up to extensive reactionary delays and cancellations.

Adverse weather in the upper airspace usually leads to aircraft rerouting. The ability to compensate longer flight paths by flight speed is limited. So rerouting may in turn result in delays. The amount of delays depends on the extend and duration of weather events as well as the degree of capacity utilisation of the airspace area. Long-lasting effects over the day have a possible impact on the performance at the following day, regardless of which part of the air transport system is affected. Disruptions on ground may also affect airport related functional areas such as apron or baggage handling facilities or even other modes of transport that have an influence on an airports supply chain or reachability by passengers.

While these are rather reactive strategies, also a few anticipatory actions are possible and implemented: Members from the airline operators, meteorology, air navigation service providers, and airport operations cooperate to find a solution for an early adaptation of flight plans. Adaptations may include flight cancellations and change of aircraft types, e.g. combination of flights using larger aircraft. These measures are taken in order to avoid a situation where demand exceeds actual supply.

Each airport has its own experience in applying suitable response measures. By intensifying the exchange among airports and stakeholders best practices can be shared and preparation for events that might become more frequent due to climate change could be fostered.

2.3 Long-Term Preparation

Changes in the weather patterns and the probabilities of adverse weather events have to be expected over Europe until the 2050s, due to climate change, (Leviäkangas et.al., 2011), (Molarius et.al., 2012), (Morse et.al., 2009), (Doll et.al., 2011). EUROCONTROL has taken this into account in a report series entitled “Challenges of Growth”, (Eurocontrol, 2013). Among other challenges, it addresses the problems the aviation sector is bound to face due to changing climatic conditions and offers some insights into enhancing airport resilience. The described climatic changes cover temperature increase, changes to precipitation, increased convective weather, changes in wind
patterns, and sea level rise and storm surges. The adverse weather events summarised in table 1 are related to these climatic changes with the exception of sea level rise which will be more experienced over the long term. Studies like “Passengers first” (Rose, 2013) and “Exploratory study on the application and possible revision of Regulation 261/2004” (Steer Davies Gleave, 2012) discuss possible measures to enhance resilience for the Air Traffic user. For a number of major events, the lessons learned are already well documented. Inspired by these studies and documentation, the following list consists of a variety of future developments that have the capability to enhance resilience within the air traffic network:

- More closely cooperation among aviation stakeholders in order to develop and implement resilience measures.
- Provision of better and more accurate meteorological information to the decision-makers as well as furthering the channels of communication between weather forecast services and decision makers.
- Building a better understanding of what the provided meteorological information means in practice.
- Training personnel on how to react on the provided information in the correct way in order to respond in a timely and effective manner to adverse weather events.
- Creating, updating and designing new standards for airport infrastructure under consideration of adverse weather threats of the future climate. Examples include building sea walls or other means of protections from storm surges and waves for coastal airports, flood defences, etc. However, cost-benefit analysis should be applied in order to determine whether such changes should be implemented or, in extreme cases, relocation of an airport should be considered. Measures shall be taken into account in Airport Master Plans.
- Aviation-specific analysis and risk assessment referring to climate aspects should be conducted and addressed in an airport’s master plan esp. in areas such as tourism preferences, high traffic demands and social needs in order to prepare for medium and long-term planning for operations and businesses.
- Awareness regarding possible geographical and seasonal demand re-distribution should be enhanced.
- Site-specific needs should be taken into account and a more in-depth approach of the relation between the airport and the local community should be pursued.
- Low cost and “no-regret” measures such as staff training, improving airport capacity, information sharing, improved management, sharing of best practice experiences, improved collaboration and intermodal cooperation, closure of knowledge gaps, adaptation of technical equipment, reduction of equipment maintenance intervals could boost the level of efficiency as well as creating solid foundations in order to build on airport resilience.
- Revise regulations that compromise cooperation between stakeholders and alliances in case of disruptions or prevent a consistent communications of reasons for disruptions.
3. Passenger Transport

3.1 Main Vulnerabilities

According to the performance review reports published by Performance Review Commission, weather is among the main reasons for ATFM delays in Europe, see figure 1. This is reflected in the study “Passengers first”, (Rose, 2013) where nearly half of the surveyed passengers experienced at least one moderate disruption over the last 1 month. It has to be pointed out that European airlines had the best overall On-Time Performance in 2012 among the airlines in this study. It has to be mentioned that irregular operations regardless of their cause can be a major factor to missed connections and cancellations.

![Figure 1: Airport ATFM delays (Top 30 airports in the order of traffic volume) from Performance Review Report, 2012](image)

Besides aviation specific disruptions, passengers are also affected by adverse weather events affecting other transport modes. These disruptions are covered by the other transport specific guidebooks but may influence passengers’ trips to and from the airport. In addition, the options for passengers in case of severe disruptions are limited.

Under current regulations, cross-modality has a major drawback for passengers: The responsibility for travel rearrangements and additional costs is not defined for journeys including multiple traffic modes. In case of a rail to air ticket, a passenger has to take initiative to rearrange his trip and take additional costs if he misses a flight because of a delayed rail connection.

3.2 Passenger Information

Currently, passengers can register for an airline’s or airport’s service to keep informed about a flight’s status. Often, knowledge about usual flight times and information from independent flight information sites as e.g. “flightradar24.com” leads to more timely information. So it is not easy for passengers to receive information about disruptions. Once disruptions occur, automated re-
accommodation technology used by airline operation centres may be efficient for operational staff but do not always solve the underlying passenger journey disruption, (Rose, 2013). As noted in the study “Passengers first”, (Rose, 2013), airlines do not offer personalised solutions for the majority of passengers. In addition, smartphone apps and websites are not matured enough to provide customised journey disruption solutions.

While sophisticated systems are available for the travel planning process starting even to incorporate multi-modal transport modes as e.g. Lufthansa Journey Planner, (Lufthansa, 2013), and offering a number of alternative travel choices, it is of no avail to look for an assisting system in case of disruptions. A more sophisticated information system for passengers should include early information about adaptations to the flight plan, suggest available travel options, and recommendations on how to proceed in case of larger disruptions.

Thinking towards even more advanced passenger information systems that allow the personalisation of solutions, more information would have to be shared. Information exchange among passengers and travel providers or organisations would allow the provision of personalised travel recommendations. Therefore, travel providers have to know not only the original travel itinerary of passengers and the actual status but also the scope and time restrictions for a trip and travel habits of a passenger. Travel providers would benefit from knowing the choices of passengers in case of rearranging a journey. For stakeholder, planning reliability during the recovery phase after a disruptive event increases. Such information exchange may even go a step further by including rail and road access to and from the airport towards better cross-modal interaction.

3.3 Adaptation Strategies

It has to be said that aviation is in general a transport mode that recovers fast from disruptions compared to other transport modes even after events with losses and damages to the infrastructure. Furthermore, disruptions on the ground affect often all transport modes and for long-haul connections the switch to other transport modes is not feasible. Usually passengers have to wait until a delayed flight is operated or they are rebooked to other flights in case of cancellations. Other options include the offer of rerouting including other transport modes.

High-speed rail connections are an alternative for so-called short-distance connections in aviation; up to 750 km depending on the availability of such connections (Cokasova, 2003). Other train connections or the use of rental cars might only be a suitable alternative for even shorter distances if proper connections or road access exists. For long-distance flights connecting continents with one another, there are no other options than waiting and / or switching to another flight connection. In these cases, the passengers concerns are related to proper information and accommodation.

The transport modes road or rail are only alternatives if the reason for a disruption in the aviation sector does not lead to disrupting infrastructure damages for the considered alternative mode. Disruptions that affect mainly the aviation sector occur seldom to such an extent that switching to another transport mode is feasible. Examples where the choice of alternative transport modes is a suitable solution are flights with rather short flight durations and large-scale closures of airspace over longer periods as e.g. in case of the volcanic eruption 2010 in Iceland.

A current restraint for rerouting is a common practice for flights consisting of more than one segment: If a passenger does not show for the first segment, he cannot use further segments. But
recommendations to the passengers to change the travel itinerary would in case of connected flights be much more flexible, if a change of one segment of the booked connected flights would be possible. In the Exploratory study on the application and possible revision of Regulation 261/2004, (Steer Davies Gleave, 2012) the implication and possible revisions of this kind of restrictions are analysed.

Loosening these restrictions would allow passengers to consider other routes and alternative airlines in case of disruptions. However, the available capacities are limited and there is currently no assistance available to allow ad-hoc rebooking. Airline staff usually receives information about how to rebook and / or accommodate passengers from the airlines operation centre. Information about a passengers time constraints and travel objectives would allow a more passenger centric approach.

4. Aviation Cargo Transport

To reveal vulnerabilities of aviation cargo transport, impacts and response measures of historic weather events have been analysed within several case studies. Two case studies focus on volcanic eruptions (“Volcano 2010”: Eyjafjojujökull, Iceland; “Volcano 2009”: Mount Redoubt, Alaska, USA); consequences of these events refer to “air operations” in terms of aircraft groundings. One case study shows the interrelations between aviation cargo transport and other transportation modes such as road and railway transport (“Storm 2012”: Hurricane Sandy, USA). Disruptions of airport “ground operations” are discussed in a snow storm case study that deals with the disruptions at Frankfurt International Airport (“Winterstorm 2010”). However, the availability of quantitative data such as, inter alia, economic losses, number of cancelled flights and monetary losses with an exclusive focus on the aviation cargo transport due to adverse weather events is sparse. This is because most cargo is delivered by commercial passenger aircrafts in their cargo compartment.

4.1 Impacts on aviation cargo transport

Severe consequences to aviation cargo transport could be particularly investigated for the cases of volcanic ash cloud eruptions. The case study “Volcano 2010” shows that air cargo services and other supply chains in the European Union were affected for several weeks. On 18.04.2010, more than 75% of the European airport network was closed. Economic damage to airlines in a two-week time frame was estimated by IATA to be between 0.85 - 1.3 Billion €. Countries out of Europe were affected by over-flight constraints and by the impossibility to buy or deliver goods. Press releases stated major losses in African countries that could not deliver goods to European customers. For instance, one million roses for the European market rotted in Kenya, Africa. Several companies could not transport up to twenty per cent of the aviation cargo volume (Alexander, 2013).

European authorities closed most of the northern Europe airspace after the eruptions. The main reason for this measure was the possibility of severe aviation accidents due to the risk of engine breakdowns. The air cargo network over Europe broke down by the closure of most of the European airspace. However, no major shortage of consumer goods occurred although some just in time productions had to be stopped and high value goods could not be delivered. Eurocontrol claims that 43 per cent of all cargo flights were cancelled. A per day calculation is shown in Table 2.
Table 2: Percentage of cancelled flights in EU 27 between 15.04.2010 and 22.04.2010

<table>
<thead>
<tr>
<th>Overflights (% 'cancelled' flights)</th>
<th>15APR</th>
<th>16APR</th>
<th>17APR</th>
<th>18APR</th>
<th>19APR</th>
<th>20APR</th>
<th>21APR</th>
<th>22APR</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business Aviation</td>
<td>15%</td>
<td>44%</td>
<td>57%</td>
<td>67%</td>
<td>52%</td>
<td>36%</td>
<td>10%</td>
<td>10%</td>
<td>33%</td>
</tr>
<tr>
<td>All-Cargo</td>
<td>29%</td>
<td>64%</td>
<td>78%</td>
<td>82%</td>
<td>67%</td>
<td>49%</td>
<td>15%</td>
<td>3%</td>
<td>43%</td>
</tr>
<tr>
<td>Low-Cost Scheduled</td>
<td>42%</td>
<td>74%</td>
<td>91%</td>
<td>95%</td>
<td>84%</td>
<td>67%</td>
<td>35%</td>
<td>7%</td>
<td>62%</td>
</tr>
<tr>
<td>Traditional Scheduled</td>
<td>23%</td>
<td>61%</td>
<td>78%</td>
<td>82%</td>
<td>74%</td>
<td>60%</td>
<td>30%</td>
<td>6%</td>
<td>51%</td>
</tr>
<tr>
<td>Non-Scheduled</td>
<td>28%</td>
<td>62%</td>
<td>75%</td>
<td>72%</td>
<td>37%</td>
<td>11%</td>
<td>0%</td>
<td>5%</td>
<td>40%</td>
</tr>
</tbody>
</table>

It has to be noticed that most cargo transport in Europe is carried out via road transport. This explains the non-affected supply of consumer goods (or: consumer products) despite the massive drop in operated flights. Besides that, for many goods there were sufficient stocks available in case of supply shortages. All international transport routes (that pass the European airspace) were hit. The biggest economic loss occurred on the routes between the UK and the USA. Germany, France and the UK suffered also significantly big losses. Shortly after the main crisis, air cargo traffic returned to scheduled flight plan (Eurocontrol, 2010).

4.2 Response & adaptation strategies

Main response actors to disruptions of the aviation cargo transport are airlines, airports and airspace control institutions. Concerning “air operations”, detailed forecasts of weather events play an important role as “Volcano 2009” and “Volcano 2010” have highlighted (e.g. forecasting the horizontal and vertical extent, particle density and composition of the ash cloud for the case of volcanic eruptions). In the case study “Volcano 2010”, the reported response measures frequently were reactive. EUROCONTROL and the national air navigation service providers cooperated closely and informed the public and companies about their actions. Information was mainly spread via press releases and social media. In the beginning of the crisis, response was not well coordinated. The European Union brought up some insights on the importance of high-quality data support and a reliable risk assessment. The European Union Commission decided afterwards to form a group of experts that shall identify and establish techniques and methods that can be used in the future if similar disruption cases occur. Moreover, they accelerated the implementation of a Single European Sky (SES) initiative. The grouping of nation-wide competencies as a European institution might make it easier to coordinate the European response on incidents (European Commission, 2010).

Concerning “ground operations”, the case study “Winterstorm 2010” showed that a main challenge for airports is to manage incoming long haul flights as they lead to cancellations of domestic flights. To respond to cancelled flights, several operators in Germany cooperated with the Deutsche Bahn AG which pitched in for passenger travel rather than for cargo transport. This reduced the number of passengers in transit who were stranded in Frankfurt and other German airports. As no adaptation strategies have been implemented for aviation cargo transport, the cargo systems gradually grounded to a halt.

It is principally possible to use road and railway transport modes as an adaptation strategy for aviation cargo transport. This is, however, primarily possible if the disruptions affect “air operations”. In 2009, some of the goods could be transported by road or train from other European
airports. Especially Madrid, Rome and Istanbul were destinations to reroute passengers and air freight. However, the Spanish airspace was closed soon as well. In the case that adverse weather events also hinder operations on the ground, adaptations are difficult as road and railway transport are equally affected.

5. Summary of Recommendations

This section summarises actions described in this document that we recommend to take into account for further developments. Some more general aspects are extended by examples in order to improve understanding of these ideas.

5.1 Recommendations for European and national policy

- Research efforts related to the analysis of disruptive effects to the aviation sector shall be encouraged. To allow an estimation of the influence of weather related disruptions, the network influence and propagation of delays has to be understood.
- The development of a measurement system to assess and compare the vulnerability of airports and airspace areas would allow the establishment of priorities for research activities. New performance measures may be developed that are able to assess performance for future scenarios under changing climatic conditions.
- More transparency in the comparison of the impacts of disruptive events shall be fostered, thereby addressing imprecision in the definition and assignment of codes and terms as e.g., when to assign which IATA delay code or the definition of consistent statistical evaluation procedures. The aim is to allow a correlation of disruptions to the original cause. Precise definitions and consistent recording of influences is the necessary basis for comparative analysis.

5.2 Recommendations for the aviation sector

- More passenger oriented approaches shall be fostered, as e.g. the use of customer profiles to provide customer-specific alternative travel solutions in case of disruptions.
- A closer cooperation among stakeholders (meteorological service providers, airlines, and airports) helps to generate a common problem understanding. Documenting measures and impacts examined in such cooperation may help other stakeholder groups to identify and learn from best practices for disruptive events. Such best practice guidebooks may especially help aviation stakeholders that will be affected in future due to climate change.
- Climate change aspects shall be taken into account as one future aspect in ATM Master Plans. Besides the direct effects of changing climate addressed in table 1, geographical and seasonal demand redistributions should be taken into account for the longer term. Robustness and constraints of constructions and pavements as well as technical infrastructure (e.g. air conditioning of buildings) should be analysed with respect to temperature and precipitation changes.

5.3 Recommendations for research and technical development

- Terms and definitions and their use shall be standardised on an international level in order to facilitate comparisons of impacts of disruptive events and enhance a common problem understanding.
- The activities to improve local weather and disruption forecasts shall be continued. Of special importance is the forecast of thunderstorms, snow, ice and icing, strong winds and wind shears as well as conditions of low visibility or low ceiling on an airport-specific basis. Forecasts with improved geographical and timely precision may help to reduce the disruptive impact.
• The inter-airline and intermodal cooperation shall be enhanced, e.g. through the generation of a new ticket category allowing intermodal flexibility (feasibility of shifting from one mode of transport to another one with one ticket, multimodal ticket use).
• Passenger and weather information services shall be developed to bring passengers into a more active role by enabling them to choose the alternative route and transport mode, respectively, which suits them best in case of disruptions.
• Possibilities for information exchange among customers (esp. passengers) and travel providers (airlines, travel agencies) in order to use customised travel advices shall be assessed.
• It shall be assessed if and how shifts in traffic flows relocate disruptive problems or even may generate new disruptions, e.g. a measure similar to a Level of Service may be developed to denote areas affected by traffic flows and switches of traffic flows, respectively.
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