The propagation of air transport delays in Europe

Thesis

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23.12.2009

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Firstly, I would like to thank Prof. Dr. Reichmuth who gave me the opportunity and Sebastian Kellner who encouraged me in the first place, to write this thesis at EUROCONTROL, Brussels.

I am very grateful for the amazing assistance and lasting mentoring I experienced from EUROCONTROL staff. I thank Dr. David Marsh and Philippe Enaud for counselling me with ideas and advice. In addition, I’d like to express my gratefulness to Yves De Wandeler who is not only a genuine expert in delay analysis, but who also kindly assisted me with helpful advice in all matters during this whole period; Magda Gregorova my personal SAS assistant and Holger Hegendörfer for his encouragement and support especially in stressful times.

It was a real pleasure working in this multicultural, multilingual and above all inspiring environment.
Abstract

This empirical study is concerned with the propagation of delays in European air traffic. The so called ‘reactionary’ delays account for about 40 percent of all departure delays in Europe but, due to data limitations, most delay studies have traditionally focused on the analysis of primary delays at the departure airports.

Using data collected by the Central Office for Delay Analysis (CODA), this study developed aircraft sequences in order to analyse the propagation of delays and to better understand the amplifying or mitigating factors.

Hub-and-spoke carriers tend to have a smaller level of propagation than point-to-point and low-cost carriers because they have a higher ability to absorb delay during the ground phases. On the other hand, low-cost operations absorb notably more delay in the block phase than the other operations.

Overall, the sequences of reactionary delays starting in the morning have a higher impact and magnitude than the ones starting in the afternoon as they propagate on average on more subsequent flight legs.

However, the level of propagation in the afternoon appears to be higher which suggests that airline efforts to mitigate delay propagation are higher in the morning than in the afternoon. Moreover, the magnitude of sequences of reactionary delays after short delays is higher, because reactionary delays increase throughout the sequence due to further primary delays in block and ground phase.

Looking at major European hubs, it was observed that they affect daily 30 to 50 other airports, but in terms of reactionary delays they mostly affect their own operations. Aircraft returning to the hub after one flight leg arrive with up to 50 percent of the original departure delay when leaving the hub airport.
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1 INTRODUCTION

This is an empirical study dealing with the propagation of delays in European air traffic.

1.1 Background

The generally accepted key performance indicator (KPI) for operational air transport performance is 'punctuality' which can be defined as the proportion of flights delayed by more than 15 minutes compared to the published schedule. Other definitions exist, looking at punctuality within 60 minutes of departure/arrival.

Figure 1 shows the schedule adherence on intra-European flights between 2000 and 2009. After a substantial improvement between 2000 and 2003, the share of flight delayed by more than 15 minutes deteriorated continuously until 2007.

2008 and 2009 show an improvement but this needs to be seen in context with the significant traffic decrease as a result of the global economic crisis.

Due to the high degree of public exposure, it is in an airline’s best interest to operate flights within the commonly accepted 15 minute window. However, there are many factors that contribute to the punctuality of a flight on which aircraft operators have no or only limited influence. In reality, punctuality is the 'end-product' of complex interactions between airlines, airport operators, airport slot coordinator and air navigation service providers (ANSPs) from the planning and scheduling phase up to the day of operation.

From a scheduling point of view, which is often months before the day of operation, the predictability of operation has a major impact to which extent the use of available resources (aircraft, crew, etc.) can be maximised. The lower the
predictability of operations in the scheduling phase, the more slack time is required to maintain a satisfactory level of punctuality and hence the higher the ‘strategic’ costs to airspace users.

The level of punctuality is closely linked to the level of departure delays. The two are related to another but the difference needs to be clear. Punctuality allows the aircraft a 30-minute window around the scheduled time to be on-time or not on-time. Delays, on the other hand, can be positive or negative. Delays are defined as “the time lapse which occurs when a planned event does not happen at the planned time” (Guest 2007: 7). A delay measures the minutes the aircraft is later or earlier than scheduled. It is the difference between the scheduled and the actual off-block time for departures, respectively on-block time for arrivals.

On-time performance and delay minutes are key indicators for all stakeholders like airlines or airports because they are linked to direct costs due to the “loss of productivity” as well as to indirect costs due to “the invisible loss of time and loyalty of passengers” (Wu 2003b: 418). Mayer (Mayer 2003: 16) states that although airlines typically blame adverse factors like weather or airport congestion for occurring delays, there are “systematic and predictable patterns to airlines' on-time performance”, meaning that certain delays are foreseeable and handling those could be implemented in the schedule from the start.

The departure delay “of a turnaround aircraft is influenced by the length of scheduled turnaround time, the arrival punctuality [...] as well as the operational efficiency of aircraft ground services” (Wu 2003a: 329). In conclusion the Performance Review Unit (PRU) (Performance Review Commission 2008: 32) stresses that “late arrivals originate mainly from late departures”. That leads to the propagation of delays throughout the aircraft rotation and the network of an airline – one delay causing another delay. “It is important to note that, for an airline, the 'value' of delay is not just its effect on an individual airframe but its effect on the operating schedule” (Beatty 1998: 2).

Taking a closer look at the different delay causes, the so called 'reactionary' delays were identified as “the largest delay cause” (Guest 2007: 29). These 'reactionary', 'knock-on' or also called 'propagated delays' are delays without an
own specific origin or cause. It is the duration of a delay which is transferred from a previous flight of the same (rotational) or a different (non-rotational) aircraft. Since generally reactionary delays result from primary delays, they have to be treated differently and are not to be seen as an individual delay 'cause'.

Even though reactionary delays have a great impact on air traffic performance, the research effort to better understand and handle them in practice was limited in the past. Typically primary delays are analysed and taken as main factor for better on-time performance. “While critically important due to its contribution to the cost of delay, it is the primary cause which must be identified if effective action is to be taken” (Guest 2007: 18). However, “cost of delay hits airlines twice: both contingency planning of a schedule (the ‘strategic’ cost of delay), and then again, when dealing with the actual delays on the day of operations (the ‘tactical’ cost of delay)” (Cook 2007: 97). Ahmad Beygi et al. (Ahmad Beygi 2008: 231) confirm the relevance of reactionary delays: “because of the interconnected use of multiple constrained resources, [...] the propagation of a delay in a flight network has greater impact than the root delay itself.” In CODAs annual DIGEST 2008 (CODA 2009: 34) the impact of reactionary delays becomes apparent, where the share of reactionary out of all delays account for about 40 percent of total generated delay minutes.

Overall, the propagation throughout the network is such an inter-related complex issue, that analysing it, finding patterns, or even trying to predict consequences is linked to many uncertain variables. Next to qualified information about airlines' scheduling, fleet and policies, as well as airport congestion and operations, exogenous factors, for example weather occurrences or in some cases politics, need to be considered.

In order to minimize the propagation of a delay, airlines “can choose a longer layover on the ground to buffer against the risk of late incoming aircraft or schedule longer flight time to absorb potential delays on the taxiways” (Mayer 2003: 1). Extra time on the ground is cheaper, but “accurate anticipation of [additional time during the block phase] helps with better […] maintenance [and crew] planning” (Cook 2007: 118). In addition to the padding of the schedule,
airlines may have a spare aircraft, flight crew, or ground personnel available. “While these measures decrease the cost of delays when they occur, they also increase costs of day-to-day operations” (Gillen 2000: 3). It is always important to bear in mind that there is a trade-off between any kind of buffer time and daily aircraft productivity: the higher the aircraft utility, the higher the revenue. Therefore a waiting aircraft with unused buffer time includes always sunk costs, because it can only gain money while flying. “Just five minutes of unused buffer, at-gate, for a B767-300ER, would amount to well over €50.000 over a period of one year, on just one leg per day” (Cook 2007: 118). €50.000 a year equals to €27,40 a minute. In “Evaluating the true cost to airlines of one minute of airborne or ground delay” the Performance Review Commission (PRC) published also different unit costs. “Passenger delay costs incurred by airlines in consideration of both ‘hard’ and ‘soft’ costs are estimated as €0,30 per average passenger, per average delay minute, per average delayed flight” (University of Westminster 2004: p.51). Based on their calculations, a delay over 15 minutes has a “network average value of €72 per minute” (University of Westminster 2004: 100). These costs were adjusted by inflation to €77 in 2006 (Performance Review Commission 2008: 42). It considers direct reactionary delay costs, but not the strategic costs through added buffer minutes. Theoretically “strategic buffer minutes should be added to the airlines' schedule up to the point at which the cost of doing this equals the expected cost of the tactical delays they are designed to absorb” (Guest 2007: 22). The break-even point was estimated to be a buffer time of the “average tactical delay [when] more than 22% of flights are expected to be delayed by more than 15 minutes” (University of Westminster 2004: 102).

Another and more drastic way of avoiding delays is cancelling flights. This enables airlines to return to scheduled times and good on-time performance. Nevertheless, analyses on costs of delays in correlation to network performance in the US indicated that “operational strategies that emphasize maintaining flights even when there are high delays are more efficient than cancelling flights” (Gillen 2000: 13). For all this, a certain amount of delay is well accepted by the airlines. Following, it is even more convenient to find out more about the consequences of an occurring delay, (in a sense of additional costs through rotational and non-rotational knock-on delays).
1.2 Objective

The objective of the study is to better understand the processes and mechanisms of delay propagation in Europe, and to identify factors which amplify or mitigate the delay propagation.

If an aircraft arrives late at its destination, the delayed inbound flight may not only be delayed on its next flight leg but it may also affect other flights within the airline network. This analysis is based on actual flight-by-flight data (and therefore on a detailed microscopic level) provided by airlines. Through the tracking of aircraft registrations throughout their rotations, and considerations of different scheduling strategies of various airlines, the actual propagation of delays is observed and push factors found.

After a high level analysis of reactionary delays in Europe, more detailed analysis is carried out to better address the following three issues:

- firstly, the delay propagation is analysed from a single airline point of view by looking at possible differences in airline business models and scheduling strategies;
- secondly, the delay propagation is analysed by looking at sequences with different number of aircraft rotations and the amplification or mitigation of delay along the sequence (i.e. how many legs are affected? What is the impact of a delay in the morning, etc.); and,
- finally, the delay propagation is analysed from an airport point of view in order to evaluate the impact of airport operations on the European air transport network and vice versa.

The findings can help to improve airline and airport planning in order to achieve a higher level of resilience towards predictable and unpredictable primary delays. Furthermore, the findings aim at providing more detailed insights on delay propagation, which can be useful for macroscopic analyses and simulations.
1.3 **Study Scope**

For data consistency reasons, the following geographical and temporal scope was applied.

1.3.1 **Geographical scope**

The geographical scope of the study is the European Civil Aviation Conference (EACA) area, as shown in Figure 2. The ECAC area currently consists of 44 Member States comprising almost all European States.

![Figure 2: Geographical scope - ECAC States (2009)](source: http://www.ecac-ceac.org/index.php?content=lstsmember&idMenu=1&idSMenu=10)

1.3.2 **Temporal scope**

Due to improvements in the quality of the data collection used for this study, the temporal scope of the study is limited to two years. It spans from the beginning of the 2007/08 IATA winter season (28. October 2007) until the end of the 2009 IATA summer season (25. October 2009).

It should be noted that the analyses are to some extent affected by the significant reduction in traffic following the economic crisis which started in the second half of 2008.
1.4 **Organisation of the study**

The study is organised as follows:

- The literature review in Chapter 2 provides an overview on previous research carried out in this area;
- Data Input and validation is described in Chapter 3;
- Chapter 4 describes the key indicators and the general approach used for the evaluation of the delay propagation;
- The analyses and the findings are presented in Chapter 5;
- Chapter 6 draws conclusions from the results in the previous chapters: and,
- Chapter 7 provides an outlook on future challenges regarding delay propagation in Europe.
2 LITERATURE REVIEW

Since detailed flight data are commonly available in the US but not in Europe, past research on reactionary delay considered mainly US air traffic.

For the lack of data it has been very difficult to analyse network effects on a macroscopic view or detailed aircraft rotation mechanisms on a microscopic view for European air traffic. Following various papers of previous research are shortly introduced.

Already in 1998 Beatty, Hsu (both American Airlines), Berry and Rome (both Oak Ridge National Laboratory) analysed flight propagation through an airline schedule with the concept of a 'Delay Multiplier'. The delay multiplier is the relation between the sum of the initial and down line delays, and the initial delay itself. Using American Airlines data, including crew and aircraft connectivity, they wanted to “develop a 'generic' total value of both the initial delay and its continuing consequences on the airline schedule” (Beatty 1998: 2) Within their concept of the delay multiplier they considered rotational as well as non-rotational reactionary delays through crew and passenger connectivity, as well as gate-space limitations. They found that a “linear increase in delay multiplier with increased departure delay […] worked well” (1998: 5) and that even a small reduction of long root delays “can have a significant affect on total delay in an airline schedule” (1998: 7). They concluded, that their results are most probably not valid for different scheduling strategies, assuming that the delay multiplier would be much smaller “for a large international operator with long turn times and little crew and aircraft branching […] while a high frequency, short turn time operator might be much larger” (1998: 8). Finally they analysed the problem of calculating costs due to cancelling flights and reassigning resources, and suggested to use the cost calculated by delay multiplier as “a conservative surrogate” (1998: 8).

Wu published in October 2003 a theoretical study on punctuality performance of aircraft rotations in a network of airports, analysing different scheduling strategies in a mathematical model. He observed that “the propagation of knock-on delays in aircraft rotations is found to be significant when short-connection-time policy is used by an airline at its hub airport” (Wu 2003b: 417). When scheduling short
turnaround times at spoke-airports, he declared long turnaround times at the hub airport as necessary “to absorb punctuality uncertainties from spoke airports” (2003b: 431f.). Also, Wu analysed rotations where all ground phases had the same turnaround time but discarded this idea because it could reduce aircraft efficiency.

In 2003 Mayer and Sinai published in “Why do airlines systematically schedule flights to arrive late?” their results, analyzing nearly 67 million flights over 12 years of different US airlines. They found out that “airlines do not adjust their schedules to incorporate predictable movements in push back delays” (Mayer 2003: 17). “While average scheduled travel time is almost exactly equal to the median time between pushing back from the gate on departure to pulling up to the arrival gate, airlines' schedules does not account for the fact that the typical flight leaves almost ten minutes late” (2003: Abstract). Airlines schedule less travel time, if it has a greater variation. Ground times are not planned longer, when inbounds are probable to be late. As an example for airlines not considering predictable delays, they pointed out that the same average scheduled flight time for January and October leads to a much worse on-time performance in January than in October. Looking at competition on different routes, they found out that “a flight that leaves its own hub is between 2.9 and 5.4 percentage points less likely to be on time than a non-hub flight on the same route” (2003: 14). In general “competition appears to be correlated with worse on-time performance” (2003: 14). Finally, they concluded that “the results imply that airlines believe that the potential revenue benefits from reducing passenger waiting time are relatively small and do not justify the additional labour (and capital) costs associated with lengthening schedules to take into account predictable push-back delays (2003: 27).

In 2003 Eurocontrol Experimental Centre in Bretigny did a study on delay propagation, looking at Air France data and a number of French airports. They created a model, which “aims at explaining the progression of delay through stations” (Eurocontrol Experimental Center 2003: 16). The itinerary of an aircraft is followed, local parameters to each airport and “a set of possible delays due other causes than local ones” are implemented. Also “the effects of ATFM slots and exceptional events are taken into account by a rule which states that a slot or
exceptional event alter the predicted delay” (2003: 16). Firstly they found out that the actual flight duration exceeds the planned or announced one, up to 6 minutes (2003: 9). Additionally, they discovered that short delays between three to fourteen minutes “result mainly from the propagation of a former delay and/or the local conditions (Load, scheduled stop time)” and that “propagation and local effects alone cannot reach values up to 15 minutes if they do not result from an event or an ATFM slot” (2003: 25). For long delays they saw the morning delays absorbed during long turnaround times by the middle of the day “whereas the propagation and the local effects sustain the level of event or ATFM delays in the evening until the night stop” (2003: 26). Finally, they stated that “a flight experiencing a disruptive event or an ATFM regulation at a station is very likely to undergo a long delay due to the propagated and local contributors alone, [...] especially [...] during the latest stations of a daily itinerary” (2003: 28).

In 2008 Ahmad Beygi, Cohn, Guan and Belobaba published the “Analysis of the potential for delay propagation in passenger airline network”. They investigated the relationship between schedules and delay propagation with flight data by two major US airlines, one with mainly hub-and-spoke and one with point-to-point operations. They examined a delay without looking at other flights at the same time. Then they created a tree-structure for the following flights of the same aircraft as well as for the ones which are affected through that single flight. Impacts through cabin crew and passengers as well as recovery options are excluded. Throughout their analysis they looked at the sum of propagated delay minutes, the ratio of the propagated to the root delay, the number of affected flights, number of flights of the longest propagation sequence, the ratio between the longest sequence and total number of affected legs, the number of flights where crew changed aircraft and the ratio of the split up of crew changes to the total number of affected flights.

They disproved the assumption that a higher number of affected flights correspond to a higher splitting rate of resources (crews). They also found out that “extreme cases are quite rare” (Ahmad Beygi 2008: 224). The maximum count of affected flights was 7 and 10, for the two operations. About 40 percent of delays of 180 minutes did not propagate at all and about 90 percent had an impact on three or
less flights. They observed that delays typically originate at a spoke airport and are absorbed either at the following or at the second stop at the hub airport. In addition they stated that the ratio of propagated to root delay decreases as the root delay occurs later into the day. Also delays benefit earlier in the day “more substantially from increased slack” (2008: 232f). “The optimal location for the slack is in the middle of the chain. This is the trade-off point, where the expected delay is minimized, trading off the lengthy of the propagation and the probability of the root delay” (2008: 236).

In October 2008 Akira Kondo from the Federal Aviation Administration, FAA, presented the “Tail Number Tracking Methodology” at INFORM in Washington DC. As an indicator for propagation performance, a multiplier was calculated by dividing the arrival delay by the previous arrival delay. Thus, they put the spotlight specifically at arrival delays. The multiplier is calculated for each leg with a previous arrival, departure and arrival delay greater than zero. By the end of the propagation sequence, an overall multiplier as a geometric mean of the single multiplier evaluates the sequence. Additionally a ‘propagation accelerator’ is calculated as the ratio of the propagated delay, which is the minimum of the previous arrival, departure and arrival delay, and the previous propagated delay. Finally they presented the ten most affected airports for propagated delay from a certain airport and to that airport.

Also in 2009, Tony Diana from the FAA published a case study for selected U.S. airports. He observed that “there is no clear evidence that market-concentrated airports are different from less concentrated ones in terms of delay propagation” (Diana 2009: 280).

According to information from Professor Amadeo R. Odoni and Nikolas Pyrgiotis from Massachusetts Institute of Technology (MIT), they are developing the Approximate Network Delays model, AND-concept. It is a macroscopic model which computes the propagation of delays within a network of airports. The computation is based on scheduled itineraries of individual aircraft and a queuing system for each airport. With this tool they want to predict network effects with different scenarios. So far, they observed that the expected delay relative to
schedule increase, and schedule reliability decrease later in the day. Also they discovered that aircraft flying for the first time to a congested airport late in the day “suffer much less delay”. Finally, they assumed that “airports affect themselves significantly within a Hub and Spoke system, returning with the outgoing return”.

The EUROCONTROL Central Office for Delay Analysis (CODA) receive operational flight data from airlines, enriched with additional delay information from the Central Flow Management Unit, CFMU, covering around 60 percent of all IFR flights in Europe (see next chapter). Based on these data CODA publish annually and monthly DIGEST-Reports, a detailed analysis of the actual delay situation in Europe. However, when looking at changes in traffic flow, year-to-year trends and delay causes, they concentrate mainly on primary delay causes. In here they analyse airports, city pairs, and an overall overview. Finally CODA present the “Percentage of all causes Delay by IATA Category” (Figure 5), which shows that the share of reactionary delays sum up for 40 to 45 percent of all delays of all generated delay minutes.

In cooperation with CODA the flight-by-flight data is now used to analyse reactionary delays within this study.
3 DATA VALIDATION & PROCESSING

This chapter describes the data sources used for the analysis. It furthermore describes difficulties and shortcomings related to the data processing and validation in order to develop a sound basis for the analysis of delay propagation in Europe in the following chapter of this report.

3.1 Data Sources

Generally, there are many different data sources for the analysis of operational air transport performance. For consistency reasons, the data in this study were drawn from a combination of centralised airline reporting and operational Air Traffic Management systems.

3.1.1 Central Flow Management Unit (CFMU)

In Europe, data are derived from the Enhanced Tactical Flow Management System (ETFMS) of the Central Flow Management Unit (CFMU) located in Brussels, Belgium.

The system stores data repositories with detailed data on individual flight plans and tracks sample points from actual flight trajectories. It enables CFMU to track Air Traffic Flow Management (ATFM) delays by airport and en route reference location.

3.1.2 Central Route Charges Office (CRCO)

The second, centralised data collection comes from the Central Route Charges Office (CRCO). As the name states, they calculate the fee for the air space use of a state, invoice it to the airlines and reimburse the states, respectively the ANSPs. For this purpose, the CRCO uses “an efficient cost-recovery system that funds air navigation facilities and services and supports Air Traffic Management developments” (CRCO homepage).

3.1.3 Central Office for Delay Analysis (CODA)

CODA aims “to provide policy makers and managers of the ECAC Air Transport System with timely, consistent and comprehensive information on the air traffic
delay situation in Europe, and to make these available to anyone with an interest in delay performance” (CODA homepage).

In Europe, CODA collects data from more than hundred airlines each month. The data collection started in 2002 and the reporting is voluntary. Currently, CODA covers 60 percent of all IFR flights in the European Civil Aviation Conference (ECAC) area which includes 44 countries. Figure 3 illustrates the coverage of CODA data by ECAC Member State for July 2009. For instance, the data submitted by airlines in July 2009 covers 69 percent of all German IFR-departures.

The data reported include what is referred to as OOOI\textsuperscript{1} times, the aircraft registration (also called tail number), schedule information and causes of delay, according to the IATA delay codes. A more detailed description of the CODA data collection is provided in Annex II.

The most important parameter for this study is the unique aircraft registration, reported for each flight, which enables to link the various rotations of an individual aircraft throughout the operational day. Together with the delay information

\textsuperscript{1} Out of the gate, Off the runway, On the runway, and Into the gate.
submitted by the airlines it is possible to evaluate the propagation of delay and the underlying causes. Airlines may use up to delay 5 codes per flight to specify the reason of a departure delay. This valuable information is neither gathered by CFMU nor by CRCO. Usually, when working with calculated propagated delay minutes, there is always one open question: which part of the departure delay is newly added and which is propagated from a previous flight leg? The regular flight data give no information about which part of the inbound delay was absorbed and how much propagated to the next flight.

With the reported delay codes the actual reactionary delay and the new primary delay can be separated from each other. They demonstrate how much of the inbound delay has been absorbed, thus, how long the delay would have been if there was no primary delay. Figure 4 illustrates this significant advantage of CODA data in more detail:

- the aircraft at the top of Figure 4 operates according to the scheduled turn-around time with no additional delays.
- the aircraft in the middle of Figure 4 is able to make up time from an inbound delay on the previous flight leg but suffers another primary delay not related to the previous flight leg.
- the aircraft at the bottom of Figure 4 is unable to make up time from the inbound delay and therefore departs with a reactionary delay from the previous flight leg.

![Figure 4: Turnaround with different types of delay](image)
Without the delay codes reported by the airlines, it would not be possible to differentiate between the new primary delay (middle bar of Figure 4) and the reactionary delay (bottom bar of Figure 4).

3.1.3.1 IATA Delay Coding

In order to foster the harmonised reporting of delay among its member airlines, The International Air Transport Association (IATA) has published a standard coding system for the classification of delays (see Annex I).

As shown in Table 1, the IATA delay codes can be broadly divided into ten parts, according to the area of accountability:

<table>
<thead>
<tr>
<th>IATA Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-9</td>
<td>Others &amp; airline internal codes</td>
</tr>
<tr>
<td>11-18</td>
<td>Passenger and baggage handling</td>
</tr>
<tr>
<td>21-29</td>
<td>Cargo and mail</td>
</tr>
<tr>
<td>31-39</td>
<td>Aircraft and ramp handling</td>
</tr>
<tr>
<td>41-48</td>
<td>Technical and aircraft equipment</td>
</tr>
<tr>
<td>51-58</td>
<td>Damage to aircraft and automated equipment failure</td>
</tr>
<tr>
<td>61-69</td>
<td>Flight operations and crewing</td>
</tr>
<tr>
<td>71-77</td>
<td>Weather</td>
</tr>
<tr>
<td>81-89</td>
<td>Air traffic flow management/ Airport and Governmental Authorities</td>
</tr>
<tr>
<td>91-96</td>
<td>Reactionary delay</td>
</tr>
<tr>
<td>97-99</td>
<td>Miscellaneous</td>
</tr>
</tbody>
</table>

Figure 5 shows the percentage distribution of all causes of departure delay by IATA category in 2008.
It is interesting to note that some 40-45 percent of all departure delays in Europe are coded as “reactionary delay” but only six of the 80 available codes are dedicated to the better description of reactionary delay. The limited granularity of data available and the complexities involved are the main reasons as to why most studies focus traditionally on the analysis of primary delay.

However in view of the scope of the problem and its importance from a network point of view there is clearly a need for further work to better understand the propagation of delays and to improve data collections in this direction.

A more detailed evaluation of the IATA delay codes available for the classification of reactionary delays further illustrates the issue. Table 2 shows the IATA codes available for the classification of reactionary delay.

### Table 2: IATA Codes for the classification of reactionary delay

<table>
<thead>
<tr>
<th>IATA Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>91</td>
<td>Awaiting load from another flight</td>
</tr>
<tr>
<td>92</td>
<td>Through check-in error, waiting for passenger and baggage from another flight</td>
</tr>
<tr>
<td>93</td>
<td>Late arrival of the aircraft on the previous flight</td>
</tr>
<tr>
<td>94</td>
<td>Awaiting cabin crew from another flight</td>
</tr>
<tr>
<td>95</td>
<td>Flight deck or entire crew from another flight (including deadheading crew members)</td>
</tr>
<tr>
<td>96</td>
<td>Operations control: rerouting, diversion, consolidation, aircraft change for reasons other than technical</td>
</tr>
</tbody>
</table>

Source: IATA Airport Handling Manual
IATA delay code 93 is also called ‘rotational reactionary delay’, because it relates to reactionary delays on successive flight legs of the same aircraft (Figure 6).

![Diagram of aircraft and delays](image)

**Figure 6: Types of reactionary delay**

However, a primary delay on one flight can also cause reactionary delays for other aircraft within the fleet as shown on the bottom of Figure 6 (i.e non-rotational reactionary delays). IATA delay codes 91 and 92 apply to cases where an aircraft has to wait for passengers, baggage or load from another delayed aircraft. Crews who are to change aircraft after a flight or are flown to an airport to start duty (deadheading) can cause reactionary delay due to IATA delay code 94 and 95, when the other aircraft has to wait for them. Finally, IATA delay code 96 represents all kind of reactionary delay due to operations control.

"Airlines normally attempt to keep the crew on the same aircraft on multiple flight legs" (Bazargan, p.84), which avoids reactionary delays due to crew changes. However, depending on airline policy and in order to achieve higher levels of crew efficiency, especially hub-and-spoke carriers schedule crew changes across different aircraft which in turn can result in reactionary delays if a flight ready to depart has to wait for crew from another flight. Likewise, the need to wait for connecting passengers or cargo may result in reactionary delays.
Figure 7 shows the distribution of the reported delay minutes in the six different IATA reactionary delay categories between winter 2007 and summer 2009. Codes 94 and 95 are grouped together in this analysis because they are used by most airlines for the same causes. Airlines also tend to group codes 91 and 92 together, but since one is for load and the other for passenger, they were kept separately in Figure 7.

By far the main share of reactionary delay is due to rotational reactionary delay which accounts for 89 percent of all reactionary delay reported during the analysed period.

Figure 8 shows the distribution of the reactionary delay categories by airline business model (low-cost, hub-and-spoke, and point-to-point) and by time of the day in summer 2008. ‘Morning’ lasts from 6:00h till 13:59h, ‘Afternoon’ from 14:00h till 21:59h and ‘Night’ from 22:00h till 5:59h.
Irrespective of the airline business model, the rotational delay accounts by far for the highest share of reactionary delay.

Hub-and-spoke operations show with 15 percent the largest share of non-rotational reactionary delay which is normal in view of the type of operations.

As can be expected, low-cost and point-to-point operations only show a small share of non-rotational reactionary delay as they often operate independent services without the need to wait for connecting passengers or load. The non-rotational delay reported by those carrier types is mostly related to crew (code 94/95) or operations control (code 96)

Irrespective of the type of operations, the main share of reactionary delay (around 60 percent) is reported in the afternoon, followed by the morning (25-30 percent) and the smallest share during night.

For all three business models codes 91, 92 and 94-95 are higher in the afternoon than during morning or night time. This indicates that airline focus in the afternoon is more on managing flight connections while in the morning the focus is more on schedule adherence.

3.2 Data validation & limitations

The most important prerequisite of the delay propagation study is the data processing and validation in order to develop a sound basis for the analysis in the next chapters of the report.

A considerable amount of time was necessary to prepare the vast amount of data available from the various data sources (see section 3.1) and to resolve inconsistencies in order to develop a data base for the analysis of delay propagation.

This section describes the encountered difficulties in the processing of the data and the applied solutions.

3.2.1 Missing or incomplete data

One of the most influencing limitations for the analysis of delay propagation is missing or incomplete data. For the development of rotation sequences of an
aircraft the exclusion of only one flight due to missing or incomplete data means that the entire rotation sequence is incomplete.

For the analysis of delay propagation, the aircraft registration is one of the key parameters needed in order to create the rotation sequences. If key parameters are missing, the data submitted by airlines is cross-validated with data from the CFMU or CRCO in order to complete the missing data (see Figure 9). In cases where the aircraft registration could not be retrieved from one of the three sources the respective data record was rejected from the analysis.

![Figure 9: Cross-validation of data](image)

Also there are reported records which do not contain all the required information. One example, as described above, is the missing aircraft registration. Another example is the especially for this analysis useful information about the callsign of the flight, which caused a non-rotational reactionary delay. Unfortunately this information is almost never provided by the companies and not available for analysis functions. This disables to follow the delay when spreading to other aircraft.

In addition, there are flights which have a reported OUT- (and OFF-) time, but no actual arrival time, respectively only the ON-time. In those cases, the missing IN-time is calculated with the ON-time plus the reported standard taxi-in time. If the ON-time is also missing, the IN-time equals the scheduled arrival time plus the departure and taxi-out delay, assuming that there was the block time passed as scheduled.

### 3.2.2 Use of different delay codes

As already described in 3.1.3.1, IATA published a standard coding system for the classification of delays (see Annex I). However, the use of the IATA codes is not
mandatory and therefore some airlines have developed their own or slightly modified delay coding schemes in order to meet their operational needs.

For comparability reasons, CODA has developed algorithms to recode tailored coding schemes into the standardised IATA coding scheme.

Only flight data using the standardised IATA delay coding or for which the data could be recoded is included in the analysis in the next chapters of the report.

3.2.3 Different coding policies

Note that the reported delays are based on a person’s decision\(^2\) and therefore are to some extent subject to interpretation and airline preferences. A different person could report the same delay differently. However, most airlines have a specific rule for exactly that issue and knowing how these strategies work, helps dealing with the reported codes.

Generally airlines aim at reporting the delays as they occur, but what if there are two reasons at the same time (i.e. ATFM delay AND boarding delay), or it is simply not known what really caused the delayed minutes? Airlines split the delays according to their respective duration, but some only report the “most penalising” or longest delay, others split the minutes in half and report both. Reporting the cause of the longest delay reduces the visibility of shorter primary delays for the respective airline (i.e. 5 min. delay due to boarding will be hidden behind a 20 minute ATFM delay). Reporting both delays would, on the other hand, reduce the visible impact of the longer delay.

One major carrier in Europe reports not the longest, but always the last delay cause. For instance when an aircraft with 30 minutes of reactionary delay gets an additional small delay all previous delay minutes are reassigned to the new primary delay cause. If this practice is not known, one would assume that the aircraft recovered from all previous delay minutes, and that the new delay had a bigger impact than it really had.

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\(^2\) The delay codes are often given by the handling agent and are then sent to the Operational Control Centre (OCC) of the airline with the aircraft movement message (MVT).
Another reporting practice particularly relevant for the analysis of reactionary delay was observed for another airline. The airline exclusively uses primary delays even if they are carried over as ‘reactionary delays’ on the next flight leg. The advantage of this technique is that the actual root cause remains visible on the subsequent flight. For the analysis it is however impossible to identify whether it was a reactionary delay or another primary delay.

Another difficulty in reporting reactionary delays is to separate them from primary delays on the ground. In practice, it is not always obvious how many minutes were transferred from a late arrival and how many minutes were added newly. In other words, it needs to be decided if there was extra buffer time considered in ground phase, and whether it was used only for the inbound delay or also for parts of an eventually new delay. When it is not clear, many airlines just split the delay in half and report both, a reactionary and a new delay.

In order to avoid any bias from different coding practices, airlines applying a coding practice which could spoil the analysis were excluded from the analysis. The results of the analysis should nevertheless be viewed with a note of caution due to possible differences in the interpretation of IATA delay codes.

### 3.2.4 Errors in datasets

During aircraft registration tracking sometimes different aircraft types showed up for one aircraft registration. As aircraft registrations are unique for every aircraft, each aircraft can only have one aircraft type. In order to resolve this issue, the actual aircraft type was determined by analysing the frequency of occurrence in the data during the analysed period. The aircraft type for the few records with a different aircraft type was then aligned with the most frequent type for this aircraft registration.

The aircraft type is used in the analysis to group each aircraft type according to its median seat capacity\(^3\). A more detailed table with aircraft types and their median seat capacity can be found in Annex V.

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\(^3\) The EUROCONTROL Pan-European Repository of Information Supporting the Management of EATM (PRISME) provides for every aircraft type the ICAO aircraft type with its corresponding median seat capacity.
When calculating the block times of flights another error occurred quite frequently. For about 170 datasets the block time exceeded 1440 minutes, which is equal to one day. Apparently in those cases the date of arrival was simply put falsely one day after the departure date. The data was cleaned by manually correcting the date.

Another problem was linked to arrival times. The calculation of automatically computed fields, like the arrival delay could for example not handle flights with an ON or IN-time at midnight. Therefore arrival, landing, and taxi-in delays were recalculated in those cases.

### 3.2.5 Missing flights

For the development of aircraft sequences the exclusion of only one flight means that the entire rotation is incomplete. For instance, some smaller non European airlines only report the flights bound for Europe.

Two regional airlines only send information about delayed flights but not about the flights which were on-time.

As it is impossible to build aircraft sequences when flights are missing, those airlines which only report a part of their flights were excluded from the analysis.

### 3.3 Input in analysis

Overall, 21 European traditional scheduled and 15 European low-cost carriers were included in the analysis. Among the 21 traditional scheduled airlines are bigger airlines with around 600.000 flights per year as well as smaller ones with only 20.000 flights per year. For the low cost carriers, the size differs from 10.000 to 300.000 flights per annum.

Table 3 shows the data input for all four seasons included in the analysis. On average, 96 percent of the flights could be identified and linked by their aircraft registration in order to build rotation sequences.
Table 3: Analysis data input

IATA winter season 2007-08 to end of IATA summer season 2009
(28.10.2007 - 25.10.2009)

<table>
<thead>
<tr>
<th>Business model</th>
<th>Cleaned data of flights of selected airlines</th>
<th>Flights in complete rotations</th>
<th>.. with more than one leg and in ECAC (excluded rotations of cargo, military and business flight types)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional scheduled</td>
<td>6.527.962</td>
<td>95.6 %</td>
<td>73.8 %</td>
</tr>
<tr>
<td>Low-cost</td>
<td>2.116.704</td>
<td>96.0 %</td>
<td>82.4 %</td>
</tr>
</tbody>
</table>

The last column in Table 3 represents the sample used for the analysis in the next chapters. It only includes sequences with more than one rotation and only pan-European flights.

Overall, about 50 percent of all IFR departures in the ECAC area are included in the sample used for the analysis of delay propagation.

3.4 Data Processing

In view of the vast amount of data that needs to be processed for the analysis, the Statistical Analysis System (SAS) Enterprise Guide was used for the entire analysis. After ‘cleaning’ the airline data, as described in the previous section, this section describes how rotation sequences of aircraft are build for the further analysis in Chapter 5.

3.4.1 Building sequences with airline rotations

Rotational sequences are built by linking individual flights through their unique aircraft registration over time. This also serves as the final control to ensure that the sequence is complete.

In order to create these sequences, all flights are grouped according to their unique aircraft registration and sorted by their actual reported off block times (Figure 10).

In a next step, the individual flight legs for each unique aircraft registration are connected by date and time and by their ICAO airport designator. For example, the arrival airport on one flight leg has to match with the departure airport on the
subsequent flight leg and so on. As the sample relates to pan-European flights, most sequences start in the early morning and end at night.

A sequence continues until there is either an error in the reported flight data or until the observed scheduled ground time (SGT) exceeds a pre-defined limit. Some airlines try to ensure schedule adherence “by placing a long period of time, usually called a ‘fire-break’, somewhere in the aircraft rotation path” (Wu 2003b: 428). These ‘fire-breaks’ can be an overnight stay or a ‘longer than usual’ ground phase during the day, usually during off peak times.

The SGT limits applied in this study are shown in Table 4. A sequence continues as long as the SGT does not exceed what is generally considered a sufficient turn-around time. In order to account for the different aircraft sizes, the SGT limits are divided into four groups according to the median seat capacity.

<table>
<thead>
<tr>
<th>median seat capacity</th>
<th>Rotation ends when SGT is ..</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 80</td>
<td>&gt; 90 min</td>
</tr>
<tr>
<td>81 - 180</td>
<td>&gt; 120 min</td>
</tr>
<tr>
<td>181 - 280</td>
<td>&gt; 150 min</td>
</tr>
<tr>
<td>&gt; 280</td>
<td>&gt; 180 min</td>
</tr>
</tbody>
</table>

The SGT limits for each of the four groups are based on median seat capacity, average observed SGT and expert judgement from EUROCONTROL staff working in this area.

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4 The SGT is the difference between the scheduled arrival time (STA) of the previous flight and the scheduled departure time (STD) of the subsequent flight.
There is only one exception to the SGT limits outlined in Table 4. When a flight exceeded the SGT limit but reported a reactionary delay on the next flight leg, the flight was kept in the sample.

3.4.2 Grouping by airline business model

The following additional attributes and groupings were applied in this study. As airline business models are expected to react differently to the propagation of delay, the flights were categorised according to three different business models:

- Hub and spoke operations;
- Low cost operations; and,
- Point-to-point operations.

As different definitions term ‘low-cost carrier’, EUROCONTROL STATFOR have developed criteria which were applied for the identification of this market segment in this study (see Annex IV).

As illustrated in Figure 11, the traditional scheduled flights are further divided into two categories: flights within a hub-and-spoke or a point-to-point system.

![Figure 11: Types of airline operations](image)

Hub-and-spoke operations enable a higher number of possible connections with fewer aircraft than point-to-point services. During a specific time of the day a number of aircraft arrive within a similar time band at the hub in order to allow
passengers to connect to other flights. This approach increases connectivity for passenger and load and thus efficiency as the usually smaller ‘feeder flights’ enable to increase load factors on long haul flights departing from the hub. Disadvantages arise through “congestion [and] delays [at hub airports], increasing passenger travel time and, for the airline, more personnel and higher operational costs”. (Radnoti 2002: 310). These advantages and disadvantages indicate already that there are principal differences in the strategy behind these two operational systems. Therefore they are separated in this study.

In the hub-and-spoke system the aircraft return to its hub after almost every leg. In order to identify hub-and-spoke operations, the number of times an aircraft starts and lands at its hub is counted and divided by the number of its total departures and arrivals. If the aircraft starts and lands at least 40 percent of all times at its hub, the rotation is marked as 'hub-system'.

Example: The left aircraft from Figure 11 stops at each airport once, starting and ending the rotation at the hub. That counts for six departures and arrivals at other airports and six at its hub. Therefore the percentage of departures and arrivals at the hub equals 50 percent (= 6/(6+6)*100) and it is classified as hub operation.

For this study only the major hub of an airline was considered as a hub. With the exception of three airlines having two hubs, all airlines were appointed to one hub.

Point–to-point operations on the other hand usually serve high density routes and are not part of a network which enables a multitude of connections. The aircraft does not return every other leg to a certain airport and has mostly no connection conditions.

The right side of Figure 11 shows a rotation with point-to-point operations. The aircraft starts for example at airport A and goes around, stopping at airport B, C and then returns to its base. Consequently there are six starts and landings at other airports and just two at the base. For the purpose of this study sequences with less than 40 percent were defined as point-to-point operations.
3.4.3 Converting Universal Time Coordinated (UTC)

As the local time of the root delay might be of interest, off-block and on-block times which are generally expressed in UTC were converted into Greenwich Mean Time (GMT), Central European Time (CET) and Eastern European Time (EET). Also the Daylight Saving Time (DST), or so called 'summer time', needs to be considered during summer season. As season changes at the same time as the DST is changed, the conversion into local times can be done by season. More details on the conversion of UTC to local times can be found in Annex III.
4 CONCEPTUAL FRAMEWORK

After the description of data processing and validation issues in the previous chapter, this chapter presents the approach of how propagation of delays is analysed.

4.1 Factors determining the level of reactionary delay

Two main elements determine the level of reactionary delay:

1. the profile of the primary delays (time of the day, length, etc.); and,

2. the ability built into the air transport network to absorb primary delay (buffers in scheduled block times or turn-around times, reserve aircraft, margins in declared airport capacity, etc.).

![Figure 12: Factors determining the level of reactionary delays](image)

4.2 KPIs of reactionary delays

This section provides an overview of the key performance indicators (KPI) which are used to measure and describe the propagation of delays. The sensitivity to primary delays, scheduling tactics, sequences of reactionary delays, as well as reactionary delays from an airport point of view are analysed. The analysis differentiated between the three different airline business models described in the previous chapter.
4.2.1 Sensitivity to primary delays in airline business models

The sensitivity of airline business models to primary delay can be measured using the reactionary/primary delay ratio.

\[ \text{Ratio} = \frac{\sum \text{reactionary delay}}{\sum \text{primary delay}} \]

The higher the ratio, the more sensitive is the operational system to primary delays and the more reactionary delay minutes are generated for each minute of primary delay. This draws a high-level picture of the impact and the importance of reactionary delays in European air traffic and reveals differences between the business models.

4.2.2 Airline scheduling matters

Scheduled turn-around and block-to-block times play an important role in absorbing and reducing primary and subsequent reactionary delays.

![Aircraft rotations diagram](image)

**Figure 13: Aircraft rotations**

4.2.2.1 Block time related indicator(s)

The block time is defined as the difference between the off-block (OUT) and the on-block (IN) time. Related indicators compare the actual to the scheduled time irrespective of the flight’s adherence to published schedule (see Figure 14).

![Block time related indicators](image)

**Figure 14: Block time related indicators**
In this study, two complementary indicators were used to get a first understanding of performance differences in the block-to-block phase.

I. Delay Difference Indicator – Flight (DDI-F)

The DDI-F provides an order of magnitude of the deviation between the scheduled block time and the actual flown block times. It is expressed as mean deviation compared to the scheduled block time.

\[
DDI - F = \text{Arrival delay} - \text{departure delay} = \text{Actual block time} - \text{scheduled block time} \quad [\text{min}]
\]

II. Block Time Overshoot (BTO)

The BTO is the share of flights exceeding the scheduled block time during a defined time period. It replenishes the DDI-F, so that both of them provide an overall picture of the block-to-block phase performance.

\[
BTO = \frac{\text{Number of flights with a longer than scheduled block time}}{\text{Number of all flights}} \times 100 \quad [%]
\]

4.2.2.2 Turn-around time related indicator(s)

Turn-around time related indicators compare the actual to the scheduled turn-around time. For example, an aircraft arrives (IN-time) on-time at its scheduled arrival time (STA), but stays longer than scheduled on the ground. As a consequence, the resulting departure delay equals the excess of the scheduled turn-around time.

Figure 15: Ground time related indicators
Similar to the DDI-F and the BTO, two complementary indicators are used to get a first understanding of whether an airline is able to stick to its scheduled ground times.

I. Delay Difference Indicator – Ground (DDI-G)

The DDI-G provides an order of magnitude of the deviation between the scheduled turn-around time and the actual observed turn-around times. It is expressed as mean deviation compared to the scheduled turn-around time.

\[
DDI - G = \text{departure delay} - \text{inbound delay} \quad \Rightarrow \quad DDI - G = \text{Actual ground time} - \text{scheduled ground time}
\]

II. Ground time overshoot (GTO)

The GTO is the share of flights exceeding the scheduled ground time during a defined time period.

\[
GTO = \frac{\text{Number of flights with a longer than scheduled ground time}}{\text{Number of all flights}} \times 100 \quad [\%]
\]

It is important to note that the DDI-G can include additional time in both directions of the schedules ground time: early arrivals are considered just like added delay during turn-around.

In order to take a deeper look at the turn-around process itself, two other related and again complementary indicator are found to be more useful in terms of delay analysis during the ground time.

III. Turn-around Delay Indicator (TDI)

The TDI equals the DDI-G but neutralizes early arrivals. The actual arrival time is set to the scheduled arrival in case of an early arrival.
\[ TDI = \text{Departure delay - inbound delay} \]

\[ \text{IF} \quad \text{Inbound delay} < 0 \]

\[ \text{THEN} \quad \text{Inbound delay} = 0 \]

\[ TDI = \text{Actual ground time} - \text{scheduled ground time} \]

\[ \text{IF} \quad \text{Actual IN}_{\text{previous flight}} < \text{STA}_{\text{previous flight}} \]

\[ \text{THEN} \quad \text{Actual Ground Time} = \text{Actual OUT} - \text{STA}_{\text{previous flight}} \]

Therefore this indicator shows the general tendency of an airline to absorb or add delay during all ground phases.

**IV. Turn-around Time Overshoot (TTO)**

Similar to the GTO, the TTO indicates the percentage of flights, which still outrun the scheduled ground time when early arrivals are neutralized.

\[
TTO = \frac{\text{Number of aircraft adding delay during turnaround time}}{\text{Number of all flights}} \times 100
\]

The TDI and TTO demonstrate whether and how much delay is added in general during the ground time.

However, for the analysis of the propagation of delays, the reaction following an inbound delay needs to be looked at individually. There the “schedule padding-Ground” is introduced as another ‘IF-indicator’ of the DDI-G.

**V. Schedule padding-Ground (sched.pad-G)**

The schedule padding-Ground measures the deviation of the actual to the scheduled ground time, IF the aircraft arrived late. It seems similar to the TDI, but reveals slightly different information.

\[
\text{Schedule padding - Ground} = \text{departure delay - inbound delay}
\]

\[ \forall \text{inbound delay} > 0 \]

When analysing calculated propagated delays this indicator presents ground time performance and finally determines the propagated delay minutes. The reported data from the airlines enable a more detailed evaluation of the ground phase as the actually absorbed inbound delay can be determined.
VI. Absorbed inbound delay (used buffer time)

The last indicator for the evaluation of the performance in the ground-phase is the “absorbed inbound delay”. It is an essential indicator because none of the previous indicators enables a distinction between reactionary and primary delays. Due to the reported IATA delay codes, it is now possible to determine how long the resulting reactionary delay was and how much new primary delay was added during the ground phase. In other words, how much of the inbound delay could be absorbed during the turn-around phase.

\[
\text{Absorbed inbound delay} = \text{reported reactionary departure delay} - \text{inbound delay}
\]

\[
\forall \text{ inbound delay} > 0
\]

4.3 Sequence of flights with reactionary delays

After looking at the sensitivity to primary delays and various performance indicators addressing the performance in the block and ground phase, the actual propagation of the delay is analysed in more detail.

4.3.1 Creating sequences of subsequent flight legs with reactionary delays

For the analysis of delay propagation, only those sequences on which reactionary delay was reported were used. A sequence of flights with reactionary delay starts with a primary delay and continues until the end of the rotational sequence of the aircraft or until the reactionary delay is absorbed (equal to zero).

Figure 16 visualizes a sequence of reactionary delays. The sequence starts with a (primary) departure delay and because the aircraft cannot absorb any delay in the first block-to-block phase it arrives with the same inbound delay.

![Figure 16: Sequence of reactionary delay](image)
During the first ground phase, the aircraft absorbs part of the inbound delay, but suffers from a new primary delay. Therefore it departs with the remainder of the inbound delay as reactionary delay and the new primary delay.

In the second block-to-block phase, the aircraft recovers a little and arrives with less inbound delay than it had on departure. In the second ground phase, the aircraft is able to absorb a big part of the inbound delay and departs finally with little reactionary delay, consisting of primary delays from the two previous flight legs.

4.3.2 Root delay

An important role in a sequence of flights with reactionary delays is the 'root delay'. The root delay is the first primary delay which caused a reactionary delay in a sequence. The root delay can be due to:

- primary departure delay (airline, airport, ATFM related etc.);
- ‘non-rotational’ delay due to awaiting crew, passengers or load; or,
- 'inbound' delay (mostly due to holdings in the terminal area).

The root delays are grouped according to their duration into the following groups:

- 1 to 15 minutes
- 16 to 60 minutes
- 61 to 120 minutes
- 121 to 180 minutes
- Over 180 minutes.

4.3.3 Depth of the sequence

The depth of the reactionary delay propagation is another interesting parameter to be evaluated. It is expressed as the number of subsequent flight legs until the original root delay is absorbed.

4.3.4 Magnitude

In other publications (see Chapter 2) concerning delay propagation, different indicator similar to the delay multiplier can be found. There are multipliers, which show the growth rate of two sequential delays, others which calculate what is
referred to as magnitude in this study: the relation of all reactionary delays following one root delay to the root delay itself.

\[ \text{Magnitude} = \frac{\sum \text{all reactionary delays}}{\text{Root delay}} \]

An important issue to point for the interpretation of the multiplier or the magnitude is its sensitivity to the length of the root delay and to the length of the sequence of reactionary delays.

For example, if a 10 minute delay results in a 10 minute reactionary delay, the multiplier equals 1 (10/10=1). If a flight has a root delay of 60 which causes a reactionary delay of also 10 minutes, the multiplier is 0,17 (10/60=0,17).

The same amount of reactionary delay results in a different multiplier depending on the length of the root delay. Hence, for the comparison of delay multipliers it is necessary to take the length of the root delay into account.

Similarly, the multiplier also depends on the number of flight legs affected by reactionary delay.
5 ANALYSIS OF REACTIONARY DELAYS

This chapter provides an analysis of the reactionary delay in Europe. The chapter consists of the following complementary parts:

- section 5.1 shows the distribution of primary delays by duration;
- section 5.2 analyses the sensitivity of the three airline business models to primary delays. The ratio between the reported reactionary and primary delay is taken to get a first understanding of fundamental differences between business models and over time (see 4.2.1);
- section 5.3 looks at differences in the scheduling of the block phase among the three airline business models and the respective impact on the propagation of reactionary delay (see 4.2.2.1);
- section 5.4 evaluates differences in the scheduling of the turn-around phase (ground phase) and the respective impact on reactionary delay (see 4.2.2.2);
- section 5.5 provides the analysis of the sequences of reactionary delays (see 4.3.1);
- section 5.6 presents the impact of the sequences in form of a delay multiplier – the magnitude of root delays (see 4.3.4); and,
- the last section 5.7 provides an evaluation of reactionary delay from an airport point of view.
5.1 Distribution of primary delays by duration

Primary delays are the main drivers of reactionary delay and their length plays a key role in the propagation of reactionary delays. Figure 17 shows the distribution of primary delays reported along the analyzed sequences (not only the root delay). It illustrates that short primary delays up to 15 minutes account for the highest share of primary delay in terms of occurrence. However in terms of minutes generated, primary delays from 16 to 60 minutes account for the highest share.

5.2 Sensitivity of airline business models to reactionary delay

As described in 4.2.1 the ratio between reactionary and primary delays is used as key performance indicator for the sensitivity of the three airline business models to reactionary delays.

The ratio describes the impact of primary delays on successive flights in form of reactionary delays. If the ratio is one, every minute of primary delay generates an additional minute of reactionary delay. If the ratio is higher than one, the total amount of reactionary delay generated is higher than the amount of initial primary delays.

5.2.1 Methods of calculating reactionary delay

As outlined in the literature review in Chapter 2 – due to the lack of available data - most studies on reactionary delay are based on models which calculate the delay propagation based on available airline schedules. The advantage of this methodology is that the assumptions made for the calculation are not influenced
by possible reporting inconsistencies and can therefore easily be used to compare airlines to another.

However, any model is only as good as the underlying assumptions and actual observations can differ considerably from the estimated results of the calculated propagation.

The CODA data collection enables a comparison between both methods.

1) **Reactionary delay (reported):** The reported reactionary delay is the sum of all the reactionary delay codes (91-96) as reported by airlines to CODA.

2) **Propagated delay (calculated):** This method is different because when calculating the propagated delay, it is not known if a delayed departure after a delayed arrival is due to the inbound delay, or if the delay was absorbed and a new primary delay caused the departure delay. The calculated propagated delay is calculated as the minimum between the inbound and departure delay, depending whether the delay was absorbed during the ground phase or not.

\[
\text{propagated delay} = \text{MIN\{inbound delay, departure delay\}}
\]

\[\forall \text{ inbound, departure delay} > 0\]

Figure 18 compares the results of the two different methodologies. The solid lines indicate the mean ratio of the (reported) reactionary delays of the different airline business models, the dotted line the ratio of the (calculated) propagated delays. With some exceptions in specific months, the correlation between the (calculated) propagated delay and the (reported) reactionary delay is generally good for all three airline business types. It is interesting to note that the reported delay (solid lines) is most of the time below the calculated delay (dotted lines). This is most likely due to the inability of the model to account for a certain level of flexibility to speed up turn-around times when required.

The analysis in the following sections only relates to reported reactionary delay.
5.2.2 Share of reactionary delay by type of operation

In Figure 19 the average delay of delayed departure (ADDD) and the share of reactionary delay are illustrated by type of operation in summer 2008. The bottom part of Figure 19 shows the percentage of delayed departures for each of the three different airline business models. Note that for the purpose of this report, delays are counted from the first minute on.

Of the three analysed airline business models, hub-and-spoke operations show with 17 minutes the lowest ADDD and also the lowest share of reactionary delay (7 minutes).

Low-cost operations have the highest ADDD (26 minutes) and also the highest share of reactionary delay (13 minutes).

On average, every minute of primary delay generated more than one minute of reactionary delay for this type of business model.
The ADDD for point-to-point operations is slightly higher than for hub-and-spoke operations, but with a comparatively higher share of reactionary delay (46 percent). Figure 19 illustrates that almost 60 percent of hub-and-spoke and low-cost operations were delayed during summer 2008.

The high level analysis in Figure 19 provides a first high level estimate of the importance of reactionary delay for each of the three airline business models.

The analysis in the next section of this report provides an analysis of the reactionary to primary delay ratio over time for the three airline models.

5.2.2.1 Evaluation of the reactionary to primary delay ratio over time

Figure 20 shows the seasonal evolution of the reactionary to primary delay ration for all three airline business models. The ratio is represented by the solid line. Additionally the mean primary (dotted yellow line) and reactionary delay (dotted purple line) of delayed departures is shown.
For hub-and-spoke operations, the ratio is on average lower than for the other two types of operation. Two peaks are observed in winter 2007 and 2008 which is most likely due to adverse weather. Starting in 2009, a big drop in primary and even more in reactionary delay can be observed resulting in a significant decrease of the ratio.

For low-cost operations, the ratio is higher than for hub-and-spoke operations. For some months such as July 2008, the amount of reactionary delay is higher than the amount of primary delay and the ratio is higher than one. It is interesting to note that the highest ratio is observed in summer 2009 when traffic levels were considerably lower than in 2008 as a result of the economic crisis.

Point-to-point operations, show the highest ratio between winter 2007 and winter 2008. With the exception of April, point-to-point operations show a significant improvement since the beginning of 2009.

Low-cost operations have the highest ADDD (26 minutes) and also the highest share of reactionary delay (13 minutes). On average, every minute of primary delay generated more than one minute of reactionary delay for this type of business model.

Figure 20: Seasonal evolution of reactionary delay ratio
The observations in Figure 20 are consistent with the findings in Figure 19. Low-cost carriers show on average the highest level of departure delay (primary + reactionary delay) and hence the highest ratio. The 51 percent accounting for reactionary delay in Figure 19 equal a ratio slightly above one.

5.2.2.2 Ratio reactionary/primary delay within the week

Figure 21 and Figure 22 show the within-week-variation of the reactionary to primary delay ratio. The ratio is furthermore put into context with the number of flights (Figure 21) and the average delay of delayed departures (Figure 22). The ratios of hub-and-spoke and point-to-point operations show a similar pattern with a clear peak on Fridays (5) and the lowest level on the weekends. Low-cost operations, on the other hand show a slight drop on Wednesdays (3) and Thursdays (4).

![Figure 21: Reactionary/primary delay and flight movements within the week](image)

Observed traffic levels for all three types of operation stay fairly constant between Monday and Friday and drop on the weekend, especially on Saturdays.
Figure 21 suggests that the ratio is not directly linked to the level of traffic. For instance, point-to-point operations have the lowest mean number of flights but the highest reactionary to primary delay ratio.

The average delay of delayed departures (ADDD) in Figure 22 shows a similar pattern for all three types of operations. An interesting difference is the behaviour of the ADDD on weekends. Whereas for hub-and-spoke operations the ADDD drops already on Saturdays, for both other types of operations the ADDD peaks on Saturdays. This is even more remarkable considering the lower traffic levels on weekends as shown in Figure 21.

5.2.2.3 Hourly distribution of reactionary to primary delay ratio

This section shows the evaluation of the reactionary to primary delay ratio by time of the day. All weekdays (1-7) were included in the analysis. Similar to the previous section, the ratio is then related to the number of flights and the average delay of delayed departures.
The ratios of all three types of operation show a similar pattern throughout the day of operations.

As most European airports have night flight restrictions and traffic demand is limited during night-time, only a limited number of flights are operated during night time. While the ratio is very high during the night, the number of flights is very low and the results should therefore be viewed with a note of caution. The ratio is to some extent artificially high because delayed departures consist mainly of propagated delay minutes which accumulated throughout the day and which therefore strongly impact the calculation of the ratio of the few flights still operating.

Airlines usually schedule their first flight of the day in the early morning. All three types of operations show a traffic peak in the morning at around 7:00h and a second peak in the afternoon at around 16:00h. The delay ratio increases continuously after each traffic peak and shows only a decrease in the early afternoon when traffic levels are reduced.
The ADDD is quite similar for all three types of operation. The low traffic volume with even fewer delayed flights, results in the strikingly high ADDD over night.

In the early morning the lowest level of ADDD is observed. The ADDD then rises until midday, stays constant until 19:00h and rises again between 19:00h and 23:00h.

Especially in the hub-and-spoke operations, it can be seen that in the morning the ADDD rises only until 09:00h and then stays quite constant, meanwhile the ratio climbs continuously until noon. This suggests that from 9:00h onwards the reactionary part of the departure delay increases steadily until noon when the ratio equals almost one.

Between noon and 16:00h the ratio of stagnates in low-cost operations and drops in the other two operations. After that the same effect can be observed again between 17:00h and 19:00h.

In the afternoon this effect is even more significant than in the morning.

**Figure 24: reactionary/ primary in relation to departure delay by hour**
The relation, between the ADDD and the mean reactionary delay of delayed departure, is shown in Figure 25. Clearly the gradient is below one, so that the mean reactionary delay does not increase as much as the mean departure delay. The trend can be caused by two factors: firstly not all primary delays propagate. Secondly, the impact of reactionary delays is lower than the impact of all primary delays together. This was already observed in Figure 5 and Figure 19 where the share of reactionary delay accounted for some 40 percent of all reported delay. However, an expected increase in form of an exponential distribution with a higher ADDD cannot be observed.

![Figure 25: Average delay and reactionary delay per delayed departure](image)

Winter 2007-08 to summer 2009

- Low-cost airlines
- Hub-and-spoke airlines
- Point-to-point airlines

Figure 25: Average delay and reactionary delay per delayed departure
5.3 Ability to absorb reactionary delays in the block-to-block phase

In this section block phase performance of the airlines is analysed with the key performance indicators detailed in 4.2.2.1: Delay Difference Indicator-Flight (DDI-F) and Block Time Overshoot (BTO). It is important to point out that the DDI-F is the mean absolute difference between the actual and the scheduled block time and the BTO is the percentage of flights exceeding the scheduled block phase.

From a scheduling point of view, the predictability of operations months before the actual day of operations has a major impact on the utilisation of available resources (aircraft, crew, etc.). The lower the predictability of the necessary block-to-block time, the more time buffer is usually required to maintain a satisfactory level of punctuality. The level of “schedule padding” is subject to airline policy and depends on the targeted level of on-time performance and notable differences between airlines can be observed.

When looking at scheduled block times or departure and arrival times, marketing strategies and airport slot allocation needs to be considered.

Figure 26 shows the relation between the BTO (horizontal axis) and the DDI-F (vertical axis) by airline and business model for the summer season of 2008.

Figure 26: DDI-F and BTO by airline business model
A clear correlation between the two can be observed. With a higher mean DDI-F, the number of flights exceeding the scheduled block time rises as well. In the graph each dot represents one airline.

Operational performance in the block-to-block phase varies among the analysed airlines, as the range of the mean DDI-F spans from minus eight to plus four minutes. Overall, the mean DDI-F is slightly negative for all business models. Low-cost airlines absorb on average some five minutes per flight, hub-and-spoke airlines three minutes and point-to-point airlines only two minutes. However, they all plan generally more block time than actually required, indicating that a certain level of buffer time is included in the scheduled block-to-block times.

Note, that the inclusion of buffer time in the block-to-block phase (DDI-F < 0) has also disadvantages as it reduces aircraft and crew efficiency. Crews are assigned to fly longer block times than they really do, which leads to additional costs due to slack time in the crew scheduling.

Apart from this negative impact on airline efficiency, time buffers in scheduled block-to-block times result in a certain level of aircraft to arrive ahead of their scheduled times (“early arrivals”). This in turn may have an impact on airport operations as facilities and stands may not be readily available.

On average, there are only a few airlines which actually generate delay as a result of insufficient scheduled block-to-block times.

Within the three operations, low-cost operators have with around minus five minutes the lowest DDI-F. Only one of the observed low-cost airlines has a positive mean DDI-F, during one season its DDI-F jumps up to even eight minutes. On average, between 70 percent and 85 percent of this specific airline’s flights exceed the scheduled block time (see also green dot in upper right corner of Figure 26). All other airlines with low-cost operations plan one to even ten minutes more than they actually need, thus, having a scheduled block time ten minutes longer than the actual block time. Most these airlines see 20 to 30 percent of flights exceeding the scheduled block time.
As can be seen in Figure 26, hub-and-spoke operators (red dots) have generally a slightly negative DDI-F of around minus three minutes and a BTO between 30 and 40 percent. However the picture is contrasted among hub-and-spoke operators. While one hub-and-spoke carrier shows for example a comparatively low DDI-F of around minus 7.5 minutes and a BTO of only 17 percent (see red dot in the bottom left corner of Figure 26) another carrier exceeded the scheduled block time by 3 minutes on average and up to 75 percent of the flights exceeded the scheduled block time.

Because of the low DDI-F, the first hub-and-spoke carrier is able to recover at least one third of its flights which departed with a departure delay during the block-to-block phase. However, this also implies that a comparatively high number of aircraft arrive even before their scheduled arrival time, in this case, between 55 and 70 percent.

The hub–and-spoke carrier (with the positive DDI-F) generates on average already delay during the block-to-block phase. Consequently the share of delayed flights increased by eight percent in the block-to-block phase. During the summer season 2008, 76 percent of arrivals were delayed with a mean arrival delay of 35 minutes. Logically this leads to an increased probability of reactionary delays.

The impact of the DDI-F in terms of number of delayed flights is visualized in Figure 27. It illustrates, that carrier with no or positive DDI-F are likely to increase the number of delayed flights on arrival, or even double them, during the first block phase.

Flights of airlines absorbing at least two minutes during the first block phase are able to reduce the number of delayed flights.
The following section evaluates the relation between inbound delays upon arrival and reactionary delays on the subsequent flight leg. The ‘inbound delay’ is the observed delay when the aircraft arrives at its destination airport. Depending on the performance during the block-to-block phase, the inbound delay can be larger, smaller or equal to the departure delay observed at the origin airport. It should be noted that inbound delays are only calculated for flights with a subsequent departure. Consequently the delay upon arrival on the last flight leg is not considered in the calculation of the average inbound delay which leads to a lower average delay than is observed for the average delay per delayed arrival (which includes the last flight leg).

Figure 28 illustrates the relation between the average delay of delayed inbounds (ADDI) and the mean reactionary delay on subsequent flight legs. The horizontal axis represents the ADDI and the size of the bubble represents the percentage of delayed inbound flights. The vertical axis shows the mean reactionary delay on the subsequent flight leg.
As an example, the point-to-point airline represented by the big blue bubble in the upper right part of the chart area is explained. This airline has a mean ADDI of 38 minutes and 74 percent of the aircraft are delayed when arriving at the gate. The mean reactionary delay on the subsequent flight leg is around 27 minutes.

A somehow logical and linear relation can be observed in Figure 28: The longer the mean inbound delay - the longer the mean reactionary delay upon departure. Note that this is true irrespective of the percentage of delayed flights, as bigger bubbles can be found on both ends of the graph.

Overall, low-cost operators have higher mean reactionary delays. They also differ more from another, so that a clear pattern is not visible. The high level of variation is to some extent due to the categorisation of the low-cost airlines (see 3.4.2). Some of the low-cost carriers operate more like a hub-and-spoke operation and others more like point-to-point operations. This needs to be kept in mind when looking at the low-cost operations.

Although the level of inbound delay has clearly an impact on delay propagation there is still a possibility to absorb parts of the experienced delay during the ground phase which is analysed next.
5.4 Ability to absorb reactionary delays in the turn-around phase

This section evaluates the ability to absorb delays in the turn-around (ground) phase. The KPIs are described in section 4.2.2.2. The turn around phase in this study is defined as the time between the IN-time (on-block) and the OUT-time (off-block).

As outlined in 4.2.2, delays can be absorbed in the block-to-block phase and in the turn-round phase. Since many different players are involved in the turn-around process, a good planning and a high level of predictability is essential for turn-around efficiency and good performance. Turn-around performance and the ability to absorb delay during this phase plays therefore an important role in the analysis of delay propagation.

5.4.1 Delay Difference Indicator-Ground and Ground Time Overshoot

The GTO (percentage of flights exceeding the scheduled ground time) and the DDI-G (mean actual absolute minutes difference to scheduled ground phase) describes the ground phase like the DDI-F and the BTO the block phase. Figure 29 shows the relation between the DDI-G and the GTO.

![Figure 29: DDI-G and GTO by airline business model](image-url)
For almost all airlines the same relation is observed: the higher the DDI-G, the more flights stay longer on the ground than scheduled. For low cost operations there were three clear outliers and the trend line for low-cost operators was removed in order to avoid confusion. It is striking that irrespective of the type of airline operations between 60 and 90 percent of all flights have a turn-around time longer than actually scheduled.

Around 70 percent of the hub-and-spoke operations exceed the scheduled ground time, leading to a mean DDI-G of almost plus five minutes. Point-to-point operators have the smallest DDI-G of plus three to four minutes. Low-cost operations tend to stay even longer and show a DDI-G of plus eight minutes.

5.4.2 Turnaround Delay Indicator and Turn-around Time Overshoot

Figure 30 depicts the turn-around delay indicator (TDI) and the turn-around time overshoot (TTO) as described in section 4.2.2.2. It is important to recall that the TDI sets all early arrivals to the scheduled arrival time in order to take out this bias.

![Figure 30: TTO and TDI by airline business model](image-url)
In comparison to Figure 29, Figure 30 has shifted to the left and a slightly downwards. The slope is flatter. This reveals information on early-arrival practices of airlines as well. Only between 10 and 50 percent of aircraft exceed the ground time because of new primary delay, whereas almost twice as many flights exceeded the scheduled turn around time because of a combination of an early arrival time with a late departure.

Note that the three low-cost carriers with the considerably high DDI-G in Figure 29 align themselves in Figure 30 along the other low-cost carrier.

On average, low-costs operations show the shortest scheduled turn-around time. Within the given sample they reach a mean scheduled ground time of 40 minutes. Point-to-point operations are scheduled on average 4 minutes longer than low cost operations and hub-and-spoke operations are scheduled on average 10 minutes longer.

However, it is important to point out that the mean turn-around time depends also on the mix of the aircraft fleet, which limits the ability to directly compare turn-around times. However, it is possible to conclude that the turn-around times of low-cost operations are scheduled quite tightly.

Consequently it is not surprising to see in Figure 30 that on average low cost operators exceeded their scheduled turn-around times more often that the other types of operation. Up to 46 percent of the analysed low cost operations exceeded their scheduled turn around phase and consequently generated delays. On average, low cost carriers added four minutes of delay in the turn around phase in summer 2008.
In comparison, hub-and-spoke operations added only around 1 minute during the turn-around phase in summer 2008.

The picture is different for point-to-point operations. On average aircraft required less turn-around time than originally scheduled. The mean TDI was around minus one minute in summer 2008 and only 25 percent of flights exceeded the scheduled turn-around time.
5.4.3 Schedule padding-Ground

The level of inbound delay and the turn-around performance determine the reactionary delay on the subsequent flight leg. As explained in 4.2.2.2, the schedule padding-Ground aims at capturing the reaction of aircraft operators to delayed inbound flights. Different to the TDI, it only looks at flights that were already delayed upon arrival. Figure 31 shows the average delay of delayed inbounds (ADDI) on the horizontal axis, the schedule passing-ground on the vertical axis and the mean reactionary delay on the subsequent flight leg is

Figure 31 shows clearly, how airlines react differently to an inbound delay and how this affects the mean reactionary delay. The schedule padding-Ground ranges from minus five to almost plus 9 minutes.

Hub-and-spoke operations are found predominantly right below the horizontal axis which indicates that they were on average able to reduce the inbound delay by one minute. Of the three different types of operations, hub-and-spoke operations have with 17 minutes the shortest mean inbound delay in summer 2008. Point-to-point operators were able to decrease the inbound delay by more than two minutes on average. However from a slightly higher average inbound delay of 18 minutes.
As the TDI already indicated, low-cost operators are not able to reduce inbound delays. On the contrary, they even add more delay.

However, one low-cost carrier notably runs on a different strategy: The low-cost carrier which showed the considerable positive DDI-F (see Figure 26) absorbs on average almost five minutes during the turn-around phase. In summer 2008, this low-cost airline had a mean DDI-F of plus 3.6 minutes, a DDI-G of 0.7 minutes, and a sched.pad.-G of minus 4.5 minutes. It runs a completely different strategy than the other low-cost airlines in the sample.

Also quite eye-catching in Figure 31 is the low-cost airline with an ADDI of 53 minutes (big green bubble on the right) and the corresponding mean reactionary delay on subsequent flight legs of 39 minutes. This high average reactionary delay is logical, considering the fact that two third of the flights arrived already delayed.
When looking closely at the values, it becomes apparent that the schedule padding-Ground actually does not directly link the ADDI to the average reactionary delay of delayed departures. The reason for this is that the schedule padding-Ground does not indicate whether the scheduled turn around time would have been sufficient in the first place.

### 5.4.4 Absorbed inbound delay

The last indicator described in 4.2.2.2 is the absorbed inbound delay. With the delay codes reported by the airlines, the actually propagated reactionary delay can be identified which enables to quantify the absorbed inbound delay.

Figure 32 shows the relation between the average delay per delayed inbound (ADDI) on the horizontal axis, the absorbed inbound delay on the vertical axis and the reactionary delay on the subsequent flight leg (size of the bubbles).

![Figure 32: Inbound, absorbed and reactionary delays](image)

The correlation between the ADDI and the absorbed inbound delay is evident. The more the bubbles are situated in the upper right corner of the chart – the bigger is the size of the bubbles. In other words, the longer the average inbound delay and
the shorter absorbed delay, the higher is the mean reactionary delay on the subsequent flight leg.

Compared to Figure 31, in which point-to-point operations show the highest ability to reduce inbound delay, Figure 32 shows that during the turn-around phase point-to-point operators absorb in reality only about as much as hub-and-spoke carriers. This is consistent with the higher ratio of reactionary to primary delay of point-to-point operations (see chapter 5.2.2) and it leads to the conclusion that point-to-point operations do not suffer as much primary delay during the turn around phase as hub-and-spoke operators. Therefore, the effect of reactionary delay is higher which consequently increases the ratio.

Furthermore Figure 32 confirms that low-cost carriers have by far the highest ADDI, but absorb the least inbound delay during the ground phase (maximum seven minutes). This leads inevitably to higher mean reactionary delays on the subsequent flight leg.

Allusively, the graph provides information about the turn-around performance in terms of additional aircraft suffering primary delay. For most of the airlines the mean reactionary delay of delayed departures is less than the difference between the ADDI and the absorbed delay. This is due to the number of aircraft which were not delayed on arrival but added delay during the turn-around phase. They impact the average delay of delayed departures but not the average delay of delayed inbounds.

As an example the airline, represented by the blue bubble on the bottom of Figure 32 is described: The airline has an ADDI of 29 minutes and was able to absorb the inbound delay by 13 minutes on average. In theory this would result in a reactionary delay of 16 minutes on the subsequent flight leg if the number of delayed aircraft stayed the same. However, the mean reactionary delay of the example airline shows only 12 minutes (instead of 16), which suggests that the number of delayed aircraft on departure has increased in comparison to the number of flights delayed upon arrival. More aircraft departing with only primary delay obviously lower the mean reactionary delay of delayed departures.
The following section provided a more detailed illustration of the concept by using the aforementioned low-cost airline which showed a somehow different behaviour than the other low-cost airlines.

The low-cost carrier outlined already in section 5.4.3 showed the following results for the analysed performance indicators:

- DDI-F = +3.6 min
- PDI = 67 %
- DDI-G = 0.8 min
- sched.pad.-G = -4.5 min.

In Figure 32 this airline is found as a green bubble with almost seven minutes of absorbed inbound delay (and still 25 minutes of mean reactionary delay). The difference between the ADDI and the absorbed inbound delay is 25 minutes and the schedule padding-Ground is almost equal to the absorbed inbound delay. This indicates two things: First, the airline mostly does not add new primary delay during the turn-around phase and secondly, more aircraft of this airline depart early than of other airlines.

The second factor is supported by the near zero value of the DDI-G. Also the comparison of its overall mean departure delay and its overall mean reactionary delay reveals that 13 of the 15 minute departure delay (87 percent) are due to reactionary delay. When looking only at delayed departures, 75 percent of the departure delay is due to reactionary delay. Both values are – especially in comparison to the other operators – are quite high and confirm that the airline does not add a lot of new delay during the turn-around phase.

The following section compares now this low cost airline to one of the more typical low-cost carriers:

- DDI-F = -5.7 min
- PDI = 53 %
- DDI-G = 9.5 min
- sched.pad.-G = 7.0 min
- used buffer time = -3.1 min.

The second low cost carrier absorbs nearly six minutes during the block phase. Only 23 percent of the flights exceed the scheduled block-to-block time.
However, 53 percent of the aircraft arrive with a mean delay of 25 minutes per delayed inbound. Of these 25 minutes only three minutes get absorbed during the turn-around phase. As the mean reported reactionary delay of delayed departures accounts only for 15 minutes, a 7-minute gap needs to be explained. The gap is due to the addition of new primary delay during the turn-around phase. This is confirmed by the share of reactionary delay within the total departure delay. 15 of the 26 minutes of departure delay per delayed departure (56 percent) are caused by reactionary delay. Also the high sched.pad.-G confirms that even delayed flights exceed the ground time on average by seven minutes and therefore add further delay.

In comparison to the others low-cost operators, the observed pattern of the first low cost carrier fits more the profile of a charter carrier.

When looking at a typical hub-and-spoke carrier the differences to low-cost carriers become apparent:

- DDI-F = -1,1 min
- PDI = 59 %
- DDI-G = 4,7 min
- Sched.pad.-G = 0,2 min
- Used buffer time = -8,1

Hub-and-spoke carriers typically use a slightly shorter block time than scheduled (here minus one minute). Almost 60 percent of all flights arrive with an average inbound delay of 21 minutes, of which about eight minutes can be recovered during the turn-around phase. The subsequent mean reactionary delay is 11 minutes, which only leaves a small gap of two minutes for new primary delay. The schedule.padding.-Ground indicates that the ground time after an inbound delay stays quite constant. Therefore the airline adds about as much delay as it had absorbed from the previous delay. Consequently, only 11 of the 25 minutes of average delay of delayed departure (=44 percent) is reactionary delay.

Finally, a typical point-to-point carrier is evaluated. In summer 2008 it had the following characteristics:
- DDI-F = -1,2 min
- PDI = 48 %
- DDI-G = 2,9 min
- Sched.pad.-G = -3,0 min
- Used buffer time = -8,9 min

Generally point-to-point carriers operate even closer to the scheduled block time than hub-and-spoke airlines (here minus 1,2 minutes). 48 percent of the flights arrive with a mean delay of 23 minutes. Almost nine minutes of these are absorbed during the turn-around phase. This leads to the reported reactionary delay of 14 minutes. However, the difference between the absorbed inbound delay and the schedule.padding-G gives a hint that the airline adds around six minutes of new primary delay after having absorbed nearly nine minutes in the turn-around phase. 13,6 of the 26,5 minutes of the mean delay per delayed departures (51 percent) are reactionary delays. This is right in the middle between the other two described carriers with different operations.

Across all hub-and-spoke carriers the mean reactionary delay of delayed departure was 6,7 minutes in summer 2008. This is about half as much as observed for low-cost operations (13,4 min).

Point-to-point operations were in-between with around 8,5 minutes. It is evident, that low-cost airlines absorb less inbound delays than traditional scheduled carriers. Point-to-point operations are somewhere between the hub-and-spoke and the low-cost operations. They absorb almost as much as hub-and-spoke carriers, but do not add as much primary delays during the turn-around phase.
5.5 **Sequential analysis of reactionary delays**

This section presents the results of the analysis of delay propagation on those sequences for which reactionary delay was reported.

5.5.1 **Key factors influencing sequences of reactionary delays**

The key factors for the analysis of sequences of reactionary delay need to link performance in the ground and in the block phase but it is necessary to differentiate between primary and reactionary delays.

![Sequential analysis of reactionary delays](image)

**Figure 33: Sequential analysis of the propagation of reactionary delay**

Sequences generally start with a (primary) root delay, which then propagates along the subsequent flight legs. Figure 33 illustrates that parts of the original primary delay can be absorbed along the sequence but new primary delay may be added generating additional reactionary delay on the next flight leg.

The key factors within sequences are therefore:

- Root delay;
- Inbound delay;
- Absorbed inbound delay (used buffer time);
- Additional primary delay; and,
- Reactionary delay.

5.5.2 **Sequences in Europe**

Firstly the frequency of sequences by time of day, delay length, and depth of the root delay is described. The time of the day is divided into three parts: ‘morning’
from 6:00h to 13:59h, ‘afternoon’ from 14:00h till 21:59h and ‘night’ from 22:00h till 5:59h.

Figure 34 shows the distribution of the sequences by airline business model. Nearly 35 percent of all sequences of low-cost operations had a root delay between one and 15 minutes and occurred in the morning. The main share (≈ +20%) of these root delays propagated only on one further flight leg (bottom part of first column of Figure 34).

Irrespective of the airline business model, the time of the day and the length of the delay, the majority of the root delays could be recovered within the first leg after the root delay occurred. Those sequences (with one affected leg) accounted for 50 to 60 percent of all the analysed sequences.

Figure 34 also indicates that more sequences start in the morning than in the afternoon or at night. Especially sequences with short root delays (up to 15 minutes) occur more often in the morning. In general, delays propagate longer when the sequence started in the morning. Low-cost and point-to-point operations have on average a higher depth than hub-and-spoke operations.
Sequences starting at night time account for about five percent of low-cost operations, whereas they are barely seen among traditional scheduled flights. In terms of occurrence, root delays larger than 60 minutes play only a minor role. They only account for six to eight percent of all sequences.

However there is a difference between the occurrence and the impact on airlines. Figure 35 illustrates that the impact of the sequences (in terms of reactionary delay minutes) is distributed quite differently. Sequences starting in the morning have the biggest impact in terms of reactionary delay minutes. This corresponds to the high number of sequences in the morning, which also propagate longer.

On the other hand it is important to notice that long sequences have a big impact, despite little frequency and/or little root delay.

Low-cost operations are especially affected by longer sequences with at least four affected flight legs. The impact of those longer sequences accounts for , about half of all reactionary delays on the sequences in the morning.
5.5.3 **Sequences in detail**

In the following section, sequences of reactionary delays are analysed in more detail for the three different airline business models. It can be observed which share of the inbound delay actually propagates, if and how much primary delay is added during the turn-around phases and what happens during block-to-block phase.

5.5.3.1 **Sequences in hub-and-spoke operations**

Figure 36 illustrates sequences of reactionary delays with four affected flight legs following departure root delays between one and 15 minutes (first chart), 16-60 minutes (second chart), 61 to 120 minutes (third chart), and 121 to 180 minutes (bottom chart) in Summer 2008 for hub-and-spoke operations.

The first column always indicates the mean root delay. The other columns represent the mean inbound and departure delays of the four affected legs. The reactionary delay (green part) is logically what would have been propagated, if there was no additional primary delay. Therefore the difference between the inbound and the reactionary delay, is what has been absorbed. The yellow part indicates the absorbed inbound delay, which is replaced by a new primary delay. Together with the orange part, they symbolise the total new primary departure delay. The difference between the inbound delay and the total departure delay visualizes what was previously called schedule padding-Ground, the general reaction to an inbound delay. The DDI-F is the difference between the root respectively previous departure delay and the inbound delay.

The green and yellow part together would have been the calculated propagated delay. This explains why the ratio of the calculated propagated delay in Figure 18 is mostly higher. Despite of errors in reporting, propagated delay is only smaller than the reported reactionary delay if there is more non-rotational reactionary delay.

It is important to bear in mind, that the charts do not give information about the impact respectively the frequency of these sequences. They only illustrate how, on average, the root delay propagates along the sequence. Sequences of reactionary
delays can end because all root delay is absorbed or because the sequence of the aircraft ends.

The first chart in Figure 36 shows that after a short mean root delay of 9 minutes, aircraft add around 7 minutes during the first block phase, arriving with 16 minutes of inbound delay.

During the first ground phase airlines seem not to react to the delay as they absorb only one minute, but add more than ten minutes of primary delay. As the propagation goes on more delay is absorbed during ground and block phase.

The increase of the reactionary delay is caused by the long additional primary delays, especially during the first ground phase.

Sequences in the second graph of Figure 36 suffer a mean root delay of 32 minutes. Again aircraft are not able to absorb any delay during the first two block phases. Also more primary delays are added during the first two ground phases.

It appears that airlines only start to really reduce departure delay when the value reaches around 40 minutes. The departure delay on the last leg is still higher as the root delay.

Figure 36: Hub-and-spoke sequences with different root delays
The mean root delay of the third graph equals 81 minutes. The difference to the previous charts is obvious. Airlines start to absorb the delay right away, with fewer minutes absorbed during the block phases and more during the ground phases. They are able to mitigate the root delay despite additional primary delay (yellow parts).

Sequences with root delays between 121 and 180 minutes show the actual potential of hub-and-spoke operators to absorb delay. The mean departure delay can be reduced from 144 to only 61 minutes. It seems that the higher the average delay, the more are airlines able to avoid further primary delay, and the more they are able to absorb existing delay.

Looking at all the various charts in Figure 36, it appears that reactionary delays only increase until a certain level is reached.

Figure 37 evaluates the depth of sequences of hub and spoke carriers with a root delay between 16 and 60 minutes in summer 2008. As illustrated in Figure 34 and Figure 35, this group has the highest impact in terms of minutes of reactionary delay.

When the delay propagates only for one leg, only a small amount is absorbed during the block and the turn-around phase. The aircraft departs with 25 minutes of delay, of which 20 minutes are propagated.

When root delay propagates for two legs, the root delay cannot be reduced during the first block-phase. During the first turn-around phase, about seven minutes are absorbed but twice as many minutes are added than on sequences with only one flight leg.
During the second turn-around phase more than nine minutes are absorbed, leading to 22 minutes of reactionary delay of 29 minutes of total departure delay. The third chart in Figure 37 shows, that reactionary delays account for about 26 minutes on all three affected legs. The new departure delay offsets the delay which is absorbed during the turn around phase.

The small differences between the mean root delays suggest that the depth of a sequence is not necessarily linked to the initial root delay. Although there is no obvious link, longer sequences show a slightly higher mean reactionary delay from the first ground phase onwards. Consequently, the depth of sequences with a root delay between 16 and 60 minutes in hub-and-spoke operations is strongly correlated with the addition of new primary delay.

![Figure 37: Depths of sequences in hub-and-spoke operations](image-url)
5.5.3.2 Sequences in low-cost operations

The first chart describes that even low-cost airlines with a mean DDI-F of around minus five minutes add delay during the block phase after short root delays. However, Figure 38 shows that the delay propagation is predominantly driven by long root delays and additional primary delays. Low-cost operators absorb almost no delay during the turn-around phase, but up to 10 minutes during the block phase, which confirms the results in sections 5.3 and 5.4.

The mean schedule padding-Ground of low-cost airlines is positive, indicating too optimistic ground time scheduling. Therefore, reactionary delay rises with every affected leg following a root delay of less than 61 minutes. It is interesting to note that on sequences with root delays of more than two hours aircraft finally also absorb delay in the turn-around phase.

Figure 38: Low-cost sequences with different root delays
As low-cost operations show a different pattern of delay propagation, Figure 39 illustrates again sequences with a root delay of 16 to 60 minutes and different depths but this time for low-cost operations.

The first chart suggests that the delay propagation on only one subsequent leg is not due to a decrease in departure delay.

The same pattern is seen for all different depths of reactionary sequences. Low-cost operators absorb more delay in block-time than in the turn-around phase, in which they on average add around eight minutes of primary delay.

Longer sequences generally start with a higher level of reactionary delay on the first affected flight leg.

The reactionary delay increases with every affected leg because of the newly added primary delay during every additional turn-around phase and the inability to absorb inbound delay.

78 percent of the analysed sequences with three affected legs and a root delay between 16 and 60 minutes end only when the actual rotational sequence ends, usually at the end of the operational day. For longer root delays, less than 20 percent of aircraft can recover within the aircraft actual sequence.

Figure 39: Different depths of sequences in low-cost operations
5.5.3.3 Sequences in point-to-point operations

Finally, sequences in point-to-point operations are illustrated in Figure 40. Point-to-point operations show a similar pattern within sequences of reactionary delays as hub-and-spoke operations. The first chart illustrates that the root delay rises significantly due to a positive DDI-F and new primary delay during the first turn-around phase. In chapter 5.3 the DDI-F of point-to-point operators indicated that they generally absorb the least delay minutes during the block-phase. This is reflected here. Within sequences with root delays of up to 60 minutes, aircraft increase the delay on every block phase. Although on average point-to-point and hub-and-spoke operations absorb about the same amount of minutes during turn around (Figure 37), point-to-point operations are not able to absorb as many minutes during a single turn-around phase. For instance, after a 144 minute root delay, hub-and-spoke operators manage to reduce the delay after the fourth leg to 60 minutes, while point-to-point operators absorb almost 20 minutes less. However, during the turn-around phases following ‘shorter’ departure delays (see first chart) they absorb more than the
hub-and-spoke operators. The yellow and orange parts of the columns suggest that overall point-to-point operators do not add as much primary delay in the turn-around phase as hub-and-spoke operators.

Figure 41 evaluates the depth of sequences of point-to-point operations with a root delay between 16 and 60 minutes in summer 2008. The average root delay increases slightly from 30 to 32 minutes. When the delay propagates only on one further flight leg, as shown in the first chart of Figure 41, aircraft actually absorb delay during the block phase and during the turn-around phase. After adding another four minutes of new primary delay, the aircraft departs with 25 minutes of delay, on average.

The chart in the middle of Figure 41 shows a rotational sequence with two affected flight legs. No delay can be absorbed during the block phases. During the first turn-around phase, the absorbed delay is similar to the newly added primary delay. During the second turn-around phase, more than eight minutes are absorbed and only four minutes of new primary delay are added, so that the aircraft leaves on the last affected leg with 26 minutes of departure delay.

Figure 41: Depth of sequences in point-to-point operations
Sequences with three affected legs, depart after the first turn around phase with an even higher delay than on arrival. During the second and third turn around phases they absorb another seven and eight minutes of inbound delay and the aircraft departs on the last flight leg with an average delay of 31 minutes.

The charts reveal that point-to-point operations react quite sensitive to primary delay. The limited ability to absorb delay, in the turn around and block-to-block phase, puts more weight on additional delay.

5.5.3.4 First reaction to short departure delays

After an initial root delay, the first opportunity for an airline to react is the following block phase. In Figure 36 to Figure 41 it was observed that airlines, despite their overall negative DDI-F, generally add further delay in the block phase following a rather short departure delay.

![Figure 42: The first reaction after the root delay – DDI-F](image)

Figure 42 illustrates the first reaction of airlines irrespective of the number of sequences in summer 2008 for each of the three airline business models. It is striking, how the effort to absorb delay in the first block phase increases as the duration of the initial root delay goes up. Consistent with the observed mean values of the DDI-F, low-cost airlines are able to absorb more delay than hub-and-
spoke or point-to-point airlines. The overall mean values of the three operations are only reached for root delays of more than 120 minutes.

5.5.3.5 Sequences in Summer 2008 and Winter 2008-09

Figure 20 in section 5.2.2 shows that the ratio of reactionary to primary delay of hub-and-spoke operations decreased noticeably from winter 2008-09 to summer 2009. Along with the drop of the ratio, the mean delay per delayed departures also decreased. While primary delays decreased only moderately from eleven to nearly ten minutes, reactionary delays dropped from eight to below six minutes, on average.

Figure 40 shows a typical, quite frequent sequence with a mean root delay of 32 minutes and three affected flight legs for hub-and-spoke operations. The comparison of the winter 2008 season to the summer 2009 season confirms the observation from Figure 20.

Primary delays in the turn-around phase (yellow and orange) do not decrease noticeably, but the level of reactionary delay drops because of two reasons: First, aircraft absorb more and do not add new delay during the block-to-block phase. Second, aircraft absorb about a minute more in the turn-around phase, especially on the first affected flight leg. As a consequence, the mean departure delay is lower.
5.5.3.6 Differences of sequences by time of the day

As an example of differences in sequences that started in the morning occurs (between 6:00h and 13:59h local time) and in the afternoon (between 14:00h and 21:59h local time). Due to the small number of flights, the night time was not evaluated in more detail.

Figure 44 and Figure 45 illustrate sequences of hub-and-spoke operations for root delays between 16 and 60 minutes (Figure 44) and 121 and 180 minutes (Figure 45) respectively.

In an earlier section of the report, it was suggested that airline priorities may change during the day (see section 3.1.3.1). Airlines appear to be focusing on punctuality in the morning while they focus on connectivity in the afternoon. The following analysis confirms this statement.

Figure 44: Sequences with root delays between 16-60 minutes during the morning and afternoon (Hub-and-spoke operations)

Figure 44 demonstrates that the mean root delay is similar in the morning and in the afternoon. Although there is a little less primary delay (yellow and orange) during the turn-around phase in the afternoon, the mean departure delay is higher. The difference results mainly from fewer absorbed delay minutes, especially in the turn-around phase.

This indicates that the increasing ratio in the afternoon (see Figure 23) is not only the result of ongoing delay propagation from root delays in the morning, but also from a higher level of delay propagation on ‘afternoon-sequences’.
Figure 45: Sequences with root delays between 121-180 minutes during the morning and afternoon (Hub-and-spoke operations)

Figure 45 shows sequences with a root delay between 121 and 180 minutes and two affected legs. Along the ‘morning-sequence’ the aircraft absorbs more than 45 minutes in each turn-around phase (difference between inbound delay and reactionary delay (green part) but adds 12 and 9 minutes of new primary delay respectively. Finally the aircraft departs with 68 minutes delay.

In contrast to the propagation of delay in the morning, the aircraft absorbs on average less than 20 minutes during the first turn-around phase in the afternoon. With even less primary delay each in each turn-around phase and 45 minutes of absorbed delay in the second turn-around phase, the aircraft finally leaves with still more than 90 minutes of delay.

It becomes evident, that airlines do not absorb as much inbound delay in the afternoon. The magnitude of the root delay is 40 percent higher in the afternoon than in the morning (154/144=1.07 in the morning and 210/143=1.47 in the afternoon).

The same operational difference was observed for point-to-point and low-cost operations.

5.6 Magnitude and depth of sequences of reactionary delay

This section analyses the magnitude and the depth of sequences of reactionary delay. As explained in section 4.3.4, the magnitude of the root delay is a simple and useful indicator, but it is quite sensitive to the length of the root delay and the depth of the sequence.
Figure 47 provides an overview of the mean magnitudes for root delays, depending on the time of the day and length of the delay, in combination with the mean depth of the sequence. Different from Figure 35, which shows the impact in terms of percentage of all reactionary delay minutes, the magnitude is independent of the frequency of a root delay. However, it is influenced by the frequency of the various depths.

The magnitude shows a clear peak for root delays between one and 15 minutes. In the morning it decreases with longer root delays, whereas in the afternoon it stays quite constant for root delays longer than 16 minutes.

In the morning the magnitude is generally higher and the sequences are generally longer—rising to an average of 2.7 legs for low-cost operations. Depth and magnitude of the sequences for root delays over 15 minutes are quite constant in the afternoon.

Figure 46: Mean magnitude and depths of root delays
In Figure 35 it was already shown that the impact of all reactionary delay minutes is lower in the afternoon due to the lower number of rotational frequencies. Figure 46 confirms that sequences are on average shorter in the afternoon, and therefore have a lower impact in terms of magnitude.

However it should be noted that Figure 40 demonstrated that despite the lower overall impact, the level of delay propagation is higher in the afternoon. Due to the small number of flights, the magnitude for flights during night time is artificially high and should be viewed with a note of caution.

It is interesting to note that the ‘morning-sequences’ with a root delay between 61-120 minutes show the highest mean depth and also the biggest difference in comparison to the afternoon.

Hub-and-spoke operators show the lowest depth and magnitude. In terms of ranking between the three business models, the magnitude reflects the ratio of reactionary to primary delay, analysed in 5.2.2.

Low-cost operators show a surprisingly high magnitude for short root delays, especially in the morning (5.8). This supports the previous observation that low-cost carriers do only have limited scope to absorb delay and are in fact more likely to add new primary delay in the turn-around phase. In Figure 42 it was already illustrated that low-cost operators even add delay during the first block phase of such a short root delay.

In 5.5.3.1 it was suggested that, the higher the actual level of delay, the more delay can be absorbed and the fewer newly added primary delay. This is also reflected in the ‘morning-magnitude’ in Figure 46. The magnitude drops although root delay and depth increase. This confirms that the delay propagation is significantly lower on flights with relatively long root delays.

It is apparent that the magnitude works well as an indicator, when including the depth of a sequence.
5.7 Reactionary delays at European airports

After the analysis of delay propagation by airline type, this section focuses on the delay propagation at European airports.

5.7.1 Reactionary to primary delay ratio at selected airports

Figure 47 shows the reactionary to primary delay ratio for six major European airports. All other airports are grouped within ‘others’. It should be noted that the analysis is still based on the validated data sample used for the analysis in the previous chapter of the report. Due to airline data confidentiality reasons, airports are dis-identified, as most of the airports have only one major carrier serving the airport.

![Figure 47: Reactionary delays at European airports](image)

While the top of Figure 47 relates to the distribution of delay on delayed flights, the bottom part of the figure shows the traffic distribution and the actual share of traffic for which a departure delay was reported (grey part).
The delay distribution enables a distinction between hub-and-spoke operations (red columns) and other operations (blue columns) and between reactionary (solid colour) and primary delay (diagonal lines).

The small chart on the right side of Figure 47 shows that the ratio between reactionary and primary delays does not vary significantly over the four analysed seasons. Only in the IATA summer season 2009 the average delay of delayed departures (ADDD) and the ratio dropped which is most likely due to lower traffic levels following the economic crisis.

The ADDD and the reactionary to primary delay ratio vary considerably among airports. The six major hubs are sorted by the length of the mean reactionary delay of the hub-operations. AP1 has with 8.4 minutes the highest mean reactionary delay and AP 6 with 4.1 minutes the lowest level of reactionary delay of the analysed airports.

With the exception of AP1 and AP2, the ADDD and the mean reactionary delay (except for AP4) are lower for hub-and-spoke operations. The share of reactionary delay for non-hub operations ranges between 34 and 50 percent and is considerably higher than for hub-operations.

It should however be noted with the exception of other airports, that the share of hub-and-spoke operations outweighs the share of other operations. Consequently, and despite the lower ADDD, hub-and-spoke operations have a considerably higher overall impact on the operations at the analysed airports.

5.7.2 Mean daily impact of an airport

The impact of selected airports on other airports and themselves is evaluated in this section of the report.

Figure 48 shows the average daily number of directly served destinations within the ECAC area and the average number affected –directly or indirectly - by a root delay originating at the analysed airport.

In absolute terms, Amsterdam-Schiphol (EHAM) affects directly or indirectly the largest number of airports (47 airports). In total, EHAM offered direct services to an average of 94 different destinations within the ECAC area.
It is striking that one of the biggest hubs in Europe – London Heathrow (EGLL) – only affects 29 airports on average. However, it should be noted that the analysis was restricted to airports within the ECAC area.

Figure 48: Number of daily affected airports by airport

Figure 48 observes merely the number of affected airports, but it does not provide an indication of the frequency or the impact in terms of delay minutes.

Figure 49 illustrates how the average daily impact of a root delay originating at the analysed airport is determined in the next sections of the report.

The first airport is affected by all reported reactionary delay minutes. For the second and the third airport in the sequence, the impact in terms of propagated delay minutes is calculated as the minimum of either the reported reactionary delay at departure airport of the inbound flight, the inbound arrival delay or the reported reactionary delay on the subsequent outbound flight leg. That way, newly added delay during the turn-around

Figure 49: Calculating the original propagated delay minutes
phase is disregarded.

For example, the second airport in Figure 49 suffered an inbound arrival delay of 43 minutes but the total departure delay on the subsequent outbound flight leg was 41 minutes of which only 35 minutes were carried over from the previous flight leg. However, only 30 minutes were caused at the ‘root airport’. Therefore the propagated delay due to the initial root delay is the minimum of 43, 35 and 30 – in this case 30 minutes.

In Figure 50 the average daily impact of selected European Hubs - on themselves and on other airports - is shown. Secondary and other hubs not included in the list of hub airports are grouped together as “secondary airports”. All other ECAC airports were grouped as “Other”.

![Summer 2008 daily impact of an airport by reactionary delay minutes](image)

**Figure 50: Daily impact of an airport by reactionary delay minutes**

Figure 50 shows nicely that major hubs affect to a large extent their own operations because a large number of aircraft return several times during the day to their hub airports.
On average, almost 6 hours of the reactionary delay reported at Munich airport (EDDM) originates from root delays at Munich airport. At Amsterdam airport (EHAM) almost 4 hours of the reactionary delay reported at the airport is generated by root delays originating at Amsterdam airport. Additionally Amsterdam airport shows a notable impact on London Heathrow (EGLL) and London City airport (EGLC).

It should be noted that these figures are for illustration only as they related only to the validated sample used for the analysis and not to all flights at the airport.

In Figure 22 differences of the average delay of delayed departures (ADDD) and the ratio of reactionary to primary delays within the week were analysed. A similar analysis was carried out to detect differences in the impact of reactionary delay on airports, as shown in Figure 51.

Similar to the decrease of the ADDD and the reactionary to primary delay ratio on Tuesdays (2), Wednesdays (3) and Saturdays (6), the impact of reactionary delays originating from London Heathrow (EGLL) decreases on those days. However, the decrease is mostly due to a lower impact of the airport on its own operations on those days.

![Figure 51: Daily impact of an airport within the week](image)
5.7.3 **Airports affecting themselves**

In order to take a closer look at the impact an airport on its own operations, a new set of sequences was created. The new data set includes only flights between the analysed airport and another airport (i.e. every second leg is by definition the analysed hub airport).

Figure 52 illustrates the average delay of delayed departures for flights returning to their origin airport on the subsequent flight leg for several European airports. The columns enable a distinction between the delay which is returned to the origin airport (solid area) and the delay which could be absorbed during the rotation (diagonal stripes).

Additionally, the blue columns represent the results for the IATA winter season 2007-08 and the green columns the IATA summer season 2008.

The share of delay returned to the origin airport varies between 20 percent for Zurich-Kloten (LSZH) to 56 percent for London-Gatwick (EGKK). In absolute terms, the average minutes of delay returned to the origin airport range from three minutes at Zurich Kloten (LSZH) to 12 minutes at Rome-Fiumicino (LIRF) airport. For Frankfurt (EDDF), London Heathrow (EGLL) and Copenhagen (EKCH) a notable difference between summer and winter season can be observed.
5.7.4 Example of bad weather in Frankfurt

The following example illustrates quite impressively how airports affect themselves and to what extent delay originating from the analysed airport is returned on the subsequent flight leg. On the 8th of December 2008, Frankfurt Airport (EDDF) was affected by adverse weather.

Figure 53 shows clearly that the main impact originates from root delays attributable to Frankfurt airport (EDDF). The impact on its own operations was more than 15 times higher than on an average day in the winter season 2008.

![Figure 53: Impact of major airports on 8.12.2008](image)

Figure 54 shows the propagation of root delays between 16 and 60 minutes along the rotational sequences on the 8th of December 2008.

Sequences on which the delay propagated on four successive flight legs, the observed root delay was 39 minutes in Frankfurt. When the aircraft returned to
Frankfurt, the inbound arrival delay was similar to the observed delay when the flight departed from Frankfurt. Although the aircraft was able to absorb nearly 19 minutes during the turn-around phase, it suffered another long primary delay of about 64 minutes (yellow and orange part). On the third leg the aircraft was able to absorb around four minutes, coming back with then 79 minutes of inbound arrival delay. However, after adding another 33 minutes in Frankfurt, the total departure delay increased to 98 minutes.

![Sequence of reactionary delay](image)

**Figure 54: Sequences from EDDF on 8.12.2008**

The bottom chart of Figure 54 shows a similar sequence with two additional flight legs. The sequence started with a lower average root delay of 21 minutes at Frankfurt. Every time the aircraft returned to Frankfurt, the impact of each turn-around phase became more evident. Each time at Frankfurt the additional
departure delay increased the total delay of the sequence by 60 respectively 40 minutes. Finally, the aircraft was able to recover even 90 minutes on the sixth leg, before the sequence of reactionary delay ended.
6 CONCLUSION

Throughout this analysis various KPIs were introduced to observe and measure delay propagation. Indicators aimed at measuring airline performance during the block-to-block and turn-around phase illustrated differences in airline strategies and formed the basis for the more detailed analysis of the delay propagation along the individual flight legs.

The ratio of reactionary to primary delays measures the sensitivity to reactionary delays. For the sample of selected airlines its mean value is slightly below one. Thus, almost half of the departure delay is due to reactionary delays.

The comparison between calculated and reported reactionary delays revealed that calculated reactionary delays appear higher than the reported ones because they do not take additional primary delay during the ground phase into account.

Over the observed four seasons, on average 50 percent (12 minutes) of delays in low-cost operations are reactionary delays. Hub-and-spoke operators have by far the lowest ratio as reactionary delays account for early 40 percent of all delays (7 minutes). Point-to-point operations lie in between the other two with around 45 percent of reactionary delay (9 minutes).

KPIs evaluating the turn-around and the block-to-block performance demonstrated the following:

The BTO shows a strong and linear correlation to the DDI-F. The larger the share of aircraft which exceed the scheduled block-to-block time, the less delay can be absorbed in the block-to-block phase. On average, irrespective of the business model, the DDI-F is negative. Therefore, buffer time is included in the scheduled block-to-block phase of all types of operation. However, with an average DDI-F of about minus five minutes, low-cost operators are best positioned to absorb delays in the block-to-block phase.

Hub-and-spoke operators showed an average DDI-F of three minutes and point-to-point operators a DDI-F of two minutes.
The correlation of the GTO to the DDI-G looks similar to that of the BTO and DDI-F. Depending on the airline business model, between 60 and 90 percent of all analysed flights exceed the scheduled turn-around time. However, only half as many flights exceed their scheduled turn-around times when additional minutes due the aircraft arriving ahead of its scheduled arrival time are removed.

Finally, the average absorbed inbound arrival delay provided an understanding of the level of delay that can be absorbed during the turn-around phase. Here, low-cost airlines appeared to have only a limited ability to absorb delay in the turn-around phase. Instead, they even added the highest level of new primary delays. Overall, hub-and-spoke and point-to-point carriers are able to absorb approximately the same amount of delay during the turn-around phase, but hub-and-spoke carriers added more new primary delays than point-to-point carriers. Thus, the ratio of reactionary to primary delay is lower for hub-and-spoke carriers.

Irrespective of the airline business model, the time of the day and the length of the delay, the majority of the root delays can be recovered within the first leg after the root delay occurred. Those sequences (with one affected leg) accounted for 50 to 60 percent of all the analysed sequences.

While of the share of sequences with a root delay between one and 15 minutes accounts for the majority of observed sequences, the impact in terms of reactionary delay minutes is the highest for root delays between 16 and 60 minutes. As can be expected, sequences starting in the morning have the most severe impact on reactionary delays and account for about 60-65 percent of all reactionary delay.

Depending on the airline business strategy notable differences in strategies to mitigate reactionary delay were observed.

Hub-and-spoke operations show a limited reduction of reactionary delay for short root delays between 1 and 15 minutes. In fact, sequences with a short root delay are likely to add new primary delay on subsequent flight legs which further increases the overall level of reactionary delay. The reaction on longer root delays (>120 min.) is very different. Aircraft are able to absorb a significant amount of delay in each turn-around phase and manage to avoid additional primary delays.
which results in a considerable reduction of the overall reactionary delay on each of the subsequent flight legs.

Low-cost carriers are generally able to absorb more delay in the block-to-block phase and only a limited amount of delay in the turn-around phase in comparison to the other operations. This makes them very sensitive to primary delays, so that reactionary delays tend to increase throughout the reactionary delay sequence. Thus, only a small share of sequences with reactionary delays is able to recover within a rotational sequence of the aircraft.

Although point-to-point operators show a similar mean value for the absorbed inbound delay as hub-and-spoke operators, they propagate a higher share of long inbound delays and are therefore, more sensitive to primary delays. This is also reflected by a higher reactionary to primary delay ratio. Apart from that the observed reactionary delay sequences show a high level of similarity to the sequences observed for hub-and-spoke operations.

For all business models, two main points were observed from the analysis of reactionary delay sequences.

First, all airlines irrespective of their mean negative DDI-F, add further delay during the block-to-block phase, following short root delays. The mean DDI-F value of all three types of operation is only observed for root delays longer than 120 minutes. Second, the longer the initial root delay, the stronger is the reaction to mitigate the propagation of the delay and the less additional new primary delay is accumulated on the subsequent flight legs.

The analysis of the mean depth and magnitude of root delays demonstrates that especially during the morning, the magnitude decreases although depth and the root delay increase (until root delays up to 120 minutes). This reflects what has been stated above: Within sequences of smaller root delays, a higher level of propagation and, therefore, an increase of reactionary delay is observed. Hence, following longer (root) delays, aircraft absorb more and suffer less primary delays, decreasing the reactionary delay of subsequent legs as well as the magnitude.
The comparison between sequences of reactionary delays in the morning and in the afternoon reveals that aircraft absorb less delay during the turn-around phase in the afternoon than they absorb in the morning while the level of newly added primary delay stays relatively constant. However, the magnitude is lower in the afternoon, because the mean depth of sequences is significantly lower in the afternoon.

The longest observed mean depth of sequences is observed for root delays between 61 and 120 minutes which occur in the morning.

Finally, it should be noted that the level of delay propagation is higher in the afternoon. The magnitude of sequences following short delays is higher than following long delays, but the highest impact have sequences following morning-root delays of 60-120 minutes.

The analysis of major European airports demonstrates that propagation is stronger in non-hub operations where reactionary delays account for up to 50 percent of total reported delays. This is however not surprising considering the higher primary to reactionary delay ratio of non-hub-and-spoke operations. The share of reactionary delay on hub-and-spoke operations was generally lower at the analysed hub airports and accounted for only up to 35 percent of all reported delays. Therefore, primary delays at the hub airports have a large impact on the subsequent legs of hub and spoke operations.

Root delays originating from major European hubs daily affect on average between 30 and 50 other airports within the ECAC area. The largest impact of the root delays originating from the respective airport is on the hub airport itself as flights return usually several times during the day.

On average, between three and six hours of the reactionary delay reported at the analysed hub airports originated from root delays experienced on previous flight legs at the same airport.

On flights only operating between the analysed hub airport and another airport, between 30 and 50 percent of the delay originating from the hub airport is returned to the same airport on successive flight legs.
7 OUTLOOK

In this study, reporting issues and uncertainties represented the greatest challenge while dealing with the data. EUROCONTROL and IATA are working on an appropriate, adjusted framework for reporting delays. A set of more specific but comprehensive delay codes needs to be developed in order to separate delay causes more clearly from another. Many major airlines already use subcategories within their internal delay code scheme. A general guideline and/or instructions applicable to all airlines need to be developed. Additionally, a very simple local quality check at the Operations Control Centre would help to further improve the quality of the data. An automatic warning should be generated if sum of individual delays reported for a flight exceeds the total departure delay or when rotational reactionary delays is larger than the reported inbound arrival delay.

All this would ensure the validity of results, reducing a possible bias from airline coding policies.

For the analysis of delay propagation, the reporting of callsigns which cause non-rotational reactionary delays is of upmost importance. If airlines started to report these callsigns, a whole new analysis addressing the actual network effect of delay propagation could be worked out. These callsigns would also enable the analysis of relations and impacts of delay propagation within airline alliances regarding the magnitude of delay propagation and consequently the costs caused by the respective alliance partners.

Whether the propagation of long delays is preferred over cancelling flights is unknown at this point and factors influencing this decision probably vary from airline to airline. Obviously, this decision has an overall impact on the propagation of delays. Therefore, different cancellation strategies should be looked at and compared. If original aircraft rotations were provided by an airline it could be compared to the actual operated rotation. Then the impact of swapping and/or cancelling flights within the fleet of an airline as well as the entire network can be analysed.
As a follow on to this study, various IF-cases could be tracked and analysed with the created sequences of reactionary delays.

For example,

- the impact of late arrivals of trans-Atlantic flights,
- the impact of EC regulation No. 261/2004 regarding denied-boarding compensation,
- changes in airport systems (i.e. CDM at Munich) or in the composition of operating airlines (eventually with different business models)
- detailed peak analysis at major airports.

Results of analyses like these could generally increase predictability, which in turn would result in the improved ability to forecast delays in more detail and to adjust flight schedules to better account for ‘predictable’ delays. The results could also present the opportunity for airlines and airports to identify best practice examples. Finally, the parameters in macroscopic network models could be determined more precisely, enabling a more realistic reproduction of the actual air traffic.
## GLOSSARY

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADDD</td>
<td>Average Delay of Delayed Departures [min.]</td>
</tr>
<tr>
<td>Afternoon</td>
<td>In this study: from 14:00h to 21:59h local time.</td>
</tr>
<tr>
<td>ANS</td>
<td>Air Navigation Service. A generic term describing the totality of services provided in order to ensure the safety, regularity and efficiency of air navigation and the appropriate functioning of the air navigation system.</td>
</tr>
<tr>
<td>ANSP</td>
<td>Air Navigation Services Provider</td>
</tr>
<tr>
<td>ATFM</td>
<td>Air Traffic Flow Management. ATFM is established to support ATC in ensuring an optimum flow of traffic to, from, through or within defined areas during times when demand exceeds, or is expected to exceed, the available capacity of the ATC system, including relevant aerodromes.</td>
</tr>
<tr>
<td>ATFM delay (CFMU)</td>
<td>The duration between the last Take-Off time requested by the aircraft operator and the Take-Off slot given by the CFMU.</td>
</tr>
<tr>
<td>ATFM Regulation</td>
<td>When traffic demand is anticipated to exceed the declared capacity in en-route control centres or at the departure/arrival airport, ATC units may call for “ATFM regulations”.</td>
</tr>
<tr>
<td>ATM</td>
<td>Air Traffic Management. A system consisting of a ground part and an air part, both of which are needed to ensure the safe and efficient movement of aircraft during all phases of operation. The airborne part of ATM consists of the functional capability which interacts with the ground part to attain the general objectives of ATM. The ground part of ATM comprises the functions of Air Traffic Services (ATS), Airspace Management (ASM) and Air Traffic Flow Management (ATFM). Air traffic services are the primary components of ATM.</td>
</tr>
<tr>
<td>Bad weather</td>
<td>For the purpose of this report, “bad weather” is defined as any weather condition (e.g. strong wind, low visibility, snow) which causes a significant drop in the available airport capacity.</td>
</tr>
<tr>
<td>Block time</td>
<td>The time between Off-block (OUT) at the departure airport and on-block (IN) at the destination airport.</td>
</tr>
<tr>
<td>CDM</td>
<td>Collaborative Decision Making</td>
</tr>
<tr>
<td>CET</td>
<td>Central European Time</td>
</tr>
<tr>
<td>CFMU</td>
<td>EUROCONTROL Central Flow Management Unit</td>
</tr>
<tr>
<td>CODA</td>
<td>EUROCONTROL Central Office for Delay Analysis</td>
</tr>
<tr>
<td>CRCO</td>
<td>EUROCONTROL Central Route Charges Office</td>
</tr>
<tr>
<td>DST</td>
<td>Daylight Saving Time</td>
</tr>
<tr>
<td>EATM</td>
<td>European Air Traffic Management (EUROCONTROL)</td>
</tr>
<tr>
<td>ECAC</td>
<td>European Civil Aviation Conference.</td>
</tr>
<tr>
<td>E-CODA</td>
<td>Enhanced Central Office for Delay Analysis (EUROCONTROL)</td>
</tr>
<tr>
<td>EET</td>
<td>Eastern European Time</td>
</tr>
<tr>
<td>ETFMS</td>
<td>Enhanced Tactical Flow Management System</td>
</tr>
<tr>
<td>EU</td>
<td>European Union [Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom]</td>
</tr>
</tbody>
</table>
| EUROCONTROL Member States | Thirty-eight Member States (31.12.2008): Albania, Armenia, Austria, Belgium, Bosnia & Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary,
Ireland, Italy, Lithuania, Luxembourg, Malta, Moldova, Monaco, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, The former Yugoslav Republic of Macedonia; Turkey, Ukraine and United Kingdom.

<table>
<thead>
<tr>
<th>GMT</th>
<th>Greenwich Mean Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground phase</td>
<td>The time between on-block (IN) and off-block (OUT) in an aircraft rotation.</td>
</tr>
<tr>
<td>IATA</td>
<td>International Air Transport Association (<a href="http://www.iata.org">www.iata.org</a>)</td>
</tr>
<tr>
<td>ICAO</td>
<td>International Civil Aviation Organization</td>
</tr>
<tr>
<td>IFR</td>
<td>Instrument Flight Rules. Properly equipped aircraft are allowed to fly under bad-weather conditions following instrument flight rules.</td>
</tr>
<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
</tr>
<tr>
<td>Morning</td>
<td>In this study: from 6:00h to 13:59h local time.</td>
</tr>
<tr>
<td>MVT</td>
<td>Aircraft Movement message</td>
</tr>
<tr>
<td>Night</td>
<td>In this study: from 22:00h to 5:59h local time.</td>
</tr>
<tr>
<td>OCC</td>
<td>Operational Control Center</td>
</tr>
<tr>
<td>OOOI-times</td>
<td>Actual OUT of the gate, OFF the runway, ON the runway, Into the gate times</td>
</tr>
<tr>
<td>PDD</td>
<td>Percentage of Delayed Departures [%]</td>
</tr>
<tr>
<td>PRC</td>
<td>Performance Review Commission</td>
</tr>
<tr>
<td>Primary Delay</td>
<td>A delay other than reactionary</td>
</tr>
<tr>
<td>PRISME</td>
<td>Pan-European Repository of Information Supporting the Management of EATM.</td>
</tr>
<tr>
<td>PRU</td>
<td>Performance Review Unit</td>
</tr>
<tr>
<td>Punctuality</td>
<td>On-time performance with respect to published departure and arrival times</td>
</tr>
<tr>
<td>Reactionary delay</td>
<td>Delay caused by late arrival of the same or different aircraft</td>
</tr>
<tr>
<td>Root delay</td>
<td>Primary delay causing a sequence of reactionary delays</td>
</tr>
<tr>
<td>Slot (ATFM)</td>
<td>A take-off time window assigned to an IFR flight for ATFM purposes</td>
</tr>
<tr>
<td>SGT</td>
<td>Scheduled ground time</td>
</tr>
<tr>
<td>STA</td>
<td>Scheduled Time of Arrival</td>
</tr>
<tr>
<td>STATFOR</td>
<td>EUROCONTROL Statistics &amp; Forecasts Service</td>
</tr>
<tr>
<td>STD</td>
<td>Scheduled Time of Departure</td>
</tr>
<tr>
<td>UTC</td>
<td>Universal Time Coordinated</td>
</tr>
</tbody>
</table>


CODA (2009): Delays to Air Transport in Europe. DIGEST Annual 2008, Brussels, Belgium, EUROCONTROL.


University of Westminster, Performance Review Commission (2004): *Evaluating the true cost to airlines of one minute of airborne or ground delay.* Brussels, Belgium, EUROCONTROL.


ANNEX 1 : IATA DELAY CODES

Standard IATA Delay Codes
(IATA Airport Handling Manual, 21st edition, Jan 2001)

Others
00-05 AIRLINE INTERNAL CODES
06 (OA) NO GATE/STAND AVAILABILITY DUE TO OWN AIRLINE ACTIVITY
09 (SG) SCHEDULED GROUND TIME LESS THAN DECLARED MINIMUM GROUND TIME

Passenger and Baggage
11 (PD) LATE CHECK-IN, acceptance after deadline
12 (PL) LATE CHECK-IN, congestions in check-in area
13 (PE) CHECK-IN ERROR, passenger and baggage
14 (PO) OVERSALES, booking errors
15 (PH) BOARDING, discrepancies and paging, missing checked-in passenger
16 (PS) COMMERCIAL PUBLICITY/PASSENGER CONVENIENCE, VIP, press, ground meals and missing personal items
17 (PC) CATERING ORDER, late or incorrect order given to supplier
18 (PB) BAGGAGE PROCESSING, sorting etc.

Cargo and Mail
21 (CD) DOCUMENTATION, errors etc.
22 (CP) LATE POSITIONING
23 (CC) LATE ACCEPTANCE
24 (CI) INADEQUATE PACKING
25 (CO) OVERSALES, booking errors
26 (CU) LATE PREPARATION IN WAREHOUSE
27 (CE) DOCUMENTATION, PACKING etc (Mail Only)
28 (CL) LATE POSITIONING (Mail Only)
29 (CA) LATE ACCEPTANCE (Mail Only)

Aircraft and Ramp Handling
31 (GD) AIRCRAFT DOCUMENTATION LATE/INACCURATE, weight and balance, general declaration, pax manifest, etc.
32 (GL) LOADING/UNLOADING, bulky, special load, cabin load, lack of loading staff
33 (GE) LOADING EQUIPMENT, lack of or breakdown, e.g. container pallet loader, lack of staff
34 (GS) SERVICING EQUIPMENT, lack of or breakdown, lack of staff, e.g. steps
35 (GC) AIRCRAFT CLEANING
36 (GF) FUELLING/DEFUELLING, fuel supplier
37 (GB) CATERING, late delivery or loading
38 (GU) ULD, lack of or serviceability
39 (GT) TECHNICAL EQUIPMENT, lack of or breakdown, lack of staff, e.g. pushback

Technical and Aircraft Equipment
41 (TD) AIRCRAFT DEFECTS.
42 (TM) SCHEDULED MAINTENANCE, late release.
43 (TN) NON-SCHEDULED MAINTENANCE, special checks and/or additional works beyond normal maintenance schedule.
44 (TS) SPARES AND MAINTENANCE EQUIPMENT, lack of or breakdown.
45 (TA) AOG SPARES, to be carried to another station.
46 (TC) AIRCRAFT CHANGE, for technical reasons.
47 (TL) STAND-BY AIRCRAFT, lack of planned stand-by aircraft for technical reasons.
48 (TV) SCHEDULED CABIN CONFIGURATION/VERSION ADJUSTMENTS.

**Damage to Aircraft & EDP/Automated Equipment Failure**
51 (DF) DAMAGE DURING FLIGHT OPERATIONS, bird or lightning strike, turbulence, heavy or overweight landing, collision during taxiing
52 (DG) DAMAGE DURING GROUND OPERATIONS, collisions (other than during taxiing), loading/off-loading damage, contamination, towing, extreme weather conditions
55 (ED) DEPARTURE CONTROL
56 (EC) CARGO PREPARATION/DOCUMENTATION
57 (EF) FLIGHT PLANS

**Flight Operations and Crewing**
61 (FP) FLIGHT PLAN, late completion or change of, flight documentation
62 (FF) OPERATIONAL REQUIREMENTS, fuel, load alteration
63 (FT) LATE CREW BOARDING OR DEPARTURE PROCEDURES, other than connection and standby (flight deck or entire crew)
64 (FS) FLIGHT DECK CREW SHORTAGE, sickness, awaiting standby, flight time limitations, crew meals, valid visa, health documents, etc.
65 (FR) FLIGHT DECK CREW SPECIAL REQUEST, not within operational requirements
66 (FL) LATE CABIN CREW BOARDING OR DEPARTURE PROCEDURES, other than connection and standby
67 (FC) CABIN CREW SHORTAGE, sickness, awaiting standby, flight time limitations, crew meals, valid visa, health documents, etc.
68 (FA) CABIN CREW ERROR OR SPECIAL REQUEST, not within operational requirements
69 (FB) CAPTAIN REQUEST FOR SECURITY CHECK, extraordinary

**Weather**
71 (WO) DEPARTURE STATION
72 (WT) DESTINATION STATION
73 (WR) EN ROUTE OR ALTERNATE
75 (WI) DE-ICING OF AIRCRAFT, removal of ice and/or snow, frost prevention excluding unserviceability of equipment
76 (WS) REMOVAL OF SNOW, ICE, WATER AND SAND FROM AIRPORT
77 (WG) GROUND HANDLING IMPAIRED BY ADVERSE WEATHER CONDITIONS

**ATFM + AIRPORT + GOVERNMENTAL AUTHORITIES**
AIR TRAFFIC FLOW MANAGEMENT RESTRICTIONS
81 (AT) ATFM due to ATC EN-ROUTE DEMAND/CAPACITY, standard demand/capacity problems
82 (AX) ATFM due to ATC STAFF/EQUIPMENT EN-ROUTE, reduced capacity caused by industrial action or staff shortage, equipment failure, military exercise or extraordinary demand due to capacity reduction in neighbouring area
83 (AE) ATFM due to RESTRICTION AT DESTINATION AIRPORT, airport and/or runway closed due to obstruction, industrial action, staff shortage, political unrest, noise abatement, night curfew, special flights
84 (AW) ATFM due to WEATHER AT DESTINATION
AIRPORT AND GOVERNMENTAL AUTHORITIES
85 (AS) MANDATORY SECURITY
86 (AG) IMMIGRATION, CUSTOMS, HEALTH
87 (AF) AIRPORT FACILITIES, parking stands, ramp congestion, lighting, buildings, gate limitations, etc.
88 (AD) RESTRICTIONS AT AIRPORT OF DESTINATION, airport and/or runway closed due to obstruction, industrial action, staff shortage, political unrest, noise abatement, night curfew, special flights
89 (AM) RESTRICTIONS AT AIRPORT OF DEPARTURE WITH OR WITHOUT ATFM RESTRICTIONS, including Air Traffic Services, start-up and pushback, airport and/or runway closed due to obstruction or weather, industrial action, staff shortage, political unrest, noise abatement, night curfew, special flights

Reactionary
91 (RL) LOAD CONNECTION, awaiting load from another flight
92 (RT) THROUGH CHECK-IN ERROR, passenger and baggage
93 (RA) AIRCRAFT ROTATION, late arrival of aircraft from another flight or previous sector
94 (RS) CABIN CREW ROTATION, awaiting cabin crew from another flight
95 (RC) CREW ROTATION, awaiting crew from another flight (flight deck or entire crew)
96 (RO) OPERATIONS CONTROL, re-routing, diversion, consolidation, aircraft change for reasons other than technical

Miscellaneous
97 (MI) INDUSTRIAL ACTION WITH OWN AIRLINE
98 (MO) INDUSTRIAL ACTION OUTSIDE OWN AIRLINE, excluding ATS
99 (MX) OTHER REASON, not matching any code above
## ANNEX 2: DESCRIPTION OF CODA DATA


<table>
<thead>
<tr>
<th>Column</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cy</strong></td>
<td>ICAO 3-letter code of the company that flies the aircraft</td>
</tr>
<tr>
<td><strong>CallSign</strong></td>
<td>ICAO 3-letter flightnumber prefix followed by the flight number (no blanks)</td>
</tr>
<tr>
<td><strong>ComFltNbr</strong></td>
<td>The commercial flightnumber (as given to airports for passenger info displays)</td>
</tr>
<tr>
<td><strong>AcReg</strong></td>
<td>5 characters (no hyphen)</td>
</tr>
<tr>
<td><strong>Dep ICAO</strong></td>
<td>4-letter code of the departure station (the IATA 3-letter code can also be accepted)</td>
</tr>
<tr>
<td><strong>Dst ICAO</strong></td>
<td>4-letter code of the destination station (the IATA 3-letter code can also be accepted)</td>
</tr>
<tr>
<td><strong>Std</strong></td>
<td>Standard Time of Departure according to the schedules including the date</td>
</tr>
<tr>
<td><strong>Sta</strong></td>
<td>Standard Time of Arrival according to the schedules including the date</td>
</tr>
<tr>
<td><strong>Eet (FP)</strong></td>
<td>Estimated Flight time in minutes according to the flight plan</td>
</tr>
<tr>
<td><strong>Out</strong></td>
<td>Actual Time of Departure from the gate including the date</td>
</tr>
<tr>
<td><strong>Off</strong></td>
<td>Actual Time of Take-off including the date</td>
</tr>
<tr>
<td><strong>On</strong></td>
<td>Actual Time of Landing including the date</td>
</tr>
<tr>
<td><strong>In</strong></td>
<td>Actual Time of Arrival at the gate including the date</td>
</tr>
<tr>
<td><strong>Dl1</strong></td>
<td>First delay cause in IATA 2 digit code</td>
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<td><strong>Time1</strong></td>
<td>First delay cause duration in minutes</td>
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<tr>
<td><strong>Time5</strong></td>
<td>Fifth delay cause duration in minutes</td>
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<tr>
<td><strong>RD</strong></td>
<td>from Flt If there is a reactionary delay, give the call sign of the flight having directly caused the reactionary delay</td>
</tr>
<tr>
<td><strong>STXO</strong></td>
<td>Standard Outbound Taxi Time in minutes</td>
</tr>
<tr>
<td><strong>STXI</strong></td>
<td>Standard Inbound Taxi Time in minutes</td>
</tr>
<tr>
<td><strong>ServType</strong></td>
<td>Service Type (See IATA SSIM appendix C) (1 character)</td>
</tr>
<tr>
<td><strong>FltType</strong></td>
<td>Flight Type (&quot;S&quot; for Scheduled or &quot;N&quot; for Non-scheduled (Charter))</td>
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<tr>
<td><strong>QC</strong></td>
<td>Quality Control (&quot;A&quot; for ACARS, &quot;M&quot; for Manual or &quot;C&quot; for Combination or both)</td>
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### ANNEX 3: CONVERSION OF UTC TO LOCAL TIME

#### Winter

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#### Summer

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ANNEX 4: LOW-COST CARRIER DEFINITION

(EUROCONTROL Glossary)

Airline operator meeting most of the following characteristics:
- Marketing emphasis predominantly on price
- Ticketless travel: low-fare airlines operate largely ticketless operations, and their flights cannot be included on a traditional IATA-form international ticket.
- Online ticket sales
- NO international offices
- In-flight services charged separately
  - Most do not offer free meals and drinks on most flights. Snacks might be available, but add additional cost;
  - For most, no seat selection;
  - No in-flight entertainment; no newspapers; no seat cushions; blankets; etc.
- No ‘frequent flyer program’
- No airport lounges
- Use of less busy secondary city airports
- High dynamism and flexibility in repositioning network
- No interlining: absence of interlining or links with other airlines
- Baggage: strict interpretation of baggage allowances
- High load factor
- Rapid aircraft turnaround (minimum time on ground)

EUROCONTROL STATFOR publishes a summary of carriers it considers satisfying the above criteria.
### ANNEX 5: AIRCRAFT TYPES AND MEDIAN SEAT CAPACITY

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DECLARATION

I, Martina Jetzki, declare that I have developed and written the enclosed thesis entitled “The propagation of air transport delays in Europe” entirely by myself and have not used sources or means without declaration in the text. Any thoughts or quotations which were inferred from these sources are clearly marked as such. This thesis was not submitted in the same or in a substantially similar version, not even partially, to any other authority to achieve an academic grading and was not published elsewhere.