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Project META-CDM

D.1.2 –Analysis of recent disruptions of the Air Transport System

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EXECUTIVE SUMMARY

Collaborative Decision Making (CDM) is a major contributor to efficient operations at airports worldwide. In Europe, the implementation of CDM processes is mainly driven by the Airport CDM programme. However, current focus is on airside processes, which are directly related to Air Traffic Control (ATC) and Aircraft Operations. Terminal processes and passenger satisfaction benefits from these recent improvements, but are not always directly addressed.

The META-CDM (Multimodal, Efficient Transportation in Airports – Collaborative Decision Making) project aims to define the future of CDM – a future where CDM techniques can much more than today be used to support resilience from crisis situations, and where the needs of the passenger are the centre of attention.

Although resilience is already supported by the current CDM programs due to collaboration between Airport Operators, ATC and Airlines, main focus is on most efficient use of available airside resources (in particular runways and airspace) and the optimization of the turn-around. The passenger is not yet adequately integrated in the CDM process. As an exemplary consequence, opportunities and advantages of multimodality concepts are not used in case of flight cancellations and delays, which are known to the stakeholders in advance, are usually not know to all passengers.

This report belongs to work package 100 of the META-CDM. It concentrates on information gathering on the state of the art in CDM, disruptive events and passenger response from literature and other publicly available information sources. It is shown that concepts and prototype solutions exists, which aim to better integrate landside processes and passengers into the CDM and to take care about passenger satisfaction based on suitable Key Performance Indicators (KPI). For instance, the TAM (Total Airport Management) concept addresses these aspects and lead in the recent years to prototype developments for the better indication of key flight information to airport stakeholders and passengers. Within the project ASSET (Aeronautic Study on Seamless Transport) concepts for better integration of landside and airside processes were assessed.

The report summarizes lessons that can be learnt from historical disruptive events. Based on a literature review it is described how they were dealt with. Recommendations for dealing with future disruption are made. The accessibility of passenger information is highlighted as a particular problem during crisis events: When faced with inadequate information about whether their flight was operating, many passengers chose to travel to the airport in search of better information, causing major congestion in the terminals. And another major problem with regard to multimodality was identified: When aviation is disrupted, often the same event is disrupting the other modes too. Several examples can be found of passengers being transferred to other modes only to experience disruption a second time. Information sharing and collaborative decision making is highlighted the prerequisite for crisis management. Best practice airports are considered to be those where the crisis command and control structures had given priority to information sharing, with coordination through a single point (the airport) and face-to-face meetings.

Passenger behaviour in case of delay situations and the impacts of disruption from the passengers' point of view is studied. Existing literature stresses that experiencing flight delays affects passengers' future choices and the quality of crisis management affects air traffic demand at the respective airports. In order to be able to fulfill the passenger needs, the report identifies performance indicators for passenger satisfaction, combining measures of subjective customer satisfaction and objective production of service. The report ends with an outlook on the next META-CDM project phases, including interviews with stakeholders to get a more detailed look into practical experiences and current procedures at airports.

Abbreviations

Abbreviation	Description
ACARE	Advisory Council for Aviation Research and Innovation in Europe
ACCES	Airport Control Centre Simulator
A-CDM	Airport Collaborative Decision Making
ACSI	American Customer Satisfaction Index
AEA	Association of European Airlines
AMAN	Arrival Manager
ANSP	Air Navigation Service Provider
AODB	Airport Operations Database
AOP	Airport Operations Plan
APM	Airport Performance Manager
APOC	Airport Operations Centre
A-SWIM	Airport – System Wide Information Management
ATIS	Advanced Transport Information System
ATC	Air Traffic Control
ATFCM	Air Traffic Flow and Capacity Management
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATUC	Air Transport Users Council
ATWP	Airside Tactical Working Position
BAA	British Airports Authority
CAA	Civil Aviation Authority
CANSO	Civil Air Navigation services Organisation
CDM	Collaborative Decision Making
CFMU	Central Flow management Unit
CLOU	Cooperative Local Resource Planner
CODA	Central Office for Delay Analysis
DMAN	Departure Manager
EC	European Commission
ECC	Emergency Control Centre
EOBT	Estimated Off-Block Time
EOC	Emergency Operations Centre
FAA	Federal Aviation Authority
FIDS	Flight Information Display System
GDP	Ground Delay Program

IATA	International Air Transport Association
ICAO	International Civil Aviation Authority
IROPS	Irregular Operations
KPI	Key Performance Indicator
LCC	Low Cost Carrier
LOS	Level Of Service
Meta-CDM	Multimodal, Efficient Transportation in Airports and Collaborative Decision Making
NATS	National Air Traffic Services
NOP	Network Operations Plan
NOR	Network Operations Report
NPC	Negotiation Process Control
ODP	Operations Delivery Plan
RBC	Reference Business Trajectory
SCATANA	Security Control of Air Traffic and Air Navigation Aids
SGMAN	Stand and Gate Manager
SMAN	Surface Manager
SRIA	Strategic Research and Innovation Agenda
TAM	Total Airport Management
TMA	Terminal Maneuvering Airspace
TMAN	Turnaround Manager
TOC	Train Operating Company
TOMICS	Traffic Oriented MICroscopic Simulator
TOP	Total Operations Planner
TSAT	Target Start-up Approval Time

1 Introduction

Airport Collaborative Decision Making (CDM) has been adopted by multiple airports across Europe and elsewhere and has proved highly valuable in reducing delays and costs to airlines and airports. As it is currently implemented, CDM focuses on day-to-day airport operation and the needs of airports and airlines.

However, the regular occurrence of significant perturbations that propagate through aviation networks and sometimes even paralyze them highlights the need for further research on system resilience and agility and for adequate coordination, both within individual airports and at the network level. As it is passengers who most often bear the brunt of system disruptions, it is vital to put passenger needs at the centre of this analysis. In addition, air transportation is intrinsically tied with other modes of transportation, such as rail, roads and water. The objective of making each passenger or cargo item's door-to-door journey seamless cannot be achieved without a better understanding of the multi-modal transportation network. In its vision for Europe in 2050, the European Commission [65] sets the goal: "90% of travelers within Europe are able to complete their journey, door-to-door within 4 hours. Passengers and freight are able to transfer seamlessly between transport modes to reach the final destination smoothly, predictably and on-time."

The META-CDM (Multimodal, Efficient Transportation in Airports – Collaborative Decision Making) project aims to define the future of Airport CDM – a future where CDM techniques can be used to address major disruptive events, and where the needs of the passenger are the centre of attention. This project examines the coherence and co-ordination of the many systems that are part of delivering the traveller through an airport, both in everyday operation and during disruptive events. Airside, landside and total airport CDM are considered, as well as the possibility of including other transportation modes within the CDM process to address passenger travel needs when flights are cancelled under crisis conditions. The final result of the project will be an extended CDM concept incorporating passenger needs under disruption into existing frameworks.

META-CDM has three main work packages. In work package 100, the existing literature on aviation system disruption and CDM is reviewed. In work package 200, this research is complemented by a series of focussed interviews of stakeholders at key airports which have experienced disruption. Work package 300 brings together the information gathered to create an extended CDM concept which better allows the handling of disruptive events and focuses more strongly on the passenger.

This report belongs to work package 100. It concentrates on information gathering on the state of the art in CDM, disruptive events and passenger response from literature and other publicly available information sources. Several different areas of literature are important to inform the interview and concept development stages of META-CDM. In order to develop techniques to deal with disruption, it is important to know how the aviation system behaves under normal and disrupted conditions. Hence, this report presents a literature review on current research into how disruption affects the air transportation system (both in theoretical and practical terms), how this impacts passengers, and how airlines and other bodies can deal with this.

As the META-CDM concept aims to extend existing CDM schemes, Section 2 presents a review of current airport CDM initiatives and of existing projects aimed at extending and further integrating CDM at airports.

Important lessons can also be learnt from historical disruptive events and how they were dealt with. This is part of informing the focus of the interview stage of META-CDM, but there is also a significant amount of available literature on these events. Section 3 reviews the frequency and impact of historical disruptive events, how these events were dealt with, and recommendations made for dealing with future disruption.

Finally, any concept developed needs to be evaluated against suitable metrics. The passenger focus of the project means that more passenger-centric impact metrics are required than those in current widespread use. Section 4 reviews studies on passenger behaviour and how best to measure the impacts of delay and disruption from the passengers' point of view.

In the second stage of META-CDM, the practical experiences of stakeholders, who may be involved in any extended CDM concept, are gathered via a series of focussed interviews and questionnaires. This allows for gaps in the literature to be filled in and potential logistical hurdles to be identified. Section 5 concludes this report by briefly discussing the selection of airports for the second stage of the project.

2 Collaborative Decision Making at Airports

2.1 Status Quo and Network Management Context

A number of European airports have, over the past decade, taken major steps that aim at collaborative decision making (CDM) between all stakeholders at airports. This process is initiated and guided by the Airport CDM (A-CDM) program, which has resulted from many years of concept work and implementation efforts. The objectives of A-CDM are to reduce delays and improve system predictability, while optimizing the utilization of resources and reducing environmental impact. This is achieved by real-time information sharing between key stakeholders, including airports, airlines and Air Navigation Service Providers (ANSPs). Current CDM efforts focus primarily on airside operations, with landside CDM usually considered separately. A-CDM is one of the five priority measures in the Flight Efficiency Plan published by IATA, CANSO and EUROCONTROL. In Europe, A-CDM has been implemented successfully at several airports. Details about A-CDM in Europe can be found in the Airport CDM Implementation Manual [64].

In the US, the CDM-based ground delay program planning and control appeared in 1998. Nowadays, more elaborate CDM-based tools are used for the control and planning of airspace flow programs. Collaborative Air Traffic Management is now a key component in both SESAR and NextGen.

One major motivation for CDM at airports is to provide the Air Traffic Flow Management (ATFM) system, in Europe provided by the Network Manager EUROCONTROL, with more precise predictions of start-up and take-off times. In [16], the authors develop and analyze two approaches to incorporate stochastic optimization models in a CDM-like setting. In their scenarios, the ANSP allocates certain resources to the flight operators and the flight operators then optimize the use of resources they are given. In [71], the authors seek to answer the following question: How should proposed enhancements to ATFM be evaluated in a CDM environment? They build a sequential evaluation procedure including airline disruption responses and a quasi-compression operation, to mimic the three stages of the CDM process. One of the first efforts to evaluate the potential of CDM at the network level is undertaken by Bertsimas and Gupta [80]. They propose an Air Traffic Flow Management model with a CDM framework from an airport setting to an airspace context incorporating fairness and airline collaboration. Their empirical results of the proposed model on national-scale, real world datasets, show promising computational times and a proof of the strength of the formulation.

A number of recent project have aimed at enhancing, extending and further integrating airside and landside CDM to reduce passenger disruption (both of the everyday sort and from major disruptive events). Two of the most important recent projects in the context of MetaCDM are the TAMS project, which looked at integrating landside and airside CDM, and the ASSET project, which looked at the efficiency of landside processes. The rest of this section discusses the findings of these projects on how CDM can be used to address disruption in practice.

2.2 The Next Step: Total Airport Management

2.2.1 Concept

As noted above, current efforts tend to consider landside and airside CDM separately. Total Airport Management (TAM) aims at bringing together both landside and airside CDM at airports. The operational concept TAM-OCD [45] was defined in 2006 as a joint initiative by EUROCONTROL and the German Aerospace Center (DLR).

The major enabler for the TAM concept is the Airport Operations Centre (APOC), a solution for busy airports to enable performance-based Air Traffic Management (ATM) systems through performance-based airport operations. The ATM system benefits from a good and predictable performance of airports, while the airports themselves benefit from better and more accurate arrival information. Furthermore, a performance-based ATM system allows the improvement of the capacity utilization of the ATC resources through better predictability and avoidance of unused slots. This should lead to a more flexible and timely ATFM slot handling for departures.

The enablers for an APOC are an Airport – System Wide Information Management (A-SWIM) and an operational A-CDM system. Within the APOC, agents from the stakeholders that are willing to participate in the collaborative decision making process elaborate and maintain a joint plan for airport operations, called the Airport Operation Plan (AOP). The AOP is consistently aligned with the Network Operation Plan (NOP) of the Air Traffic Flow and Capacity Management (ATFCM) providing all users of the ATM system accessing the NOP with a common situational awareness.

The TAM concept was largely derived from the projects FAMOUS (Future Airport Management Operating Utility System) and EPISODE 3. FAMOUS already concretised many of the ideas of the TAM-OCD and implemented some of the needed tools for enabling performance based airport operations, like the prototypes Cooperative Local Resource Planner (CLOU, later TOP – Total Operation Planner) and Negotiation Process Control (NPC). The TOP already included many airport resources in its planning and optimisation process, while the NPC was built to manage the CDM-processes defined in the operational concept of FAMOUS [46]. EPISODE 3 defined many new procedures, such as the introduction of the Reference Business Trajectory (RBT) and described scenarios and use cases for the later use within SESAR.

2.2.2 TAMS – A Total Airport Management Prototype

Based on the conceptual work in the TAM domain, a prototype for a Total Airport Management infrastructure, consisting of several coupled decision support tools, was developed within the Research & Development project TAMS, Total Airport Management Suite [118][116]. The project runtime of TAMS was from 2009 until 2012.

The state of the art analysis was carried out and a joint vision was developed. Also already at an early project stage the project partners started the integration of their tools Arrival Manager (AMAN), Surface Manager (SMAN), Turnaround Manager (TMAN) and Departure Manager (DMAN), encompassing air-to-air process planning with the best available target times.

The major focus of TAMS was to set the concepts and implementation of the Airport Operational Database (AODB) as a key component of both the A-CDM as well as the TAM concept. The fulfilment of A-CDM compliance was very important in TAMS as this was seen as an enabler for TAM. While most management tools for stakeholders' processes such as AMAN, SMAN, TMAN and DMAN already existed, the information exchange of the available planning times on processes and their communication to the outside was missing, e.g. feedback of airport operational data into the network. Thus a plan had to be developed regarding how the missing data exchange could be implemented in TAMS. An A-CDM GAP-Analysis was accomplished in the second iteration to identify gaps to be addressed during the integration for provision of the needed A-CDM functionality for TAMS.

As a first step towards TAM, the TAMS concept envisioned the realization of A-SWIM, Airport – System Wide Information Management, supported by the integration of all available management tools from the partners to enhance accuracy and timeliness of available data for collaborative decision making. The first integration of all identified tools for realization of an APOC took place in iteration three. The Airport Control Centre Simulator (ACCES) of the DLR, Institute of flight guidance was used as simulation environment of the implemented APOC. Besides writing the concept for simulation, the DLR was responsible for the validation according to their TAMS Validation Concept Document, TAMS-VCD [47].

The final integration tests with all tools were conducted by the TAMS partners in the first quarter of 2012, followed by extensive simulation trials using some of the predefined scenarios in the TAMS-OS/BUC [115]. The validation took two months and the results were presented at the closing event in May 2012. The mobile demonstrator build in TAMS was first presented at the Passenger Terminal Expo 2012 in Vienna.

Integrated Systems in TAMS are:

- The tactical systems AMAN, DMAN and SMAN to sequence arriving, taxiing and departing aircrafts and for calculation of the variable taxi-time
- The tactical systems Turnaround Manager to manage the turnaround process and Stand and Gate Manager (SGMAN) to allocate aircrafts to stands
- An Airside Tactical Working Position (ATWP) and an Airport Performance Monitor (APM) for creating common situational awareness, calculating rough flow estimation during the pre-tactical phase and displaying key performance indicators (KPI) regarding the airport performance and offering a common interface to the aforementioned tactical systems
- The integration platform to provide an integration "backbone" and a central repository for flight related operational data
- The simulation environment for simulation of aircraft movements during arrival, taxi-in, taxi-out and departure (NARSIM), which also provides an airport schedule (flight plans) and the simulation environment for simulation of the turnaround process (TAMODES)
- The simulation environment for simulation of passenger movements within the terminal section of an airport (TOMICS), Stand2gate to couple the stands allocated by the SGMAN with the TOMICS gate allocation and, as an optional extension (not realized), the FIDS for displaying key flight information to operator and passengers

TAMS looked at the entire airport in a holistic way, including land- and airside processes in its scenarios and use cases. This included the development of innovative management tools for better prediction of the landside processes. One example is that the boarding process was supported by a Passenger Manager (PaxMAN), which interacted with the Turnaround Manger (TMAN) from Inform. In TAMS following definitions were used:

- "Airside" was defined within TAMS as all processes related to the movement and handling aircraft on the airports surface,
- "Landside" was defined within TAMS as all processes related to Terminal Operations to handle passengers arriving/departing the airport terminal building and moving through the terminal building to board the aircrafts.

Note that this differs from other definitions, where airside and landside is related to non-public and public areas at an airport.

The Key Performance Indicators were defined in the TAMS-OCD [118] to assess the performance of airport operations. Further, the roles and responsibilities of the Agents of each stakeholder in the APOC were concretized. This included a description of their working position within the APOC, its functionality and interfaces. Business Use Cases for describing the interaction of the working positions for a given scenario were developed and listed in [115].

To support the CDM-process itself, new working positions for the agents in the APOC were designed, see TAM-OCD [45] for details on agents and their duties. One example is the Airside Tactical Working Position (ATWP, [18]) that supports the ATC-Agent in its task within the APOC. It is designed to enhance the common situational awareness of the ATC-Agent and provides a direct interface to ATC-tools like AMAN and DMAN. To better maintain the Airport Operations Plan (AOP), a dynamic joint plan for operating the airport based on the adherence to selected KPIs, the ATWP supports the CDM-process through the possibility of joint what-if probing with the working environment / tools (e.g. TMAN) of other agents in the APOC.

For providing the agents within the APOC with a common situational awareness a concept for the HMI was developed that took care especially of the video wall, a large screen in the middle of the APOC that displays commonly needed information to everybody in the APOC. This concept foresaw a trisection of the video wall:

- A static section presenting aggregated information suitable at all times like weather and airport performance parameter,
- A dynamic section presenting the actual situation including forecasts and
- A dynamic section presenting planning, e.g. the what-if probing results.

To enable a common monitoring and planning of the overall performance of the airport, the Airport Performance Manager (APM) was developed. The APM has a look-ahead horizon of several hours and thus enables a pre-tactical planning of the AOP, while most of the decision support tools (AMAN, DMAN, SMAN etc.) work within a tactical time horizon. The following definitions regarding different planning phases were agreed in TAMS (although some overlapping of these phases remains):

The **Long Term Phase** encompasses the time horizon of several years until approximately 6 month before the day-of-ops. The **Medium Term phase** starts around 6 months prior the flight event and ends at Estimated Off-Block Time (EOBT) -24 hrs. The **Pre-tactical Short Term Phase** begins with EOBT -24hrs and ends with filing of the ATC flight plan (around EOBT – 3h) for each particular flight. The **Tactical Short Term Phase** for a particular flight begins with filing of its ATC flight plan (around EOBT -3hrs) and ends with issuing of TSAT for this flight (A-CDM milestone 10, at TOBT -45min). The **Trajectory Execution Phase** starts at the end of the Tactical Short Term Phase (TOBT -45min) and ends if the flight finished his flight trajectory with the in-block at the destination airport. The **Post Flight Phase** starts at the day after the day-of-ops and contains analysis of the processed flight.

The TAMS system provided information on following performance indicators:

- Delay (Arrival, Departure, Total),
- Punctuality according to IATA definition,
- CFMU slot adherence,
- Passenger missing rate (connectivity),
- Waiting time at runway and
- Engine running time.

Some of these performance indicators were calculated by the APM and displayed at the large display wall in the APOC to enhance the common situation awareness of the Agents (see TAM-OCD [45] for definition of Agents). Additionally some of the working positions, e.g. the ATWP [18], enabled monitoring of resources on a flow basis. Further the tactical airside assistance tools (AMAN, SMAN, TMAN and DMAN) enabled joint what-if probing of the whole air to air process planning to evaluate decisions before they are taken.

The results of TAMS, beginning with the concepts and definitions and ending with the validation, are summarized in the following documents:

- Operational Concept Document [118],
- Operational Scenarios and Business Use Cases[115],
- Glossary [117] and
- Simulation Concept Document [119].

The functionality and benefits were accessed during two months of simulation and validation. The reference scenario consisted out of 120 flights with around 12500 passengers and was four hours long. Different setups/variations of the reference scenario were tested, such as arrival and departure peaks which exceeded the available runway capacity, landside bottlenecks and random variations of flight data (e.g. delay). The outcome of the validation was that TAMS

- Reduces average departure delay by 2 minutes per flight (without negative effects onto arrival delays),
- Decreases number of flights delayed by more than 15 minutes by 47%,
- Reduces taxi-out time by 12%
- 63% of the passengers that missed their flights without TAMS reached their flights [120].

Relevance to META-CDM

Three aspects of TAMS are relevant to META-CDM:

First, TAMS is the first project that implemented, simulated and validated a whole Airport Operation Centre. This can be taken as reference for what can be done to enhance collaboration with more information becoming available on the landside, see integration of Passenger Management (PaxMan) into the Turnaround Manager of an Airline or Ground Handler. Of particular interest to META-CDM are the gaps left or simplifications made in the TAMS-OCD. They give a hint where a more passenger focused project can provide benefit to the overall process optimisation.

Second, the developed operational scenarios and business use cases can be used for further development, e.g. enhancing them to describe the involvement of the passenger in detail or to concretizing them with defined critical events that are of interest for META-CDM.

Third, it can be deduced from TAMS what information can be made available in an enhanced A-CDM environment: when, from whom and in which quality will the information be available, what information will help the process planning and what has to be provided, how and when to be of benefit. Furthermore, the defined KPA and KPI are applicable for further projects in this domain, such as META-CDM.

2.3 ASSET – Focussing on Landside Processes at Airports

Landside CDM operations aim to reduce passenger traffic delay and congestion within airports, including passenger and baggage handling processes and aircraft turnaround. Whilst landside CDM has a shorter history than airside CDM, it also has an important role to play in the efficient airports concept.

The project ASSET, Aeronautic Study on Seamless Transport, was supported by the European Community within the Seventh European Framework Program to address this topic. [6], [9] and [7]. The aim of ASSET was to develop and assess solutions for airport process improvements in terms of punctuality regarding passenger, baggage handling and aircraft turnaround processes in an integrated approach. The intended result was to be improved predictability and punctuality of the off-block time of departures should increase, enabling a higher punctuality and performance of the whole air transport network in Europe.

To achieve an integrated approach to improve processes at airports, representatives of directly or indirectly involved stakeholders (users, supply deliverers etc.) were chosen to work together on this project. Based on a study of the state of the art [13] and an assessment of the most promising processes to be improved, first single improvement solutions and, in a later phase, integrated solution scenarios were developed. One aspect for judging these solutions was their technological readiness for the ACARE vision 2020. For evaluation of the chosen / developed solutions and for usage within future projects, two generic airport reference models representing a hub and a medium sized airport were developed. With those models different scenarios were simulated which served as standard of comparison for the developed integrated solution scenarios.

Four main outcomes of ASSET were planned:

- a list of solutions to enhance punctuality at airports which includes technical, operational and strategic approaches,
- a ranking of the above mentioned measures according to their level of target contribution towards a more time efficient and thus economically viable air transport,
- an objective and comparable scheme to assess future technological and/or procedural changes in typical airport environments,
- a financial approach that will clearly indicate what are the benefits for the various stakeholders.

At an early stage (already within the planning phase) of the project, TOMICS (Traffic-Oriented MICroscopic Simulator) was chosen for conducting simulations to analyse the impact of the improvement solution. Besides evaluating the impact of developed solutions and integrated solution scenarios on time performance, the results were completed by an assessment of the solutions' economic impact on the relevant stakeholders' businesses. This included a cost appraisal in particular, but also commented on the compatibility with today's systems and the possible time of implementation. The analysis was split into medium size airports and hub airports which are dealt with separately, because of major differences in the airport processes of point-to-point and connecting flights. The two different airport models allowed the assessing of long haul and short haul flight processes as well as transfer processes.

Description of the state of the art

To get an overview on the state of the art of integrated system approaches at airports, the ARDEP Database of Eurocontrol and EU programmes on air transport related projects were inspected. It was found that research activities in Europe, but also in US are more advanced on airside aspects, as noted in the report on state of the art [13].

Based on the literature review, the projects and concepts that incorporate landside topics found in this survey were:

- A-CDM (Airport - Collaborative Decision Making) improving the way Air Traffic Management, airlines and airports work together at an operational level.
- SPADE (Supporting Platform for Airport Decision-Making and Efficiency Analysis) focused on specification and design of decision-support systems for airport stakeholders to support them in policy and political decisions related to airport (airside and landside) development, planning and operations.
- TAM-OCD (Total Airport Management – Operational Concept Document) as proposed in 2008 by EUROCONTROL and DLR.
- TITAN (Turnaround Integration in Trajectory and Network) described additional CDM milestones triggered by landside processes and encouraged a change to SWIM principles drawing from a common data repository.
- AIRNET was a project focused on the surveillance, control and management of airport vehicles.

- AVITRACK focused on a decision-aid tool for airport actors concerned by turnover operations. Of interest is the development of an intelligent survey system on the apron, addressing aircraft, vehicles and people's presence and movements, automatically checking the sequence and timing of movements on the airport apron.

- SPT-IG (Simplifying Passenger Travel – Interest Group) was an aviation program launched in 1999 and driven by IATA. It focused on the passenger and aimed to streamline the airport control procedures based on smart card and biometrics.

Assessment of requirements and bottlenecks

ASSET collected requirements from all stakeholders to contribute to an in-depth analysis of relevant airport processes regarding passenger-, baggage- and aircraft handling on the ground. Critical elements were identified that constitute the bottlenecks of operation and whose criticalities depend on the stakeholders' view. These elements can be infrastructural like certain points within the airport operation process chain (passengers, baggage and turnaround) but can also be immaterial like laws and regulations.

Identified bottlenecks regarding the relevant airport processes are:

- way finding
- check-in process
- security check process
- boarder control process
- implementation of new technology/automation, delay thereof
- information system/data interfaces
- transfer baggage handling system
- general turnaround time
- security regulations and necessity/ban of new equipment thereof

Definition of objectives

Derived from the assessed requirements are objectives to be achieved. General objectives are:

- speed up the passenger process across the various airport steps,

- demonstrate financial benefits to all parties,
- improve the airport's infrastructure,
- facilitate average aircraft turnaround times,
- increase the satisfaction of passengers,
- reduce the security risks,
- minimize security delays,
- decrease the cost of baggage lost.

Connected to these objectives are parameters that are necessary for measuring changes and improvements to processes made by the implemented solution(s). The two paramount parameters for measurement are predictability and duration. The general objectives were broken down by ASSET onto the interests of each stakeholder. This was discussed and confirmed by the ASSET Advisory Group, see [7] chapter 1.3.1.4 for details.

Definition of quantifiable performance parameters

Time and Financials were defined as global assessment parameters by ASSET. These two parameters were broken down to meet process specific characteristics. The resulting parameters were categorized as simulation based and analytical parameters. Simulation compatible parameters are:

- **Times** (duration and variances) for single processes, walking/transportation times and overall process, distinguished after waiting time and service time,
- **Costs**, including fixed costs, variable costs, investments and revenue,
- **Supporting parameters**, including space consumption, robustness, level of service, security level, safety level, privacy constraints, compatibility and effort of implementation.

Simulations

Two different generic models were built by ASSET to cover the specific needs of medium-sized airports and hub-airports. To keep the models close to real airports the medium-sized reference airport model was based on Hamburg (HAM) airport and the hub reference airport model was based on Paris Charles-de-Gaulle (CDG) airport. Both airports were judged to fit project criteria well, to be representative and to have data availability that was comparably high for the ASSET consortium needs. To ensure the generic characteristic, both models were not 1-to-1 implementations of the two airports, but were streamlined to avoid distortion by airport-specific peculiarities. These two abstract models were transferred into the simulation environment thus defining the infrastructure and location of POAs in the terminal building.

Scenarios representing both peak-day traffic and average day traffic were produced for both airport type models. Low-level details including passenger–linked distributions of process times were included in the models corresponding to normal operations and peak traffic. The corresponding parameters were evaluated and inserted into the models. The required number of passengers is taken from the flight schedule. It was calculated from the aircraft type and the load factor. The destination group defined the split between business travelers and tourists.

Each passenger was modeled individually in the simulation. As an enabler, a list of passengers including their attributes and derived process times was compiled. The arrival flow of passengers is used to derive the schedules for gates and counters. Because of limited calculation power, only security control was broken down into different steps (e.g. placing luggage and body check) whereas all other process stations were modeled with a single interaction point (i.e. check-in counter or self-service boarding gate). Furthermore, the hub model was simplified by replacing the detailed security control by a single interaction point, based on the results obtained from the detailed simulation in the medium-sized model.

Analysis of simulation results

Outputs of the simulation using TOMICS with the generic models were values for key performance indicators (KPIs) such as waiting time, level of service etc. These values were used as a baseline for evaluation of the advantages of the single and combined solutions. Further, bottlenecks suitable to be addressed by single solution development were identified.

In order to compare the simulation results an indicator capturing the overall positive or negative effects of a simulation run was defined. The comparison was made between the value in the reference scenario and the value in the single solution scenario. The most important single solutions were:

- Reduction of Security Checks through Common Rules,
- Skip Check-In,
- Award Self-Service,
- Information exchange (stakeholder) and Coordinated Operations.

Relevance to META-CDM

Two aspects of ASSET are relevant to META-CDM:

First, the methodology used within the project to identify the bottlenecks and to assess possible solutions for them. The way bottlenecks were identified can be adapted for use in META-CDM, because the first steps for their assessment (literature study, questionnaire for involved airports, studying of processes for improvement) is similar. But there is a break after identifying the processes that have potential for improvement, because META-CDM does not aim to improve a single process or the implementation of solutions. Nevertheless, the methodology the identification of bottlenecks and the quantification of advantages (e.g. measures) of new procedures/solutions for later fostering through funded projects should be considered for use in META-CDM.

Second, the results of the assessment of single and integrated solutions will be considered in META-CDM. ASSET has already applied significant effort into identifying solutions that it deemed to influence the overall performance of the monitored processes in a positive way. META-CDM should build upon this assessment and pay attention to processes that were undocumented by ASSET and to (new) procedures that positively influence the overall performance of passenger transport. Further, the measures used to rate the solutions is interesting for META-CDM and should be recognized for the questionnaire.

3 Disruptive Events affecting Airport Operations

In order to formulate an extended CDM concept to deal with disruption, it is important to understand both how disruption affects aviation networks in general, and to look at specific examples of historical disruption and lessons learnt from their handling. This section reviews the literature in these two areas.

3.1 Air Transportation Networks and Delay Propagation

The world transportation industry is a critical infrastructure with a significant impact on local, national and international economies. The worldwide air transportation network is a small-world network, for which the number of non-stop connections from a given city and the number of shortest paths going through a given city have distributions that are scale-free [78]. Guimera et al. find that the cities with the most connections are not always the most central in the network though. Most cities, or nodes, are peripheral, meaning that the majority of their connections are within their own community. The nodes that connect different communities are usually hubs, but not necessarily global hubs.

Many complex systems, such as networks, can display strong fluctuations at various time scales. To understand such complex networks, it is necessary to study the dynamics of the processes taking advantage of these networks. In [75], the authors take the example of the US airport network between 1990 and 2000. Even if the statistical distributions of most indicators are stationary, the microscopic level is dynamic, with the appearance and disappearance of several connections between airports. These connections have a very broad distribution of lifetimes. Moreover, the links that disappear have essentially the same properties as the ones that appear, and links which connect airports with very different traffic are very volatile.

In [75], the authors aim to determine which network between China, Europe and the US is the most beneficial to passengers in terms of travel time and accessibility, and analyse the associated network features. To account for travel times and scheduling coordination, they calculate departure time-dependent minimum paths between each airport pair in the network. They evaluate the quality of indirect connections in terms of circuitry times and routing factors. The European network has the highest percentage of destinations. Waiting times for indirect connections account for between 30% and 50% of the overall travel times. The European network has the highest number of direct flights per airport, but connections requiring intermediate airports require larger waiting times than in the American and Chinese networks. There is evidence for a trade-off between the "openness" of the network and the average waiting time spent at intermediate airports. In Europe, there is a high percentage of airports accessible within a single day, probably because each country favors connectivity towards its own local airports. Such policies reduce the efficiency of coordination between countries, resulting in higher waiting times. On the contrary, the US network shows better coordination although its routes to secondary airports have gradually been marginalized.

Current air traffic forecast methods employed by the FAA assume that the structure of the network of routes operated by airlines does not change. Because of the dynamic nature of connections, this creates a gap between the forecasted and actual state of the US Air Transportation System in the long term, providing insufficient situational awareness to major stakeholders and decision-makers in their consideration of major technology and policy changes. Research is undertaken by Zhang et al. in [133] that shows that airports in close vicinity tend to have collaborative rather than competing effect on air passenger demand. Airports within a 550km radius have strong interactions in terms of attracting long distance international air passengers. Travel generation seems dissimilar for the studied hub airports and their connected spoke airports.

In [79], experts from the FAA and Eurocontrol provide a comparison of ATM-related performance on both sides of the Atlantic Ocean. They record similar arrival punctuality levels in Europe and the US, but higher variability in delays and related costs in the US. In the US, departure punctuality is better but taxi out delays are longer and associated with higher unit fuel burn. Direct route extension, i.e. the difference between the actual trajectory and the direct path between origin and destination, is approximately 1% lower in the US than in Europe, providing the corresponding fuel burn benefits. There is no superior performance in terms of arrival transit time in the Terminal Maneuvering Airspace (TMA), except for London Heathrow.

Significant effort has gone into trying to better understand delay propagation in the air transportation network over the past few years. Indeed the cost of congestion in such a tightly interconnected network of airports and aircraft is huge, $41 billion in the US in 2008.

Pyrgiotis et al. design an analytical queuing and network decomposition model that computes the delays due to local congestion at individual airports and captures the "ripple effect" causing the propagation of such delays [106], both in the US and in Europe.

AhmadBeygi et al. study the relationship between the scheduling of aircraft and crew members, and the operational performance of such schedules [4], in order to develop more robust airline planning tools. They make the following observations:

- Propagated delays create significantly more impact than the original root delays themselves,

- A single delay can "snowball" through the entire network,
- Keeping aircraft and crews together can help to mitigate the impact of disruptions,
- Delays that occur early in the day can cause greater propagation than delays later in the day,
- It is most important to prevent delay propagation early in the day.

From a more theoretic point of view, Kondo shows that the propagated delays are exponentially distributed by fitting the Weibull or Gamma probability density functions [87]. Seelhorst et al. [112] investigate the relationship between flight cancellations and delays. They identify the factors inducing flight cancellations, using the characteristics of the routes, airports, aircrafts, passenger traffic and delay for domestic flights.

In [43], De Neufville points out that airport traffic used to be dependent on regional population and economic activity is becoming more dependent on airline and airport management. The development of "no-frills" airlines and low-cost carriers, and the expansion of secondary airports in metropolitan regions have led to the emergence of a parallel airport system. This parallel network can be distinguished from the traditional airlines network by the following characteristics: a distinct low-fare, no-frills product; an almost total lack of connectivity with the traditional full-service airlines; operations focused on uncongested, low-cost airports; distinct geographical networks with links that traditional full-service airlines do not duplicate. The growth of this parallel network could lead to the shift of passenger traffic from congested airports to low-cost secondary airports, the growth of suburban regions with low-cost airports and the decrease of traffic growth rates at major airports.

The multi-airport system is defined as a system with a set of airports that serve the air traffic of a metropolitan area. Nayak [100] provides valuable insight on quantifying the interdependencies between airports in a multi-airport system and investigates the delay propagation from the system to the rest of the air traffic system and vice-versa. They show that queuing delay and adverse weather are major causal factors of delay in most of the studied regions. In [129], the authors challenge traditional network theory and its applications to airline networks. They propose network rewiring schemes that increase resilience to different level of perturbations while maintaining the total number of flight and gate requirements. Although other studies have shown the optimality of the hub-and-spoke networks for nominal operating conditions, their findings suggest that point-to-point networks can be more resilient to perturbations. Hubs located in the core of the network increase efficient connectivity but are critical targets. Hubs in the periphery offer smaller benefits with respect to efficiency but their failures do not destroy the connectivity of the rest of the network.

In Europe, reactionary delays, or "knock-on" effects, add up to nearly half of the delay minutes. Cook et al. [36] evaluate the costs of reactionary delays as a non-linear function of primary delay duration. They contrast flight-centric and passenger-centric delay propagation, and highlight the need for tactical delay models, taking into account marginal costs, reactionary costs and non-linearities.

3.2 Historical disruptive events

3.2.1 Delay and disruption data sources

For Europe, a summary of all major disruptive events is included in the Eurocontrol Network Operations Reports (NOR; Eurocontrol, 2013a [60]) - and the CODA delay digest (Eurocontrol, 2013b [61]). These review network activities and disruptive events across Europe by month and season. A summary of individual events over the 2008-2012 period is given in Annex 1 to this report. The most common disruptive events noted in the NOR are weather (mainly snow, low visibility, high winds and thunderstorms), strikes and disruption caused by the implementation of new infrastructure. Eurocontrol also gathers detailed delay data for the CODA database (Eurocontrol, 2013c [62]) and publishes reports about specific disruptive events as well as about its data collection, KPI calculation and delay cost estimation processes (e.g. Eurocontrol 2009 [57]; Cook & Tanner 2011 [39]; see Annex 4). The Association of European Airlines (AEA) publishes regular Consumer Reports which also list major disruptive events affecting AEA member airlines (e.g. AEA, 2008 [3]).

For the US, detailed delay data is available from 1988 via the BTS RITA On-Time Performance database (OTP; BTS 2013 [31]). As with the European delay database, delay data coverage is not complete – around 70% coverage is typical. A summary of major disruptive events extracted from the OTP database is given in Annex 2. Similarly to the situation in Europe, weather – particularly winter weather – is a major cause of airport disruption. This tallies with the survey responses gathered at the first META-CDM workshop (Marzuoli et al., 2013 [99]). Other US government data sources do not go into detail about disruption but do establish a baseline for delay levels and passenger impacts. These include the FAA's yearly Network Reviews (e.g. FAA 2012 [69]) and the DoT Air Traveller Consumer Reports (e.g. US DoT 2012 [125]) establish a baseline.

For other world regions, less data is available. Many disruptive events have similar impacts to those in the US and Europe, and are a potential source of further data about how to handle these events. For example, a recent major disruptive event in South America (and other regions of the Southern Hemisphere) was the Puyuhue-Cordon Caulle eruption ash cloud in Chile in June 2011. Other types of disruption, such as sandstorms or tsunamis, are more common in other world regions but may represent rare but highly damaging hazards for the US and Europe, or may become more common in future due to the impacts of climate change.

3.2.2 Types of Disruption

In many respects, the exact source of airport disruption is relatively unimportant in dealing with that disruption. What is key is its impact on airport functioning, the amount of lead time that the airport has to prepare a response and the geographic and temporal scale of its impacts. For example, various types of disruption may lead to runway closure, but the impacts in terms of passenger disruption may be the same.

Table 1 below includes all major sources of disruption covered in the META-CDM workshop questionnaire responses, the Eurocontrol NOR reports, CODA delay digests and the US OTP database. Estimated warning lead times and scales are also given. More detail is given on specific NOR disruptive events Annex 1 to this report, and on the OTP data in Annex 2.

Table 1: Major sources of disruption by type and impact

Source of Disruption		Type of Impact	Warning time	Scale of Impact
Weather	Snow	Runway closure, disrupted ground transport	Hours – days	Multiple airports, hours-days
	Fog	Reduced throughput	Hours – days	Multiple airports, hours
	Convective	Closed airspace	Hours – days	Multiple airports, hours
	Strong winds/ hurricanes	Closed airspace, disrupted ground transport	Days	Multiple airports, hours-days
	Flooding	Runway closure, disrupted ground transport	Hours – days	Single airport, hours-days
	Sandstorms	Runway closure, disrupted ground transport	Hours-days	Multiple airports, hours-days

Source of Disruption		Type of Impact	Warning time	Scale of Impact
Geology	Volcanic Ash	Closed airspace	Hours – days	Multiple airports, days-weeks
	Earthquakes	Runway closure, disrupted ground transport	None	Single airport, hours-weeks
	Tsunami	Runway closure, disrupted ground transport	None – hours	Single-multiple airports, hours-weeks
Accidents	Crashes	Runway closure	None	Single airport, hours-days
	Aircraft Maneuvering Incidents	Taxiway/runway closure	None	Single airport, hours
	Blocked access road to airport	Absent/late staff, passengers etc.	None	Single airport, hours
	Ground transport disruption near airport	Absent/late staff, passengers etc.	None	Single airport, hours - weeks
	Safety-related groundings	Lack of aircraft	None	Multiple airports, days-months
Security	Security Alerts	Extra passenger/baggage checks	None	Single airport – global, hours-months
	Terrorist attacks/bombing	Various	None	Single airport – global, hours-ongoing
	Cyber Attack	Loss of IT systems	None	Single airport, hours
	Wars/unrest	Airspace/airport closure, disrupted ground transport	None-weeks	Country-level, months-years
IT Systems	Systems Failure	Loss of IT systems	None	Single airport, hours
Disease	Pandemics	Extra passenger checks	Days	Global, weeks – months
Infrastructure upgrades	New runways, systems upgrades, etc.	Various	Years – months	Single airport or regional, hours-months

Source of Disruption		Type of Impact	Warning time	Scale of Impact
Industrial Action	Strike (Airport Staff)	Absent staff	None-months	Single airport – country-level, hours-days
	Strike (ATC)	Absent staff	None-months	Regional/country-level, hours-days
	Strike (Airline staff)	Absent staff	None-months	Regional-country-level, hours-days
	Strike (Ground transport)	Absent/late staff, passengers	None-months	Regional-country-level, hours-days
Major Events	Olympics, Hajj, Thanksgiving, World Cup, etc.	Increased demand	Years	Regional, days-weeks
Financial	Airline or Tour Operator collapse	Abandoned passengers	None-weeks	Regional-country level, days

META-CDM questionnaire respondents also mentioned mechanicals, late arrival of aircraft, high runway utilisation, lost passengers and diversions. However, as these are common occurrences and form part of normal airport operation we do not address them further in this report.

In Annex 3, we compare the rate of occurrence and impact of the different types of disruption to gain a more qualitative (but still approximate) idea of which are the most important types to investigate further. Of the types of disruption specified above, the most important on an 'impact x frequency' metric are snow and volcanic ash events. These are also the type of events most discussed in the literature (Section 3.3).

3.2.3 Specific examples by type of disruption

The second stage of the META-CDM project involves carrying out a series of surveys and interviews at airports affected by major disruptive events, both to find out how past events were handled and to investigate what methods would help in the handling of future events. To facilitate the selection of airports for this process, it is useful to identify specific, representative examples for major types of disruption. In many cases these specific events have been widely reported on and discussed in the literature; a literature review of these reports is given in Section 3.3 below for key disruptive events. A selection of representative event-airport pairs for different types of disruption is given in Table 2 below. If not otherwise stated, the event information was retrieved from Eurocontrol (2013a) and Eurocontrol (2013b) for airports within Europe and from press releases and news websites for airports outside Europe.

Table 2: Example events by type of disruption

Source of Disruption		Event	Example affected airport
Weather	Snow	17th – 23rd December 2010 snow event	London Heathrow (Begg, 2011 [25]; CAA, 2011 [32]; Quarmby, 2010 [107])
	Fog	20th October 2012	Zurich airport (Heathrow and Munich also affected)
	Convective	20th May 2012	Geneva airport
	Strong winds/ Hurricanes	28th-30th October, Hurricane Sandy	New York JFK; disruption was also experienced at the main European hubs
	Flooding	9th September 2009, flash flooding in Turkey	Istanbul Atatürk
	Sandstorms	8th February 2012, Harmattan sandstorms	Boa Vista Airport, Cape Verde Islands
Geology	Volcanic Ash	21st – 25th April 2010, Eyjafjallajokul eruption	Frankfurt airport; disruption across Europe so many other possible choices (Eurocontrol, 2010 [58]; Falconer & O'Meara, 2010 [70])
	Earthquakes	23rd October 2011, Van Earthquake	Van Ferit Melen Airport, Turkey
	Tsunami	11th March 2011, Tōhoku earthquake and tsunami	Sendai Airport, Japan
Accidents	Crashes	25th February 2009, Turkish Airlines Flight 1951	Amsterdam Schiphol
	Aircraft Maneuvering Incidents	17th March 2009, Cargolux incident	Maastricht airport
	Blocked access road to airport		Heathrow airport access tunnel
	Ground transport disruption	8th January 1989, Kegworth M1 Embankment crash	East Midlands Airport

Source of Disruption		Event	Example affected airport
	near airport		
	Safety-related aircraft groundings	9-10th April 2008, FAA MD-80 grounding	Chicago O'Hare
Security	Security Alerts	August 2006, transatlantic aircraft bombing plot/hand luggage ban	London Heathrow
	Terrorist attacks/bombing	30th June 2007, airport terminal bombing	Glasgow International Airport (Crichton, 2007 [42])
	Cyber Attack	29th June 2011, possible airport cyber attack in Delhi	Delhi Indira Gandhi International Airport
	Wars/unrest	Libyan airspace closure, 2011	Malta International Airport
IT Systems	Systems Failure	29th September 2012, radar failure in Greece	Athens Airport
Disease	Pandemics	2009 Swine flu pandemic	Beijing Capital airport
Infrastructure upgrades	New runways, systems upgrades, etc.	September 2010, runway maintenance	Warsaw airport
Industrial Action	Strike (Airport Staff)	16-19th February 2012, apron and marshalling staff strike	Frankfurt airport
	Strike (ATC)	29th February 2012, French ATC strike	Paris Charles de Gaulle Airport
	Strike (Airline staff)	31st August 2012, Lufthansa cabin crew strike	Frankfurt Airport
	Strike (Ground transport)	14th November 2012, European general day of industrial action	Lisbon airport

Source of Disruption		Event	Example affected airport
Major Events	Olympics, Hajj, Thanksgiving, World Cup, etc.	27th June – 1st October 2012, London Olympics period	London Heathrow (BAA, 2012 [14])
Financial	Airline or Tour Operator collapse	16th December 2006, Air Madrid collapse	Madrid Barajas Airport

Leviäkangas et al. (2011 [93]) discuss the geographic location of disruptive events by type, for a review of 25 disruptive weather events affecting aviation. They find that high winds, thunderstorms and low visibility cause problems for aviation across Europe; ice affects primarily Northern and Central Europe, and sandstorms affect only the Mediterranean region. However, the frequency of disruption is also a function of how common the extreme weather is in each region. As snow is common in Scandinavia, airports are better-equipped to cope with it and a snow event which would cause extreme disruption in Athens or Istanbul will have only minor impact. The frequency of non-weather events is less predictable and depends on a number of factors. For example, Europe's major hub airports are more vulnerable to disruption because they typically operate close to capacity, leaving little room to recover from unexpected events.

In addition, the frequency of disruptive events is likely to change in the future. Respondents to the first META-CDM workshop questionnaire (Marzuoli et al. 2013 [99]) identified several factors which will likely be important. As the aviation system grows, more airports will be operating close to capacity, leading to decreased ability to recover from or mitigate disruption. However, progress on technologies will likely facilitate increased warning times of disruptive events, recovery from disruption, increased safety (hence fewer accident/incident-related disruptions) and increased systems robustness. Climate change will also play a part. For example, by 2050, we might expect fewer snow and icing events and more extreme heat, convective weather events and sandstorms, depending on the region of Europe in question. This is discussed further in Vajda et al. (2011 [126]). They note that low visibility conditions may become significantly rarer in future, as will individual snow events, but heavy snowfalls may become marginally more common. Convective weather is more difficult to project and may show no overall change in frequency, but the intensity of individual convective weather events may increase. These projections suggest that, in aggregate, aviation disruptive events will probably occur at a similar rate to those seen in the present day, but the distribution of different types of event may change, as may the ability of airports to cope with and/or recover from potentially disruptive occurrences. Bläsche et al. (2011 [27]) projects that the lack of spare capacity at airports means that the frequency and severity of aviation disruption related to weather will increase.

3.2.4 Recovery from Disruptions

When a disruption occurs, airline schedule recovery tries to maintain operations and get back to schedule as quickly as possible while minimizing additional costs. The different mechanisms they rely on are aircraft swaps, flight cancellations, crew swaps, reserve crews and passenger rebooking. Usually airlines react by solving the problem in a sequential manner. First, infeasibility of the aircraft schedule is examined, then crewing problems, ground problems and finally the impact on passengers. In this process, the passengers' issues are the last accommodated. In [98], Marla et al. introduce flight planning, to enable flight speed changes, to trade off flying time and fuel burn, in combination with the available mechanisms. Their computational model for integrated aircraft and passenger recovery with flight planning could bring up to an 83% reduction in passenger disruptions, as well as a 5% cost savings to airlines.

From a more theoretical standpoint, Lacasa et al. [91] study the diffusion of aircraft as dynamic agents in the European air transport network, comprised of 858 airports and 11,170 flight routes. They distinguish between a free phase, i.e. an efficient regime with no airport queues and high diffusivity, and a congested phase, where there exist bottlenecks and poor diffusivity, separated by a jamming transition. This behavior does not depend on the network topology. They suggest that this could be the basis for testing cooperative behaviors aiming at optimizing the dynamics of the system.

Balakrishnan [15] examines the design of slot reallocation mechanisms for the Ground Delay Programs adopted at airports during adverse weather disruptions. A range of airline strategies in the prioritization of flights is offered compared to the existing techniques in use. Yet transfers between airlines during slot reallocation need further analysis to determine its acceptability from the policy and stakeholder standpoints. In [91] a control theory approach is adopted to address disruptions due to weather in the air traffic system. Their work covers the management of airport arrivals and departures constrained by runway capacity, which are sensitive to weather.

Vaze [127] find that at the current level of passenger demand, delays are avoidable to a large extent by controlling the negative effects of competitive airline scheduling practices. The level of congestion in a system of competing airlines is shown to be an increasing function of the number of competing airlines, a measure of the gross profit margin and the frequency sensitivity of passenger demand.

3.2.5 Contribution of Multi-modal Transportation

The Eyjafjallajokull volcanic eruption in 2010 had such an impact on aviation that it also had a series of knock-on effects on other modes of transportation. These can be explained by the rigidity and complex nature of transport networks, as well as by the lack of appropriate preparation. Steele et al. pose the problem of predicting the changes in passenger demand between different modes of transports during a disturbance of one or more of its systems [113]. Their research develops a simplified dual-mode UK transport model using system dynamics and recent data, to test responses to disturbances.

Similarly, Lewe et al. tackle the problem of forecasting multi-modal transportation demand. They combine a Systems Dynamics Approach with an agent-based model, and use historical data to calibrate predictions.

The partial substitution of some short-haul flights with High Speed Rail transport, either through modal competition or complementarity, is already in place in four European hubs (Frankfurt Main, Paris CDG, Madrid Barajas, Amsterdam Schipol). Janic [86] assesses the potential savings in the quantities and related costs of social and environmental impacts, such as airport air side delays, noise and emissions of greenhouse gases. The results show that the High Speed Rail substitutive capacity does not act as a barrier to developing air/rail substitutions at the airport. Even a modest substitution may produce substantial savings in airline costs and passenger delays.

The recent growth of Low Cost Carriers and their use of secondary airports imply that air traffic is further scattered across several airports in the same metropolitan area. This has multimodal implications for airport access planning, and explains the cooperations between some LCCs and bus or coach companies (such as Terravision with Ryanair). In [33], Castillo-Manzano studies the transport mode to reach the airport of more than 20,000 passengers at seven Spanish airports, none of which had efficient rail-based public transportation at the time. He shows that LCC passengers are less likely to use a taxi to go to the airport and more likely to choose a rented car or a public mode of transportation.

In her dissertation Zhang [132] develops a framework to reduce passenger "disutility" due to delay and missed connections, to help airlines reduce operating cost and recover schedule more promptly, and to assist traffic flow managers to utilize and distribute scarce resources more efficiently and equitably. The study suggests that when there is a significant capacity shortfall, airlines with hub-and-spoke networks could incorporate ground transport modes into their operations. Real-time intermodalism includes the substitution of flights by surface vehicle trips and, when the hub is part of a regional airport system, the use of inter-airport ground transport to enable diversion of flights to alternate hubs. It recommends that the current CDM system be enhanced to realize a regional Ground Delay Program (GDP) by including regional transport agencies, regional airport authorities, airlines serving regional airports and others. These enhancements cannot be realized without collaboration between FAA, airlines, airports, passengers, and consensus on the importance of integrating underutilized regional airports into disruption recovery strategies.

For the passengers, traveling across several modes of transportation to complete their journey can be difficult, especially when it comes to planning travel times. To improve the passenger's experience, more and more advanced transport information systems (ATIS) provide services such as route planning, navigation, updates on disruptions, real time information alerts and replanning tools. Zhang et al. [131] build a supernetwork, where the networks for different modalities are integrated. They distinguish road, rail, air, and water transportation as well as private (e.g. foot, bike, car) or public modes (e.g. bus, train, tram, metro). While routing in this supernetwork, the switch between modes occurs only when the transfer is possible. Some links are time independent, others time dependent or stochastic time dependent. The travel time and monetary cost may also be computed. The authors tested their tool for the Eindhoven region with success and are working on improving the computation time of their model.

Reliability of the schedule in a multi-modal trip is essential. Also, the traveling time in each mode and the waiting times in between should be balanced to improve passengers' experience. Hsu [84] develops a simple model to represent the transfer waiting time for a connecting service at multi-modal stations, where waiting time takes into account the characteristics of both the connecting service and its feeder service. The results show that transfer waiting time is mostly affected by the capacities and headways of the connecting and feeder services. They suggest that transfer waiting time cannot be improved without operational coordination with the feeder service.

The Strategic Research and Innovation Agenda (SRIA) is the new strategic roadmap for aviation research, development and innovation developed by ACARE. In the customer-centric mobility topic, "planning, payment and single ticketing support for intermodal journey selection" is expected to have started by 2020. By 2050, "door-to-door integrated journey planning, payment and single ticketing & accountability, and automatic journey monitoring and disruption management for over 90% of journeys" are to be in place.

3.3 Historical Disruptive Events – Literature Review

Over the past few years, severe weather perturbations have paralyzed the air transportation system. On the European side, the eruption of the Icelandic volcano in 2010 had the longest and biggest economic impact on aviation [28], with more than 100,000 flights canceled. Bolic et al. offer recommendations to better address such large disruptions, stressing the need for harmonization of volcanic ash risk thresholds and better information exchanges between all the stakeholders, with for instance a central repository of all information related to a given crisis. The response by airports, governments and aviation authorities to major airport disruption events is often to commission reports looking in to what happened and whether the disruption could have been handled better. The recommendations made as part of these investigations give an insight into current best practice, and share a number of common themes even where the events differ significantly. For example, the importance of good relationships and communication with other stakeholders; the need for early action when disruption is forecast; for a proactive approach to cancellations and airport closures; regularly updated contingency plans with clearly defined roles and responsibilities; and the importance of providing timely and correct passenger information. In this section we look at both more general recommendations on how airport could perform better, and specific investigations of individual events.

3.3.1 General recommendations

The most comprehensive set of recommendations for airports dealing with disruption is made by ACRP (2012 [1]). This report discusses in a US context how airports can best develop, evaluate and update contingency plans for the occurrence of irregular operations (IROPS) as a result of disruptive events. Following major weather-related disruption at US airports in 2007 and 2008 (see Annex 2) a number of workshops were held to identify best practice in dealing with disruption. The recommendations of those workshops were:

- That airlines, airports, government agencies, and other system partners should update contingency plans and that these plans should include sufficient collaboration.
- That communication among these parties should be collaborative, coordinated, and ongoing.
- That service providers (e.g., concessionaires, ground transportation) should continually evaluate the level of services provided in meeting customer needs during IROPS.

ACRP (2012 [1]) is a response to these recommendations providing a more formal framework which airports can adopt. It focuses on situations affecting the passenger in the wake of disruptive events – for example, terminal passenger capacity, passenger surges in terminals and security areas, and conditions for passengers during extended stays in the terminals or off-site. The report stresses that communication is key to successful IROPS response. It is recommended that airport appoint an 'IROPS champion' to act as a point person for communication between aviation service providers (here comprising the airport, airlines, government agencies such as the FAA, immigration and security agencies, concessionaires, ground transportation agencies, fixed base operators, overnight accommodation, emergency response providers, the military and diversion airports). A culture of collaboration and communication between these bodies is vital, as is a firm commitment to work on the joint IROPS plan.

Four types of IROPS impact situations are identified: *surge*, in which extra aircraft and passengers flow into an airport; *capacity*, in which the airport terminal becomes full of passengers or ramp space/gates become full of aircraft; *after-hours*, in which aircraft land and passengers need to deplane at irregular hours; and *extended stay*, in which passengers and aircraft may be stuck at the airport for an extended period of time.

Specific steps in the IROPS response process identified by the report include:

- That the airport's IROPS contingency response committee review existing emergency response plans from all service providers, evaluates them for adequacy during different types of IROPS events, and ensures that communication and coordination occurs between them. Passenger needs for information, food and water, safe and secure facilities (including clean toilet facilities) and lodging should be provided for, as should services for special needs passengers, ground transportation, and the needs of live cargo. Existing FAA, immigration and security agency procedures should be taken into account.
- That clear procedures are established for cooperation with local service providers. Existing technologies should be used for cooperation before developing any new unique systems.
- Existing IROPS plans should be improved where necessary, and co-ordinated training exercises held based on the new plans. The plans should be tested against the four identified types of IROPS impact situations. A schedule of biannual IROPS coordination workshops is recommended for developing and updating IROPS plans, providing information to stakeholders on the necessity of IROPS planning, and providing training.
- That an airport create a 24/7 contact list of major airport stakeholders using the most appropriate contact method for their situation (e.g. phone/email/text message).

- That hub airports host a conference call with key service providers at least 24 to 48 hours before a predicted severe weather event, including National Weather Service representatives.
- That airport IROPS contingency response committees ensure the capability exists for coordinating shared information on aircraft status and airport capacity during an IROPS event between aviation service providers. This includes the monitoring of likely indicators of an upcoming IROPS event (e.g. weather reports, aircraft status) so that a developing event can be identified as early as possible. A communication plan should be made which also includes external communication with customers and passengers.
- Following the return to normal operations after an IROPS event, the airport should host a meeting to debrief and review performance during the event.

ACRP (2012 [1]) also discusses available technology solutions to facilitate these recommendations at different cost levels (Resource C, Tool 10). For example, at low cost ($5K) flight tracking may be carried out via internet applications; at high cost ($500K) a dedicated flight tracking management system may be utilised.

On a more global scope, Tanger & Clayton (2011 [121]) review resilience capabilities and practices at nearly 30 of the world's major airports. They conclude that the best practice airports have clearly defined command and control; collaboratively plan for disruption with stakeholders; have well-coordinated management of passenger welfare; and have dedicated operational equipment and resources for dealing with disruption. They provide a number of examples of airports which display best practice in different areas of crisis management:

- Command and Control
  - Hong Kong (HKG) has a single integrated Airport Centre handling real time management of airport operations, and an adjacent Airport Emergency Centre for major incidents. More than 90 seminars and drills are conducted each year. Consolidated airport-wide information is available from a single airport operations database.
  - Dallas-Fort Worth (DFW) has a single integrated Airport Operations Center co-located with an Emergency Operations Center.
- Collaborative Planning
  - Minneapolis-St. Paul (MSP) has a tradition of joint planning between the airport and base carrier Delta Airlines. Capacity and cancellation decisions are carried out proactively to avoid terminal congestion and aid rapid recovery. An

annual cost/benefit analysis is carried out on emergency response preparation and deployment.
    - Amsterdam Schiphol (AMS) makes use of a strong relationship with base carrier KLM. Roles and responsibilities and timelines for emergency response are clearly defined.
- Passenger Welfare Management
    - London Heathrow (LHR) led the joint development of a passenger welfare charter articulating the common ambitions of all airport stakeholders to support the passenger during disruption, following the 2011 Winter Resilience Program. Roles and responsibilities for passenger support are clearly defined, and over 900 non-operational airport staff act as reservists who can be deployed in terminals during disruption.
    - Hong Kong (HKG) has worked together with airlines to establish a dedicated area for stranded passengers, including separate rebooking facilities. The airport has its own stock of provisions for stranded passengers, and proactively communicates with embassies on matter such as visa requirements.
- Operational Equipment and Resources
    - Chicago O'Hare (ORD) can draw on an enormous off—airport contingency force as part of the City of Chicago, including emergency response staff and transport resources (e.g. city buses).
    - Frankfurt (FRA) makes effective use of third party contractors to respond to events; for example, full-time ground operations personnel are complemented by a large pool of contractor staff who can be onsite with eight hours' notice.

More general best practice guidelines discussed are: that strong collaborative working relationships with stakeholders are maintained (particularly base carriers, ATC, emergency response, security and immigration); that proactive rather than reactive approaches should be used to manage disruption[1]; that the airport has a single information platform bringing together all airport data in one place; that airport performance is quantified (for example with KPIs); that command and control are as integrated as possible (for example with a single control centre for normal airport functioning linked to a single crisis response centre); that innovative technologies are used (for example, CCTV with automatic incident detection); that scenario planning, training and testing is carried out; that the airport has a passenger welfare plan; and that contingency plans should be subject to regular review.

[1] This approach is also highlighted by Quarmby (2010), who note that there is some evidence that earlier, more decisive cancellations and rescheduling are helpful in managing snow disruption.

CAA (2011 [32]) also addresses airport best practice in the event of disruption, in the context of the severe snow disruption experienced by the UK in 2010. In particular, an online survey of passengers was carried out to assess how passenger welfare could be improved during disruption. Considerable room for improvement was found; 74% of respondents were dissatisfied with the quality of information they were given, 75% were not informed of their rights, and 60% received no care or assistance from their airline. The following areas of good practice were identified:

- Accurate and accessible information available on airline websites.
- Rebooking available by website as well as telephone helpline; rebooking should be free of charge, smartphone-accessible and flexible (e.g. allowing passengers to rebook via a different airport) and websites should be able to cope with high demand.
- The ability to reroute telephone queries to overseas call centres so that core call-centre operations could be focused on rebooking.
- Passenger rerouting, and making additional flights and/or capacity available, to minimise the number of passengers unable to travel.
- Learning from past experience (e.g. investing in additional snow clearing equipment after earlier snow experiences)
- Airports providing care and assistance to stranded passengers[2], including free wi-fi for rebooking.
- Airlines and airports redeploying back-office staff to help passenger-facing staff.

The accessibility of passenger information was highlighted as a particular problem during the snow crisis; when faced with inadequate information about whether their flight was operating, many passengers chose to travel to the airport in search of better information; and, when they were at the airport, many passengers were reluctant to leave for similar reasons. In some cases passengers visited the airport daily to see if there was any news of their flight being rescheduled. Some passengers travelled to the airport unnecessarily because they had been told they needed to check in before the airline could give them assistance. The need for clarity on information about what costs airlines would refund if passengers organised hotels, food or onward journeys themselves was also noted.

As well as accessible information, information sharing and decision making between different stakeholders was highlighted as a problem; for example, one airport told the enquiry that although they updated cancellation information on their website in real time, it could take some time for correct information from the airlines about cancellations to reach it. Best

[2] As noted below, under EU regulations it is the legal responsibility of the airline and not the airport to care for passengers, so airport-provided assistance is not mandatory.

practice airports were considered to be those where the crisis command and control structures had given priority to information sharing, where the information sharing included a wide range of stakeholders but was co-ordinated through a single point (the airport), where crisis structures were initiated early, and which carried out face-to-face meetings. Input from all stakeholders into decision making is also important. For example, the airports interviewed tended to favour pausing airport operations for unspecified periods when faced with disruption, whereas many airlines preferred clear decisions about airport closure, even if for a longer period, due to the long lead times associated with long-haul flights.

The report concludes that the passenger experience can be improved in three main areas. The first is increased coordination and communication between airports, airlines and ground handlers to maintain operations, thereby reducing the number of passengers affected by disruption. The second is to provide better information to passengers at an earlier stage. The third is that airlines should adhere to EU regulations about passenger care and assistance. To achieve these aims a number of measures are suggested. First, airports should have a major disruption plan clearly setting out the roles and responsibilities of all stakeholders, information sharing between them, and the timing of airport closure and re-opening decisions. The plan should include processes for determining slot allocation in the case of reduced capacity and processes for handling diverted aircraft. Such plans should have redress mechanisms in case of stakeholders failing to meet their obligations, and should be reviewed at least annually. Second, airlines' plans for communicating with passengers should be discussed with other relevant stakeholders. These plans should include the roles and responsibilities of all stakeholders in passenger communication, the procedures for passenger communication and mass media strategies. They should consider website and call centre resilience under high demand conditions, rebooking flexibility and the speed with which cancellations and delays can be communicated to passengers. Third, a welfare capability assessment should be carried out by all airlines investigating their likely obligations under EU regulations in a severe disruption event, and whether the resources available to that airline are sufficient to meet them; following this, a passenger welfare plan should be created to specify how the airlines plans to meet its obligations to passengers.

Quarmby (2010 [107]), notes that rail passengers have access to comprehensive historical performance indicators. This facility does not currently exist for air passengers in the UK, although there have been some past initiatives by ATUC, the EC and AEA.

3.3.2 London Heathrow, 17th-23rd December 2010 Snow Event

In December 2010, airports around Europe experienced severe weather disruption following unusually heavy snow and cold weather. London Heathrow was particularly badly affected, with over 4,000 flights cancelled. In the wake of this event, a number of reports were compiled about how the snow disruption was handled, and what improvements could be made. These include Begg (2011 [25]), focusing specifically on events at Heathrow; CAA (2011 [32]), focusing on the passenger experience; and Quarmby (2010), focusing more generally on winter weather resilience across modes. The Heathrow Winter Resilience Enquiry (Begg, 2011) was set up to investigate BAA's performace during this event and make recommendations as to how future events should be handled. This enquiry focused on BAA's role in handling the snow disruption and did not examine the actions of other stakeholders in detail.

The weather experienced in December 2010 was unusually severe; previous weather events at Heathrow had been dealt with well. However, many other airports in Europe were also affected by the severe weather and had comparatively lower levels of disruption. Weather forecasts had correctly projected heavy snow four days before the main snow event, and a warning was made available to passengers two days beforehand via the heathrow.com website. A number of individual factors were identified as having contributed to the disruption experienced:

- The severity of the weather was not fully anticipated beforehand, so sufficient preparation had not been made.
- Aircraft stand clearance was slower than required; there was no agreed protocol between BAA and airlines for handling this, and BAA did not have specialised stand clearance equipment. As noted by CAA (2011 [32]), some UK airports and airlines did not agree on whose job it was to clear snow which had accumulated under parked aircraft.
- There were failures in communication and coordination within BAA and between BAA and airlines, leading to delays in response. Confused and conflicting messages led to airlines and passengers receiving incorrect information. BAA's response to terminal congestion was delayed and resulted in passenger distress.
- Some airlines did not comply with EC regulations[3] requiring passenger compensation and assistance in the event of cancellations/long delays/denied boarding. Many passengers refused to leave the airport as they were determined to fly and worried they would lose their place in a queue.
- However, once a response was mobilized it was effective.

[3] Regulation EC 261/04. It is the responsibility of the airline rather than the airport to provide this assistance. However, in common with other major airports, Heathrow also has a plan to respond to mass congestion in the airport involving the provisions of emergency welfare items (water, blankets etc.) when disruption is projected to exceed 6-8 hours.

- The weekend of 18-19th December was expected to be Heathrow's busiest of the year with full schedules and close to 100% load factors. This lead to problems in rebooking passengers from cancelled flights.
- Local roads were also severely affected by the snow. This affected airport access, including for lorries bringing supplies for stranded passengers. Many passengers sought refuge in the subways leading to the airport's train stations, making access by train difficult. Further congestion was caused by passengers exiting vehicles in Heathrow's road access tunnel and continuing on foot with their luggage.

A number of specific areas were identified where practice at other airports differed from each other and from that at Heathrow at the time:

- Some airports have minimum performance standards for airfield clearance (e.g. as set by the FAA in the United States).
- De-icing facilities differ; some airports de-ice on stand, some have shared de-icing pads and some airports with more frequent severe weather have 'drive-through' de-icing facilities.
- Some airports have specialist facilities for snow clearance from stands (e.g. under-stand heating).
- Airports vary widely in the amount and capabilities of snow-clearing equipment available.
- Airports also vary widely in the level of detail in their snow plans, and the amount of training and rehearsals carried out to prepare for snow events.

These observations are complemented by the review of CAA (2011 [32]). They note that responsibilities for snow clearance differ between airports, with the best-performing airports taking responsibility for snow clearance for the entire airfield as opposed to just the taxiways and runways; this allows for economies of scale with clearance equipment. Airports also differ in how long crisis command and control centres are left in operation after the immediate crisis has eased. Here best practice was felt to be a period of continued operation of the crisis centre, in recognition of the possibility of unforeseen knock-on effects of the disruption at that airport or elsewhere.

A number of recommendations are made by Begg (2010 [25]) regarding increased cooperation between shareholders, the establishment of a single physical control centre for crisis events, and passenger welfare plans. In respect of the airport itself, the report notes:

"The panel recommends that Heathrow Airport should adopt an improved resilience target that the airport never closes as a result of circumstances under its control, except for immediate safety or other emergency threats. ... The panel recommends that [stakeholders] actively work together to implement improved snow plans, improve command and control processes, and establish approaches to passenger welfare that are focused on the needs of the passenger. "

The specific recommendations made by the panel include:

- That BAA work with airlines, NATS and the CAA on an enhanced snow plan which recognises the constraints of Heathrow and which defines clearly the sequence of actions required, equipment needed, logistical requirements, roles of different parties and de-icing standards to be used for different levels of snow event.
- That BAA work with airlines, NATS and other stakeholders to review de-icing procedures and infrastructure, including potentially the provision of remote de-icing facilities.
- Heathrow's snow plan should be subject to regular review.
- When a forecast indicates a possible snow event, BAA should hold a snow contingency meeting with the airlines, their ground handlers, NATS and the AOC to plan an effective response and contingencies.
- BAA should dynamically maintain stock of de-icing media and other emergency supplies at levels driven by forecast weather, expected rate of use and reliability of supply.
- BAA's emergency planning response should be simplified to the standard three-tier (Gold, Silver and Bronze) structure used by other UK bodies (see boxed discussion on the next page). Key stakeholders should be involved in these teams, including the Metropolitan Police and representatives dedicated to passenger welfare, and a formal, disciplined communications structure with clear interfaces should be established between stakeholders.
- Clear triggers for escalation of crisis response should be defined which ensure early deployment of the higher level command and control structures.
- BAA and airlines should take steps to ensure that all crisis response teams have enough on-call resources available to them to function 24/7 for a sustained period.
- A review is needed of the process by which airport status changes are converted into updated flight schedules, and how these schedules are communicated to passengers, media, government and the public.

- A single physical control centre should be established for the management of major incidents[4].
- Systems should be updated to make more real-time airport status data available, including real-time digital CCTV at telemetry; a secure web-based system for making this data available to stakeholders; and a real-time incident management system, available to all stakeholders, that tracks and supports decision making.
- The enforcement of EC regulations on airline responsibilities for passengers in the event of disruption should be investigated.
- BAA, airlines and retailers should work together to establish a sustainable passenger welfare plan for emergency events. This includes providing easy and clear communications to passengers in terminals on airport status, in a number of languages.

In terms of increasing intermodality in times of crisis, the review of Quarmby (2010 [107]) into how other modes coped with the snow disruption is also useful. In particular, this and the previous prolonged period of cold weather in 2009 also had strongly disruptive effects on alternative modes. Eurostar rail services to France suffered widely-reported breakdowns and were cancelled entirely for three days in 2009, leaving many passengers stranded at stations. Similarly, delays, congestion and closures affected the UK road network in both years. Local road congestion may also result in the regions around airports if the airport disruption leads to increased traffic to or from the airport on roads that may be capacity-constrained by the weather.

UK Emergency Services Crisis Response

The UK emergency services use a hierarchical framework for the command and control of crisis response. Three levels (gold, silver and bronze, corresponding to strategic, tactical and operational levels of response) are defined. Following the December 2010 snow crisis at Heathrow, Begg (2011 [25]) recommended that Heathrow adopt a similar structure for crisis response. More details on this type of crisis response plan and its implementation by the UK emergency services is given in LESLP (2012 [92]). The Gold level of response looks at strategic planning and is in overall change of each service. It determines a strategy at the beginning of an incident, and monitors and reviews that strategy as the incident progresses. Tactical decisions are delegated to the Silver level of response. Silver responders attend the scene, take charge and are responsible for formulating the tactics required to achieve the strategic goals set by Gold. Bronze responders control and deploy the resources available to them to implement the tactics formulated by Silver.

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[4] The panel noted that they considered this best practice from their review of how crises are dealt with at other large global airports; for example, LAX and MAD both follow this practice.

3.3.3 April 2010 Volcanic Ash Crisis

The eruption of the Icelandic volcano Eyjafjallajokul in 2010 and subsequent ash cloud caused EU-wide disruption to flights. According to Eurocontrol (2010 [58]), approximately 10 million passengers were unable to board their flights. Around 100,000 flights were cancelled; in addition, 5,000 extra flights were flown to reposition aircraft or crews or to accelerate the repatriation of stranded passengers.

On the 14th of April 2010, Eurocontrol Central Flow Management Unit (CFMU) received the first messages relating to the volcanic eruption in Iceland from the London Volcanic Ash Advisory Centre. Two teleconferences were held, chaired by London, discussing preparations for the worst case scenario. Norway, the UK, Sweden and Finland imposed airspace restrictions and these restrictions spread progressively across Europe on the following days. Eurocontrol began issuing twice-daily press updates as well as public communication via Twitter. Airspace closures remained widespread until the 20th of April, with flights almost back to normal by the 22nd. However, a further ash event occurred in May. This led primarily to rerouting delays rather than cancellations. Eurocontrol (2010 [58]) notes that low-cost carriers were disproportionately affected – both because more low-cost carriers operated in the most-hit regions, and because the business model of low-cost carriers is better-suited to an all-or-nothing approach to operations in extreme circumstances.

As a disruptive event affecting the whole European aviation system, two levels of response are interesting in the context of META-CDM; first, the response of individual airports (and the lessons learned from this) and second, the whole-system response (and lessons learned there). These areas are discussed individually below.

Individual airports and passenger experience

A brief summary of some of the actions taken by individual airports in response to the volcanic ash crisis is given in Falconer & O'Meara (2010 [70]). Many airports provided beds, blankets, water and medical support, and some airports (for example, Amsterdam Schiphol and Frankfurt) provided further facilities to stranded passengers such as entertainment, free internet and showers. The scale of the crisis meant that there were many unanticipated consequences – for example, shortages of hotel rooms, rental cars and rail tickets, and interactions with ground transport problems such as a French rail strike at the same time. The situation of transit passengers was particularly difficult, as many were unable to leave terminals due to customs restrictions.

Jain & Guiver (2011 [85]) discuss the results of a survey of passengers affected by the crisis. They found 20% of affected passengers due to depart on intra-European flights chose not to travel, and 43% delayed travel (12% and 62% respectively for intercontinental trips). 39% of intra-European stranded passengers chose to return via surface travel (8% of intercontinental passengers), with 19% returning by rail and 11% by ferry. The communications made by passengers were also analysed. Airlines were contacted by over 80% of passengers, followed by friends and family, employers, travel agents, accommodation providers and insurers. 10% or fewer of passengers contacted tour operators, embassies, train operators, tour guides or coach operators. Of these bodies, airlines were the most difficult to contact – 30% of respondents had difficulty in contacting their airline (mainly due to overloaded call centres and websites; in particular, many stranded passengers had no access to the internet). Embassies and insurers were the next most difficult bodies to contact, and around 25% and 20% respectively. Airlines were also the most likely to be judged ‘unwilling to help’ by respondents. The needs of passengers with internet access, fully charged mobile phones, credit cards and local language knowledge were different to those without these advantages. Most passengers, however, expected that they would pay the majority of the costs they incurred.

Whole-system response

EC (2011 [51]) gives an update on the steps that have been taken to improve crisis preparedness at an EU and global level since the volcanic ash crisis. These include reviews of the safety guidelines in place at the time of the crisis, work on increasing the co-ordination within EU air traffic management systems, and work towards increasing co-ordination with other modes of transport.

Existing ICAO guidelines were based on a very strict precautionary principle and these proved to be unsuitable, preventing many flights from operating even when conditions were safe. As a result, ICAO guidelines for operating in volcanic ash conditions were revised and allowed for different degrees of ash contamination. Standardised procedures were put in place for the alerting of aircraft and the closure of airspace. A significant amount of work was carried out into identifying and codifying safe thresholds for volcanic ash exposure[5], and into improving meteorological models. Leviäkangas et al. (2011 [93]) note that rapid data sharing between volcanologists, atmospheric scientists and aircraft engineers is also vital for the first stage of response to an eruption, where projections of likely disruption are made.

[5] This was entirely new work as a threshold model for flying with ash contamination is not used even in areas such as South America or Southeast Asia which have more experience of dealing with volcanic ash clouds.

EC(2011a [51]) notes that the crisis was exacerbated by the existing national fragmentation of air traffic control. As a result, the European Council gave high priority to accelerating the Single European Sky (SES) initiative to provide greater co-ordination in the European air traffic management system. Two notable features of this acceleration are:

- The establishment of the European Aviation Crisis Coordination Cell (EACCC), chaired by the EC and Eurocontrol and including participation from the EU presidency, ANSPs, airspace users, airports and other stakeholders depending on the nature of the crisis.
- Accelerated technology deployment for SESAR, the technological arm of SES.

A further hazard identified in the original ash crisis response was the uneven application and/or interpretation of passenger rights legislation. The EC's assessment is that the majority of airlines took their responsibilities seriously during the ash crisis; in the weeks following the crisis the EC co-ordinated national authorities to agree on a common interpretative guidance. Following a review, EC communication 2011/174 (EC 2011b [52]) gives more detailed guidance on passenger rights in the event of disruption; one of its main suggestions is that more data be made available to facilitate improved passenger information. Consultation is currently underway about legislative changes. EC (2011c [53]) gives further information on the rights passengers have by mode of transport; this includes the right to information in the case of disruption. Notably, rail, bus and waterborne transport regulations include a provision that information on disruption be provided within a specified timeframe (for example, 30 minutes after scheduled departure time for bus transport). This provision does not exist in the air transport legislation.

Even with airlines providing assistance, many passengers were still stranded for lengthy periods of time. As a result, EC work on pan-European mobility plans was also accelerated. As noted by EC (2011a [51]):

> *'It was clear in both the volcanic crisis and snow crisis in December 2010, that when one mode of transport is severely affected, other modes were not easily able to step in and fill the gap. At the Transport Council of 2/3 December 2010 the Commission provided a detailed brief to ministers on its initiative to strengthen the resilience of the European transport system by ensuring the uninterrupted mobility of passengers and goods in the event of a sudden transport crisis.'*

EC (2010 [50]) suggests this mobility plan should focus on national and regional (including cross-border) emergency plans; the possibility of rescheduling ground traffic and mobilising all available rolling stock and personnel; improvement of intermodality (particularly rail/air intermodality) and rebooking systems which allow exchange of tickets and schedule information between modes. However, switching to alternative modes is still dependent on capacity existing in those modes; for example, Eurostar tickets for the 15th and 16th of April sold out within 3 ½ hours of the closure of British airspace. By putting on 33 extra trains, Eurostar was able to carry 50,000 extra passengers between the 15th and 20th April, against a scheduled baseline of around 115,000.

The risk of such an event occurring again is discussed by Sammonds et al. (2010). They note that volcanic eruptions are fundamentally unpredictable; however, given the number of volcanoes in or near Europe there is the potential for other highly disruptive events, and similar widespread disruption to the air transport system may also occur for other reasons (e.g. terrorist attacks). They recommend contingency plans be made for such large disruptive events, including potential regulation to manage the actions of airlines. This could include, for example, emergency approval of night operations, removal of seat class restrictions, or fixing fares. A further recommendation is that a single communications centre be set up to advise the public in cases of disruption, supported by aviation stakeholders. This would then avoid individual airlines and airports having to maintain excess call centre capacity for cases of disruption.

3.3.4 Olympic Games, 2004 and 2012

Major sporting, religious and cultural events differ from other sources of disruption in that long lead times are normal and extensive preparation beforehand is possible. In consequence, these events are usually handled without major problems and in some cases overall delays can decrease from baseline levels (e.g. the London Olympics; Eurocontrol 2013 [60]). The main challenge for airports dealing with major events is handling the temporary increase in demand. Individual events may have their own specific challenges; for example, the Olympics sees an increase in unusual cargo and state or general aviation VIP flights, and the Paralympics an increase in passengers with special mobility requirements.

Odoni et al. (2009 [101]) discuss the successful preparations for Athens airport to deal with Olympic traffic in 2004. Athens International Airport opened in 2001, leaving three years for Olympic preparations. The main concerns for the airport were handling the large increase in demand over normal levels and providing security. The security concerns were partly addressed by handling Olympic Family traffic (athletes, sponsors, media etc.) separately from regular traffic. An overlay organisational structure was used, in which normal day-to-day airport operations were unaffected by the extra layer of functions for the Olympics. This was considered to have worked well, but a high degree of cooperation from institutions involved in welcoming, processing and transporting Olympic Family members was needed, as well as additional infrastructure. A small new terminal for express processing was constructed to alleviate the pressure on check-in desks. Check-in for departures was also handled at the Olympic Village rather than the airport.

Athens integrated the detailed operating plans for the Olympics into the airport's Operations Delivery Plan (ODP), which continually evolved during the period before the Games with review from all relevant stakeholders. Similarly, demand forecasts evolved as more information became available in the run-up to the Games. These forecasts were used to estimate needs for facilities, personnel and equipment. In general, preparations erred on the conservative/risk averse side, assuming maximum demand levels and creating extensive contingency plans for adverse events. This was recommended for future similar events – Odoni et al. (2009 [101]) note that the cost of failure in such cases is very high and more than justifies the costs of a risk averse approach. Training was carried out to enable the airport to temporarily operate at a higher number of movements per hour than the previous declared capacity, and restrictions were put in place on slot requests, aircraft stay time on the ground and the use of Athens as a diversion airport in flight plans. In the worst-case envisaged scenario, the forecast suggested a shortage of stands due to the large number of state VIP aircraft expected. Temporary extra stands were created by redesign of some apron areas and the closure of some taxiway segments. On the busiest days, passenger flows were managed by directing coaches, taxis, cars and arriving rail passengers to appropriate airport entrances with the shortest walking distance to their flight, and directing early arrivals to a special waiting area outside the terminal.

Information about the preparation of London Heathrow for the 2012 Olympic Games are given in BAA (2012 [14]). Planning teams consulted extensively with previous Olympic host airports, who were invited to provide peer review. An Olympic readiness working group was set up involving all stakeholders; including the Olympic organising committee LOCOG. Security arrangements were based on existing security at Heathrow, reflecting the idea that under conditions in 2012 hosting the Olympics did not represent a significant increase in Heathrow's security risk level. However, as with Athens, a temporary Games Terminal was constructed for the Olympic family and check-in and baggage collection were offered at the Olympic village. As with the rest of the London Olympics, extensive use was made of volunteers to assist passengers. This applied particularly to language services. Airport forecourts were reconfigured to cope with increased coach traffic and a specific on-demand fleet service was set up in the terminal short stay car parks for Olympic family members, operated by LOCOG. As Heathrow already operates close to capacity, increases in demand can be difficult to accommodate. However, as London is a multi-airport system, charter flights and private jets were able to avoid Heathrow and were directed to other London airports instead.

As with Athens, Heathrow's preparations were considered to be effective, and delays in August 2012 actually decreased compared to those seen in August 2011 (Eurocontrol 2013 [60]). This pattern is relatively common for disruptive events that can be anticipated and planned for with long lead times.

3.3.5 Glasgow Airport, 30th June 2007 Terrorist Attack

At 15:11 on Saturday the 30th June 2007, a car bomb attack was directed at Glasgow Airport's main terminal building. The response to this event was relatively successful, and is detailed by Crichton (2007 [42]). The attack resulted in a small fire, which was extinguished within 30 minutes. However, the terminal forecourt area was now a crime scene and hence access was limited whilst police investigation took place. Similarly, police investigations required the interview of travellers in the airport at the time, leading to around 1,000 passengers being held on board aircraft for several hours and the evacuation of all travellers to a central location (the Scottish Exhibition and Conference Centre in Glasgow). Although smoke damage within the terminal was minor, flooding resulting from the airport sprinkler system required extensive cleanup. Flights resumed 16 ½ hours after the incident using alternative areas of the terminal, although some airlines cancelled flights beyond this as they were not prepared for an early resumption of operations. The crime scene was handed back to airport authorities 54 hours after the incident. Thereafter only minor layout changes while repairs were carried out were needed for full functioning of the terminal.

Glasgow airport's emergency plans include a support mechanism to call in off duty staff to support front line staff if necessary. A crisis management team exists to look after tactical command in the event of a crisis, and a business recovery team look after strategic command on behalf of the airport. The crisis team was initiated and operational within 45 minutes and the business recovery team operational an hour later. As this was a complex incident involving many stakeholders an individual recovery plan did not exist[6]. Instead, recovery plans for short term loss of the terminal building and loss of road infrastructure were combined. The recovery team drew on existing relationships with the local police force to negotiate terminal building access via alternative routes so that the overflow check-in areas could be readied for use when the terminal was handed back. Crichton (2007 [42]) notes that the key to dealing with this event was having robust, workable plans in place; these plans were tested regularly and all members of the responding teams fully participated in those tests.

[6] As noted by Crichton (2007), the majority of Glasgow airport's emergency plans assume an aircraft-related incident involving a single airline.

A further notable feature of this event was the media attention it attracted. Pictures and video of the event were rapidly distributed globally via camera phones. As the bombing was a globally-reported news event, the airport crisis teams also had to deal extensively with the media (in particular to make sure that the public were given correct information about the continuing operation of the airport). Information was disseminated via politicians, the BAA website, screens in Glasgow city centre, E-bulletins and an ad campaign on local radio.

3.3.6 September 11, 2001 terrorist attacks

On September 11th, 2001, a series of coordinated terrorist attacks were carried out in the US using hijacked aircraft to crash into major buildings. As a result of this, the US Plan for the Security Control of Air Traffic and Air Navigation Aids (SCATANA) was implemented, closing all US and some other airspace to non-emergency civilian aircraft. Many incoming flights were diverted to Canadian airports, and large numbers of passengers were stranded.

The response of Gander Airport in Canada is discussed by Scanlon (2003 [111]). Gander's location in relation to the North Atlantic flight tracks on September 11th meant that it received a high number of diverted flights – 38, and 6,600 passengers, in total. This corresponded to a 63% increase in Gander's population. Planning had already taken place in Gander for a situation in which large numbers of diversions were received, in the context of concerns about how the 'millennium bug' might affect aircraft. Once it was realised that the airport would be accepting diversions, a number of Emergency Operations Centres (EOCs) were set up according to existing plans. These included a town EOC, a hospital EOC and the airport Emergency Control Centre (ECC). With police and military assistance, the airport ECC dealt with flight unloading, passenger screening and immigration issues. The Red Cross, assisted by Salvation Army volunteers, registered the arriving passengers. The local fire and school bus departments organised transportation. The town EOC organised shelters, and the provision of food and supplies was run by the Salvation Army. Other bodies provided services as required. The hospital EOC organised medical and related treatment (for example, insulin for diabetic patients, nicorette for smokers). Other requirements, including providing Kosher food, were dealt with on a case-by-case basis by volunteers. Communications were set up in each shelter; a new cellphone tower was also installed after existing networks became overloaded. By agreement, shops remained open 24 hours.

A small number of passengers tried to organise their own onward journeys from Gander, either by booking taxis or purchasing cars. One group of passengers tried to charter a bus. However, the majority of passengers waited for flights to resume.

Because of the nature of the emergency, security rules were constantly being updated. This led to considerable uncertainty in when departing flights would be ready to take passengers home. This in turn led to problems anticipating supply stocking for the shelters. However, in the most part the emergency response in Gander was extremely successful. As noted by Scanlon (2003 [111]), it is not unusual for multiple existing emergency agencies to each establish their own command post in the event of an emergency, and for conflict to then arise between those posts. Several reasons were put forward as to why this was not the case in Gander, some of which are relevant to META-CDM. Amongst these was the town's previous experience in airport emergency response (due to its location, Gander often deals with North Atlantic flight emergencies). Another was that extensive plans existed for dealing with such a situation. Staff were well-informed of these plans and the airport ECC had been activated numerous times before. Lessons from previous emergency events were applied about mutual communication and collaboration between the different emergency centres, and each emergency centre dealt with a separate aspect of the crisis with minimal overlap in responsibility. The overall response was effectively led by the airport ECC as actions by the other agencies were triggered by its decisions about loading and unloading aircraft.

Many passengers stranded at airports closer to US land borders attempted to journey onwards via alternative modes. A review of the actions taken by US rail companies is given by APTA (2002 [5]). This includes both actions taken to deal with disruption in those modes (for example, PATH trains in New York, where two major stations were disabled by the attack), and actions taken to provide assistance to stranded air passengers.

3.3.7 February 2010 and December 2004, US Snowstorms and Systems Failure

Severe snowstorms in several regions of the United States led to 20,000 flights being cancelled (4.2% of the total scheduled) in February 2010. Guarino and Firestine (2010 [77]) discuss this event and its impacts. Over the entire month, weather cancellations are estimated to have cost $80-100 million. The peak day, February 10, saw the complete or near closure of several large Northeastern hub airports and 23% of system flights cancelled. The storms in February 2010 were not individually more severe than those seen in previous years (for example, 2007). Rather, the sequence of storms in 2010 created a stressed system which each additional storm added to, resulting in increasing disruption. Data related to this event is discussed further in Annex 2.

In December 2004, a combination of severe winter weather and the failure of a scheduling system led to severe delays in flights to and from the US East Coast. DoT (2005 [124]) investigates this event, including a discussion of how passenger needs were dealt with (a particular feature of this event was a large number of misdirected bags). The main system problems were: severe weather, in particular ice at Comair's base airport in Cincinnati; the failure of Comair's crew scheduling system, which was related to schedule changes made to handle the severe weather; and staffing shortages at US Airways. This resulted in severe disruption. For example, 87% (3,900) of Comair flights between the 25th and 28th December were delayed or cancelled. Comair's backup plan for failure of the scheduling system involved a highly labour-intensive manual scheduling process which could only support a small number of flights, necessitating the cancellation of nearly all Comair flights. The scheduling software was restored by the end of the 25th, but flight crews and aircraft were out of position and so several days were required to return to full operations.

Although Comair had committed to a voluntary Customer Service Plan which included procedures for notifying customers about delay, baggage delivery, dealing with bumped passengers and ticket refunds, the extent of the disruption compromised its ability to adhere to this plan. Around 200,000 itineraries were affected by cancellations; approximately half of these passengers were informed before reaching the airport. 50,000 of these passengers were notified via an automated system for rebooking which contacts passengers via email or pager. Another 48,000 were called by a Comair or Delta representative. The remaining passengers were informed at the airport, with many not finding out until they reached the head of long check-in queues, or found out by other means. Comair reserved around 2,000 hotel rooms near Cincinnati airport to provide to stranded passengers at a reduced rate for the 22nd and 23rd. Around 900 customers stayed overnight at Cincinnati airport on the nights of the 22nd, 23rd and 24th and were provided with food, bedding and telephone vouchers. However the US DoT received a number of complaints about the inadequacy of these supplies. 11,000 bags were mishandled. Comair's stated goal is to return lost baggage within 24 hours; only 35% of bags met this goal. 90% of baggage was redelivered within 5 days.

In the case of US Airways, an ongoing restructure program (involving wage reductions and mandatory overtime for baggage handlers) together with ineffective plans to offset staff shortages with overtime resulted in severe baggage handling problems at its hub, Philadelphia, during the same time period. A similar problem affected the number of flight attendants available. 72,000 claims for mishandled baggage during the severe weather period were received. Flight cancellations were made as staff realised that capacity was inadequate for the initial schedule. Due to a high volume of calls, US Airways call centres were overwhelmed with only around 55% of calls answered. Customer notification was carried out via US Airways' automated telephone system and at the airport via monitors and agents; customers were allowed to change or cancel flights without penalty and some were provided with vouchers for future travel and/or reimbursed for rental cars, hotels, train tickets and costs incurred as a result of mishandled bags. However, a high level of customer complaints were still received (200% above those in the comparable period for 2003) including many customers complaining that they had not received promised refunds.

3.3.8 Air Madrid Collapse, December 2006

Airline insolvencies present a different set of passenger problems to other sorts of disruption. As the airline (which is usually obligated to help stranded passengers) is not available to help, many passengers are obligated to arrange their own accommodation and/or transport home at their own cost.

EC (2011d [54]) identify 96 airline insolvencies of European airlines operating scheduled services between 2000 and 2010. Whilst most of these were of small airlines, insolvencies such as those of Air Madrid, SkyEurope and Stirling created significant issues for passengers, with more than 10,000 passengers stranded in each case. Protection available to passengers is limited in such cases and large numbers of stranded passengers may result. EC (2011d [54]) estimate average costs incurred by stranded passengers of €796, primarily made up of replacement flights for the journey home. In some cases, but not all, assistance was provided by national authorities or by other airlines (e.g. by the provision of flights at 'rescue fares'), and in some cases the traveller can be reimbursed by travel or credit card agencies. However, currently there is no body which is obliged to help passengers stranded in this way.

Typically, the impact of airline insolvencies on airports is small compared to other disruptive events, although this depends on the specific event (EC 2011d [54]). Stranded passengers are distributed between airports served by the airline, with each airport handling only a proportion of the total. However, if the airport is small or if it is the home base for the insolvent carrier, the impact may be greater. In some cases (e.g. the Air Comet and Air Madrid failures) airports have offered limited assistance to passengers (e.g. providing refreshments) but in general there is no obligation to provide help. However EC (2011d [54]) notes that information provided by airports has been very useful to passengers, particularly where the airline cannot provide information and national authorities have no staff at airports.

3.3.9 Lessons learned from disruption in other modes

Quarmby (2010 [107]) discusses how other modes coped with the snow disruption which affected Britain in 2009 and 2010. Rail and road transport were both seriously disrupted. In particular, Eurostar services suffered serious problems which have some useful parallels to the incidents of airport disruption discussed in this report. They also highlight potential hurdles in organising transportation via alternative modes when those modes may themselves be disrupted. The 2009 breakdown of multiple trains in the channel tunnel, and subsequent suspension of the service for three days, is discussed in Garnett & Gressier (2010 [74]).

Around 90,000 passengers were affected by the disruption. Of these, only a small number were able to travel on the day they intended to; most suffered severe delays or opted not to travel. Around 15,000 passengers made their journey by ferry instead. Many of the problems suffered by delayed passengers were similar to those experienced by air passengers; for example, lack of information, difficulties in getting through to call centres to rebook tickets, confusion over what expenses would be refunded by Eurostar, and high demand leading to a shortage of taxis at stations and hotel rooms near stations.

Plans to book coaches to take passengers to their destinations via ferry crossings of the Channel were made. However, roads on both sides of the Channel were also affected by the weather conditions. For example, no lorries were able to leave the Port of Calais after it opened on Saturday the 19th of December. Snow and tailbacks of traffic waiting to board Eurostar at Dover meant that the UK's M20 motorway was virtually closed. A shortage of available coaches was also experienced, and in some cases passengers were stranded again when coach drivers reached the limit of their available working hours. Eurostar also arranged a number of charter flights to carry passengers to their destinations. However, Charles de Gaulle airport was also operating under capacity restrictions due to the snow. Charter flights were of low priority to the airport, so three of the five planned flights on the 20th of December were not operated. An additional charter flight on the 21st was delayed for a day after the weather-related closure of Stansted Airport. A number of passengers opted to travel by car to cross-Channel ferries, leading to further congestion there and problems with a lack of co-ordination of bus and taxi services at the destination ports.

A number of recommendations were made regarding passenger welfare which are also relevant to META-CDM. These include the recommendation that Eurostar make advance plans with other transport operators about accepting Eurostar tickets in cases of disruption; that plans for transport by alternative modes be made, specifically a coach service to and from cross-Channel ferries; that a 24-hour call centre with sufficient staffing for emergency situations be set up; that the Eurostar website be updated on disruption in real time and that passenger contact via email or text be considered; that there should be more visible staff at stations in crisis situations, and clear, regular and proactive information given over the loudspeaker system; that there is information available on alternative modes of transport and on which expenses Eurostar will refund; and the Eurostar reviews its systems for providing delay information to other train companies.

Quarmby (2010 [107]) notes that many rail companies dealt with the 2010 snow disruption by introducing pre-planned 'snow timetables' concentrating on the most important services. Train Operating Companies (TOCs) are required to produce such timetables in agreement with the track operator Network Rail. However, not all rail companies decided to use these timetables when faced with the December 2010 snow disruption. The evidence gathered by Quarmby (2010 [107]) suggested that early implementation of reduced timetables was key to providing a resilient service against snow disruption. The report suggests communication mechanisms be strengthened between Network Rail and TOCs to facilitate rapid decision-making about reduced schedules and that TOCs relax ticket restrictions in times of disruption. The rail industry also faced problems to do with de-icing and salt provision; similarly to problems faced at airports, mention was made of the need for a clear division of responsibilities for de-icing and salting ambiguous areas (for example, are station forecourts the responsibility of the Highways Agency or the rail industry?). The report noted, however, that the rail industry was generally successful at providing passenger information. For example, the National Rail website coped well with the increase in demand; a project on Passenger Information During Disruption is in place; and TOCs have taken steps to communicate with passengers via a range of channels including email, texting and social media.

4 Passenger perspective

4.1 Shifting the focus of transport operations towards the passenger

Flight delays do not accurately reflect the passenger experience or even the delays imposed upon passengers' full multi-modal itinerary. The growing interest to measure ATM performance calls for metrics that reflect the passenger's experience. Cook and al. [37] design propagation-centric and passenger-centric performance metrics, and compare them with existing classical metrics, with regard to intelligibility, sensitivity and consistency. Their list of propagation oriented metrics comprises: departure and arrival delays, canceled flights, extra flight time, extra gate time, reactionary minutes, back-propagation, reactionary disruptions and their depth. The passenger oriented metrics cover: departure and arrival delays, the ratio of scheduled trip time to final arrival delay, canceled flights, missed connections, re-routes, extra flights, extra flight time, weighted load factor, aborted trips and extra wait time. The authors also identify the top ten critical airports in Europe according to three different network classifications.

In [29], Bratu et al. calculate passenger delay using monthly data from a major airline operating a hub-and-spoke network. They show that disrupted passengers, whose journey was interrupted by a capacity reduction, are only 3% of the total passengers, but suffer 39% of the total passenger delay.

The objectives of Wang [128] are to estimate Air Transportation System-wide passenger trip delay using publicly accessible flight data, and investigate passenger trip dynamics out of the range of historical data by building a passenger flow simulation model to predict the impact on passenger trip time given anticipated changes in the future. The author did not have access to airline proprietary data. Airline data is also protected by anti-trust collusion concerns and civil liberty privacy restrictions. This is an obstacle to a straightforward way of evaluating passenger-centric metrics. The major findings from this research are as follows:

- High passenger trip delays are disproportionately generated by canceled flights and missed connections.
- Trend analysis for passenger trip delays from 2000 to 2006 shows the increase in flight operations slowed down and level off in 2006, while enplanements kept increasing, due to a continuous increase in load factor. Passenger performance is very sensitive to changes in flight operations, with an increase in annual total passenger trip delay in 2006, while flight operations barely grew.

- Route delay is shown to have an asymmetric performance on passenger trip delay in terms of routes and airports. 17% of routes generate 50% of total passenger trip delays. 9 of the busiest 35 airports generate 50 % of the total passenger trip delays.
- Congestion flight delay, load factor, flight cancellation time and airline cooperation policy are the most significant factors affecting total passenger trip delay.
- New system performance measurements from the passenger's view are developed, based on the Estimated Passenger Trip Delay.

Understanding the passengers' preferences is essential in a period of multi-airport regions' growth and intense competition between airlines, whether legacy airlines or low-cost. This is especially the case in regions where the increase in air traffic is most important. Four major competing airports are now located in the Hong Kong-Pearl River Delta region. Loo et al. [95] model the choices of air travelers for international and domestic flights, and describe scenarios of regional airport competition and airport coordination. Their continuum approach offers good results to understand the geography of air transportation, with possible simultaneous changes in variables. These variables comprise average propensity to travel, spatial distribution of air travelers, regional inflows and outflows of passengers, ground transportation infrastructure capacities, number and physical location of airports, ground transportation cost, congestion effect, cross-border cost, airport Level Of Service (LOS) and government's aviation policy. Later, Loo [94] identifies the determinants conditioning why passengers choose an airport over another within the same multi-airport region. Using stated preference data, the most important airport LOS attributes are air fare, access time, flight frequency and the number of airlines. In comparison, the number of airport access modes, access cost, airport shopping area and queue time at check-in counters were not significant. Slight differences are noted between long, medium and short haul, business or leisure passengers.

The needs and priorities of passengers once inside the terminal are hard to quantify. Correia et al. [40][41] study LOS measures for airport passenger terminals. They combine user perceptions and regression analysis to derive quantitative relationships and provide an illustration at Sao Paula Guarulhos International Airport. 119 passengers were interviewed. The following components are evaluated: emplaning curbside, ticket counter and baggage deposit, security screening, departure lounge, circulation areas and concessions. A similar effort regarding transfer passengers was carried at Banadaranaike International Airport in Sri Lanka, an international hub from Europe to South Asia and India. This research identified the factors that most mattered to improve the transfer passengers' experience.

Airports provide aeronautical and non-aeronautical services. Commercial activities are essential to the sustainability of many airports. Torres et al. [122] show that passengers' waiting times to board influence their possibilities for consumption. They also distinguish patterns specific to business and leisure travelers. Popovic et al. [105] examine how activities influence people's experiences in the airport, as part of a larger project to investigate passenger experiences and interactions with information, services, processes, equipment and technology at the airport. The macro-level encompasses the overall passenger flow at departure, including entering the terminal, check-in, security, customs and boarding. The micro-level focuses on passenger interactions at the domain level, such as the check-in counter, currency exchange, security check and discretionary activities.

Ma et al. [96] tackle the problem of simulating and understanding passenger flows to predict future capacity constraints and level of services. Their work uses agent-based models to simulate advanced passenger traits to enable detailed modeling behaviors in terminal buildings, particularly the check-in areas. Their scenarios demonstrate the progression of adding self-service check-in use, use of cafe, information and phone booth, based on passenger' comfort with technology, hunger, travel frequency. The simulations show a spread of passengers in the space and the peak check-in queuing times, which can be reduced by spreading passengers amongst the full range of facilities. Passengers also show more instantaneous utilization of the departure hall area than when only check-in is simulated.

4.2 Impacts of flight delays on passengers behaviour

Flight delays have a direct impacts on airlines operating costs; with an average additional cost of 72€ per minute (Cook, Tanner, & Jovanović, [38]); they may also have non negligible indirect impacts on a longer term on their passenger demand for travel.

When studying the behavioral consequences of repeated flights delays on airlines, Ferrer and Al. [72] analyze the effects of flight delays on passengers' future purchasing behavior. Their model, applied to flight data from a major international company on a 20 months period, shows the following results:

- Passengers who experienced delays tend to travel less with that airline than passengers who didn't experience any delay,
- The impact on the passenger future demand of travel is more important when the passenger experiences multiple delays: passengers who experience multiple delays travel less by air than passengers experiencing only one delay,
- The negative impact of delays on passenger demand persists during the entire period studied: passengers do not forgive the company for their delay experience.

However, if the bad experience of a passenger when experiencing flight delays can affect his/her future demand of air travel, another reason mainly explains this effect: the increase in airline fares. Britto et al. [30] demonstrate that flight delays lead airlines to increase their fares (in order to cover their operating cost increase) which has a negative impact on their passengers' demand. To summarize, after experiencing delays with an airline, passengers combine a decreased willingness to pay for air travel with increased air fares [134], which lead them to reduce their air travel demand to this airline.

If these findings tend to show that experiencing delays affects the passenger demand to airlines, it is also important to note that it also may affect the airport choice. Gelhausen [76] analyses the effects of limited airport capacity on air travelers' airport choice. By taking the region of Stuttgart in Germany as case study, Gelhausen shows that the airport accessibility, the number of destinations as well as the weekly flight frequencies play an important role in the airport attractiveness; the level of airport capacity constraints (impacting the passengers in terms of flight delays) is also an important factor considered by air passengers in their airport choice. This study indeed shows that an airport B initially less attractive in the region than an airport A (because of its location, its accessibility or because of its flight schedule), increases its attractiveness and as a consequence its traffic level if the airport A is congested. Capacity constraints therefore impact the air travel demand served at other airports of the region and consequently may potentially lead to new capacity constraints in these airports.

If all these studies highlight the change in travelling behavior of air passengers resulting from flight delays, they do not address the particular impact of flight delays due to disruptive events. Such events are not related to the behavior of one airline at one airport. In other words these studies do not study the potential impact that disruptive events can have on future air travelers' behaviors. The literature on this subject is not very developed yet.

4.3 Performance Indicators for Passenger Satisfaction

4.3.1 Satisfaction performance parameters used in praxis

The current methods used for assessing aviation system performance typically focus on metrics more relevant to airports and airlines than to passengers (for example, number of aircraft delayed rather than number of passengers delayed). As discussed above, the META-CDM project takes a passenger-centric approach and so the concept development stage of the project needs to be assessed via more passenger-centric metrics. However, passenger-centric quality criteria do exist, particularly in other modes of transport. This section discusses metrics which are in use currently and could be adapted for use within META-CDM. The European norm EN 13816:2002 [66] defines quality criteria connected to passenger satisfaction and a quality assessment procedure for assurance of these criteria. Eight criteria for quality are defined:

- Availability,
- Accessibility,
- Information,
- Time,
- Customer Support,
- Comfort
- Safety and
- Environmental Impact.

Directly connected with the norm EN 13816:2002 [66] is the presentation "DIN EN 13816 and its Implementation by DB Regio (German Railways, Regional) [83] form Dipl.-Ing. Hinrich Brümmer. It deals with "Instruments to measure and appraise quality of services in rail-bound passenger transport" and how it is implemented by DB Regio. The presentation provides an overview on the implementation of the constant quality assessment procedure which includes measuring the subjective customer satisfaction as well as the objective production of service. The customer satisfaction is measured by interviewing passengers and provides together with the monitoring of the objective quality an assumption on the actions for improvement.

A similar approach for quality assurance is described in chapter 2 of the Local Traffic Plan 2008 of the region Hannover [102]. Like DB Regio, the local traffic companies ÖPNV and SPNV of the region Hannover use the quality assessment procedure defined by EN 13816:2002. The performance of the provided service and the satisfaction of customers is constantly measured and weighed up against the costs for improvement of the service.

The Gallup Organization used slightly different quality criteria for its survey on passengers' satisfaction with rail services [73], which are mostly a sub-set of the quality criteria defined by the EN 13816:2002. The survey was conducted in June 2011 at the request of the Directorate-General Mobility and Transportation. The following criteria for measuring the satisfaction with various features of railway stations were used:

- Access to tickets

- Provision of information about train schedules / platforms
- Security in the station
- Connections with other modes of public transport
- Cleanness / good maintenance of station facilities
- Quality of the facilities and services (e.g. public lavatories, shops, cafes, etc.)
- Facilities for car parking
- Easy and accessible complaint handling mechanism

The criteria for measuring the satisfaction with various features of trains and train services used in the survey were:

- Security on board
- Journey time
- Comfort of the seating area and sufficient capacity for passengers
- Punctuality / Reliability
- Availability of staff
- Connections with other train services
- Cleanliness and good maintenance
- The provision of information during the journey, in particular in case of delay
- Assistance and information for disabled or elderly people in station and in rail cars

Another source of information is the National Rail Passenger Survey that is conducted in the UK. Over 50,000 passengers are consulted each year [20], [21], [22] [23] [24]. The Western Australian Department of Transport conducts an annual survey concerning satisfaction with bus transfer simply called "Passenger Satisfaction", e.g. [114].

Criteria observed are:

- Overall satisfaction

- Access to ticket purchasing facilities
- Staff experience and kindness
- Journey duration
- Punctuality

For the American Customer Satisfaction Index (ACSI), see www.theacsi.org, regular surveys are undertaken on customer satisfaction. Because the results that are publically available are of a more general nature, e.g. a certain area is expected to grow by a certain percentage, they are not deemed to be useful for META-CDM WP100 and WP200, but they may be interesting for weighing proposed investigations in WP300.

4.3.2 Satisfaction performance parameters used in R&D

Passenger-centric quality criteria are also subject of a number of R&D studies. Some of them relate directly to the norm EN 13816:2002 [66], like [123], [48] and [2]. The integrated project CityMobil [34] within the sixth framework programme of the European Commission performed a study that aimed at the "Identification of the Key Parameters affecting Passenger and Operator Satisfaction with the Heathrow Pilot PRT Scheme, and the Key Benefits Anticipated". It included three demonstrations of advanced transport systems for Heathrow Airport in London, UK. Success of a demonstration was determined by following targets:

- better quality of service than the alternative shuttle buses,
- more reliable operations,
- more safe and secure operations,
- environmental friendliness, in terms of minimum emissions of pollutants, greenhouse gases and noise (deemed as very important),
- higher preference by passengers compared to the alternative bus system,
- operates at the predicted operating cost,
- extendable at the projected infrastructure costs,
- flexible in the way that it can be extended with minimum disruption to operations during construction and

- provision of an exciting and technically advanced image for the airport.

For standardizing the evaluation of their results the study referred to the two projects CONVERGE [35] and MAESTRO [97] within the fourth framework programme (FP4) of the European Commission and to the project HEATCO [81] within the sixth framework programme (FP6).

In his work “Customer Satisfaction in local transport considering safety sensation” [123], Ulf Schulze-Bramey refers to the quality criteria defined by the DIN EN 13816:2002-07 with focus on the safety aspect. He points out that the individual safety sensation of customers becomes more relevant due to mega events leading to large crowds of people and criminal acts that diminish the perceived safety even if the person is not directly affected by the criminal act (e.g. seeing the criminal act in the news). At some airports long distances have to be travelled by the customer to reach the train and/or bus connections, which will affect the customer satisfaction. Additionally, some train and/or bus stations do not appear comely compared to the terminal(s) of the airport, which may affect the willingness of passengers to use them as alternative transport modes.

Yannis Tyrinopoulos and Georgia Aifadopoulou from the Hellenic Institute of Transport / Centre for Research and Technology Hellas on Thessaloniki in Greece proposed “A complete methodology for the quality control of passenger services in the public transport business” [130]. The methodology is based on 39 indicators classified in seven major categories. These seven major categories are:

- Safety – Comfort – Cleanliness,
- Information – Communication with the passengers,
- Accessibility,
- Terminals and stop points performance,
- Lines performance,
- General elements of the public transport system and
- Compound indicators consisting of customer satisfaction, vehicle scheduling performance and easiness in the tickets purchase and validation.

In her work “Application of the customer satisfaction index (CSI) to transport services” [2], Adela Poliaková demonstrates how the customer satisfaction index as described in the norm

EN 13816:2002 [66] can be used to measure the quality of service. In her work Dr. Angelika Klein [48] deals with the problem of how the quality of service can be improved or at least kept at the same level while at the same time the budget is shortened. The author points out that incentive must be installed in a way that improving quality becomes a rewarding goal. Dr. Angelika Klein investigates on the balancing of improving quality and the costs for doing it. She favors the KANO-model, as discussed in [26] for example, to collect feedback from customers in surveys.

The company DKMA, Airport focused research & advisory services, gives as example following KPIs for measuring current satisfaction of passengers [44]:

- Availability of parking
- Baggage carts
- Waiting at check-in
- Courtesy of check-in staff
- Waiting at security
- Ease of finding your way
- Flight information screens
- Helpfulness of staff
- Shopping
- Restaurants
- Internet access / wi-fi
- Business lounges
- Availability of washrooms
- Cleanliness of washrooms
- Comfort of gate areas
- Cleanliness of airport
- Speed of baggage delivery

In [108] Quartapelle and Larsen state that in a market, where the range of products or services becomes more and more similar, differentiation can and should be done through improving customer satisfaction. This will improve the customer loyality which is an important target for each airline (e.g. “Miles & More” program). It is stated that the customer has twelve desires:

- Reputation,
- Credibility,
- Communication,
- Reactivity,
- Courtesy,
- Accessibility,
- Reliability,
- Safety,
- Appearance,
- Cleanliness,
- Comfort and
- Ability to solve problems.

There are many more studies concerned with customer satisfaction that were inspected for this survey. Not all studies were included, because many are not deemed to be fitting for META-CDM.

5 Concluding remarks: Preliminary selection of airports for the second stage of META-CDM

In the second stage of the META-CDM project, a targeted series of interviews and questionnaires will be carried out at airports and airport stakeholders affected by disruption to assess how CDM techniques can help address the passenger experience (as measured by the KPIs discussed in Section 5) under disrupted conditions. Appropriate airports are those which have experience of at least one type of major disruption, and preferably multiple types; which have implemented or may be considering implementing CDM; and for which the META-CDM team have existing contacts, facilitating the interview organisation process. It is also instructive to gather information from airports with a wide range of conditions – for example, hub and spoke airports; capacity-limited airports and those with room to accommodate extra flights; different airports serving the same city; airports with different levels of ground transport connections; and airports in different geographic regions.

Importantly, the emphasis of WP200 will be upon the passenger experience and the potential to extend A-CDM beyond the normal aviation participants in CDM. As will be seen from this report, understanding and analysis of conventional CDM amongst airports, airlines and ANSPs is reasonably mature so the main issue to explore is how the wider network operates in crisis situations. As a result, the role and experience of ground transport operators, authorities, emergency services and providers of support services to airports will be key to the next stage. Additionally, the way that all of these interface with airports and are involved in the planning and decision-making processes will be important. The airports selected above represent have significant operational dependency and connectivity with wider communities and between each other. It is intended to understand better how crisis events spread through the airport system and the extent of wider communication beyond an airport's own immediate network functions. This applies both in the case of planning and contingency arrangements as well crisis management and mitigation.

The essence of WP200 is upon questionnaires and interviews. An electronic survey submitted to a wider airport audience than those noted above will draw out views from across the world and this will be supplemented and extended through more in-depth work concentrating on the airports listed above. This work package will also report upon and extend the initial survey questions that were put to attendees participating in the first META_CDM workshop in January 2013. More details on the interview process and the final selection of airports will be given in the META-CDM final report for Work Package 200.

With the benefit of accumulated knowledge from the literature survey and survey/interviews, Work Package 300 will set about the design of a new concept of operations for CDM that embraces a wider network of stakeholders and provides for greater resilience in crisis situations from the passenger perspective. Key to this work will be working out what could be changed from an airport operational, multimodality and legislative perspective to improve resilience and how to improve the passenger experience in terms of communication, delay time and contingency offerings for journey connectivity and achievement. Ways will be sought in which to bring together better airside and landside operations in multimodal CDM. This will include looking at technologies that would facilitate this transition but accounting for risks, barriers and costs of broadening the field of CDM operation.

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Table 3: Referenced Documents

Annex 1: Individual disruptive events from the Eurocontrol NOR reports (2008-2012)

Eurocontrol NOR reports are publically available from 2008 (Eurocontrol, 2013a), and CODA delay digests are available from 1998 (Eurocontrol, 2013b). These list important disruptive events affecting the European aviation system. These events are interesting from the META-CDM perspective both as a way of assessing the relative frequency and impact of different types of disruption (see Annex 3) and to allow a set of representative airport/event combinations to be defined for further investigation in the interview stage of META-CDM.

Eurocontrol NOR 2012

The major disruptive events of 2012 were:

- Widespread strong winds and low visibility on the 5th, and widespread snow from the 27th January. This affected Istanbul, Amsterdam, London Heathrow, Zurich, Munich and Oslo amongst others.
- En-route delays at Malmo due to the implementation of the COOPANS ATC system (January)
- Apron and marshalling personnel strike at Frankfurt between the 16th- 19th February, and non-ATC personnel strike on the 29th March.
- ATC Strikes in France on the 28th and 29th February (responsible for 60% of system delay on the 29th)
- ATC strikes at Nicosia on the 3rd and 8th March (Nicosia also had ongoing capacity problems, potentially exacerbating the impact of disruption there, until a fourth sector was implemented in September 2012).
- Low visibility conditions at London Heathrow, Munich, Paris (Orly and CDG), Amsterdam and Brussels on the 1st and 2nd March.
- French industrial action between the 2nd – 4th April. This led to 400,000 extra delay minutes and around 5,000 cancellations.
- Long delays at Tirana on the 3rd April due to a new ACC implementation.
- Thunderstorms on the 20th May affecting various ACCs and airports in France, Germany and surrounding regions, on the 21st June affecting London, Zurich and Paris, and on the 29th June affecting various German airports. There were also ten days in July and three in August with average delay per flight above 2 minutes, primarily due to thunderstorms .

- Weekends in June and July, particularly the 30th June, were affected by ATC and airport capacity and staffing delays. Oslo ATCC was particularly affected. These capacity issues meant that other sources of disruption (e.g. thunderstorms) had a greater effect than they otherwise would have.
- Systems failure at Langen and Munich ACCs on the 6th July.
- Disposal of a World War II bomb at Amsterdam Schiphol on the 29th August.
- Lufthansa cabin crew strike on the 31st August, affecting mainly Frankfurt; also on the 4th and 7th September, leading to around 1000 flight cancellations.
- The London 2012 Olympics did *not* cause disruption; in fact, delays at London ACC in August were lower than in the previous year even though traffic in London TMA was increased by 3.5%. This was due to good preparation, e.g. full staffing at London ACC and Maastricht UAC.
- Power failure leading to loss of secondary radar coverage in Greece on the 29th September, leading to 36000 extra delay minutes, around 300 flight cancellations and a further 200 flights rerouting around Greek airspace.
- Industrial action in Greece affecting ATC staff on the 26th September (200-250 flights cancelled, 4700 minutes of extra delay) and the 18th October (no cancellations, 1403 minutes of extra delay).
- Industrial action in France on the 22nd-24th October, leading to 70000 extra delay minutes.
- Indirect impacts of Hurricane Sandy on the 28th-30th October; around 1000 North Atlantic flights were cancelled.
- Low visibility in the London area and at Munich, Zurich and Frankfurt on the 20th October, with high weather delays at major airports continuing to the 23rd October.
- The European general day of industrial action on the 14th November. This resulted in around 1500 cancellations in Spain, Portugal and France.
- Industrial action at Marseille ACC on the 15th November (around 49000 delay minutes and 250 cancellations), combined with fog in London, Geneva and Amsterdam.
- Flight rerouting at Tel Aviv/Ben Gurion airport from the 17th to the 23rd November to reduce flight risks from rockets fired from Gaza, leading to capacity restrictions.
- Widespread snow on the 7th December. Affected airports included Amsterdam, Geneva, Dusseldorf and Frankfurt. On the 9th December snow affected Frankfurt, Munich and Copenhagen and strong winds affected Amsterdam and London Heathrow.
- There were also several planned disruptions in December to trials of new ATM systems, e.g. VOLMUK at Karlsruhe and Munich ACCs , reducing capacity in the 7-10th December by 25%.

Eurocontrol NOR 2011

Here the main problems at the most affected airports were weather and infrastructure upgrading works (particularly at Frankfurt) and capacity issues at holiday destinations during the summer (particularly at Kos and Zakinthos).

Specific disruptive events noted in the 2011 NOR included:

- Social difficulties in Greece (staff availability, social unrest, rerouting of flights to avoid Greek airspace – particularly July, August, September, October) . As a result, traffic was pushed into Turkey and Bulgaria, leading to capacity problems. Specific strikes occurred on the 11th May, 28-29th June, 22nd September and 5th October, with 340, 700, 227 and 825 flights cancelled respectively. Increased delay totals were 2336, 37065, 7000 and 9600 minutes respectively and for the second strike 4850 extra minutes of delay in Albania and Croatia also resulted.
- Adverse winter weather, particularly at Frankfurt, Amsterdam, London Heathrow
- VAFORIT implementation in Karlsruhe UAC (January-February)
- New paperless strip system in Munich ACC (March-April)
- Reconfiguration of airspace (Langen ACC, March)
- Closed airspace due to the Libyan conflict. This also led to travellers changing their holiday destinations from North Africa to other areas (e.g. Spain) leading to greater-than-expected demand and delays there.
- Implementation of new ATC system at Oslo airport (April)
- Industrial action in Italy (6th May, partially cancelled, 6th September, and 17th November). This led to 400 fewer flights in Italy and 2114 extra minutes of delay in the first case, 1100 fewer flights and 7300 extra minutes of delay in the second case, and 160 fewer flights and 1600 minutes of delay in the third.
- Industrial action in France (31st May and 10-12th October). No flights were cancelled but 18000 and 51300 extra minutes of delay resulted respectively. For the second strike 810 extra minutes of delay also affected Spain.
- Eruption of Grimsvötn volcano (23-24 May), leading to 1200 fewer flights in Scotland and Germany. Due to flight planning restrictions there was no increase in delays.
- Belgrade ACC implementation of FAMUS system (May)
- New tower and runway at Frankfurt Airport (June, 21st October)
- Demand exceeding agreed airport capacity limits (particularly Greek island airport during the summer; new systems were implemented in 2012 reducing this delay)
- Two-day closure of Warsaw airport (November). This led to the cancellation of 650 flights, but no extra delay.

- Portugese strikes on the 23-24th November. These led to 892 fewer flights in Portugal, 400 fewer in Madrid, but 200 extra flights in Seville. No extra delays occurred in Portugal, but delay was increased by 6360 minutes in Spain.
- Technical failure at Lisbon ACC with OLDI links to Morocco (December)
- Capacity limitations imposed on Ankara ACC by Baghdad FIR (December, continuing into January 2012)

Eurocontrol NOR 2010

2010 was a year of significant disruption. Although less detail was given in the NOR than for later years, the major disruptive events included:

- Numerous ATC strikes, affecting Madrid, Barcelona, Paris and Brussels amongst other airports.
- Technical radar failure in Lyon (May).
- Greek industrial action in July.
- Storms in early summer, particularly affecting Spain.
- The eruption of Eyjafjallajokul from the 14th April, leading to the grounding of most flights in Western Europe between the 25th and 21st April with an estimated 101127 cancellations. This was the most significant disruption to European airspace ever. A second eruption from the 3rd of May caused further disruption to Irish, UK, Spanish, Portuguese and Moroccan airspace.
- Closure of Warsaw airport for three consecutive weekends in September for runway maintenance. Flights were diverted to other Polish airports.
- Significant snowfall in December, leading to an estimated 46856 flight cancellations.

CODA delay digests 2009

The NOR is not directly downloadable for 2009, but CODA delay digests per month are available.

- January saw weather-related delays affecting London, Paris, Frankfurt, Munich, Brussels, Vienna, Geneva, Milan, Madrid and Istanbul. There were aircraft incidents at Pisa and Charleroi airports, a strike of security staff in Budapest and industrial action in France, Greece and at Milan airport.
- February saw heavy snowfall affecting Paris, Munich, London, Frankfurt, Istanbul, Zurich and Berlin. Turkish Airlines flight 1951 crashed in Amsterdam, there was an accident on the runway at London City and oil on the runway at London Gatwick. There was industrial action in Greece.

- In March there was a national strike in France. Strong winds caused single runway operations in Brussels, Rome and Istanbul, there were security alerts at Aberdeen and London Gatwick and an aircraft incident on the runway at Maastricht.
- April saw the failure of the check-in system at London City and the implementation of a paperless strip system at Bremen ACC.
- May saw ATC industrial action at Athens, Stuttgart, Paris Orly and Marseille, an aircraft incident at Catania, and construction work at Athens and Palma de Mallorca.
- In June there was construction work at Pisa and Paris Orly (continuing to July), a WWII bomb alert at Dusseldorf, and emergency landing at Stockholm Arlanda and radar failure at Stockholm.
- In July there was a computer failure at Vienna ACC; security alerts at Madrid Barajas and Palma de Mallorca; and an aircraft incident at Berlin Schönefeld.
- In August there was runway damage at Manchester, disruption from a firework display in Ibiza, a power failure at Goteborg ACC and ATC equipment problems at Pisa, Ankara and Charles de Gaulle ACCs.
- In September there was severe flooding at Istanbul and severe weather delays at Frankfurt, as well as more minor weather delays elsewhere. German airports were affected by an airline IT failure, and there was an aircraft incident at Naples.
- In October there was a public sector strike at Bordeaux and Brest ACCs, industrial action at Basle/Mulhouse and various technical issues, including radar failure at Shanwick OACC.
- In November adverse weather affected various airports; a new paperless system was introduced at Bremen ACC; there was a tower evacuation at Prague; and aircraft accidents at Pisa and Cannes Mandelieu.
- In December there were extreme cold weather conditions across Europe, resulting in widespread disruption. Radar failure affected Zakinthos, there was a power failure at Stavanger ACC and runway lighting failure at London Luton.

Eurocontrol NOR 2008

Weather delays were significant in 2008, with London, Amsterdam, Karlsruhe and Munich being most-affected. Delays related to special events were also higher than in previous years. Although less detail was given in the NOR than for later years, the major disruptive events included:

- B777 incident at Heathrow on the 17th January. This led to the cancellation of over 400 flights over the following four days and 70000 extra minutes of system delay – on the 17th the average delay per arrival at Heathrow was 80 minutes.

- System maintenance delays following the implementation of a new ATC system in Copenhagen ACC during January-April.
- Strong winds in Amsterdam, Frankfurt, Munich combined with capacity problems on the 1st March; system delay was 152056 minutes.
- The upgrading of Turkey's ATC system in the second half of April.
- Euro 2008 in Switzerland and Austria in June. The 2008 NOR gives details of how this event was planned for; its handling was considered very effective.
- Thunderstorms in Frankfurt and Munich and radar problems in Dublin on the 11th July, leading to 183338 system delay minutes.
- Transition to new ATC system/systems failure in Istanbul on the 20th June (combined with capacity issues and bad weather elsewhere, leading to 153547 system delay minutes)
- Two ATC equipment problems in July at Heathrow – on the 25th system delay was 180963 minutes but there were also capacity and staffing problems elsewhere.
- The crash of Spanair Flight JK5022 at Madrid Barajas on the 20th August 2008.
- Introduction of the new FDPS system at Maastricht in December. Special event measures were introduced during the transition resulting in a total extra delay of less than 100000 minutes (considered 'relatively low').

Other delay events were primarily related to demand exceeding capacity rather than disruption from outside the aviation system.

Annex 2: Individual disruptive events in US OTP data, 2008-2012

The US on-time performance (OTP) database is freely downloadable (BTS 2013). Data on delay causes is also available from 2003. Days with high disruption can be identified primarily by high numbers of cancellations. Figure 1 -Figure 6 show OTP data for 2008-2012, with days on which over 1000 cancellations took place highlighted. As well as the years examined in detail there are two events of interest in earlier years. These are the North-Eastern US/Canada electricity blackout of 2003, affecting flights from the 14th August; and flight disruptions from the 22nd-27th December 2004, which were caused by a combination of weather and the failure of a scheduling system (a full report is given in DoT, 2005).

OTP 2012

Delays, cancellations and diversions by date for 2012 are plotted below.

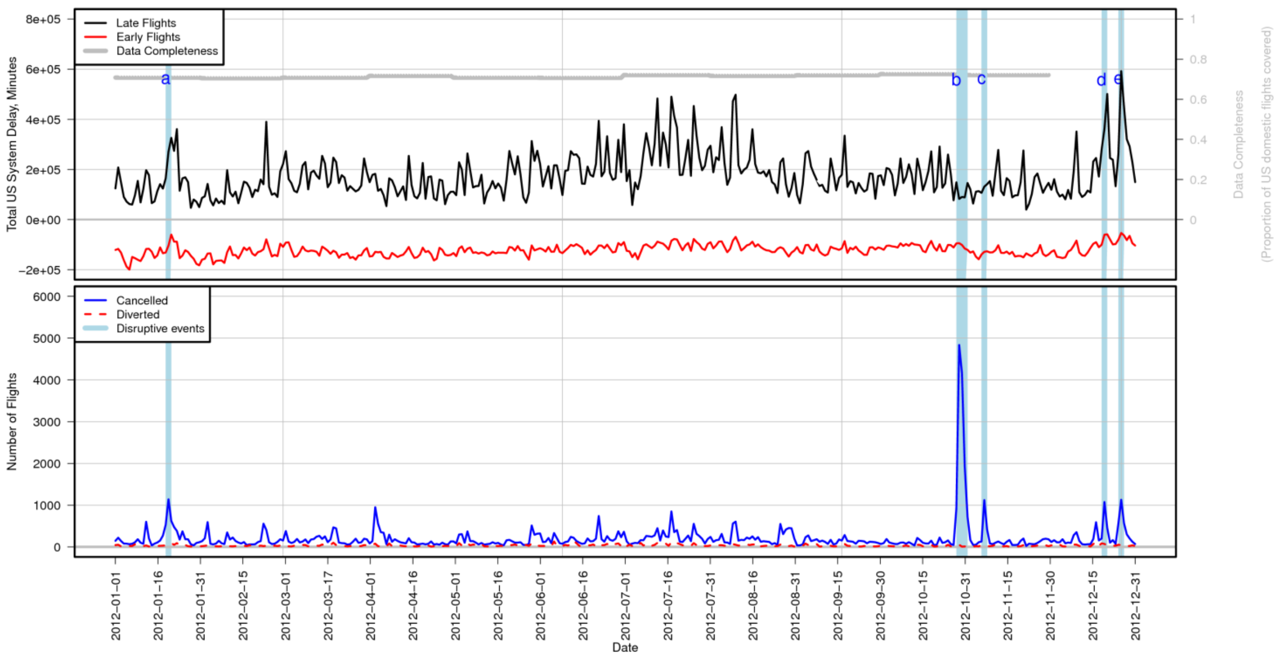

Figure 1. Delays and cancellations in US OTP data for 2012, identifying major disruptive events.

The labelled events in the figure above are as follows:

- **a:** 20th January 2012; Snow/ice storm in Washington State.
- **b:** 29-30th October 2012, Hurricane Sandy.
- **c:** 7th November 2012, storms/low visibility in North-East.

- **d:** 20th December 2012, winter storm in central US.
- **e:** 26th December 2012, winter storms in Southern/Midwest/Eastern US.

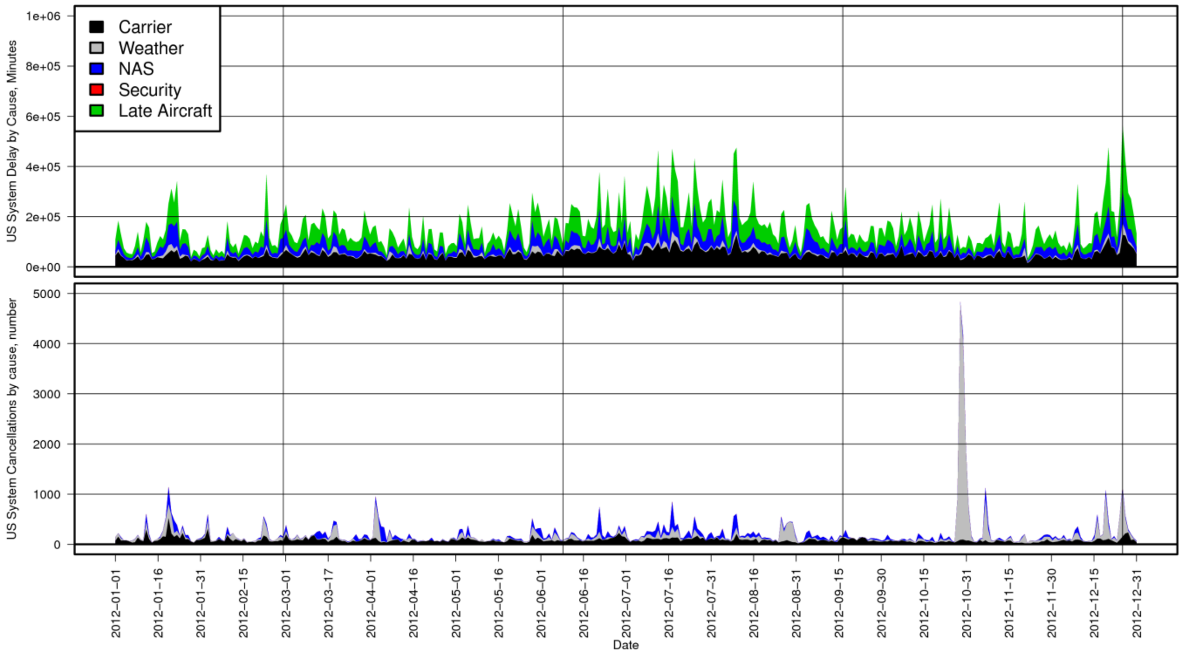

Figure 2. As for Figure 1, but showing the cause of delays and cancellations.

The corresponding breakdown into delays and cancellations by cause is given above; this shows that weather is the primary reason for most of the specific disruptive events causing cancellations in the OTP data. Delay causes are attributed at arrival rather than departure (note that this differs from the Eurocontrol data). Secondary delays are marked 'late aircraft'.

OTP 2011

Delays, cancellations and diversions by date for 2011 are plotted below.

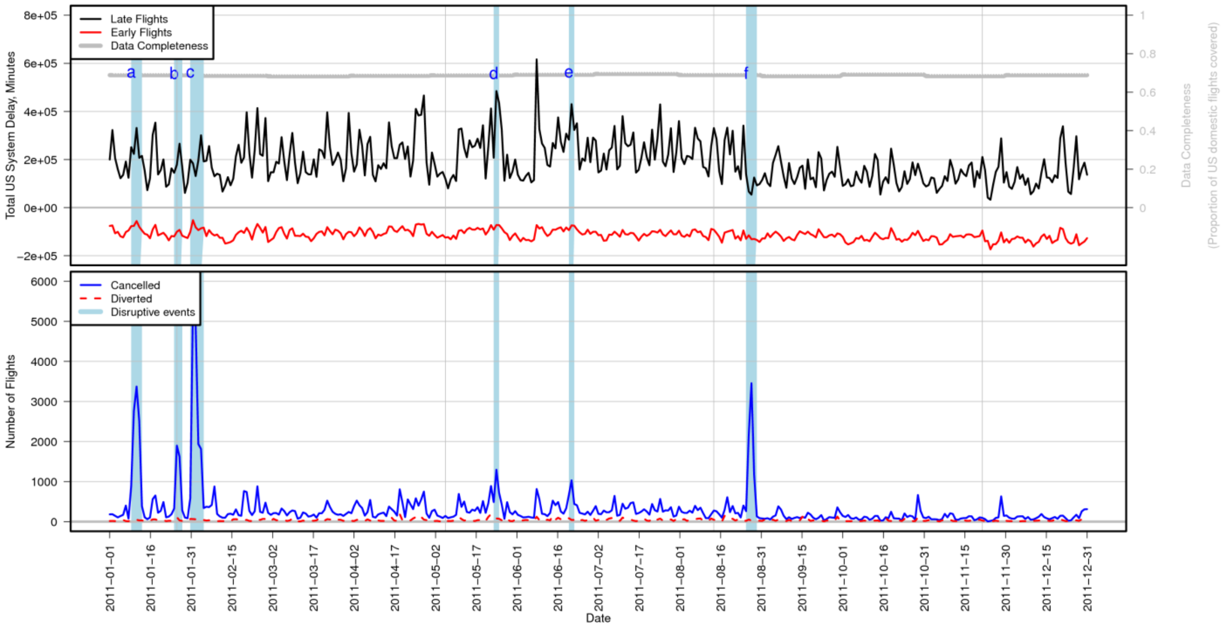

Figure 3. Delays and cancellations from the OTP database for 2011,with major disruptive events highlighted.

Major labelled events in the figure above are as follows:

- **a:** 10-12th January 2011; Ice storm in South-East.
- **b:** 26-27th January 2011, Nor'easter/winter storm in New England.
- **c:** 1st-4th February 2011, "Groundhog day blizzard".
- **f:** 27-29th August 2011, Hurricane Irene (East Coast).

Other events are weather-related.

OTP 2010

Delays, cancellations and diversions by date for 2010 are plotted below. The major labelled events in the figure below are as follows:

- **a:** 7th January 2010, snow and low visibility in the MidWest.
- **c, d, e:** 5-7th, 9-12th and 25-26th February 2010, major snowstorms; 4.2% of all flights for February were cancelled (Guarino & Firestone, 2010)
- **h:** 25th – 28th December 2010, snow and strong winds, East Coast.

Other events are weather-related.

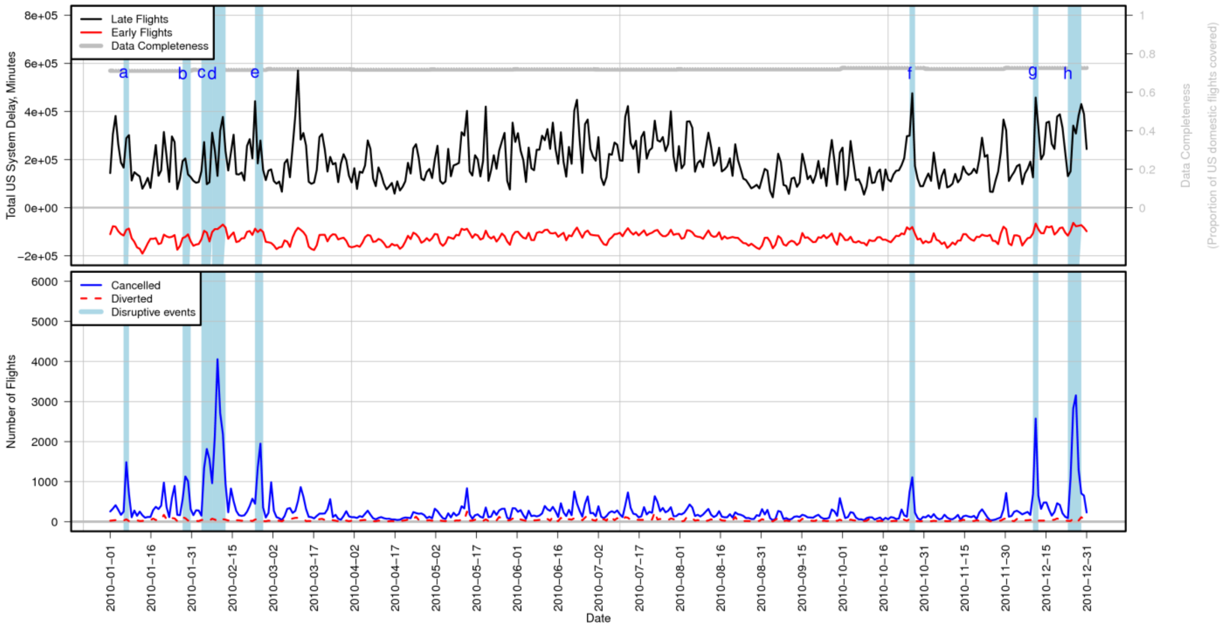

Figure 4. Delays and cancellations from the US OTP database for 2010, with major disruptive events highlighted.

OTP 2009

Delays, cancellations and diversions by date for 2009 are plotted below.

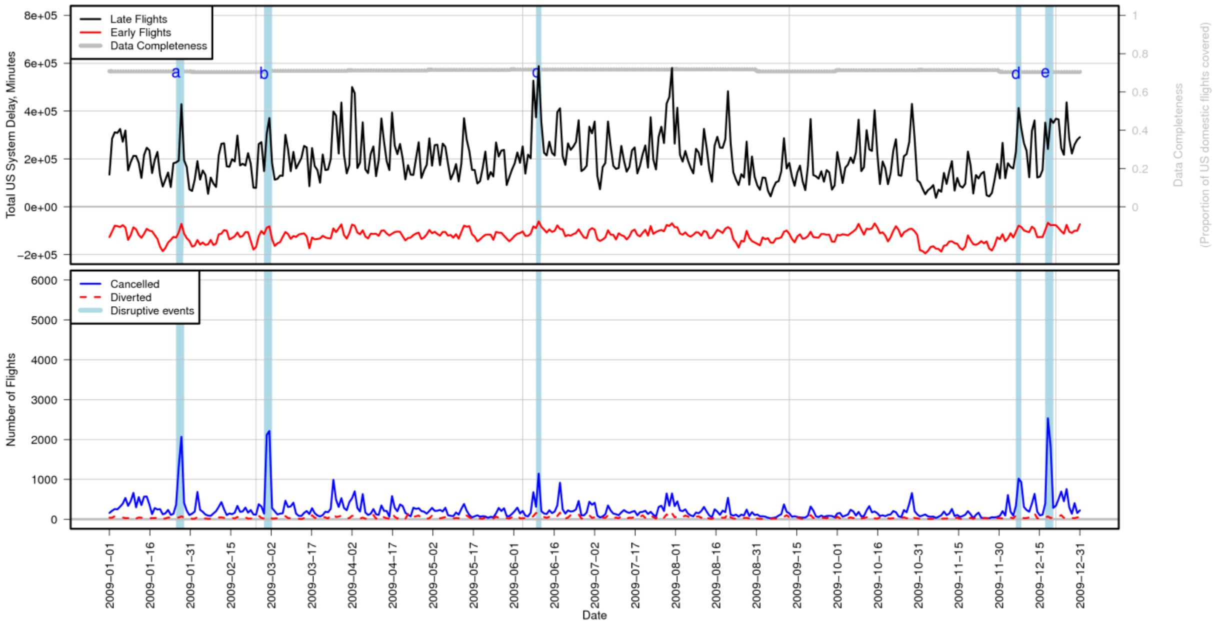

Figure 5. Delays and cancellations from the US OTP database for 2009, with major disruptive events highlighted.

Major labelled events in the figure above are as follows:

- **a:** 27-28th January 2009, weather, including ice storm in Dallas.
- **b:** 1st-2nd March 2009, heavy snow on East Coast.
- **c:** 11th June 2009, convective weather in Colorado.
- **e:** 19th- 20th December 2009, snowstorm in North-East.

Other events are weather-related.

OTP 2008

Delays, cancellations and diversions by date for 2008 are plotted below.

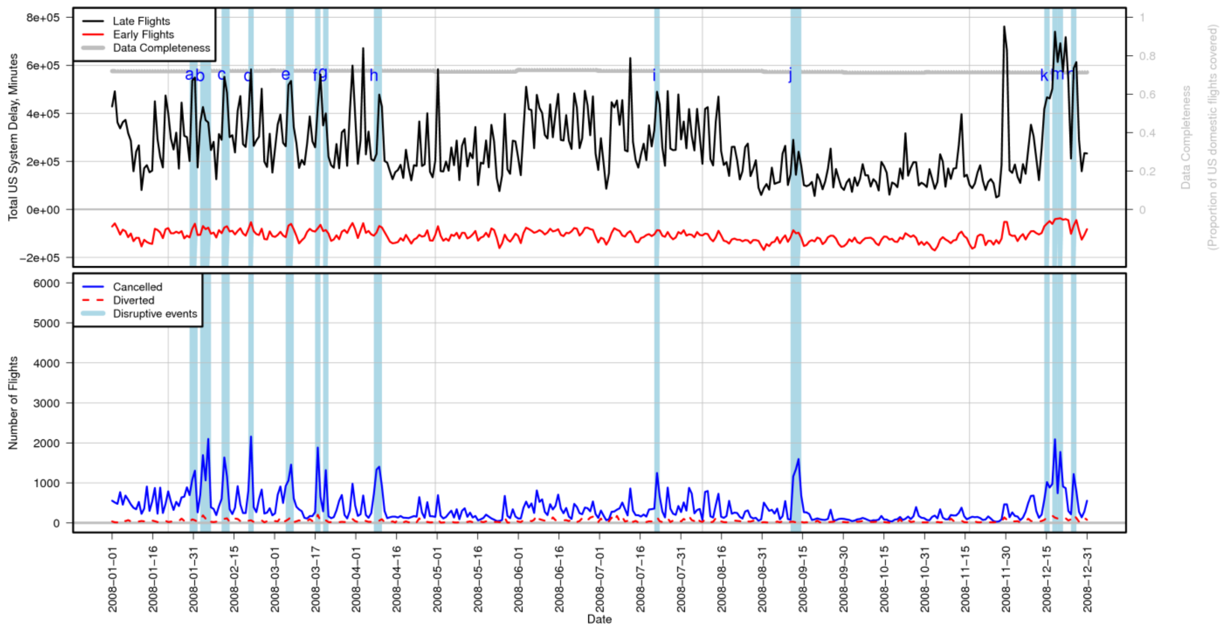

Figure 6. Delays and cancellations from the US OTP database for 2008, with major disruptive events highlighted.

Most events are weather-related, but of particular interest is **h**. On the 9-10th April 2008, the FAA grounded the MD-80 fleet for not meeting specifications, leading to widespread delays for carriers still using MD-80s (e.g. American).

Annex 3: Relative impact of different types of disruption

The Eurocontrol NOR and CODA reports give qualitative discussions of disruptive events per month. For major events, the impact in terms of delays and cancellations is also noted. The most common sources of disruption in the NOR reports are weather (particularly snow, fog and thunderstorms), strikes and planned infrastructure upgrades. The largest single disruptive event is the 2010 volcanic ash cloud.

Table 4 shows the number of mentions of different disruption types in the 'Significant Events' Eurocontrol CODA Delay Digest for the ten years from January 2003 to December 2012. This does not provide an exact indicator of the frequency of different event types; for example, the impact of weather is underestimated, as multiple weather events of the same type during one month may still only get one mention. However, it provides an approximate indicator of the relative frequency of each type of disruption in Europe. Only the impact of disruptive events on Europe is considered (thus the impact of Hurricane Sandy is minor). Capacity and staffing problems (both enroute and airport capacity) are assumed part of everyday delay-generating events rather than disruption; it should be noted that capacity problems are a major source of delay. The range of noted impacts is also given, where noted in the CODA delay digest or (for years after 2007) in the corresponding NOR report.

To roughly compare the impact of different types of event, we define an impact metric

M = (number of mentions) x (cost of delays and cancellations for most severe event)/10^9

where the cost of delays and cancellations is taken from Eurocontrol (2012 [59]); see 'Costing Delays and Cancellations' in Annex 4. The most severe event used is the one for which the combined cost of cancellations and delays is highest out of those events for which this data is provided (either in CODA or NOR reports or via press releases). As data is not provided for all events, in many cases these are likely not the most severe events that occurred over the entire ten year period.

Table 4. Frequency and impact of different types of disruption

Source of Disruption		Number of Mentions	Notes and range of mentioned impacts	Impact Metric, M
Weather	Snow/Ice	61	Includes disruption from problems with de-icing equipment (2). Range: up to 47000 cancellations.	48
	Fog/Low Visibility	106	Highest mentioned is 255 cancellations, fog at London airports (November 2011)	0.6
	Convective/ thunderstorms	68	Highest mentioned is 80 cancellations	0.1
	Strong winds	101	Includes hurricanes (1), tornadoes (1). Hurricane Sandy resulted in cancellation of 1000 Atlantic flights	8
	Flooding	2	No data on impact	-
	Sandstorms	0	No mentioned events	0
Geological	Volcanic Ash	6	Primarily closures of Catania due to Etna eruptions. Range: up to 101000 cancellations.	10
	Earthquakes	4	Impact varies – e.g. Genoa, April 2004, airport closed due to earth tremors;	-

			Morocco, February 2004, no direct impact on airports but resulted in high demand which in turn caused delays.	
	Tsunami	0	No impact on Europe	0
Accidents	'Accidents'	15	Impact varies – e.g. Helios airways flight 522 accident was not at an airport. Range: up to 70000 extra delay minutes plus 400 cancellations.	0.2
	'Incidents' and 'accidents/incidents'	126	Included: non-crash emergency landings (8), oil on the runway (1), blocked runway (8), disabled aircraft on runway (21), unspecified 'emergency situation' (3), aircraft evacuation (1).	0.4
	Blocked access road to airport	0	May not be noted in CODA reports.	0
	Ground transport disruption near airport	2	Both incidents relate to reduced fire cover due to a local ground incident.	-
	Safety-related aircraft groundings	0	No European incidents mentioned in time period.	0
Security	Security Alerts	37	Included: emergency landing due to bomb threat (1), alert due to light aircraft in airspace (1), airfield fence violation (1).	0.001-0.003
	Terrorist	10	Included: WWII bomb disposal (6), bomb near	0.007

	attacks/bombing		airport (1), hijack (1).	
	Cyber Attack	0	No European incidents mentioned in time period.	0
	Wars/unrest	3	Impact: ‘Capacity restrictions’/ ’Unanticipated changes in traffic patterns’	-
IT Systems	Systems Failure	307	Included: control tower evacuation (10), ATC evacuation (3). Radar failure, power cuts and lighting failure are also included in this category. Impacts: 761 delay minutes + 40 cancellations to 36000 delay minutes + 100 cancellations and 200 rerouted flights.	1.1 - 2.1
Disease	Pandemics	0	Not mentioned in CODA delay digests; however, SARS (2003) and swine flu (2009) fall within the time period covered.	0
Infrastructure upgrades	New runways, systems upgrades, etc.	326	Included: fire fighting exercise (1).	3.6
Industrial Action	Strike (Airport Staff)	40	Included: fire brigade strikes/unavailability (9)	1.1 - 1.4
	Strike (ATC)	63	Impact range: ‘Minimal’ to 49000 delay minutes and 250 cancellations/69300 delay minutes, no significant cancellations	0.3 – 0.6

	Strike (Airline staff)	8	Impact range: 'some' - 1000 cancellations	0.1
	Strike (Ground transport)	0	No specific mentions, but likely covered in 'general/unspecified' below.	0
	Strike (general, unspecified, or 'social issues')	50	Included: demonstrations on runway (2). Impact range: minimal to 13206 delay minutes/ 1500 cancellations (separate events).	4.7 - 6.5
Major Events	Olympics, Hajj, Thanksgiving, World Cup, etc.	110	Included: Tel Aviv FIR closure for day of atonement. Impacts: Reduction in overall delay is common (e.g. London ACC recorded 95% lower delays for Olympics than in previous August)	-
Financial	Airline or Tour Operator collapse	3	For example: Spanair collapse (Jan 2012)	0.01
Other	Fires near airport	3		-
	Birds on runway	3		-
	Solar activity	1		-

The results are broadly in line with responses received at the first META-CDM workshop (Marzuoli et al. 2013 [99]). Snow has the highest impact, as snow events are common and may result in large numbers of cancellations. Volcanic ash, which is rare but which is responsible for the single biggest disruption event over the time period looked at, comes second, and other major causes of disruption include high winds, strikes, systems failures and planned upgrades/maintenance.

Annex 4: Costing Delays and Cancellations

The cost impacts of delays and cancellations are multiple, and affect multiple stakeholders. Airlines may face increased crew and fuel costs, expenses associated with aircraft being out of position, increased wear and tear on airframes and costs associated with accommodating and compensating passengers, amongst others. In order to plan and buffer against delays they may also need to purchase additional aircraft beyond the minimum needed to serve their schedule. As a response to delays, passengers may look to travel elsewhere, reducing airline revenues. Passengers face costs associated with not being at their final destination with their luggage at the scheduled time, as well as costs associated with their value of time. Airports may also face costs dealing with stranded passengers. As any concept developed in MetaCDM needs to be evaluated, it is useful to be able to have cost estimates for the impacts of disruption.

For the calculations here, we use reference values for delay and cancellation costs from Eurocontrol (2012). These are given at June 2011 price levels and assume 2011 fuel prices. They distinguish between strategic delays, which can be accounted for in advance (e.g. by adding a buffer to the airline schedule) and tactical delays (which cannot be accounted for in advance). We assume that all delays related to disruptive events are in the latter category. The costs assessed in Cook & Tanner (2011) associated with the tactical delay category include fuel, crew, maintenance and passenger costs. Reactionary delay, caused by the initial delays leaving aircraft late or out of position, is accounted for. However only the cost to the airline, rather than any wider societal cost, is considered. For the volcanic ash crisis of 2010, a more comprehensive cost analysis is given by Oxford Economics (2010) including factors such as deferred travel, productivity losses and disruption to supply chains. They estimate the overall cost impact to the aviation sector of the first week's disruption was US$ 2.2 billion, with an additional cost to hospitality sectors of $1.6 billion and productivity losses of US$ 490 million. For comparison, Quarmby (2011) estimate the overall cost of winter transport disruption in the UK over all modes is around US$ 1.5 billion, of which half is made up of welfare costs.

Including network effects, the cost of tactical ground delay is given at €23.3 – €114.1 per minute. Airborne delay is costed at €33.8 – €133.9 per minute (Cook & Tanner 2011). As a large component of these costs is fuel, these values are subject to change over time; an analysis is given in Eurocontrol (2012). However, for the purposes of this analysis we use the most recent values only. For cancellations, Eurocontrol recommends a cost of €3,600 for the cancellation of a 50 seat narrowbody, €16,900 for the cancellation of a 120 seat narrowbody, and €78,900 for the cancellation of a 400 seat widebody. These values include passenger compensation, rebooking costs, passenger opportunity costs and operational savings. However they exclude ground handling, luggage delivery and missed connection compensation costs. Diversions are costed at €790 - €5,630 for a regional flight, €1,130 - €8,430 for a continental flight and €5,630 - €62,000 for an intercontinental flight, with typical values for a 120 seat narrowbody and a 400 seat widebody being given as €5,630 and €19,160. We assume that a 120 seat narrowbody incurring delay primarily on the ground is typical for most events unless intercontinental flights are specified (e.g. North Atlantic) in which case a 400 seat widebody is assumed.For comparison, the FAA estimates that diverting a passenger aircraft comes at an average cost in year 2011 dollars of $19,618 (around €13,700); the corresponding cost for a cargo aircraft is $15,119 (around €10,500; FAA, 2011). Cancellations were costed by FAA (2012) at a fixed level of $4,977 (around €3,500) per cancellation for aircraft operators; the same document calculated costs to passengers of cancellations by assuming an estimated average of 457 minutes of passenger delay per cancelled flight.