Virtual Institute

Airport Planning and Management

Study on the usage of declared capacity at major German airports

Study in cooperation with the Performance Review Unit (PRU), Eurocontrol

2007-01-18

Dipl.-Ing. Daniel Kösters

RWTH Aachen University
Department of Airport and Air Transportation Research
Institute of Transport Science (VIA)

Mies-van-der-Rohe-Str.1
D-52056 Aachen
Germany

Tel.: +49 (0)241 - 8025814
Fax: +49 (0)241 - 8022292
koesters@via.rwth-aachen.de
http://www.via.rwth-aachen.de

Index

1 Scope and objective 3

2 Previous studies on airport slot allocation 5

2.1 ACI Europe: Study on the use of airport capacity 5

2.2 ECAC: Study on slot allocation procedures 6

2.3 NERA: Study to assess the effects of different slot allocation schemes 7

3 Air Traffic Scheduling 8

3.1 Airport Scheduling according to EC Regulation 95/93 10

3.2 Scheduling at German airports, summer 2005 season 12

4 Part1: Utilisation of declared capacity 19

4.1 Methodology 19

4.1.1 Available data, input parameters 19

4.1.2 Proceeding 20

4.2 Capacity utilisation: From initial request to final status 21

4.2.1 Slot demand at the initial slot request deadline 21

4.2.2 From initial allocation to final status: Loss of capacity utilisation 24

4.2.3 From initial request to final status: Slot demand processing 29

4.3 Drivers to unsatisfying capacity utilisation at the final status 33

4.3.1 Local airport reasons 34

4.3.2 Airline network reasons 40

4.3.3 Lack of slot demand 44

5 Part2: Predictability during scheduling phase 46

5.1 Methodology 46

5.1.1 Available data 46

5.1.2 Proceeding 47

5.2 Operational adherence to scheduling results and presumptions 49

5.2.1 Demand variations: No show rate 49

5.2.2 Demand variations: Flight concentration 51

5.2.3 Verification of scheduling standard taxi times 56

6 Résumé 59

7 References 61

1 Scope and objective

The study at hand, by the Department of Airport and Air Transportation Research at the RWTH Aachen University in conjunction with Eurocontrol's Performance Review Unit, analyses the relevant processes and developments within the sequence of allocating and using declared airport capacity at 5 German coordinated airports in the summer 2005 schedule season. Against the background of previous studies' accordant conclusions it can be assumed that certain inefficiencies and false estimations characterise the aforementioned process chain. Being based on an extensive data analysis it is this study's objective to clearly identify and quantify possible inefficiencies and false assumptions within the usage of declared airport capacity. Adequate recommendations for possible amendments of the course of relevant processes are to be deduced from those conclusions.

To approach the problem this investigation is subdivided into two main parts. Part 1 focuses on the utilisation of declared airport capacity between the time of the airlines' initial slot requests and a defined final status of airport coordination office's scheduling activities (Cp. Figure 1). Major developments to balance slot demand and supply and to implement the relevant Council Regulation No. 95/93 are in the centre of chapter 4. Part 2 of the analysis investigates the schedule's actual realisation at the day of operations. Compliance with scheduling agreements such as total demand figures (no show rate) and limited flight concentration is verified.

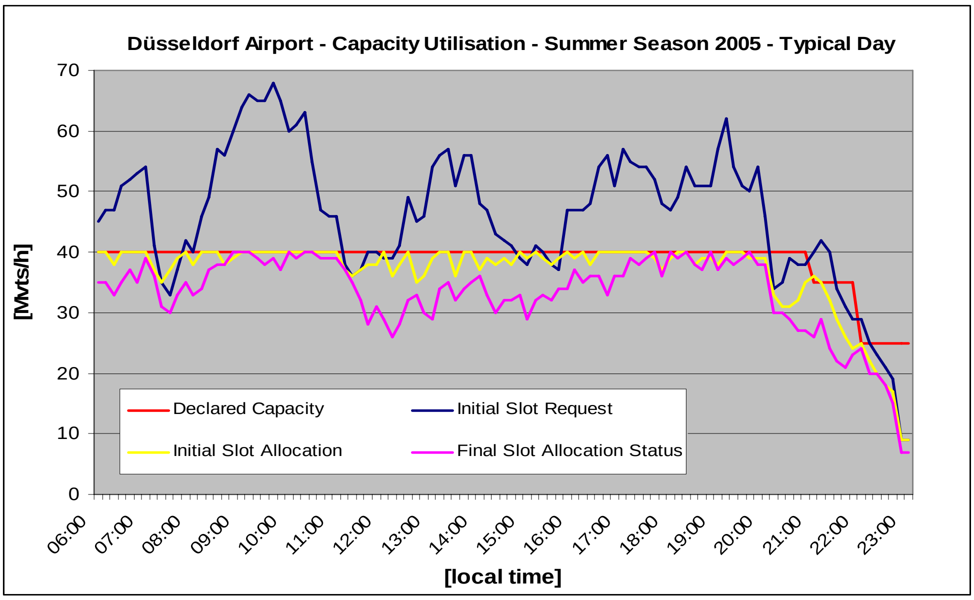


Figure 1: Düsseldorf Airport – Declared capacity utilisation at relevant stages of slot allocation

Declared capacity values as determined by the coordination committee are used as input parameters for this investigation's part 1. Given levels of service quality at which an airport's coordination parameters are declared usually (e.g. punctuality, waiting time) are not questioned. Thus any discussion on the quality of service is out of this study's scope. Within part 2 the final status of the airport coordination office's scheduling activities (=coordinated schedule) is used as a reference programme and input parameter. Again service quality is excluded; the investigation focuses on operational compliance with agreed total demand figures and particular scheduling assumptions but does not consider single flight punctuality or waiting times.

With regard to slot allocation and airport scheduling the study at hand is based on RWTH Aachen University's database on airport coordination and slot allocation at German coordinated airports in the summer 2005 schedule season. Precise data is provided by the German airport coordination office (FHKD – Flughafenkoordination Deutschland) due to a data cooperation agreement. To complete the sequence of processes, scheduling data is matched to corresponding information on the operational performance. The latter is available due to the cooperation with Eurocontrol's Performance Review Unit which allows the usage of CFMU and CODA data on the actual day-to-day operations.

2 Previous studies on airport slot allocation

With the problem of scarce airport capacity growing over the past years significantly, applied policy and procedures to assign the declared capacity arrived into the centre of interest of aviation stakeholders, decision-makers and relevant authorities. Thus a certain number of reports and studies published in recent years deal with this topic. The vast majority of those investigations focus on economic inefficiencies of the recent slot allocation procedures and discuss possible alternative market-based allocation systems and thus feature scope and objectives slightly different from the study on hand. But with an analysis of the current system's strengths and weaknesses being the basis for possible modifications and alternatives, those cognitions have been taken into consideration while undertaking the present investigation.

Chapter 2 summarises the results of the most relevant airport slot allocation studies as far as the current slot allocation procedures are addressed. Next to ACI Europe's "Study on the use of airport capacity" and ECAC's "Study on slot allocation procedures" which both focus on the (non-economic) inefficiencies of the current system primarily and thus address this study's scope partially, major aspects of NERA's "Study to assess the effects of different slot allocation schemes" are recapitulated as well because of the detailed discussion on the present slot allocation procedures.

2.1 ACI Europe: Study on the use of airport capacity

ACI's report intends to detect the factors within the slot allocation procedures and thus to demonstrate the shortcomings of the current system leading to a non-optimal utilisation of limited declared capacity. It is this study's objective to identify areas for modification and improvement.

For 21 European airports and within a reference period of two adjacent scheduling seasons the allocation of slots is displayed by the total number of

- slots initially requested,
- slots initially allocated (IATA Scheduling Conference),
- slots allocated at the slot return date,
- slots allocated at the start of season,
- slots allocated at the end of the season, and
- operations realised at the end of the season.

Available figures allow an estimation of the course of capacity utilisation from the initial slot request to the days of operations and to the end of the season also. At most airports a certain amount of unsatisfied demand is existent. The proportion of slots returned before the slot return date is considered as, to some extent, an indication of the efficiency of the initial allocation. Besides those slot returns on time, slot returns by the airlines can be late either before season or even during season. The probability of repeated allocation of returned slots will diminish if the return is late. Because a considerable number of slots is returned late, most airports experience a drop of capacity utilisation coming to the end of the season.

With the availability of the total number of operations realised at the end of the season, an estimation is possible on the amount of slots allocated and not returned, but not used anyway (no shows). Thus the ACI report states the main factors leading to non-optimal capacity utilisation as follows:

- late returns before season
- late returns during season
- slots allocated, but not used (no shows)

Those elements are contrary to an efficient use of scarce airport capacity. Accordingly the ACI study proposes to implement measures to ensure airlines to use the slots allocated. A slot reservation fee is mentioned as one possibility. Certain local rules already applied at some airports might be adequate to address the problems Europe-wide, but before implementation a full understanding of their impact is required.

2.2 ECAC: Study on slot allocation procedures

The ECAC study focuses on a field of interest rather similar to the ACI's approach and rather relevant for the report on hand: Detection of inefficiency within the current airport slot allocation procedures. Inefficiency as understand here does not refer to economic (financial) aspects; likewise inefficient use of capacity due to traffic structure reasons is disregarded. The study excludes opportunities to increase capacity at European airports, but concentrates on how to get the optimum utilisation from existing capacity.

The study's results and recommendations are based on the responses to a questionnaire sent to all ECAC Member States (Airport Slot Departments, Airport Coordination Offices, Airport Authorities etc.) and relevant organisations (ACI, IACA, EUACA etc.). From the view of the responders, this questionnaire aims at possible examples of practices in the present slot allocation process that could lead to certain inefficiencies and it additionally aims at advantages and disadvantages of local guidelines and practices possibly added to the relevant EU Regulation 95/93 procedures and applied in a particular area of responsibility.

As derived from the responses to the questionnaire and as commonly agreed in the ECAC Task Force meetings, the principal operational practices within slot allocation procedures that might lead to inefficient utilisation of available capacity are:

- overbidding (more slots requested than intended to use actually)
- late slot returns
- no shows
- seasonality

Besides those main factors some additional elements were raised such as set aside of slots for specific operators, reservation of slots by "paper airlines", off-slots operations, positioning flights etc.

As a résumé of the investigation the ECAC proposes some recommendations. It could be worth to consider local guidelines and practices that show a certain impact on the efficiency of slot allocation procedures on a wider ECAC level. Additionally some other or modified allocation (priority) criteria such as precedence for long series of slots or lower priority for slot requests of misbehaving air carriers (operating air services repeatedly and intentionally at a time or in a way significantly different from the allocated slots). Post allocations procedures within a slot performance monitoring committee that might decide about considerable sanctions towards misbehaving airlines could increase the utilisation of available airport capacity as well.

2.3 NERA: Study to assess the effects of different slot allocation schemes

On behalf of European Commission's DG TREN the National Economics Research Associates (NERA) prepared the most comprehensive study on airport scheduling and slot allocation in recent years. Besides some data examination, this report is based on an extensive programme of interviews with industry participants. While NERA's study focuses on an examination of both feasibility and impact of using market mechanisms and thus represents an economic approach, the results of the opening investigation on the existing slot allocation framework are of significant relevance for the paper on hand. Accordingly only those aspects – mainly impact and inefficiencies of the current procedures – will be summarised in the following.

Following a precise introduction into the current slot allocation procedures, Chapter 3 describes its impact with regard to scheduling and operations at EU Category 1 airports. The extent of excess demand for slots at these airports is analysed and compared. NERA differentiates three groups of airports by the level of excess demand observed in 2002. Uneven distribution of arrival and departure flights might lead to seeming availability of declared capacity (total movements) despite of the existence of excess demand for slots. Unused slots during operations even at the most severely constrained airports might result from this, but it may be that airlines have not used the slot for operational reasons as well. Anyway slot utilisation at highly congested EU airports is high.

Airports with excess demand throughout the day accommodate a significantly greater proportion of long haul traffic than airports with excess demand at peak times only or with little or no excess demand, while the proportion of charter and general aviation traffic is considerably smaller. Variations between those airport categories can be noticed in aircraft size and loadings as well. Resulting form capacity scarcity, higher average loads as well as a greater proportion of large aircraft utilised can be noticed at congested airports. Most of those airports are used as a hub by a major network carrier, thus they feature a typical operational pattern of alternating departure and arrival peaks. Accordingly the average proportionate slot holdings of the major carrier are particular higher during certain times of the day (e.g. morning peak).

Chapter 4 describes inefficiencies in the current framework from an economic perspective mainly. With regard to the causes of inefficiencies, NERA observes certain barriers to market entry and expansion, high air fares due to limited competition, little incentives to minimise costs as well as to return slots in good time. The latter reduces opportunities for the coordinator to reallocate those slots to scheduled services again. Amongst others this results in a low utilisation of available slots. NERA realises such a low utilisation of available capacity as one of the major inefficiencies in the current framework – this perception confirms the paper on hand's approach in chapter 4 on the utilisation of available capacity. In contrast to the NERA study, precise data is available to analyse, quantify and evaluate the utilisation of available capacity at different airports.

NERA defines "economic inefficiency" on a net benefits basis. To indicate efficient/inefficient use of slots, certain indicators are depicted: Use of small aircraft, high frequency services with small aircraft as well as high external costs. Chapter 4 is closed with an investigation on slot mobility at EU category 1 airports. As anticipated the average proportion of historic slots at airports with excess demand throughout the day is significantly greater (93 %) than at airports with excess demand at peak times of the day (78 %) or than at airports with little or no excess demand (75 %).

3 Air Traffic Scheduling

To establish a basis for the subsequent analysis on slot allocation activities at German coordinated airports, chapter 3 describes all relevant elements of air traffic scheduling briefly. After integrating slot allocation and airport scheduling into the overall air traffic scheduling processes at the beginning, chapters 3.1 and 3.2 focus on the current EU slot allocation framework and on the summer 2005 airport scheduling season in Germany in particular.

The scheduling of air traffic operations includes all strategic (up to about 6 days before operations), tactical (up to about 1 day before operations) and operational (day of operations) planning activities undertaken by the airport community, the airline scheduling department and the ATFM community. Although being inter-related closely, activities of each of these parties are managed independently. A chronologically ordered summary of all relevant processes is illustrated in Figure 2. With the study on hand focussing on airport community's scheduling activities and slot allocation in particular, accordant processes being in the study's centre of interest are marked with a red circle.

	Airport Capacity	**Airline Scheduling**	**En-route capacity**
Parties Involved	Airport community (local ATC, airline, airport)	Airline scheduling department	ATFM community (EUROCONTROL, ANSPs)
12 – 7 months before season	Analysis of available data to determine airport scheduling capacity at a given quality of service		Strategic ATFM capacity planning (post analysis & traffic forecast STATFOR)
7 – 6 months before season	Airport scheduling capacity declaration (incl. Hourly capacities at a given quality of service	Draft schedule based on the business plan of the airline	Strategic ATFM capacity planning (post analysis & traffic forecast STATFOR). Coordination EUROCONTROL and ANSPs. Focus on RNDSG, ATCOs staff roster, RAD, EAW
6 months to 2 months before season	Scheduling conference – Airport slot allocation & adjustments / reallocation of returned slots	Formulation of schedule and planning of necessary resources (crew, aircraft) – Publication of schedule	
6 days before operations	Further assignment of airport slots and minor adjustments up to 48 hours before operations	Minor amendments to the schedule up to 72 hours before the operations	Pre-tactical ATFM planning
1 day before operations	Preparing for next day of operation	Preparing for the next day of operation	ATFM daily plan for next day of operation. Strategic ATFM measures
Day of operations	Day-to-day airport operations management	Day-to-day airline operations management	Monitoring of available capacity and traffic. ATFM measures (re-routeing, level capping, regulations)

Figure 2: Air traffic scheduling and strategic/tactical/operational planning processes

Despite being managed independently, airport and en-route capacity planning as well as airline scheduling are highly interdependent and inter-related. Major interrelations with regard to strategic scheduling are described in the following. With the en-route capacity planning being less relevant to airport and airline schedulers but reacting to (airport and airline) scheduling results instead, in turn it is disregarded by the depiction of the strategic planning phase's network interrelation afterwards.

Local airport scheduling and slot allocation focus on one single airport (or one single airport system including several airports at one city) only. But to arrange any flight movement at least two of those independently scheduled airports have to be connected. This connection is conducted by airlines which include airports into the air traffic network by their scheduling activities. Any kind of network effect at the airports results from the airline scheduling.

To meet their requirements during scheduling, airlines face – at least – two major challenges which are related closely:

- Reconciliation of their draft schedule (depending on airline business plan, available resources etc.) with local airport scheduling opportunities (available slots).
- Reconciliation of local airport scheduling opportunities at different airports of departure and of destination.

Due to the airlines' need of adjusting arrival and departure slot times at different airports, the latter become part of the air traffic network despite of being scheduled independently and locally. Network implication is obtained only indirectly by the airports. In contrast it is essential with regard to the airline scheduling. Thus airline network requirements impact on the local scheduling performance significantly. This conclusion is relevant to chapter 4.3's analysis on drivers to insufficient utilisation of declared airport capacity. The accordant network interrelation is depicted in Figure 3.

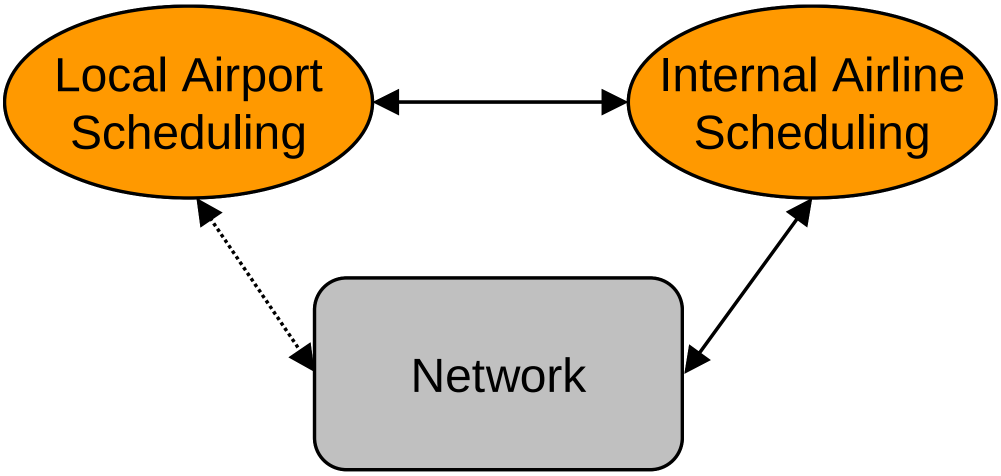


Figure 3: Network interrelation - airport and airline scheduling

For the most part air traffic operations (excluding military/general aviation) at major European airports are scheduled at an early stage. Besides airlines' commercial reasons regarding planning purposes and timely customer information to sell tickets, limited availability of airport infrastructure in particular requires an early assignment of the permission to use scarce capacity during operations. Thus at airports which experience excess demand throughout the day or at certain times of the day tight scheduling is inevitable to balance capacity and demand and to avoid permanent overload during later operations.

At such capacity constrained airports the early assignment of infrastructure usage rights is carried out in the form of a standardised allocation of airport slots. Airport slot allocation is the second step of two processes forming the airport scheduling phase. At first the competent airport authority declares an airport's scheduling capacity. Afterwards this declared capacity can be allocated in the form of airport slots.

3.1 Airport Scheduling according to EC Regulation 95/93

The present airport scheduling processes in the EU and thus in Germany are based on Council Regulation 95/93 which has endorsed the IATA Worldwide Scheduling Guidelines. Chapter 3.1 will provide a summary of Regulation 95/93, its current amendments (Regulations No. 894/2002, 1554/2003, 793/2004) and its actual implementation.

Slot Definition. Article 2 of the Regulation defines the term "slot" as "*the permission given by a coordinator in accordance with this Regulation to use the full range of airport infrastructure necessary to operate an air service at a coordinated airport on a specific date and time for the purpose of landing or take-off as allocated by a coordinator in accordance of this Regulation*".

Airport Classification. Depending on the level of congestion and capacity scarcity all Community airports belong to one of the following groups of airports:

- *Airports with no designation status*: Available airport capacity is at all times sufficient to accommodate demand. Access to those airports is open and not subject to any regulations.

- *Schedules facilitated airports*: Airports where there is potential for congestion at some periods of the day, week or year which is amenable to resolution by voluntary cooperation between air carriers and where a schedules facilitator has been appointed to facilitate the operations of air carriers operating services or intending to operate services at those airports.

- *Coordinated airports*: Airports where, in order to land or take off, it is necessary for an air carrier or any other aircraft operator to have been allocated a slot by a coordinator. At those airports slot demand exceeds available capacity at peak times of the day at least.

Designation as a schedules facilitated or coordinated airport will be carried out by a Community Member State taking into account the principles of transparency, neutrality and non-discrimination. If an airport is designated coordinated, according to Council Regulation 95/93 it is supposed to take place upon a thorough capacity analysis confirming a sustainable imbalance of capacity and demand. Designation as schedule facilitated or coordinated commits the Member State to appoint a qualified natural or legal person as schedules facilitator or airport coordinator respectively. The same schedules facilitator or coordinator may be appointed for more than one airport.

Coordination Parameters. Basis for the allocation of slots at coordinated airports is the determination of the coordination parameters twice yearly following the year's splitting into winter and summer scheduling season. The determination shall take into account all relevant technical, operational and environmental constraints as well as any changes thereto. A coordination committee at each coordinated airport amongst others consisting of air carriers, the managing body of the airport, the relevant air traffic control authorities as well as the regulatory authority, is responsible for the timely provision of the coordination parameters to the coordinator.

Declared Capacity. Typically coordination parameters are provided in the form of a declared capacity for an airport. The declared capacity describes a maximum number of slots per unit of time (block period) that can be allocated by the coordinator. The duration of blocks can vary; in addition several blocks with different duration can be superposed to control the concentration of flights within a certain time period. The use of declared capacity values for the whole season means a fixing of the seasonal airport infrastructure capacity at an early stage.

Initial Request. About 5 month before the start of a scheduling season (winter or summer) airlines have to provide details of their planned schedules for the upcoming season to the responsible airport coordination office prior to the initial slot request deadline.

Initial Allocation. After processing all slot requests the airport coordination office informs the airlines about the initial slot allocation. To meet capacity limitations as expressed in the declared capacity, coordinators might have to retime or even reject a certain number of slot requests if demand is above available capacity. The allocation of slots is carried out using administrative priority criteria which can be found in Article 8 of the Regulation. The key provision specifies that a slot or a series of slots will be assigned to an airline for the upcoming season if it had been used at least 80 per cent of the time for which the slot or the series of slots had been allocated in the previous equivalent season (winter or summer). This rule is known as the use-it-or-loose-it rule or the 80/20 rule as well. Besides those grandfather rights ensuring so called historical slots to be allocated again, a certain priority is granted to airlines that comply with conditions for being considered as new entrant at that specific airport.

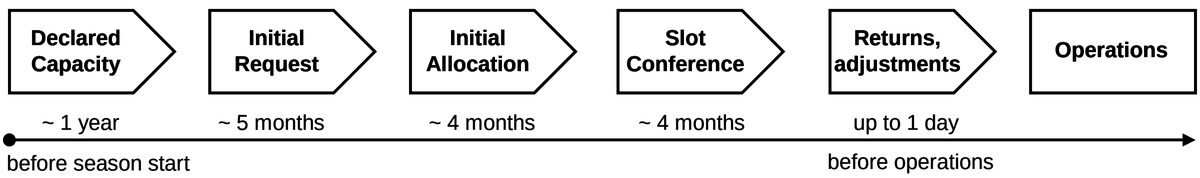


Figure 4: Airport scheduling key moments

Schedules Conference. Twice a year, right after the initial slot allocation, the Worldwide IATA Schedules Conference takes place. Thus representatives of airlines and airports as well as airport coordinators are provided an opportunity to negotiate slots allocated initially, to arrange slot amendments and alternatives or to exchange slots between airlines. Schedules adjustments are carried out through bilateral discussions between airlines and coordinators mainly. At the 116th Schedules Conference in Berlin in June 2005, nearly 900 delegates were present, of which about 670 from airlines and about 170 from airport coordination offices.

Post Schedules Conference. Due to the presence of worldwide airlines and coordinators the schedules conference is the main opportunity for schedules adjustments particularly if there is more than one airport/coordinator affected. But scheduling processes continue after the conference as well. Council Regulation 95/93 allows for various ways to fine tune schedules by airlines. Slots may be transferred by an airline from one route or type of service to another route or type or service operated by the same airline. In addition, slots may be transferred between parent and subsidiary companies. Slot exchange, one for one, is allowed between airlines. Airlines may reschedule their slots according to coordinators' current slot availability. Minor changes e.g. 5 minutes may be possible within the airlines' own slot holdings. This is a result of the particularly used declared capacity characteristics (e.g. static or rolling blocks, duration of blocks). Major changes require accordant availability of adequate slots to swap which might exist due to preceding slot returns at congested airports only. The described ways of possible schedules adjustments may continue not only until the start of the season but also until the day of operations.

Slot Returns. As early as possible airlines are supposed to return slots that had been allocated but are not intended to be used actually. To comply with the current rules returns are required until the slot return date at the latest to allow better opportunities for a successful reallocation by the coordinators and to provide available capacity for schedules adjustments as described above. The slot return date of each schedule season is dated about 2 month before its start – January 31st for summer scheduling season, August 31st for winter season. Late slot returns are considered as unused slots and thus will diminish an airline's opportunity to achieve historical status for certain slots or series of slots. This procedure features characteristics of a slight penalisation for late slot returns.

3.2 Scheduling at German airports, summer 2005 season

Airports. Airport scheduling in Germany takes place according to Council Regulation 95/93. As this regulation allows some room for interpretation, national coordinators might take into account additional rules and guidelines on a local/national basis as far as those are approved by the Member State's relevant authorities. For this reason the following detailed description of the airport scheduling and coordination processes is valid for the German airport coordination office's area of responsibility only.

With regard to summer 2005 season's airport scheduling processes, the German airport coordinator is responsible for the coordination and slot allocation of all IFR flights operating to 17 German international airports. Of these airports 7 are designated as "coordinated" (including 3 Berlin airports forming the Berlin airport system) while another 12 are designated as "schedules facilitated".

Schedules Facilitated	Coordinated
▪Bremen ▪Dresden ▪Erfurt ▪Hamburg ▪Hannover ▪Köln / Bonn ▪Leipzig / Halle ▪Münster / Osnabrück ▪Nürnberg ▪Saarbrücken	▪Berlin Tegel ▪Berlin Tempelhof ▪Berlin Schönefeld ▪Düsseldorf ▪Frankfurt ▪München ▪Stuttgart

Table 1: German Schedules Facilitated and Coordinated Facilitated Airports

With the study on hand focusing on the usage of available capacity issues at airports where a certain imbalance between demand and capacity can be noticed, in the following German schedules facilitated airports will be disregarded. Thus in the centre of interest within this analysis there are 5 coordinated airports:

- Berlin Tegel (TXL)[1]
- Düsseldorf (DUS)
- Frankfurt (FRA)
- München (MUC)
- Stuttgart (STR)

Airport opening hours / night curfew. Each of the 5 relevant coordinated airports features a kind of night curfew. Specifications of such night curfews as formulated in an airport's approval of operation vary depending on severeness of environmental restrictions to comply with. While Düsseldorf, Berlin Tegel, München and Stuttgart face a nearly complete airport closure during night time, Frankfurt might operate a reduced number of movements which have to comply with a specified noise points system. Certain precedence to operations of less noisy aircraft type and of home-based airlines is granted as well.

Thus airport slot allocation processes are subject to specified local guidelines during night times. To sustain comparability of present investigations on every single airport the analysis includes operating hours in the daytime only (06:00-23:00 LT). This excludes night curfew restrictions' impact on the analysis' results as far as possible.

Declared Capacity. Initially airport authorities provide the airport coordinator with required coordination parameters in the form of declared capacity values [arrival/departure/total flight movements per time period] for each coordinated airport. As most European coordinated airports do, all coordinated airports in Germany feature a similar structure of declared capacity values, usually a mixing of different type and different duration of blocks as follows:

- 10 min (static)
- 30 min (rolling, 10 min steps)
- 60 min (rolling, 10 min steps)

While a limit on total movements (TOT) within 60 minutes is given in either case, additional time spans (30min, 10min) or the differentiation between arrival and departure flights (ARR/DEP) are alternative possibilities to specify the declared capacity. Declared capacity values might vary on the hour of the day and thus be variable, a dependence on the day of the week does not exist at one of the considered airports. All those airports feature a kind of night curfew as described above. Additionally some airport specific measures can complete the declared capacity (e.g. a limitation to 4 departure flights to North-America within 15 minutes at Frankfurt).

A summary of relevant declared capacity values at coordinated German airports valid for summer 2005 season is given in Table 2:

[1] With Berlin Tegel being the only airport of the Berlin airport system where capacity scarcity occurs, this study disregards Berlin Tempelhof and Berlin Schönefeld.

	Time	10min (static)			30min (rolling)			60min (rolling)		
	[UTC]	ARR	DEP	TOT	ARR	DEP	TOT	ARR	DEP	TOT
Berlin Tegel	06:00-23:00			8						40
Düsseldorf	06:00-21:00			10						40
	21:00-22:00			10						35
	22:00-23:00			10				25	0	25
Frankfurt	06:00-14:00	9	9	16	23	25	43	41	43	80
	14:00-20:00	9	9	16	23	25	43	42	45	82
	20:00-22:00	9	9	16	23	25	43	42	50	82
	22:00-23:00	9	9	16	23	25	43	43	48	78
München	06:00-23:00	12	12	15				58	58	89
Stuttgart	06:00-23:00	6	6	8				30	30	40

Table 2: Declared capacity [Mvts/time unit] summer season 2005

Implementation and enforcement of afore-mentioned different capacity values (ARR/DEP/TOT movements within static 10min, rolling 30/60min) significantly restrict the coordinator's scope to fulfil airlines' slot requests. Contemporaneous compliance with all relevant parameters is required to avoid rescheduling or even rejection. Declared capacity specifications result from the necessity not only to limit the total number of hourly movements, but also to cope with available airport resources and to be able to manage the expected arrival and departure flow queues lengths (limitation on flight concentration).

Elements affecting the declared capacity determination can be broken down into runway capacity, terminal passenger capacity, aircraft stand capacity and additional requirements e.g. environmental/political restrictions (as formulated in the approval of operation). Due to being the relevant bottleneck the following airport capacity elements can be considered decisive for the determination of declared capacity at coordinated German airports (no consideration of restrictions on overnight operations):

- Runway capacity: Frankfurt, München, Stuttgart
- Terminal passenger capacity: Berlin Tegel
- Environmental/political restrictions: Düsseldorf

Runway capacity is defined as the maximum number of aircraft which can be handled within a certain time period and thus will be addressed by the declared capacity [e.g. movements per 60 min] directly.

Terminal passenger capacity cannot be addressed by a limitation on flight movements per time period directly. Thus a consideration of other aspects is required to balance available terminal passenger capacity and demand in Berlin. Here the declaration of capacity enforces restrictions on the number of passenger seats and the gate occupancy time per aircraft.

Environmental/political restrictions in Düsseldorf as formulated in the approval of operation consist in a limit on total movements in 6 peak months of the year. Accordingly the declared capacity [movements per 60 min] has to be derived from those restrictions.

Slot Allocation Calendar. An airport's declared capacity represents the input parameter for the following slot allocation as second part of the airport scheduling processes. Worldwide airport slot allocation takes place according to the IATA Calendar of Schedule Coordination Activities. The relevant dates for the summer 2005 season can be found in Table 3.

23 October 2004	Deadline for submission of Initial Slot Requests
13 November 2004	Initial Slot Allocation
19 November 2004	1st day of IATA Schedules Conference
31 January 2005	Slot Return Date
27 March 2005	Start of Season
29 October 2005	End of Season

Table 3: IATA Calendar of Schedule Coordination Activities - summer 2005 season

About 5 month before the start of the summer 2005 season, on October 23rd, 2004, the deadline is reached to submit slot requests by the airlines. Those slot requests include all kind of historical slots that had been used in the summer 2004 season already, as well as slots for new services that are intended to start in summer 2005 season. At that day the airport coordinator is aware of the total amount of initial demand at each of the 5 considered coordinated airports. In the following days and weeks the airport coordinator processes the available slot requests to prepare the initial slot allocation, using aforementioned priority criteria.

About 1 week before the start of the schedules conference, on November 13th, 2004, the initial slot allocation takes place. Airlines are informed about the results of their slot requests' processing. Slots that had been requested by the airlines can be

- allocated as requested,
- allocated not as requested, but rescheduled (time shift), or
- rejected by the airport coordinator.

If slots are rescheduled, the airport coordinator will try to suggest alternative slot times in periods without excess demand to avoid rejection of those slots due to capacity scarcity. If excess demand ranges throughout the day and no reasonable alternative slot times can be offered, requested slots have to be rejected by the coordinator.

Until the beginning of the schedules conference which takes place in Boston, November 19th – 22nd, 2004, the airlines can decide about acceptance or return of slots allocated initially. The conference itself provides opportunities for schedules adjustments and slot exchange through bilateral discussions between airlines or between airlines and coordinators. Due to allocated slots being returned there might be slots available again even in periods of initial excess demand which can be used for schedules fine tuning and adjustments. Returns and rescheduling of slots keep the whole process in motion.

Before the season starts on March 27th, 2005, there is one more distinctive date to be mentioned: The Slot return date on January 31st, 2005. As described above airlines are supposed to return all slots that they do not intended to use by that date at the latest. Late return of slots might cause some disadvantages when attempting to achieve historical priority for the following equivalent season.

Finally slots that have not been returned and thus that still are allocated about one day before the particular day of operations, form the coordinated schedule when coordination activities end. Within this study the result of coordinator's airport scheduling activities is defined as "final status" (of coordination activities). Besides slots that had been allocated initially two more types of slots might exist at the Final Status:

- Slots allocated additionally (slot requests after initial allocation)
- Reallocated slots

The latter mean a late accommodation of slot requests that had been rejected initially because of capacity scarcity and excess demand. Newly available slots due to returns or rescheduling could provide such opportunity. In contrast to that slots allocated additionally have not been appeared in scheduling processes before but are requested after the initial slot allocation. Reallocated or additionally allocated slots can be requested up to the final status, acceptance depends on the availability of slots at the time of request.

Summer 2005 season starts on March 27th, 2005, and ends on October 29th, 2005. The full course of processes with all given alternatives to airlines and coordinator is depicted in Figure 5's flowchart.

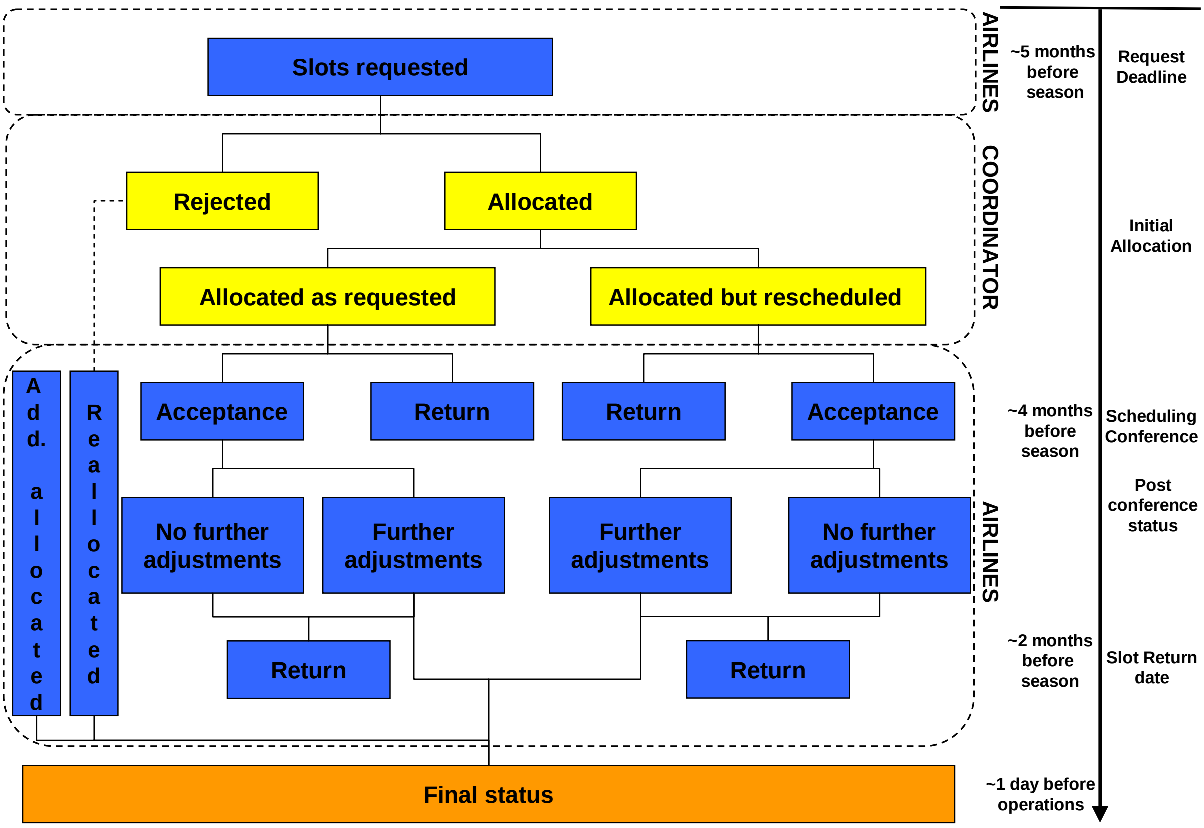


Figure 5: Slot Allocation Processes from Initial Request to Final Status

Slot Allocation Procedures. Within this section the methodology used to allocate slots during airport scheduling processes is described. The usage of the declared capacity values to cope with given capacity limitations is the focal point.

All slots for arrival and departure flights at German coordinated airports are requested and allocated as on-block/off-block times at 5 minutes intervals (e.g. 10:00; 10:05; 10:10 etc.). Despite this apparent usage of block (gate) times the coordinator uses (calculated) runway times to balance declared capacity values and the number of slots to be allocated. Thus a declared capacity value does not refer to flights going on-block/off-block but refers to flight movements on the runway. To calculate runway times during coordination processes internally, the following standard taxi times for arrival and departure flights are used at German coordinated airports (Table 4).

Airport	Standard Taxi Time [min]	
	ARR	DEP
TXL	5	5
DUS	5	5
FRA	5	10
MUC	5	10
STR	5	5

Table 4: Standard Taxi Times at German Coordinated Airports

Accordingly the required calculation is done as follows:

1) Take-off time (Runway time departure) = Off-block time + Standard taxi time (DEP)

2) Landing time (Runway time arrival) = On-block time – Standard taxi time (ARR)

At German airports for coordination reasons a 10 min time span is used as smallest coordination unit. With coordinated flights being scheduled at 5 minutes intervals, 2 adjacent slot times will be combined and considered within one 10 min coordination interval. Table 5 shows an example for an accordant computation.

10 min Coordination Unit	Includes all flights scheduled at
10:00-10:09	10:00; 10:05
10:10-10:19	10:10; 10:15
10:20-10:29	10:20; 10:25

Table 5: Coordination Units and Included Scheduled Times – Example

The combination of the use of runway times derived from scheduled block times and of the determination of 10 min intervals as smallest coordination units leads to the following procedure during coordination as demonstrated in Figure 6.

Due to addition or subtraction of a standard taxi time, arrival and departure flights are adjusted differently. To compute runway times from scheduled block times in FRA and MUC, departure flights are postponed by 10 minutes while arrival flights are brought forward by 5 minutes. With respect to 10 minutes intervals of runway times which are relevant for coordination, flights that are adjacent with regard to scheduled block times are not necessarily summed up. For example a coordination unit describing a (runway) time span from 10:10 up to and including 10:19 contains arrival flights scheduled at 10:15 and 10:20 (block times) and departure flights scheduled at 10:00 and 10:05 (block times) (cp. Figure 6).

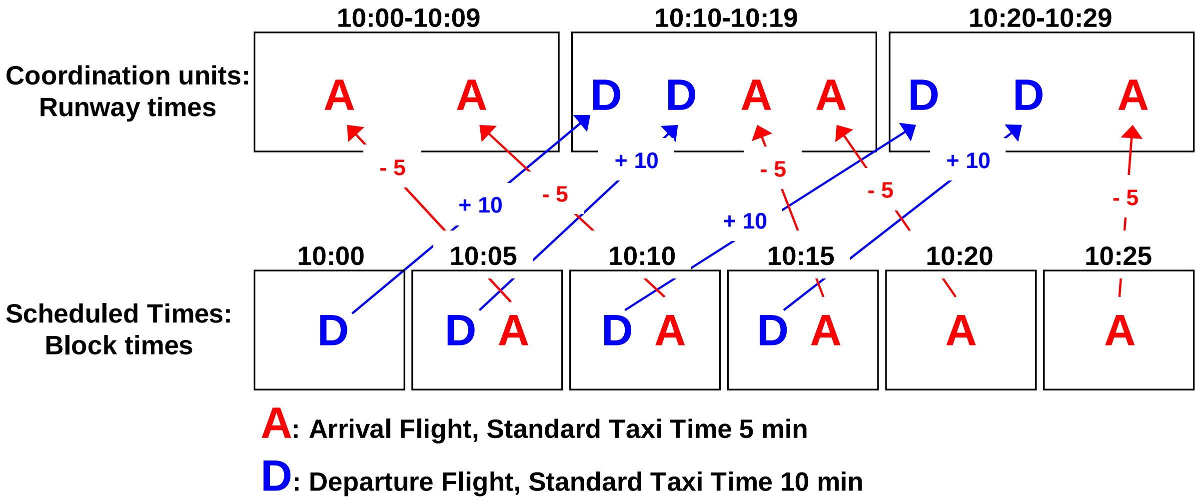


Figure 6: Interrelation of Scheduled Time and Coordination Unit – Example FRA or MUC

For airport coordination in Germany the afore-mentioned 10 minutes intervals are used as a basis for the coordination process. The number of scheduled flights and thus allocated slots usually has to comply with 3 different declared capacity values (10/30/60min). While the 10 minutes declared capacity matches the 10 minute coordination unit and thus can be applied as a *static* block, for the 30 (60) minutes declared capacity 3 (6) adjacent coordination units are summed up. This 30 (60) minutes interval then is shifted by 10 minutes steps. Accordingly 30 (60) minutes declared capacity values are applied as *rolling* blocks.

Additionally all extra regulations (e.g. noise/destination/number of passenger seats restrictions) included in the coordination parameters have to be complied with.

4 Part1: Utilisation of declared capacity

The study's first part addresses possible inefficiency during the process of slot allocation ranging from the airlines' initial slot request until the final status of coordination activities, but disregards the final schedule's realisation during operations. Being in this analysis' centre of interest, coordinated airports feature excess demand throughout the day or during peak times of the day at least, and thus a certain proportion of slots cannot be allocated as requested or even has to be rejected by the airport coordinator. If despite this initial excess demand the available declared capacity is not utilised completely at the end of the scheduling processes, from an aviation community's perspective those processes feature certain inefficiencies. For this reason the first part of the study focuses on the ability to allocate all available slots (=declared capacity) and thus on the utilisation of available capacity during this phase.

Previous studies as shown in chapter 2 pointed out certain inefficiencies during allocation processes resulting from non-optimal utilisation of available capacity. Additionally a number of possible drivers to such inefficiencies (e.g. overbidding, late slot returns before/during season etc.) are stated. The analysis on hand seizes those approaches and continues them consequentially. Compared to the investigations done by ACI Europe and ECAC, a more precise analysis considering every single flight within one scheduling season at German coordinated airports is elaborated. This allows an estimation of magnitude and relevance of inefficiency during scheduling processes at different airports, for different demand patterns and during different time periods. The non-optimal utilisation of capacity can be quantified.

Chapter 4 includes the investigation to detail and to comprehend the inefficiencies during slot allocation due to non-optimal utilisation of available capacity. With a technical introduction addressing data availability and processing in 4.1, the actual results of the analysis are stated in 4.2. With a discussion on possible drivers to non-optimal capacity utilisation in 4.3 the first part of the report is finalised.

4.1 Methodology

4.1.1 Available data, input parameters

The analysis is based on the airport slot allocation data for the summer 2005 season as provided by the German slot coordination office. The dataset covers all planned commercial flight movements for all 217 season days at the coordinated airports Berlin Tegel (TXL), Düsseldorf (DUS), Frankfurt (FRA), München (MUC) and Stuttgart (STR). Provision of data started at the airlines' initial request deadline. To follow the process of the airport slot allocation and coordination through all relevant stages, the dataset was updated weekly every Friday until the end of the season. This allows the consideration of the following relevant key moments of airport slot allocation processes:

- Initial slot request
- Initial slot allocation
- Post conference status
- Slot return date
- Final status of airport coordination office's activities

Due to the dataset's weekly update, the "final status" needs to be defined. Within this analysis, "final status" means the status of coordination activities at each last Friday before operations. Thus the final status represents a coordination status between 1 day (if operations are on Saturdays) and 7 days (if operations are on Fridays) before operations[2].

In detail each planned flight movement is specified by the information shown in Table 6:

	Data sample
Airport	DUS
Flightnumber	XY 1234
Arrival / Departure	A
Block time	0100
Start date	20050402
End date	20051029
Days of operation	0030060
Final / Origin	IBZ
Next / Previous	PMI
Aircraft type	322
Market segment	C
weekly / bi-weekly	1

Table 6: Data sample as provided by the German airport coordination office (FHKD)

Available slot allocation data including all commercial flight movements at German coordinated airports (no general aviation, military) allows a complete reproduction of the available demand at each stage of the coordination processes.

In addition each airport's declared capacity values as determined by the coordination committee in the run-up to the coordination processes are input parameters to the recent analysis. With the determination of the declared capacity being out of this analysis' scope, it is assumed that the given values represent a reasonable and sustainable seasonal fixing of the airports' actual technical and/or administrative capacity. Declared capacity has been used as published by the German airport coordination office. Table 2 includes all capacity values used as input parameters to the investigation.

4.1.2 Proceeding

Available slot allocation data is transformed into a daily schedule for each coordinated airport. Thus a recent planning status representing the planned demand is available for each airport slot allocation processes' key moment. Using given declared capacity values the planned demand allows the computation of an updated level of capacity utilisation for each relevant stage of the coordination processes.

Knowledge of the composition of demand (each single flight is covered by the slot allocation data, see above) allows a more precise investigation. To meet the study's objectives – quantification of scheduling inefficiencies and nomination of possible drivers – the complete slot allocation process is reproduced including a precise determination of number, proportion and type of rejected, rescheduled, additionally allocated, reallocated and returned slots.

[2] The accordant approach was justified by control sample investigations which could detect only minor changes with regard to capacity utilisation within the last days of coordination activities.

4.2 Capacity utilisation: From initial request to final status

To allow comparability between slot allocation performances at all coordinated airports, the investigation on hand focuses on time periods during which access to the airports is restricted by the relevant declared capacity [Mvts/time unit] only. Thus all results within this chapter refer to the following airport operation time:

06:00 – 23:00 LT

This approach excludes local regulations such as night curfew, noise points, precedence to home carrier/less noisy aircraft during night time/late evening/early morning or any comparable rules. A complete exclusion of all local regulations cannot be obtained (e.g. FRA: No more than 4 departure flights to North America per 15 min) which should be kept in mind with regard to a comparison of slot allocation performances at different airports. This applies to TXL in particular: Here slot allocation results have to comply with capacity restrictions resulting from the passenger terminal building's insufficiency. Thus not only the number of aircraft movements has to be considered during coordination but the number of passengers per aircraft as well which is not included in this investigation. For this reason slot allocation performance at TXL is hardly comparable to other German coordinated airports.

This chapter analyses the slot demand changes from the initial slot request deadline ("initial request") to the completion of slot allocation activities ("final status"), focussing on the utilisation of declared capacity. While 4.2.1 describes the different characteristics of excess demand at different coordinated airports at the initial request, in chapter 4.2.2 certain inefficiencies are stated being measured as loss of capacity utilisation from the coordinator's initial slot allocation to the final status. Chapter 4.2 is completed by a detailed analysis to specify slots causing demand changes and loss of capacity utilisation (4.2.3).

4.2.1 Slot demand at the initial slot request deadline

According to their designation as coordinated airports, at all relevant airports slot demand exceeds declared airport capacity throughout the day or during peak times of the day at least. But levels of excess demand and courses of demand profiles vary between the airports significantly. With regard to arrival and departure slots (= total number of slots), the number of requested slots exceeds the number of available slots (217 season days, 06:00-23:00 LT, static 60min blocks, mixed movements) at FRA and DUS (cp. Figure 7). While slot demand exceeds total declared capacity about 2 % at FRA, about 8 % excess demand can be noticed at DUS. MUC, STR and TXL feature about 20 % to 30 % excess supply – this implies significant slot scarcity during peak times of the day/week/season only.

Figure 7 underlines major differences in demand pattern and demand constancy in particular between those airports. FRA is the only airport featuring constant demand on a daily basis – weekdays and weekends. All other airports – including highly congested DUS – show significantly less demand and thus less utilisation of available capacity at weekends. Besides differences between weekends and weekdays, hourly demand patterns vary between the airports significantly. Figure 8 and Figure 9 illustrate the hourly slot demand at FRA and MUC on a summer season's typical day (ARR/DEP/TOT, rolling 60min blocks, runway times). For assessment reasons relevant declared capacity values are added as well. FRA features a very constant hourly demand and a complete utilisation of available capacity throughout the day. With regard to arrival/departure flights, despite FRA being Germany's major hub airport, no significant departure/arrival peak periods can be noticed except very little in the afternoon and evening hours. In contrast MUC shows a distinctive arrival/departure wave pattern. Slot demand concentrates on three periods of the day. Accordingly there is no constant slot shortage, but excess demand and excess supply alternate.

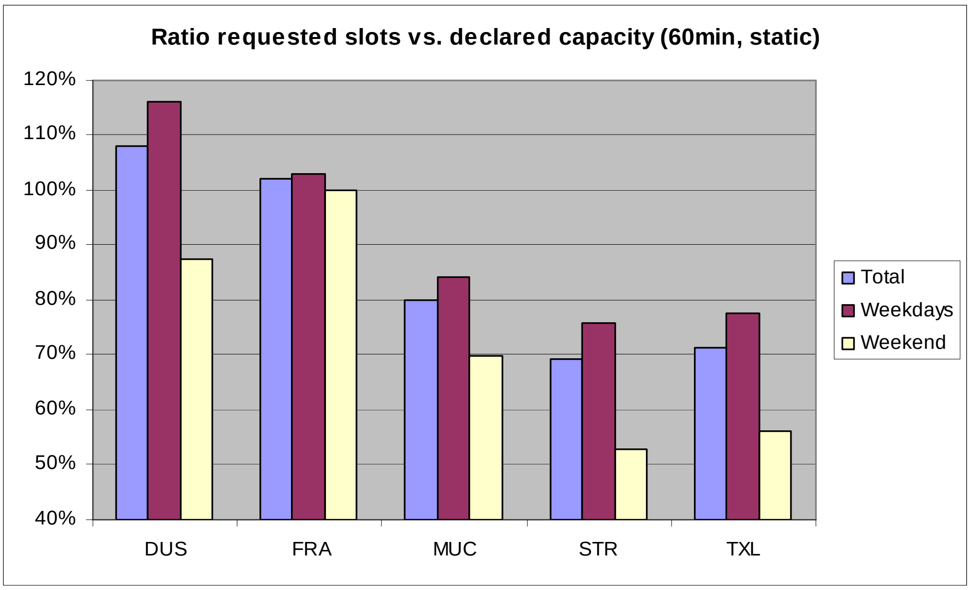


Figure 7: Capacity utilisation at the initial slot request deadline

Besides the level of hourly demand variation, Figure 8 and Figure 9 depict the existence of separate declared arrival and departure capacity values. FRA, MUC and STR feature such declared capacity which is an additional limitation with regard to the allocation of available capacity (cp. Table 2). To compare the significance of each type of declared capacity at the different airports, a corresponding overview is illustrated in Figure 10. With regard to the proportion of rolling 60min blocks with excess demand, the mixed movements declared capacity (TOT) is exceeded most frequently at all three airports. While MUC and FRA see higher proportion of blocks with excess arrival demand than with excess departure demand, arrival demand is not a problem at all at STR. DUS and TXL do not appear in columns “ARR” or “DEP” because of the inexistence of accordant declared capacity values at those airports.

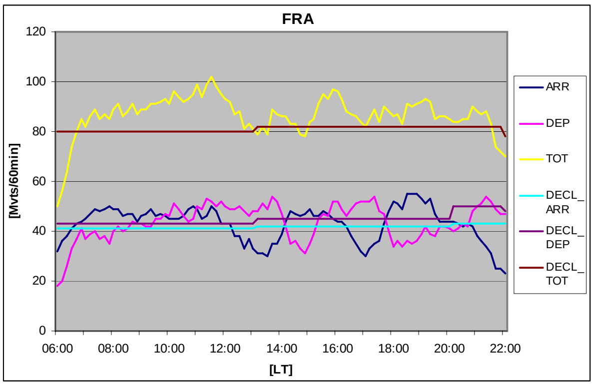


Figure 8: FRA – Initial slot demand/declared capacity pattern (ARR/DEP/TOT), typical day

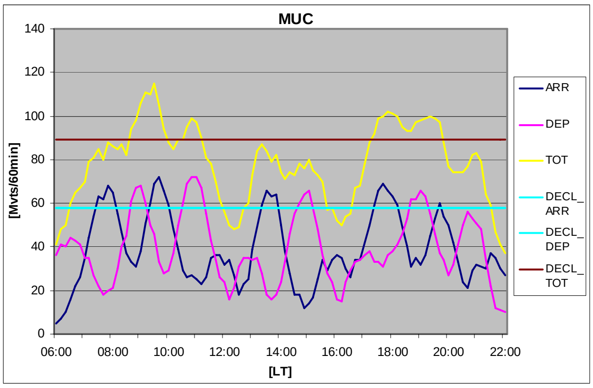


Figure 9: MUC – Initial slot demand/declared capacity pattern (ARR/DEP/TOT), typical day

Block periods with any kind of excess demand might overlap, but might be in succession as well. The extent of overlapping points out the right column “Any_DECL” (Figure 10) which illustrates the proportion of rolling 60min blocks which are limited by at least one type of declared capacity, ARR and/or DEP and/or TOT. Here DUS and TXL feature the same proportion noticed for mixed movements’ (TOT) also which results from this declared capacity being the only existing one. In contrast MUC and FRA show a significant increase of the proportion of blocks with any type of excess demand compared to the separate consideration of ARR/DEP/TOT. Those airports feature certain periods of the season in which only the declared arrival and/or departure capacity is limiting. In terms of relative increase, this effect is more significant at MUC which is an airport with a distinctive departure/arrival wave pattern (cp. Figure 9). At FRA, a proportion of more than 90 % of blocks featuring any kind of excess demand emphasises the constant high-level demand and thus a heavy utilisation of declared capacity or, in other words, a significant slot shortage.

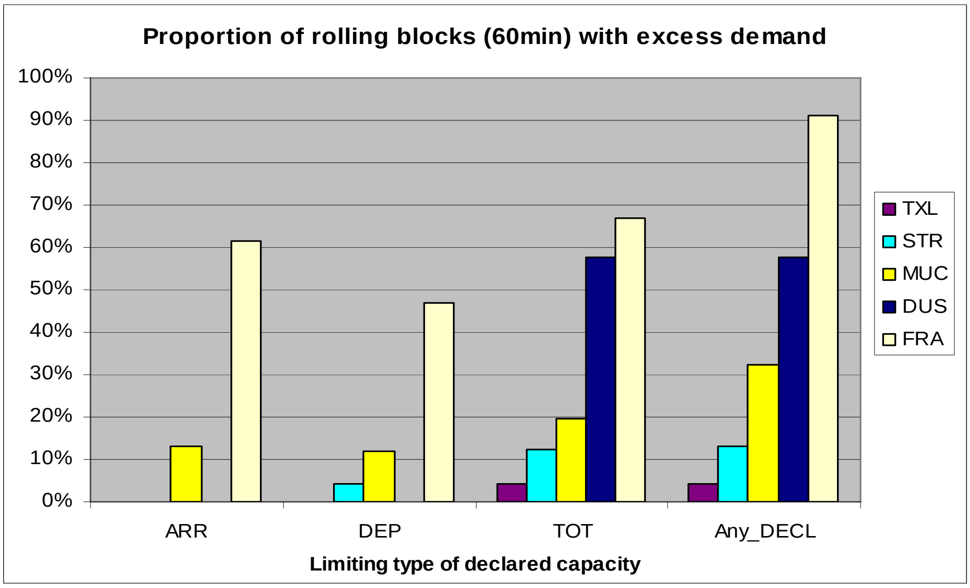


Figure 10: Arrival/departure/mixed capacity utilisation at the initial slot request deadline

Besides the possible specification of arrival and departure flights, an airport’s declared capacity might consists of a mixing of different type (rolling, static) and different duration (10/30/60min) of blocks. The latter is used to control the concentration of flights within a given time period. For the relevant coordinated German airports, Figure 11 illustrates the capacity utilisation at the initial request deadline with regard to the different type and duration of blocks as well as the specification of arrival/departure flights. While all airports feature static 10min blocks, rolling 30min blocks are applied at FRA only. Consequently at FRA 9 different capacity restrictions have to be complied with in parallel: ARR 10min, ARR 30min, ARR 60min, DEP 10min, DEP 30min, DEP 60min, TOT 10min, TOT 30min, TOT 60min. Those restrictions’ effectivity to limit flight concentration and thus to control operational flows has to be verified because they represent significant additional difficulty to allocate declared capacity completely. An accordant approach is conducted in this study’s part 2.

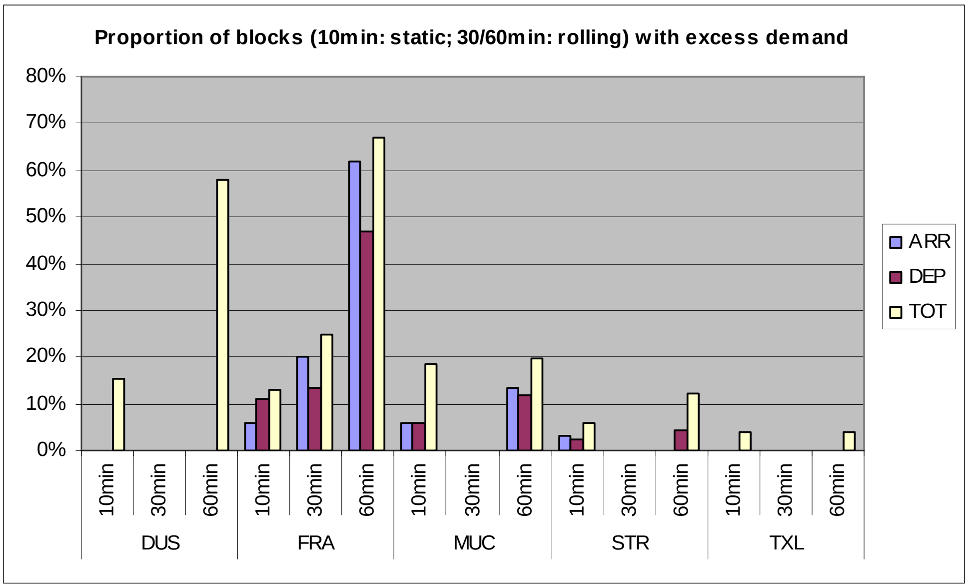


Figure 11: Capacity utilisation (ARR/DEP/TOT) at the initial request deadline with regard to different type and duration of blocks

With the sum of the number of acceptable flight movements within six 10min blocks exceeding the number of acceptable flight movements within one 60min block (cp. Table 2), the proportion of blocks with excess demand rises according to the duration of blocks at all airports. This emphasises the relevance of 10min and 30min blocks to control the concentration of flights, while in contrast rolling 60min blocks are used to limit the total number of flight movements.

While at airports with no or very limited excess demand only one can assume that the airlines' initial slot request meets their real slot wishes, at highly congested airports the initial request might not represent the actual needs for two main reasons. At the outset some airlines might abandon any slot request because of the very limited chance to receive any slot at an acceptable time. This would diminish the slot demand at the initial slot request deadline. But on the other hand, some airlines might request more slots than actually required to increase chances to receive any slot at any time and thus to be well prepared for the following period of slot exchanges and adjustments. This would raise the slot demand at the initial slot request. The dimension of those effects can not be evidenced but may only be estimated.

4.2.2 From initial allocation to final status: Loss of capacity utilisation

To balance demand and available declared capacity, initial slot requests are processed by the coordination office. A few weeks after the initial slot request deadline, airlines are informed about the initial slot allocation. Utilisation of declared capacity meets 100 % at most. But due to the necessity to allocate slot pairs (arrival and departure) and to comply with declared capacity's different modes (ARR/DEP/TOT, static/rolling blocks, 10/30/60min), capacity utilisation falls below 100 % in most times. Figure 12 illustrates the change of capacity utilisation from the initial request to the initial allocation at coordinated German airports (217 season days, 06:00-23:00 LT, static 60min blocks, mixed movements). While capacity utilisation at DUS and FRA drops and thus falls below 100 % significantly, it remains stable (or nearly stable at least) at all other airports.

Depending on the demand profile at the initial request, coordinator's processing opportunities vary. Slot requests might be allocated as requested, might be rejected or might be allocated but rescheduled/retimed. The latter leads to a slot time proposal different from the one requested. To reschedule flights and to offer alternative slot times, a reasonable number of slots being still available at the initial request is required. At airports with demand excess throughout the day retiming is hardly ever possible.

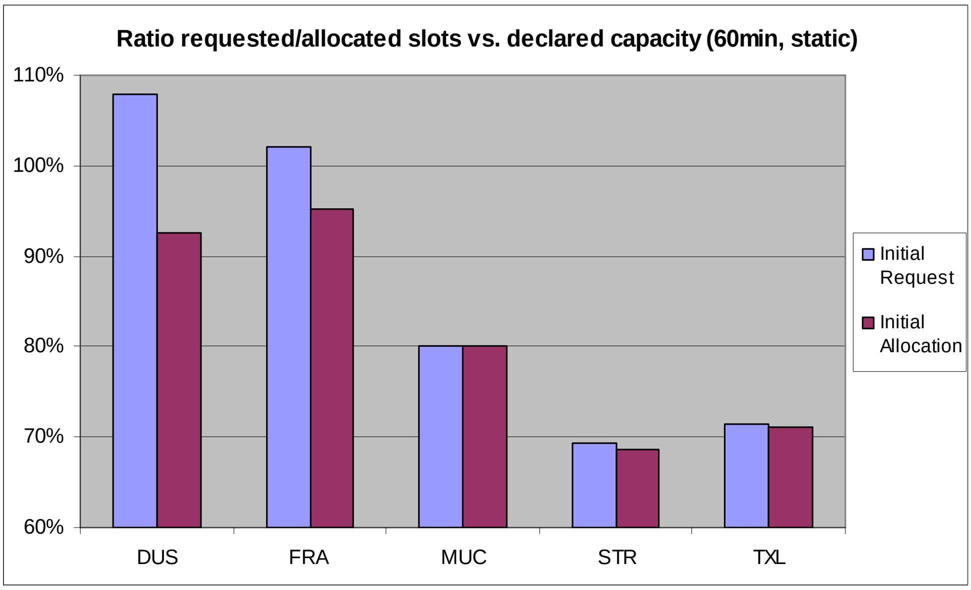


Figure 12: Capacity utilisation change from initial request to initial allocation

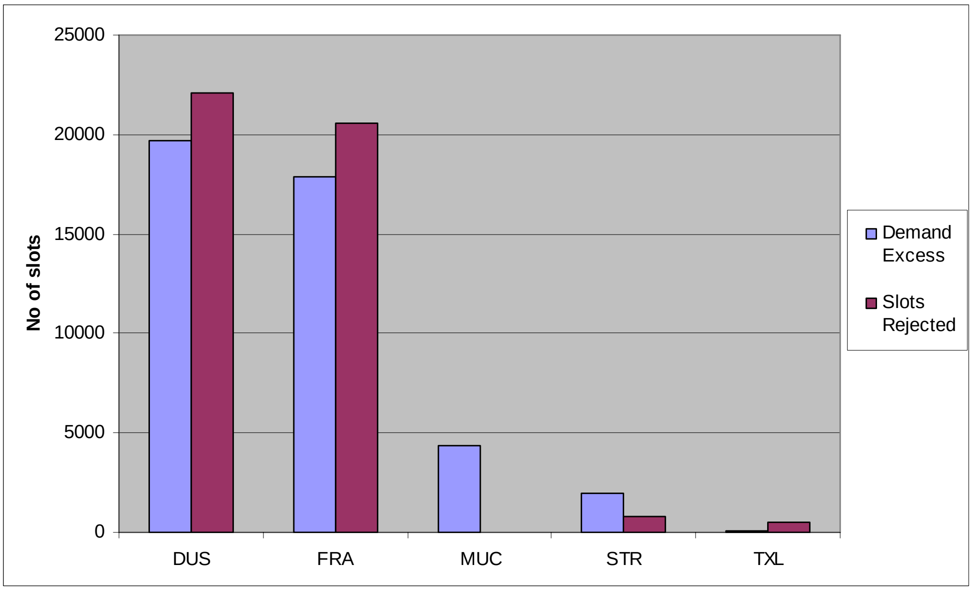


Figure 13: No. of excess demand slots compared to No. of slots rejected

According to this summer 2005 schedule season's initial slot allocation proceeds at German coordinated airports (cp. Figure 13). With DUS and FRA featuring excess demand throughout the day almost, a large number of slots are rejected at these airports because there are no reasonable options available for rescheduling. Rejections do not only result from the total movements 60min slot limit, but might follow from ARR/DEP/10min/30min constraints as well - even in periods with no excess demand with regard to total movements 60min declared capacity. Additionally the number of rejected slots exceeds the number of slots in excess demand periods, which results from the necessity to allocate slot pairs (arrival and departure): When a slot in an excess demand period is rejected, the corresponding slot request (arrival or departure) will be refused as well although it might be in a period not being overloaded. In contrast, MUC, STR and TXL see no or no important number of rejected slot requests. Nearly all requested slots can be allocated, either as requested or with an alternative slot time proposal at least.

This chapter focuses on demand changes between the initial allocation and the final status. With regard to the utilisation of declared capacity, Figure 14 illustrates its status at each key moment of the slot allocation process (Initial request, initial allocation, post conference, slot return date, final status). Figure 14 is based on average values of all season's rolling 60min blocks and differentiates between blocks with excess demand (ED – solid lines) and with no excess demand (nED – dashed lines).

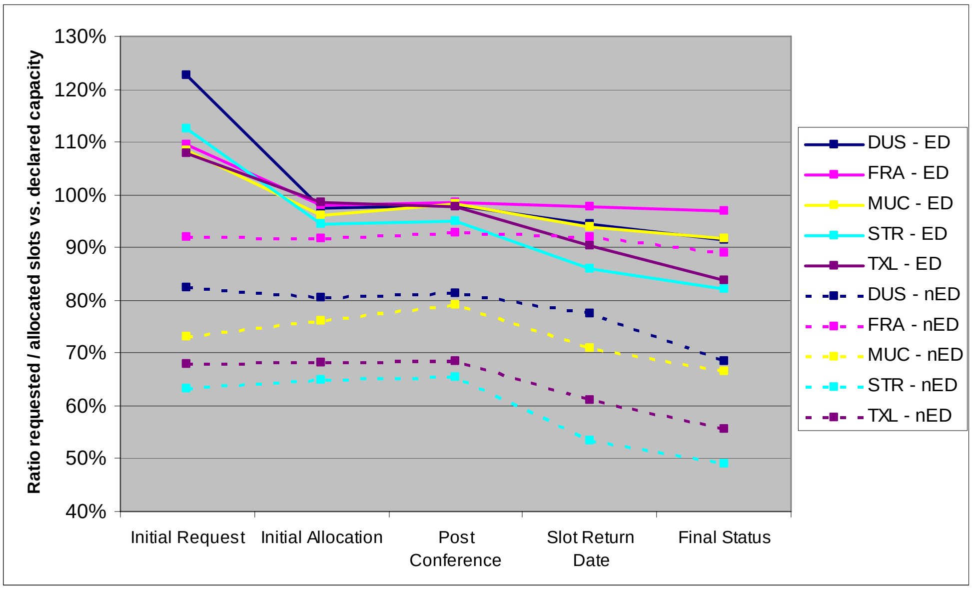


Figure 14: Capacity utilisation - rolling 60min blocks with/without excess demand (ED/nED)

To comply with the declared 60min capacity (mixed movements), capacity utilisation in blocks with excess demand is shortened to 100 % or below at the initial allocation (Figure 14: Solid lines). High average capacity utilisation at FRA (> 90 %) even in no-overload periods strsses the stability of slot demand at that particular airport. At the initial allocation, capacity utilisation in blocks without excess demand is nearly constant or increases slightly due to the rescheduling of slots to periods with no overload (MUC, STR). All blocks (with and without excess demand) feature a slight increase of capacity utilisation at the post conference status. It can be assumed that this results from successful schedule negotiations and adjustments at the conference as well as additional (late) slot requests which could have been accommodated. Until the post conference status, capacity utilisation at all airports is close to its particular optimum – no loss of capacity utilisation can be noticed and thus no scheduling inefficiency.

From the post conference status on, capacity utilisation decreases at all relevant airports until the slot return date and further up to the final status of coordination activities. The number of returned slots cannot be compensated by slots requested additionally. This loss of capacity utilisation concerns blocks both with excess demand and without overload, although the latter are affected more intensively. Less congested airports (STR, TXL) feature higher percentages of returned slots and thus higher loss of capacity utilisation, while the highly utilised capacity at FRA sees minor changes only.

With regard to inefficiency during slot allocation processes, the non-optimal utilisation of available capacity at the end of those processes is in the centre of interest. Non-optimal utilisation of available capacity develops through the loss of capacity utilisation between the initial allocation and the final status. This loss of capacity utilisation can be seen as one important parameter to measure an airport's scheduling performance. Within this investigation the loss of capacity utilisation (capacity utilisation is based on rolling 60min blocks and mixed movements (TOT)) is defined as follows (cp. Figure 15):

Capacity utilisation (initial allocation) [%] minus capacity utilisation (final status) [%]

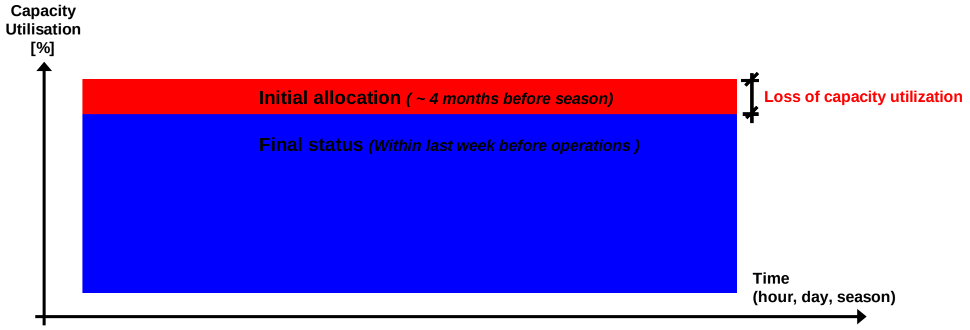


Figure 15: Loss of capacity utilisation - schematic diagram

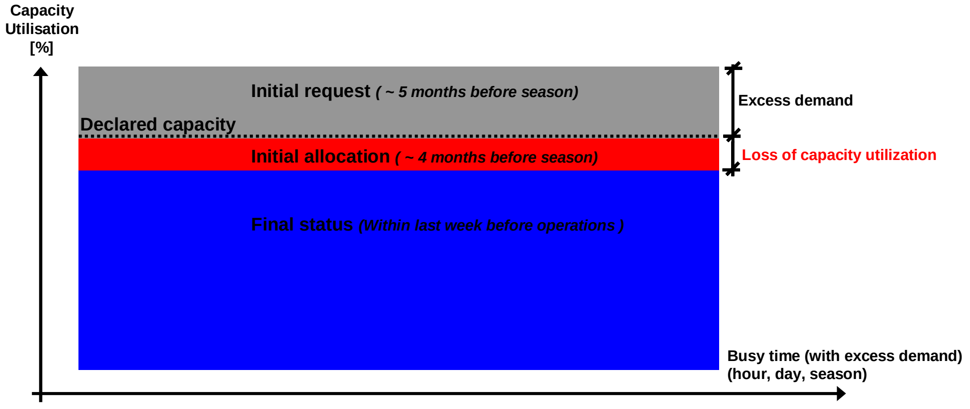


Figure 16: Loss of capacity utilisation in excess demand periods - schematic diagram

Loss of capacity utilisation results from two different parameters which are important with regard to the specification of slot demand changes (Chapter 4.2.3) and the detection of drivers to the loss of capacity utilisation (Chapter 4.3) in particular: Slot returns and inadequate compensation of those slot returns during the same period of time. Only if both parameters occur, loss of capacity utilisation will develop.

With regard to the airport scheduling performance, the relevance of the loss of capacity utilisation is different for periods with and without excess demand. Due to capacity scarcity at coordinated airports in general, the loss of capacity utilisation and thus unused capacity at the end of the scheduling process states an unsatisfying situation. But it is inefficient in particular if the loss of capacity utilisation falls in periods of initial excess demand: Although a certain number of slots has been rejected – or rescheduled from their requested slot time at least – at the initial allocation, the given declared capacity is not utilised at the end of the coordination activities completely. For this reason loss of capacity utilisation in excess demand periods is relevant in particular (Cp. Figure 16).

Besides the differentiation between periods with and without excess demand, the loss of capacity utilisation resulting from the return of allocated slots requires a temporal classification. As far as slots are returned before the official slot return date, any resulting non-optimal utilisation of available capacity complies with the relevant Council Regulation 95/93. All additional slot returns, from the slot return date until the final status, violate the current rules. For this reason a temporal differentiation is required with regard to scheduling inefficiencies resulting from the loss of capacity utilisation.

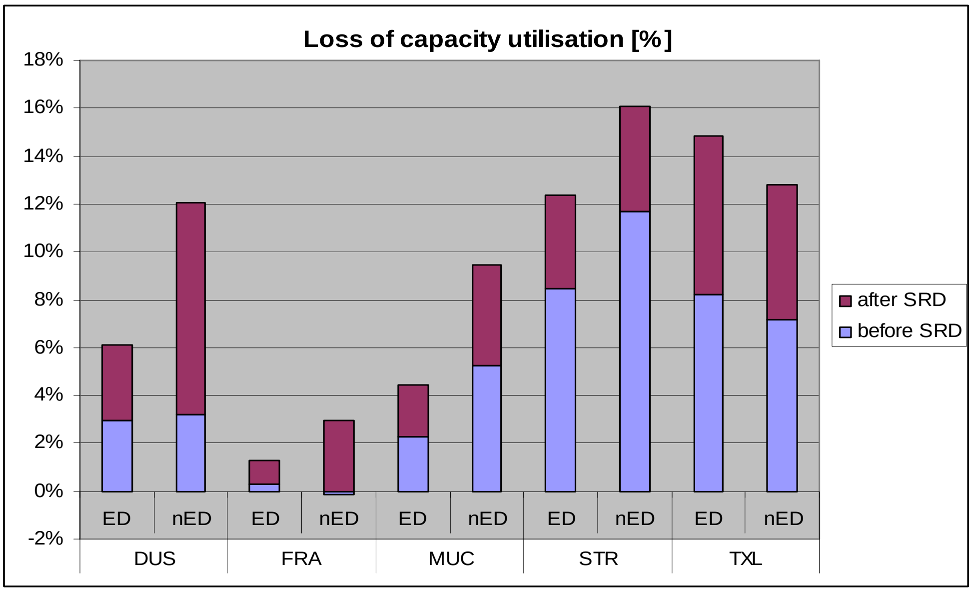


Figure 17: Loss of capacity utilisation in periods with/without excess demand (ED/nED)

Figure 17 illustrates the results of the investigation on the loss of capacity utilisation at German coordinated airports. The following major results are based on these results:

1. With the exception of TXL (see 4.2 for the reason of TXL's limited comparability) all coordinated German airports feature a more significant loss of capacity utilisation in periods without excess demand compared to periods with excess demand.

2. Highly congested airports – FRA in particular – see a less significant percentage loss of capacity utilisation than less utilised airports. Consequently FRA is the only airport at which a slight increase of capacity utilisation occurs (periods without excess demand (nED), before slot return day).

3. A significant number of slots is returned after the slot return date and thus causes loss of capacity utilisation violating the current rules (Council Regulation No. 05/93).

To understand the magnitude of those losses of capacity utilisation, Table 7 depicts the absolute numbers of slots being returned but not compensated again at 5 coordinated German airports (all season days, mixed movements, 06:00 – 23:00 LT). Slots lost in periods with excess demand (ED) are of particular importance. Accordingly this problem's significance at DUS is confirmed – despite heavy slot scarcity throughout the day at the initial request, an outstanding number of slots is lost in periods with excess demand even. With regard to the most congested German hub airport FRA, even a slight percentage loss of capacity utilisation in periods with excess demand of about 1 % only (cp. Figure 17) represents a significant absolute number of lost slots. At MUC, STR and TXL the loss of capacity utilisation focuses on periods without excess demand.

	DUS	**FRA**	**MUC**	**STR**	**TXL**
Total no. of lost slots	21696	6222	29249	22609	18880
In ED periods	9919	3136	3708	3058	1267
In nED periods	11777	3086	25541	19551	17613

Table 7: Absolute number of lost slots from initial allocation to final status

These results confirm the non-optimal utilisation of declared capacity established at the final status of slot allocation processes as one major form of scheduling and slot allocation inefficiency. In contrast to the results of ECAC's study on slot allocation procedures (Cp. 2.2) as well as ACI's study on the use of available capacity (Cp. 2.1) which both stated slot allocation inefficiency with regard to capacity utilisation, the paper on hand allows a quantification of this inefficiency at different airports, stating percentage values and absolute slot numbers. It is the objective of this report's chapters 4.2 and 4.3 to deepen the current conclusions, to analyse and specify the effect of lost capacity utilisation at coordinated German airports and thus to detect possible drivers to it.

4.2.3 From initial request to final status: Slot demand processing

Availability of detailed weekly updated slot data specifying every single planned flight movement allows a microscopic approach and thus an analysis of the utilisation of declared capacity. The precise slot demand processing and adjustments can be comprehended through all relevant stages of slot allocation procedures. This kind of analysis provides one major basis for the detection of possible drivers to unsatisfying capacity utilisation at the final status.

Slot demand changes during allocation procedures will be connected to treatments/adjustments of single slots. To differentiate between such treatments/adjustments which might be applied between initial request and final status, definitions as described in Table 8 will be used within the investigation on hand.

At the initial allocation the coordinator cannot allocate a certain number of requested slots due to significant excess demand. Slots have to be rejected, if no reasonable temporal alternative can be suggested. In particular this occurs at airports with excess demand nearly throughout the entire day. Figure 13 illustrates the amount of rejected slots at German coordinated airports.

Slot characteristic	Related slot allocation key moment(s)	Definition
Rejected	Initial allocation	Requested slots which cannot be allocated by the coordinator – not even at a different time than the requested one – due to slot shortage and excess demand
Rescheduled	Initial allocation	Allocated slots which have been rescheduled by the coordinator and which at the initial allocation thus differ from the slot time requested initially by an airline.
Returned	Between initial allocation and final status	Allocated slots which have been returned by an airline. Due to data availability reasons any changes to an allocated slot's related flight number by an airline will rank among returned slots.
Reallocated	Between initial allocation and final status	Initially requested but rejected slots which could be allocated at a later stage due to an airline's repeated request.
Allocated additionally	Between initial allocation and final status	Allocated slots which have not been included in the initial slot request and initial slot allocation but have been requested at a later stage. Any changes by an airline to an allocated slot's related flight number will rank among additionally allocated slots.

Table 8: Definitions of slot characteristics

Except those slots which have been rejected all slots requested initially are allocated at the initial allocation. But allocated slots differ in the level of compliance with the initially requested slot time significantly: Slots can be allocated as requested or can be allocated but rescheduled. The latter are allocated by the coordinator at a time different from the one requested by the airline. A flight movement associated to such a rescheduled slot experiences a deviation from the flight time planned originally during scheduling already – a scheduled delay (which might be negative as well when a slot request is brought forward). The proportion of slots allocated as requested/but rescheduled at German coordinated airports in all summer 2005 season days is depicted in Figure 18.

At German coordinated airports the proportion of slots allocated exactly as requested varies from 84 % (DUS) to 94 % (TXL) of all allocated slots. The reason for a high proportion of slots allocated as requested is quite different at FRA (89 %) and TXL (94 %). While TXL is an airport with excess demand only during short peak times of the day and thus most slots can be allocated as requested, FRA in contrast features excess demand throughout the day – the schedule pattern of the previous equivalent season is adopted completely nearly (historic slots), and thus there are only few opportunities to propose alternative slot times. Slots in excess demand periods thus have to be rejected rather than rescheduled.

Besides the reason for rescheduling its quality varies. Some slots are rescheduled for a few minutes only and airlines are likely to accept such slot time proposals. Others are rescheduled for up to several hours – the acceptance probability depends on the airline business plan/draft schedule, on the slot time flexibility at the adjacent arrival/departure airport and the number of slots held by this particular airline (or alliance partners/subsidiaries/parent companies) for internal fine adjustment. With regard to the loss of capacity utilisation it is in the centre of interest if airlines tend to accept slot alternatives or if they do not. The issue of rescheduling quality/acceptance probability/scheduled delays requires further investigation.

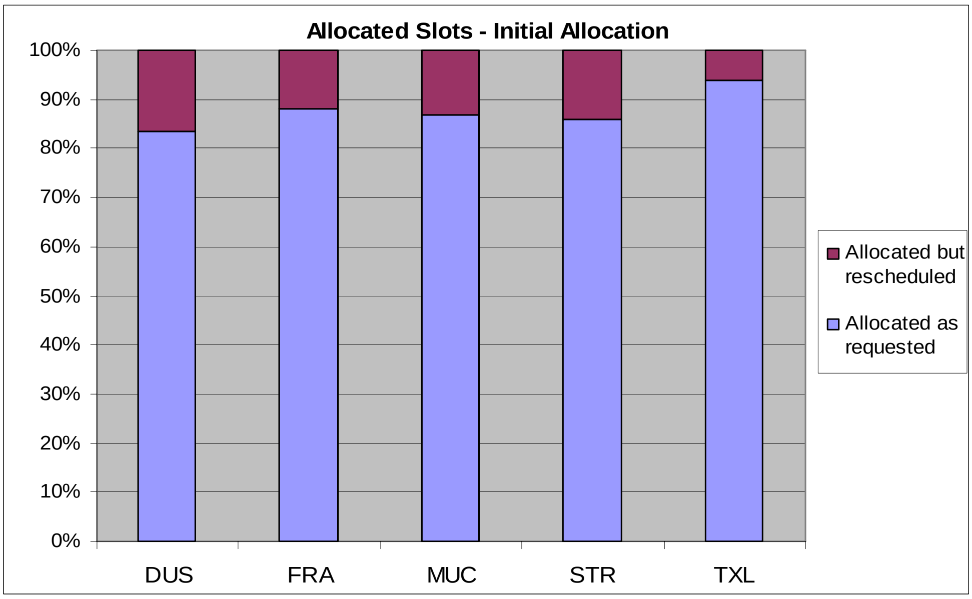


Figure 18: Proportion of slots allocated as requested/but rescheduled

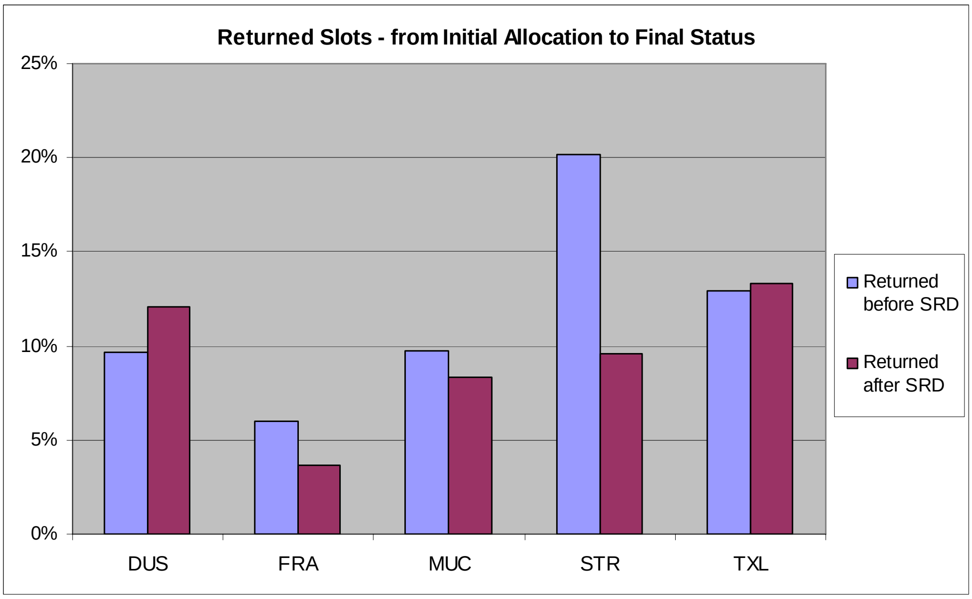


Figure 19: Proportion of returned slots (before/after SRD) in all slots allocated

The loss of capacity utilisation and thus unsatisfying capacity utilisation at the final status of coordination activities is a direct consequence of slot returns. With regard to the rescheduling issue described above, a slot return can be expected if it follows an initial allocation significantly different from the slot time requested originally. Returns of slots being allocated as requested are less explicable. Within this investigation a slot is considered to be returned, if its associated flight number which was used at the initial allocation does not appear at the final status. This includes all slots being actually returned, but all amendments to airline flight numbers as well. Slots (flight numbers) being adjusted temporally do not rank among returned slots, as far as they still appear at the same day. Figure 19 illustrates the proportion of slot returns (before/after slot return day) in all allocated slots.

Council Regulation 95/93 determines the 31st of January as the official slot return day (SRD). But due to a lack of incentive and/or penalty to return slots at that date at the latest, a significant proportion of slots is returned after the slot return day. Except for STR, slot returns are broken down into about 50 % before SRD and 50 % after SRD. Less congested airports (TXL, STR, MUC) feature a higher proportion of returned slots (about 20 % to 30 %) than highly utilised FRA (about 10 %). The amount of slot returns at 5 German coordinated airports develops proportionally to the loss of capacity utilisation (cp. Figure 17).

But the proportion of returned slots does not correspond to the loss of capacity utilisation completely. The loss of capacity utilisation can be compensated by both additionally allocated and reallocated slots. The higher the proportion of additionally allocated/reallocated slots to returned slots, the less disadvantageously is the impact returned slots have on the utilisation of available capacity. Reallocated slots do only appear if a certain number of slots was rejected at the initial allocation. The proportion of additionally allocated/reallocated slots to slots returned at DUS, FRA, MUC, STR and TXL is depicted in Figure 20.

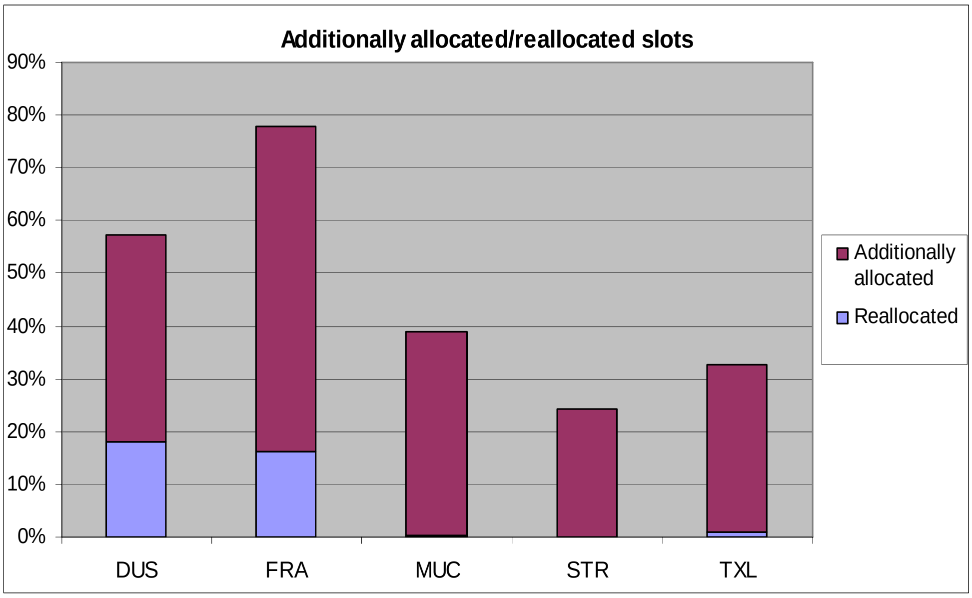


Figure 20: Compensation ratio - additionally allocated/reallocated slots vs. slots returned

With MUC, STR and TXL featuring just a very limited number of slots rejected (Cp. Figure 13), those airports do not have any or almost none reallocated slots. In contrast at DUS and FRA reallocated slots can compensate between 15 % (FRA) and 18 % (DUS) of all returned slots and thus limit the loss of capacity utilisation. With regard to the latter, at all airports the amount of additionally allocated slots is more significant. Between 25 % (STR) and 65 % (FRA) of all returned slots can be replaced by additional slot requests. In general cognitions from the investigation on both the loss of capacity utilisation and the returned slots can be adopted: Less congested airports feature a higher proportion of returned slots as well as a lower probability to compensate this loss by additionally allocated/reallocated slots, and thus those airports suffer from a more significant loss of capacity utilisation between the initial allocation and the final status.

4.3 Drivers to unsatisfying capacity utilisation at the final status

Chapter 4.2 contains a precise analysis of relevant slot demand changes and resulting losses of capacity utilisation between the initial slot allocation and the final status of coordination activities at 5 German coordinated airports. The accordant inefficiency can be quantified (percentage values and absolute numbers to specify losses) and evaluated (greater significance in periods with initial excess demand). A detailed investigation allows a slot classification to differentiate rejected, rescheduled, returned, reallocated and additionally allocated slots.

Based on those preceding analyses, in chapter 4.3 a detection of possible drivers to scheduling inefficiency in the form of loss of capacity utilisation is to be conducted. With regard to slot allocation data being the only base for the investigation at hand, most demonstrated drivers result from empirical studies, some of them from presumptions even. The derivation of conclusions cannot be considered as being statistical significant. Additionally this list of drivers does not claim to be complete – other drivers might exist and might be detected within following investigation approaches different from the one at hand.

Drivers to loss of capacity utilisation within this chapter are classified into three different driver categories:

- Local airport reasons
- Airline network reasons
- Lack of local slot demand

Differentiation of airline and airport reasons is derived from the network interrelation of airport and airline scheduling as described in chapter 3. While local airport reasons include all relevant slot allocation procedures and arrangements which are applied to one single airport locally, airline network reasons cover all difficulties arising from the expansion of local scheduling results to multiple airports and thus the network. With airlines being responsible for this reconciliation of local scheduling results, the second driver category deals with airline commercial and logistic/operational matters mainly. Airlines require a certain network flexibility to realise the airline internal planning with regard to commercial and operational specifications. Apart from this differentiation of airline and airport reasons to explain the overall loss of capacity utilisation on a day-to-day basis, the lack of local slot demand can be estimated as adequate driver to different utilisation performances during periods with/without excess demand within a more microscopic hourly analysis. Drivers of all categories can be related to one of the parameters resulting in loss of capacity utilisation: Slot returns or insufficient/incomplete compensation of slot returns by additionally allocated or reallocated slots (cp. Chapter 4.2.2).

4.3.1 Local airport reasons

Slot allocation at German coordinated airports is based on EU Council Regulation 95/93. The German airport coordinator is responsible for the implementation of the current framework. According to this, slot allocation processes at coordinated airports are managed independently – current regulations are applied for each airport autonomously, disregarding any network effects. Local slot demand has to be accommodated according to the current framework (including possible local guidelines) and considering local capacity constraints. To investigate each local airport's impact on scheduling inefficiency in the form of loss of capacity utilisation, this chapter focuses on the airport slot allocation regulation/scheduling rules which are identical at all German coordinated airports and on any local particularity such as different type of declared capacity.

Loss of capacity utilisation results from both slot returns and non-compensation of returned slots. With regard to the current framework, the following local airport scheduling parameters might impact on the scheduling performance and cause undesirable inefficiency:

- Declared capacity/limitation of slot concentration
- Quality and acceptance of coordinator's rescheduling proposals (initial allocation)
- Slot return date: Return of allocated slots and compensation of returned slots
- Enforcement of regulation compliance

The following investigation aims to demonstrate possible interrelations between the loss of capacity utilisation and the parameters above.

Declared capacity. With regard to declared capacity values, type and duration of blocks are the only differences between German coordinated airports (Cp. 3.2). All airports apply static 10min and rolling 60min blocks at least, FRA rolling 30min blocks additionally. Except DUS and TXL, relevant declared capacity is classified into arrival, departure and total capacity. The proportion of excess demand blocks at all airports is depicted in Table 9.

	DUS			FRA			MUC			STR			TXL		
block duration [min]	**10**	**30**	**60**	**10**	**30**	**60**	**10**	**30**	**60**	**10**	**30**	**60**	**10**	**30**	**60**
ARR [%]				6	2	62	6		13	3		0			
DEP [%]				11	14	47	6		12	2		4			
TOT [%]	15		58	13	25	67	19		20	6		12	4		4

Table 9: Proportion of excess demand blocks (10min: static; 30/60min: rolling)

With total 60min blocks (red) being the most constrained ones at all airports, it can be assumed that mainly those blocks limit the total number of slots. 10min/30min blocks regulate the concentration of flights. Any direct impact of the application of different block types and durations on the loss of capacity utilisation cannot be detected. Due to the need of limiting the slot concentration and spreading demand peaks, a certain number of slots has to be rescheduled. The quality of rescheduling's impact on the loss of capacity utilisation will be addressed in the following section.

Rescheduled slots. As far as additional slots are available from the slot pool, the coordinator proposes alternative slot times for a certain number of excess demand slots at the initial allocation (Cp. 4.2.3). With those rescheduled slots differing from the airline's initial slot request and thus from the airline's internal network planning, later acceptance is uncertain. If the proportion of slot returns in rescheduled slots exceeds the accordant proportion in slots allocated as requested significantly, a strong interrelation between the acceptance of rescheduled slots and the loss of capacity utilisation during scheduling processes can be demonstrated.

Comparing rescheduled slots and allocated as requested ones, Figure 21 depicts the proportion of slot returns. At all airports rescheduled slots are returned significantly more frequently than slots which have been allocated as requested. While at most constrained airports DUS and FRA airlines tend towards accepting rescheduling proposals more prevalently, at airports with excess demand during short periods of the day only the return rate is about 50 % (MUC, STR) or even exceeds 50 % significantly (TXL). Although the proportion of rescheduled slots only ranks among 5 to 15 % of all allocated slots (Cp. Figure 18), due to the high return ratio the airlines' handling of rescheduled slots is an important parameter resulting in loss of capacity utilisation.

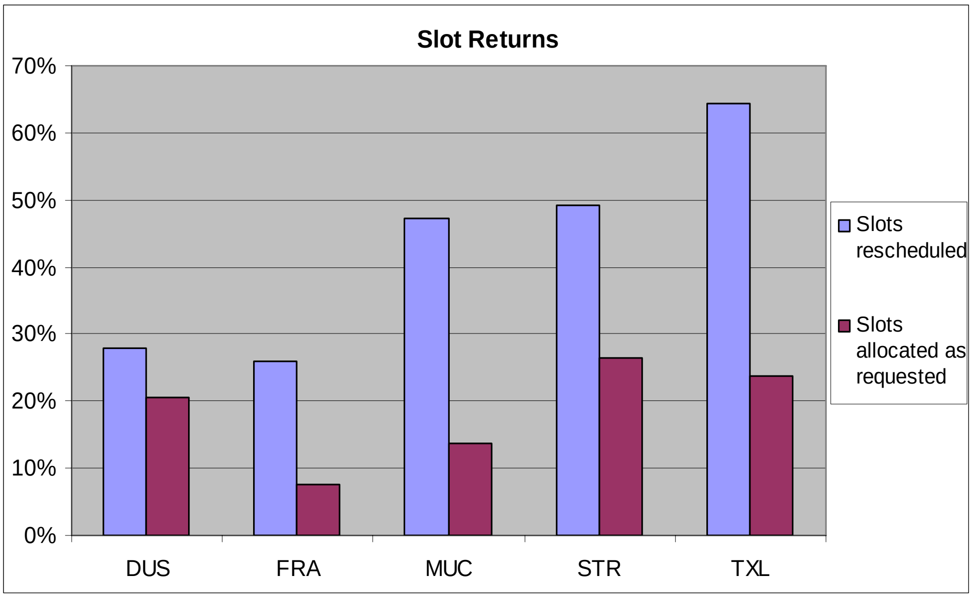


Figure 21: Proportion of slot returns in slots rescheduled/allocated as requested

The acceptance of rescheduling proposals thus is strongly interrelated to the loss of capacity utilisation at any coordinated airport. It is assumed that the acceptance/return rate depends on both the dimension of slot time adjustment and an airport's level of excess demand/difficulty to obtain additionally allocated slots. An evaluation of acceptability and suitability of coordinator's rescheduling proposals is required with regard to airline needs (business strategy) and with regard to the interrelation to the level of scheduling performance in the form of loss of capacity utilisation as well. Accordingly the quality of rescheduling depending on the airline acceptance is to be determined in a future investigation.

Slot return date. According to Council Regulation 95/93, airlines are supposed to return unwanted/surplus slots to the coordinator/slot pool until the official slot return date about two months before season start. Compliance with this seasonal return deadline shall facilitate the compensation of returned slots due to the allocation of additional or reallocated slots and thus reduce returned slots' negative impact on the utilisation of declared capacity. Being part of the current slot allocation framework, the slot return date is interrelated to both the return of slots and the feasibility of slot return compensation. Accordingly the connection to the loss of capacity utilisation is obvious. The current analysis will demonstrate consequences of airlines' compliance and non-compliance of the slot return date, discuss the deadline's date (about two months before the season start) and its general suitability to reduce loss of capacity utilisation. An evaluation of the slot return date as a possible driver to loss of capacity utilisation is conducted.

The slot return date's importance is resulting from one major precondition for the prevention of unsatisfying capacity utilisation at the end of the scheduling processes: Early return of unwanted/surplus slots. With airlines requiring time to prepare a new service's introduction (due to e.g. planning of airline resources, marketing measures), it is assumed that returned slots can only be allocated again if they are available in the slot pool in sufficient time.

To enforce the early return of slots, the current slot allocation framework uses the slot return date as one fixed seasonal return deadline. Depending on the date of operations, the slot return date is scheduled between two and nine months before the operational realisation of a slot related flight movement. Thus the time span between return deadline and operations varies from two to nine months. The fixing of only one return deadline – as well as the whole seasonal scheduling process itself – is justified by an assumed high level of seasonality within airline schedules. Additionally this high level of seasonality is supposed to be strengthened by the seasonal slot return date, because schedule seasonality is required to achieve slot returns as early as possible.

To assess the slot return date's impact on the loss of capacity utilisation at German coordinated airports, the analysis at hand concentrates on both the effect of early slot returns with regard to compensation opportunity/success and the slot return date's suitability to enforce seasonality. The latter is required to have returned slots available for reallocation again in sufficient time. The results of these investigations will allow an evaluation of the slot return date as the current framework's mechanism to reduce scheduling inefficiency in the form of loss of capacity utilisation.

First of all a detailed analysis on both the slot return and the return compensation behaviour is conducted. With regard to slot return patterns, all coordinated German airports feature very similar results. Because absolute figures are unimportant within this analysis and because the demonstration of all airports' results is too extensive, the DUS case is depicted exemplarily. Figure 22 illustrates the cumulative percentage slot returns at DUS in the summer 2005 season. Slot returns are accumulated monthly from the initial allocation (November 2004) until about one month before the end of the season (October 29th). Missing percentage to 100 % results from slot returns within the last days before operations which are disregarded here. The slot return date (January 31st) is included in the accumulation dates. Different months of operations (April to October) are displayed in different colours.

For all month of operations slot return behaviour is very similar until December 31st. From that date on the gradient varies in dependence on the month of operations slightly: On January 31st (Slot return date) a higher proportion of April slots than of October slots is returned. The return ratio at that date is between 38 % (October) and 48 % (April). From the return deadline on the runs of the curves spread: Late season slots (September, October) are returned significantly more gradually than early season slots (April, May). The spread of curves from January 31st on confirms the slot return date's effectivity. Airlines slot return behaviour is influenced by the slot return date significantly.

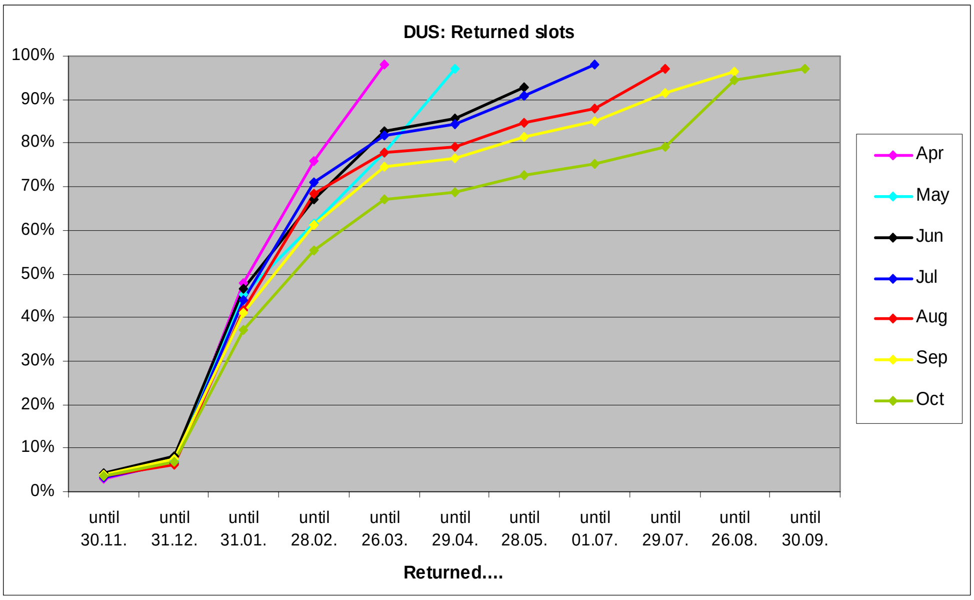


Figure 22: Time of slot return in dependence on month of operations – DUS

The slot return pattern at DUS – which is similar to that of other coordinated airports – features at least two characteristics being relevant for the investigation at hand. First of all slot returns are influenced by seasonality decisively until January 31st. Until then percentage return of April slots and of October slots varies only slightly. The fixing of only one return deadline leads to an at least partial transfer of the seasonal patterns from airline schedules to airline return behaviours. From that date on the run of curves spreads significantly.

Additionally seasonality in slot return patterns results in a different percentage of availability of returned slots with identical time intervals until operations. While about 40 % of all returned April slots are only available about 2 to 3 months before operations, the same 40 % of returned October slots are available about 8 months before operations. At least 5 months before operations about 70 % of October slot returns are in the slot pool again. Thus late season slots are available for reallocation significantly earlier than early season slots. According to the assumption that successful slot return compensation depends on the early availability of returned slots, the compensation ratio should increase from the beginning to the end of the season.

Thus the analysis at hand focuses on the compensation of capacity utilisation losses due to returned slots. Compensation occurs in the form of allocation of additional slots or reallocation of slots which have been rejected initially. According to Figure 22's depiction of slot returns at DUS, the compensation of capacity utilisation at DUS is illustrated as well in Figure 23 (reallocated slots) and Figure 24 (slots allocated additionally). Reallocation and additional allocation behaviours vary significantly. While the allocation of additional slots increases with the approaching of the days of operations, slot reallocation concentrates on the period between initial allocation and slot return date. Again the airline behaviour is affected by the slot return date significantly: All months of operations show a very similar development until the return deadline (except reallocated slots, month of operations: April) – significant variations do occur for slots allocated additionally from that date on only.

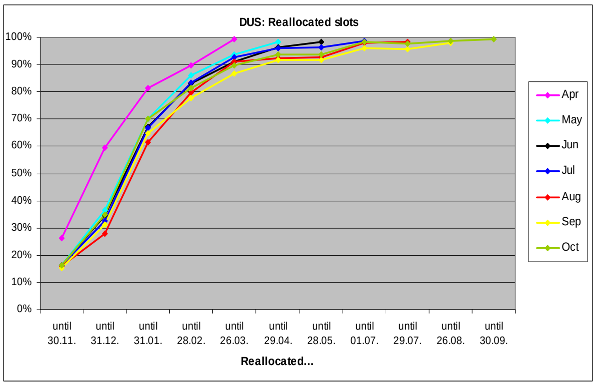


Figure 23: Time of slot reallocation in dependence on month of operations – DUS

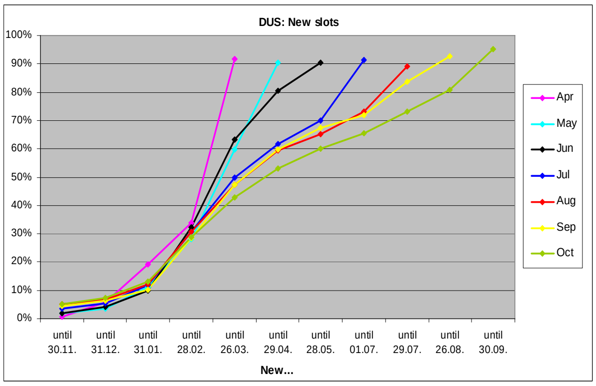


Figure 24: Time of additional slot allocation in dependence on month of operations – DUS

Afore-mentioned results of the investigation on slot returns and return compensation could demonstrate the slot return date's significant impact on seasonality. The compensation rate's dependence on the early availability of returned slots could not be detected so far. To do so, monthly returned slots' compensation rates at all coordinated airports are depicted in Figure 25 which includes single values as well as trend lines (based on linear regression). Expected compensation characteristics can be confirmed: At all airports the proportion of returned slots being compensated by additionally allocated or reallocated slots increases from the beginning to the end of the season. The later in season a returned slot is scheduled, the higher the probability to compensate this particular returned slot by repeated allocation. Considering the afore-mentioned earlier average return date of late season slots as well, the success of compensation and thus the reduction of capacity utilisation losses depends on the timeliness of slot returns. Any mechanism enforcing the early return of unwanted/surplus slots positively impacts on scheduling inefficiency in the form of loss of capacity utilisation.

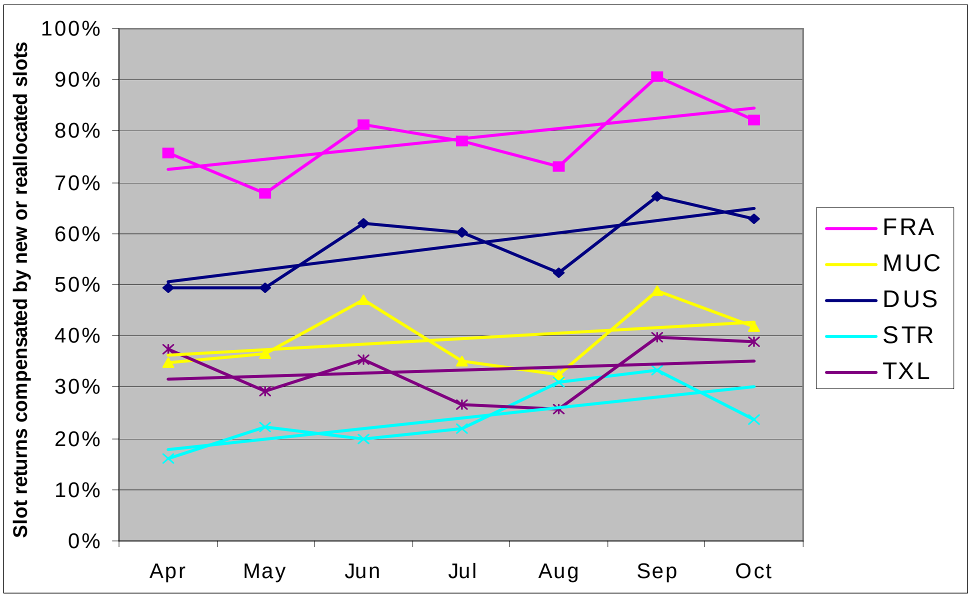


Figure 25: Compensation of returned slots - variations depending on the month of operations

As to minimisation of capacity utilisation losses, the importance of early availability of returned flights to be allocated again could be demonstrated. Compliance with scheduling seasonality is one major basis for the timely return of slots. October slots are supposed to be returned as early as April slots – this requires seasonality not only in airline schedules, but in airlines' slot return behaviour as well.

The fixing of one seasonal return deadline encourages seasonality in airlines' slot return behaviour. Thus the current framework's slot return date is the right mechanism to make unwanted/surplus slots available for repeated allocation on time. The slot return date is a driver to minimisation of scheduling inefficiency in the form of loss of capacity utilisation. To be used effectively, airline compliance with the slot return date has to be enforced.

Regulation compliance. Although non-compliance with the current slot allocation regulations is conceivable in some ways, non-consideration of the slot return date and thus late return of slots is significant in particular with regard to the loss of capacity utilisation. Figure 26 illustrates the monthly variations of slot return date compliance at all German coordinated airports in the summer 2005 season (single values and trend lines based on linear regression). A significant proportion of returned slots is returned lately (after the slot return date), and non-compliance even worsens by the end of the scheduling season. Taking into consideration the relevance of early availability of returned slots for repeated allocation and return compensation, non-compliance's negative impact on the loss of capacity utilisation becomes obvious.

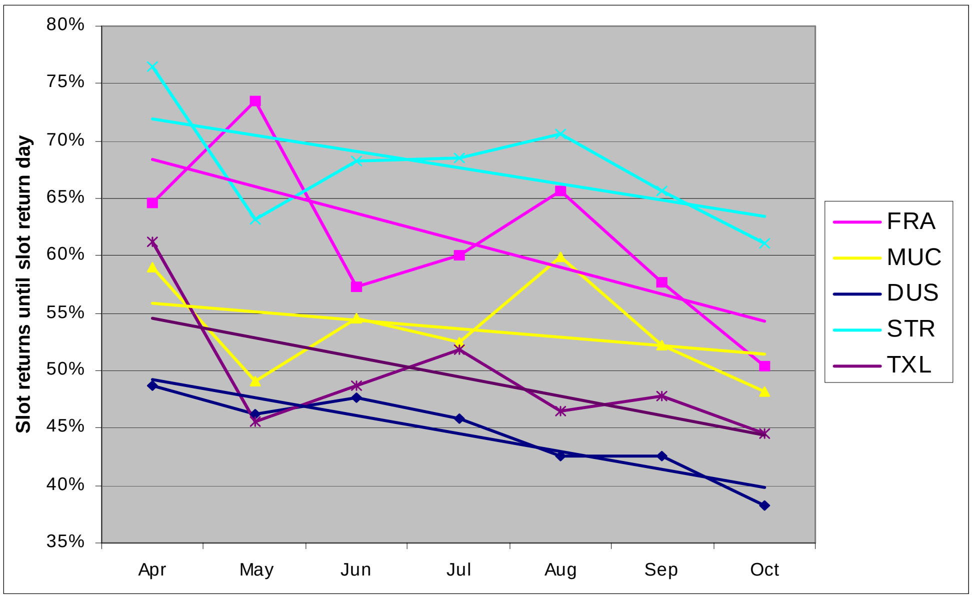


Figure 26: Compliance with return deadline - variations depending on month of operations

Current framework's measures to enforce compliance with the slot return date are of little effectiveness only. Consequences of breaking the rules are limited – prosecution as well as serious penalties are not included in the current regulation. With regard to the relevance of timely returns of slots an effective enforcement of slot return date compliance is required urgently. This does not necessarily imply the implementation of serious penalties, but could be realised in the form of attractive incentives in the case of slot return date compliance.

4.3.2 Airline network reasons

Besides the airport coordinator/airport coordination offices, airlines are among the main participators in the slot allocation/airport coordination processes. Airline decisions' impact on scheduling inefficiency which is measured as loss of capacity utilisation within the study at hand is rather significant. Both returning slots and not requesting additional or accepting reallocated slots are located within the airlines' responsibility. Accordingly both parameters resulting in loss of capacity utilisation (slot return and non-compensation of returns) can be addressed by airline drivers.

Without specifying any reasons more precisely, a first quick analysis is supposed to demonstrate this interrelation between the loss of capacity utilisation and airline decisions. To include the latter exclusively and to disregard different reasons, the accordant investigation focuses on the return of such slots which had been allocated exactly as requested (no rescheduled slots included): Airlines return slots although they have received exactly what they had requested initially. Those returns cannot be attributed to any external influences (such as unacceptable rescheduling proposals by the coordinator) but are driven by airline reasons only.

Figure 27 depicts the results of the aforementioned analysis. The proportion of returned slots in all slots allocated as requested ([%]; axis of ordinates) is related to the loss of capacity utilisation ([%]; axis of abscissae). Percentage values on a day-to-day basis are calculated and processed by using linear regression. At all coordinated German airports a very similar performance can be noticed: The higher the proportion of returned slots in all slots allocated as requested (and those returns are purely driven by airline decisions, because the airlines have received exactly what they had requested), the greater the percentage loss of capacity utilisation. Except STR the describing straight lines are nearly parallel even. A clear interrelation of airline decision and loss of capacity utilisation is demonstrated at all coordinated German airports.

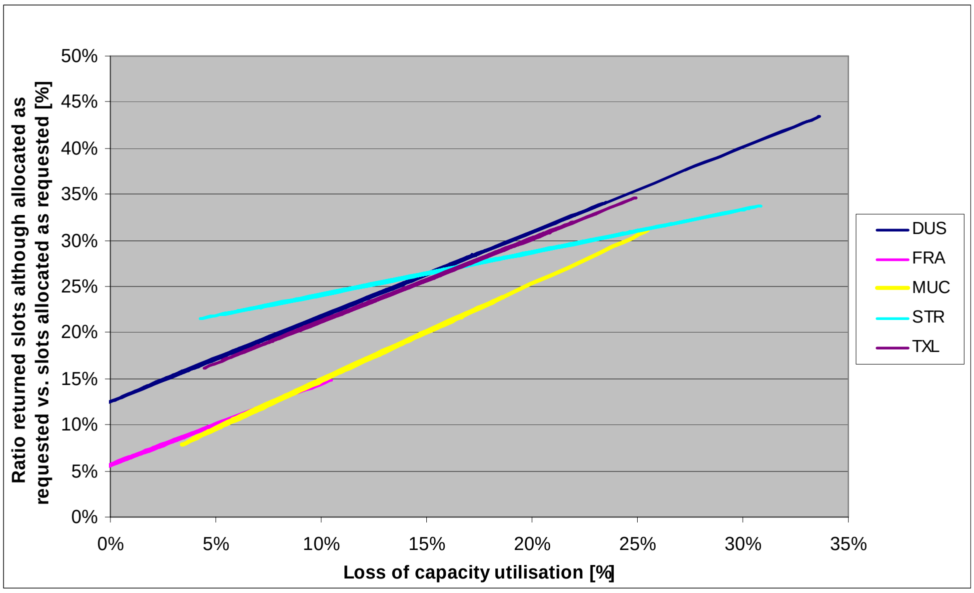


Figure 27: Interrelation of loss of capacity utilisation and return of allocated as requested slots

For a more specified analysis airline reasons have to be classified. This classification is based on chapter 3's description on airport, airline and network scheduling. Airlines have to transfer the local scheduling at every single airport into a highly complex and extensive network planning. Compatibility of airline and airport scheduling with regard to airline commercial and operational (logistic) needs is required. Requirements and constraints within this planning horizon's expansion might cause slot returns as well as low readiness to compensate reduction in the capacity utilisation at short notice. For those reasons airline network drivers to loss of capacity utilisation are classified into commercial and operational reasons.

Commercial reasons. Airline commercial reasons originating loss of capacity utilisation and inefficient airport scheduling performance are diversified – parameters such as increasing competition, realisation of certain business strategies or direct financial interests impact on an airline's slot allocation policy. Changes in an airline's route network or weak booking numbers might result in short-term slot returns. Impossibility of sufficient commercialisation of routes launched at short notice prevents from requesting available slots late.

Thus airline commercial reasons address both parameters resulting in loss of capacity utilisation: Slot returns and non-compensation of returned slots. The latter is based on comprehensible and understandable airline commercial requirements. With regard to slot returns instead significant scheduling inefficiency follows from airline malpractice of the current slot allocation framework. To gain scheduling flexibility and to prevent competitors from receiving slots, slot overbidding at the initial request is a common proceeding. Additionally those dispensable slots as well as needless slots due to route network adjustments might be returned too lately to be reallocated again to any other demanding airline. It can be assumed that both slot overbidding and late slot returns are based on commercial reasons predominantly. Within the current framework such airline malpractice is not prosecuted effectively.

Airline commercial reasons with regard to airport scheduling inefficiency can hardly be quantified. An extensive interview programme of industry participants might be a possible approach, although presumably the importance of business secrets within this topic will be limiting quality and comprehension of information. Anyway an accordant research and information programme is out of this study's scope.

Operational reasons. Operational reasons for loss of capacity utilisation and thus scheduling inefficiency result from the need of compatibility between the airline internal network scheduling and the local airport slot allocation. Airlines require a precise adjustment between the logistical planning of resources (aircraft, crew etc.) and the availability of adequate airport slots. A lack of slot time flexibility might lead to an increase in the relevance of operational reasons for loss of capacity utilisation. At coordinated airports with excess demand during certain periods of the day at least, slot time flexibility and availability is limited significantly.

Major difficulties might arise from the necessary matching of departure and arrival slots at different airports. If due to rescheduling allocated slot times differ from the time requested initially at one airport at least, compliance with planned block times might be impossible. In the case of complete incompatibility between airline network scheduling and local airport scheduling airlines might prefer to return a slot instead of using it. Besides slot matching difficulties in particular cases slot returns are imaginable due to incompatibility with regard to airport infrastructure (gate/aircraft stand size) or ground handling equipment. It is assumed that the number of occurrence is negligible.

This chapter's analysis on operational airline reasons for loss of capacity utilisation focuses on slot matching: Availability of required flexibility to transfer the airline network scheduling to the local scheduling of network nodes (airports) only. It is assumed that the required flexibility decreases with the relevant slot pair airport's level of slot shortage, but rises with the number of slots held by one particular airline (or airline alliance/group). Accordingly the following investigation concentrates on those parameters to demonstrate the operational airline requirements' impact on the loss of capacity utilisation.

To approach the difficulty of combining adequate slot pairs connecting a German coordinated airport to any related arrival or departure airport which features slot scarcity during certain periods of the day at least, the following investigation includes worldwide IATA Level 3 airports (coordinated airports) only. With the problem of slot pair combination occurring at those airports exclusively, the proportion of corresponding slots being returned is expected to exceed the proportion of all slots being returned. Figure 28 depicts the proportion of IATA Level 3 slots in all allocated and all returned slots (all flight connections between German coordinated airports and worldwide IATA Level 3 airports).

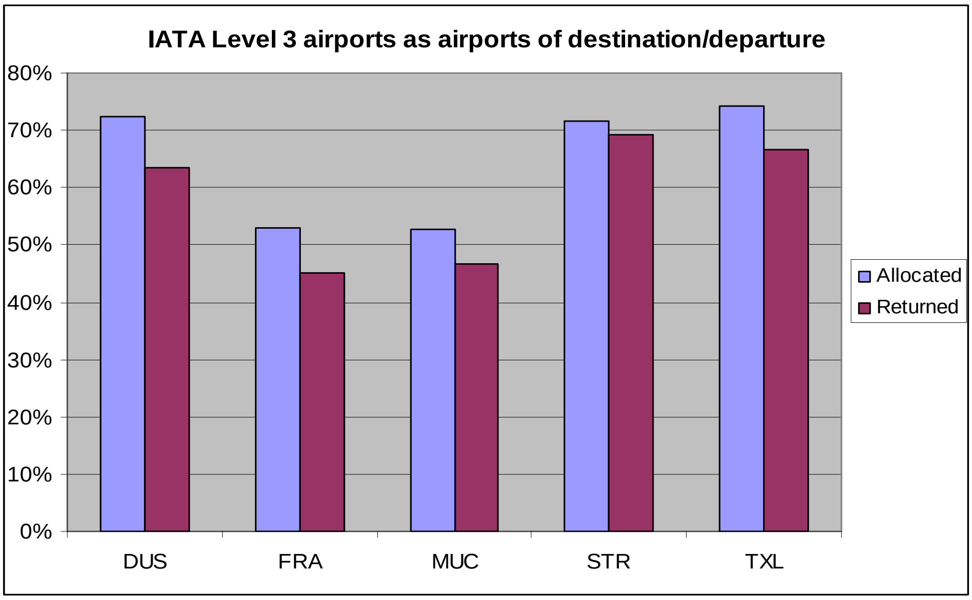


Figure 28: Proportion of IATA Level 3 airports in all allocated/returned slots

The analysis' results are contrary to the expected behaviour derived from the possible problem of slot pair matching at highly congested airports. At all German coordinated airports the proportion of IATA Level 3 slots in all slots being returned falls below the appropriate proportion in all slots being allocated. Thus slots being related to less congested airports (IATA Level 1 and 2) are returned more frequently. Operational reasons resulting from the necessary matching of departure and arrival slots at different airports cannot be confirmed as driver to loss of capacity utilisation by the investigation above. Possible explanations for this behaviour are as follows:

- Due to both arrival and departure airports being coordinated, a great proportion of related flight connections are adopted from the precedent equivalent season. These established structures do not require significant matching/adjustment activity whose failure would result in slot returns and thus loss of capacity utilisation.

- Coordinators anticipate airlines network planning requirements and do not allocate impossible slot pairs.

The second approach to demonstrate airline operational reasons' impact on the loss of capacity utilisation focuses on one airline's extent of slot holding at one particular coordinated German airport. It is assumed that airlines require a certain slot flexibility/mobility to transfer their internal network planning to the local airport slot allocation. With Council Regulation 95/93 granting the opportunity to exchange slots, airlines benefit from a maximum slot holding with regard to feasibility of internal adjustments and thus slot flexibility at all. It can be expected, that airlines with a voluminous slot holding at one particular airport face less necessity to return slots due to operational reasons than airlines holding just a few slots at one airport. Figure 29 depicts the interrelation of one airline's proportion in one airport's total slot demand at the initial allocation and the proportion of returned slots in that particular airline's total slot holding.

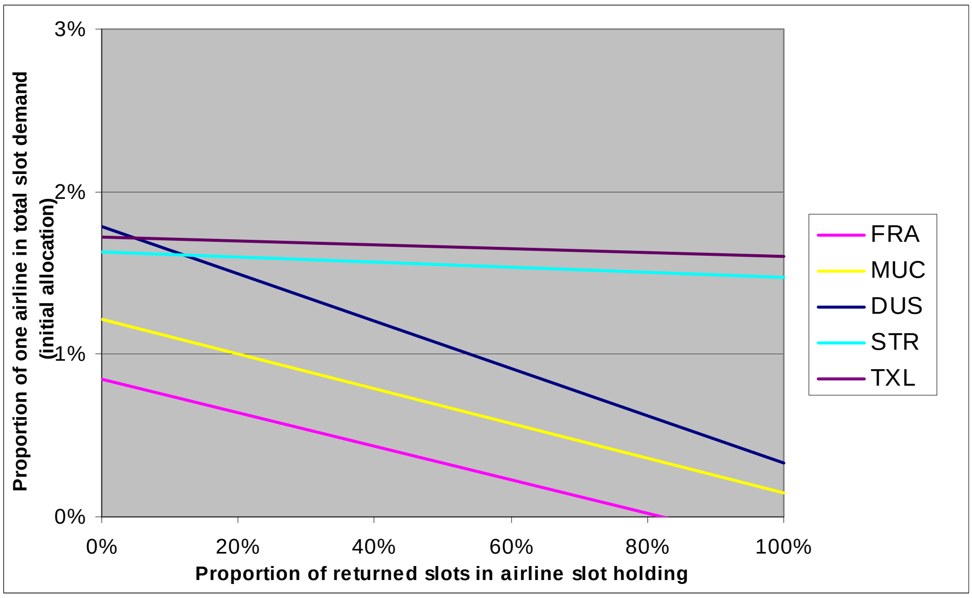


Figure 29: Airline return behaviour in dependence of extent of slot holding (trend lines)

The above-mentioned expectation can be confirmed. At all coordinated German airports airlines holding a large proportion in all slots allocated return a lower proportion of those slots than airlines holding few slots only (trend lines (!!) calculated by linear regression). This interrelation is significant in particular at FRA, DUS and MUC. Due to slots being available in the slot pool, less constrained TXL and STR probably offer sufficient slot flexibility/mobility to satisfy airlines possessing less voluminous slot holdings as well. This investigation's results demonstrate a possible impact of the extent of slot holdings on an airline's return behaviour and thus on the loss of capacity utilisation. It has to be taken into consideration that slot exchange within airline groups (between parent company and subsidiaries) and airline alliances have not been included in this analysis.

Although airlines holding just a few slots tend to return a higher proportion of allocated slots, this behaviour's impact on the loss of capacity utilisation is very limited at some airports. With the absolute quantity of slots allocated to small slot holders being minimal, even a higher proportion of returned slots appears nearly irrelevant with regard to the total number of slots returned. The accordant interrelations are depicted in Figure 30. Returns at MUC and FRA in particular comprise a very limited proportion of small slot holders' returns only, while airlines with large holdings dominate. Those results suggest not to overestimate the extent of slot holding's significance with regard to the overall loss of capacity utilisation.

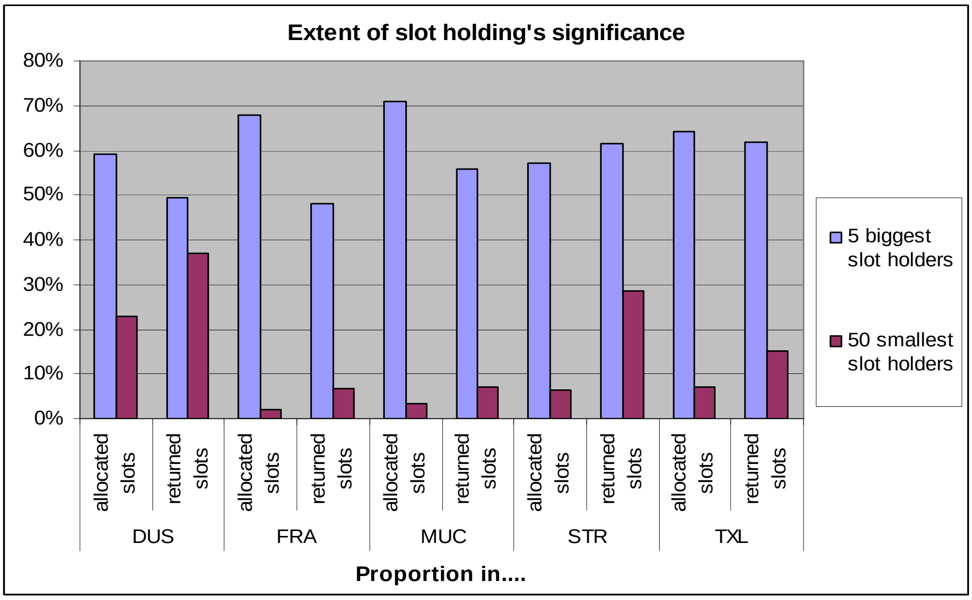


Figure 30: Proportion of 5 biggest/50 smallest slot holders in all allocated/returned slots

4.3.3 Lack of slot demand

At all coordinated German airports there are at least small periods of the day when slot supply exceeds slot demand. While these periods can be disregarded at FRA and DUS (DUS: Except during the weekends, cp. Figure 7), they cannot at MUC, STR and TXL where excess demand occurs only during short peak periods of the day. With regard to the latter, it can be assumed that a significant proportion of the loss of capacity utilisation is attributable to the lack of demand. Additionally the more extensive loss of capacity utilisation with regard to percentage losses during periods without excess demand might be explainable – at all airports regarded including DUS and FRA.

During periods without excess demand nearly all requested slots can be allocated. Single slot rejections might results from the necessity to allocate slot pairs (the related slot is in an excess demand period) or from the non-compliance with arrival/departure/flight concentration limitations. In addition periods with no excess demand can accommodate rescheduled slots which have been retimed from excess demand periods to be allocated at all. Thus a kind of artificial demand is generated which was not requested initially.

For several reasons (of which some are stated in chapter 4.3.2) a certain number of slots is returned after the initial allocation. Periods of excess demand are affected as well, and thus some slots become available for allocation again even during congested peak times. Rescheduled slot holders can use this opportunity to retime their slots closer to the slot time requested initially. Thus periods without excess demand are affected by demand losses twice: By those slots which are actually returned, and by those which are not returned, but retimed to more attractive peak periods. The off-peak period's capacity utilisation is affected by both parameters identically. And due to a lack of additional demand (all requested slots have been allocated at the initial allocation), those losses of capacity utilisation cannot be compensated adequately.

Thus in periods with spare capacity, lack of demand as a driver is related to both relevant parameters resulting in a loss of capacity utilisation between the initial request and the final status: Slot returns (although here “return” means “retime back to excess demand periods”) as well as inadequate compensation of returned slots. It has to be taken into consideration that loss of capacity utilisation due to retiming of slots does not result in capacity losses on a daily basis (because of those slots not being returned, but retimed only), but is related to losses in particular off-peak periods of the day only.

With the lack of demand drivers focussing on periods without excess demand mainly, loss of capacity utilisation resulting from it is widely negligible with regard to the airport scheduling performance and scheduling inefficiency. Disadvantages resulting from lack of demand have to be addressed by the airport slot marketing/airline acquisition department. Any stimulation of off-peak periods slot demand will reduce the loss of capacity utilisation due to lack of demand significantly.

5 Part2: Predictability during scheduling phase

During airport scheduling procedures the coordinated flight plan as reference programme determining the planned cycle of later day-to-day airport operations is developed. With the coordinated flight plan being an instrument to regulate the demand only roughly, additional planning specifications are required until the days of operations to obtain complete temporal precision. Additionally a multiplicity of internal and external influencing parameters (weather, technical parameters, passenger behaviour etc.) prevents the coordinated flight plan from being realised without any variations.

The availability of a reference programme allows an examination on the level of adherence to it during operations. Reasons to conduct this analysis on the operational activities' predictability during scheduling are stated in the following. On the one hand assumptions and appraisal values being the basis for several scheduling decisions can be verified. If necessary, adequate recommendations can be made to improve the current estimates. On the other hand an evaluation of the level of operational predictability achievable during scheduling could provide relevant conclusions on the interrelation between demand regulation during scheduling (airport coordination) and demand and flow variability during operations. This would allow the formulation of recommendations how to optimise the usage of available capacity and to minimise the waste/overload of airport resources.

The problem of compliance with scheduling results is in the centre of air traffic performance measurement in the majority of cases. Differences between flight movements' target (scheduled) times and actual times are calculated to determine operational delays and thus to measure punctuality. "Delay" and "punctuality" are widely-used quality criteria to evaluate operational performance - accordingly a multiplicity of studies and reports focus on this topic. For that reason an analysis on operational punctuality/delay is out of this study's scope.

With the study at hand focussing on the usage of available capacity at German coordinated airports, this chapter's analysis concentrates on demand volume variation from coordinated values as determined during scheduling. Demand variation includes differences from the scheduled number of total movements (no shows rate, additional flight movements) as well as operational compliance with agreed declared capacity values (flight movement concentration: static/rolling 10/30/60min values). With regard to presumptions during scheduling an investigation on taxi time variations is conducted to verify standard values as used during the coordination process.

5.1 Methodology

5.1.1 Available data

Focussing on the realisation of agreed schedules, besides the German airport coordination office's slot allocation data used in this study's first part, additional data sources are required within the current analysis on scheduling predictability. Details on the operational air transport performance at coordinated airports in Germany were drawn from extensive data bases of both the EUROCONTROL Central Flow Management Unit (CFMU) and the Central Office for Delay Analysis (CODA). Simultaneous availability of CFMU data and CODA data was necessary to conduct this chapter's investigations successfully.

CODA data is supplied by airline operators voluntarily and includes the scheduled and the actual pushback time, actual take-off time, actual landing time, and scheduled and actual gate arrival times often referred to as Out, Off, On, In (OOOI) data. The CODA sample used in this investigation covers about 65 % of all IFR flight movements at German coordinated airports in the summer 2005 season (cp. Figure 31). Due to this incomplete demand coverage CODA data cannot be used to analyse variations of demand volume during operations compared to agreed schedules (no shows, flight movement concentration), but is appropriate to check scheduling standard taxi times and to verify accuracy of calculated CFMU model data.

CFMU data covers all IFR departures and arrivals at German coordinated airports in the relevant season. Complete coverage of relevant IFR movements makes this data essential with regard to investigations on the variations of demand volume during operations. Extent and specifications of available CFMU data result from Air Traffic Flow Management (ATFM) requirements. Only a limited selection of this data representing each single flight movement is necessary for the current investigation. With runway times being relevant coordination reference times within the airport slot allocation processes (cp. chapter 3.2), take-off and landing times are used CFMU data to specify the accordant operational performance.

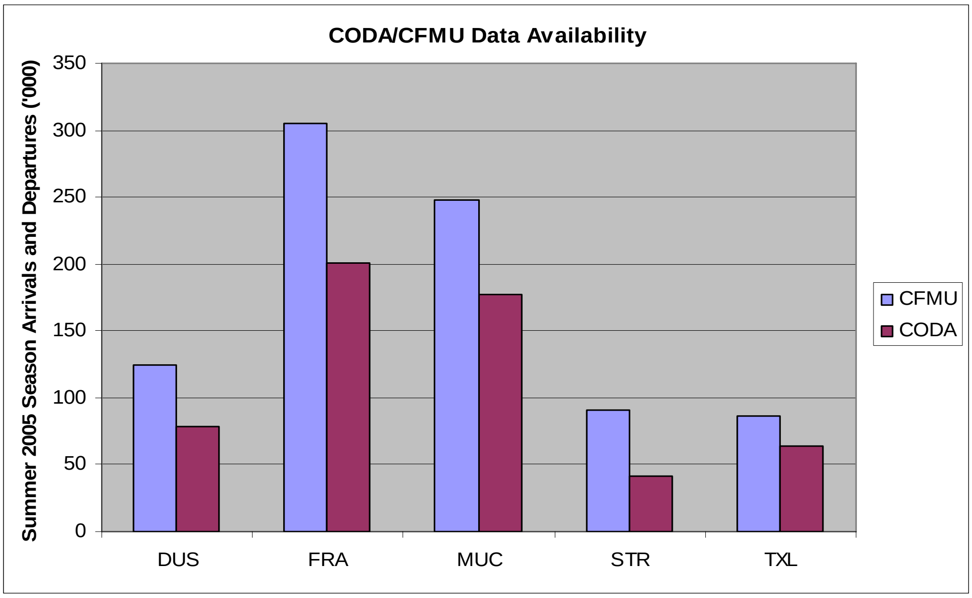


Figure 31: Data available for analysis on scheduling predictability

5.1.2 Proceeding

The analysis at hand focuses on the realisation of coordinated schedules during day-to-day operations. A linking between operational CODA/CFMU data and airport coordination office's scheduling data is required to accomplish the accordant approach. Scheduled/realised flight movements are the relevant link to be connected.

Lacking adequate systematisation, the matching of identical flight movements from scheduling data and from operational data was processed manually. Appropriate links are particular airlines, origin/destination airports, times and compliances with regard to aircraft ID/flight ID/scheduled flight number/call sign. About 99% of all operated and scheduled flight movements could be linked in this way unambiguously. Due to the missing 1 % the following results feature certain unsteadiness which should be kept in mind with regard to the evaluation.

Due to the full coverage of all IFR movements at German coordinated airports, CFMU data is of particular interest. As mentioned before, extent and specifications of CFMU data result from ATFM requirements. Initially flight times are predicted using only input from airline flight plans. The accordant model data is updated progressively during operations using actual flight data. Model data is updated only if any deviation from actual times exceeds about 5 minutes. For each flight movement the updates stop when an aircraft approaches its destination airport. For this reason it can be expected that CFMU data is quite accurate with regard to flight phases before updates stop (e.g. take-off time), but continues to be a prediction only and thus to be less accurate with regard to flight phases following the updates' stop (e.g. landing time).

With runway times being the relevant slot allocation/scheduling reference times, the current analysis focuses on take-off and landing times. Accuracy of CFMU take-off and landing times is verified by a comparison with available accordant CODA data which represent about 65 % of available CFMU data (CFMU and CODA data: Summer 2005 season, German coordinated airports DUS, FRA, MUC, STR, TXL). To qualify accuracy, CFMU times' average deviation [min] is determined from CODA take-off/landing times as well as the percentage of flight times differing +/- 5 minutes. This verification's results are depicted in Table 10.

	DUS		FRA		MUC		STR		TXL	
	ARR	DEP	ARR	DEP	ARR	DEP	ARR	DEP	ARR	DEP
Average deviation [min]	**03:34**	**00:47**	**04:52**	**00:44**	**04:09**	**00:37**	**03:57**	**00:58**	**02:44**	**01:05**
within +/- 5min	**79,4%**	**99,5%**	**62,4%**	**99,7%**	**70,2%**	**99,5%**	**71,1%**	**98,7%**	**89,1%**	**98,3%**

Table 10: CFMU data accuracy - comparison with CODA take-off and landing times

Results confirm the expected difference between arrival and departure time accuracy. (Actual) CFMU take-off times deviate less than 1 minute from take-off times as provided by the airlines (CODA) on average. Between 98,3 % (TXL) and 99,7 % (FRA) of all take-off times are within +/- 5 minutes from CODA times. In contrast arrival (landing) times show average differences of about 4 minutes at all airports. Only between 62,4 % (FRA) and 89,1 % (TXL) of all landing times are within +/- 5 minutes from CODA values. It is assumed that TMA/holding structure's high complexity causes significant deviation from CFMU model's predicted landing times (FRA, MUC).

With the current investigation on predictability achievable during scheduling focussing on total demand variations (no shows, flight concentration) but not on single flight delays/punctuality, CFMU data seems to be a sufficiently accurate analysis base. Significant differences between arrival and departure time accuracy suggest the inclusion of a separate examination of arrival and departure demand.

On the basis of CFMU data covering all IFR movements at the relevant airports, the no show rate will be determined initially. Scheduling reference point is the final status of airport coordinator's scheduling activities as defined in chapter 4.1.1. Allocated at the final status but unused slots are detected by a comparison of the final status slot demand and the equivalent actual demand (flow) during operations. Results are of significance with regard to the utilisation of declared capacity - this study's first part analysis on the capacity utilisation's development during scheduling thus is expanded to day-to-day operations.

Afterwards demand variations in terms of compliance with scheduled numbers of flight movements per time unit (flight concentration) are at the centre of interest. Conclusions on predictability achievable during scheduling are derived from comparisons of actual CFMU demand - as scheduled at final status and total IFR movements - to scheduling results. The implementation of different type and length of declared capacity blocks' impact on operational demand variations is addressed by this analysis. Differences between airports with and without implementation of different block type and length are stated. The accordant analysis will allow initial appraisal of necessity, signification and impact of strict compliance with different block length during scheduling to control flow concentration during operations.

To verify standard taxi times used in the scheduling process at German coordinated airports, for about 65 % of flight movements covered by CODA data the actual distribution of taxi times is determined as provided by the airlines.

5.2 Operational adherence to scheduling results and presumptions

The following investigations on predictability achievable during scheduling include all airport operating hours at all 217 season days. If relevant at a particular airport, night operations are regarded as well. Any timely limitation of the particular period under consideration within any part of the analysis is notified separately.

5.2.1 Demand variations: No show rate

With the coordinated schedule being a reference program for the day-to-day operations, deviations can be expected during operational activities with regard to both timely and quantitative agreements. The coordinated schedule represents an anticipated demand volume which complies with relevant limitations specified by the particular airport's declared capacity. Within this chapter the relevance of scheduled demand volume reduction resulting from non-operation of allocated slots (no shows) at German coordinated airports is analysed.

A significant portion of no shows causes non-optimal capacity utilisation inevitably. Available infrastructure is blocked due to slots being allocated but not returned, short-term additional allocation/reallocation of slots is nearly impossible. The occurrence of no shows means an additional loss of capacity utilisation at the days of operations, increasing any possible losses as noticed during scheduling (cp. chapter 4). Precedent studies and reports by NERA, ACI Europe and ECAC (cp. chapter 2) emphasise the relevance of no shows with regard to scheduling inefficiencies.

To determine the relevant no show rates at DUS, FRA, MUC, STR and TXL and thus to evaluate their significance with regard to non-optimal airport capacity utilisation, slots being allocated at the final status of airport coordination office's scheduling activities (final status as defined in chapter 4.1.1) are checked for operational realisation using CFMU data on IFR flight movements. With available slot allocation data being the accordant comparisons' reference base, percentage compliance with this slot schedule during operations is calculated. The total number of IFR movements during operations is completed by general aviation, military and all other flights being scheduled in the short term which are not included in the slot allocation final status data. To understand the relevance of those flights and the actual utilisation of airport capacity, the total number of IFR movements is related to the total number of slots being allocated at the final status. The accordant results are depicted in Figure 32 and Figure 33.

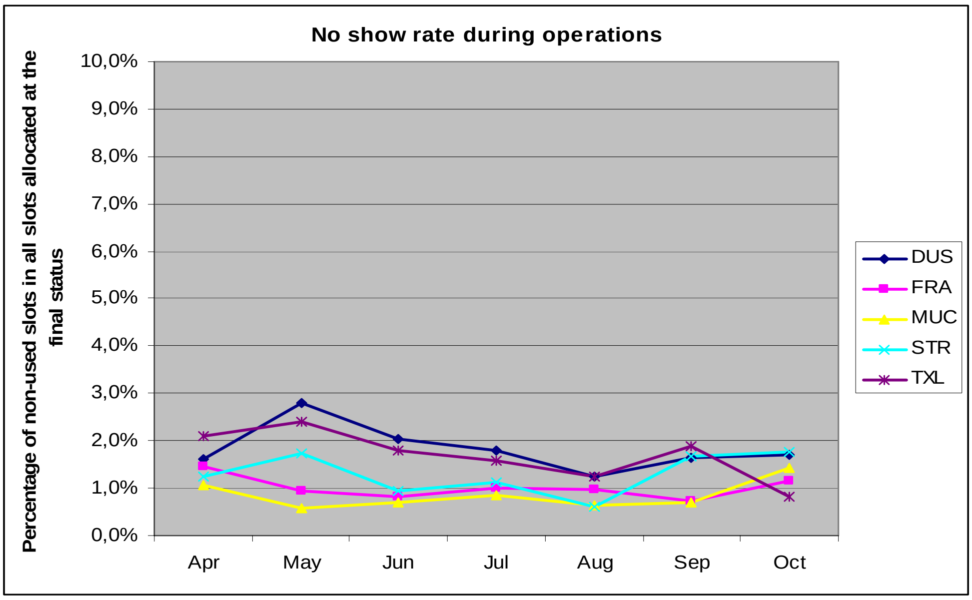


Figure 32: No show rate - proportion of non-used slots in all slots allocated at the final status

The current approach to determine the proportion of no shows in slots being allocated at the final status includes all kinds of slot disuse. Although not being attributable to any relevant stakeholder (airline, airport, ATC), weather, airport closure due to security/safety reasons or any other reason for slot disuse being inevitable is not excluded here. Despite applying this methodology which results in a slight overweighting of no shows in terms of avoidable scheduling inefficiency, actual no show rates are unexpected low at all German coordinated airports in summer 2005 season.

No show rates vary from 0,5 % to 2,8 %. Major airports MUC and FRA feature slightly lower proportions of unused slots (about 1 % on average), while DUS and TXL see no show rates of about 1,5 % to 2,0 % on average. With regard to the achievable accuracy within this investigation on no shows (required manual matching of CFMU and slot data is unambiguously for about 99 % of all flights; possible slot allocation status developments from final status to days of operations due to this study's final status definition), no show rates of about 1 % to 2 % or even lower are negligible. Any major impact of no shows on the optimal utilisation of available capacity at German coordinated airports cannot be detected.

For several reasons the number of IFR flights actually operated is not consistent with the number of slots allocated at the final status minus possible no shows. Airlines might request short-term slots to operate charter or ferry flights in particular. General aviation slots are not included in the available coordinator's slot data and additionally they are requested and allocated at short notice in general. Only parts of the military air traffic have to use slots to take-off and land at one of the German coordinated airports. Afore-mentioned data accuracy issues might explain another portion of the differences detected. Figure 33 depicts the percentage increase or reduction of the number of flight movements from the final status (slots) to the days of operations (total IFR flights). Despite of the existence of no shows at all airports the number of flight movements increases from the final status to the day-to-day operations. Additional short-term slot requests or IFR flights without allocated slot (e.g. partly military air traffic) exceed the number of no shows.

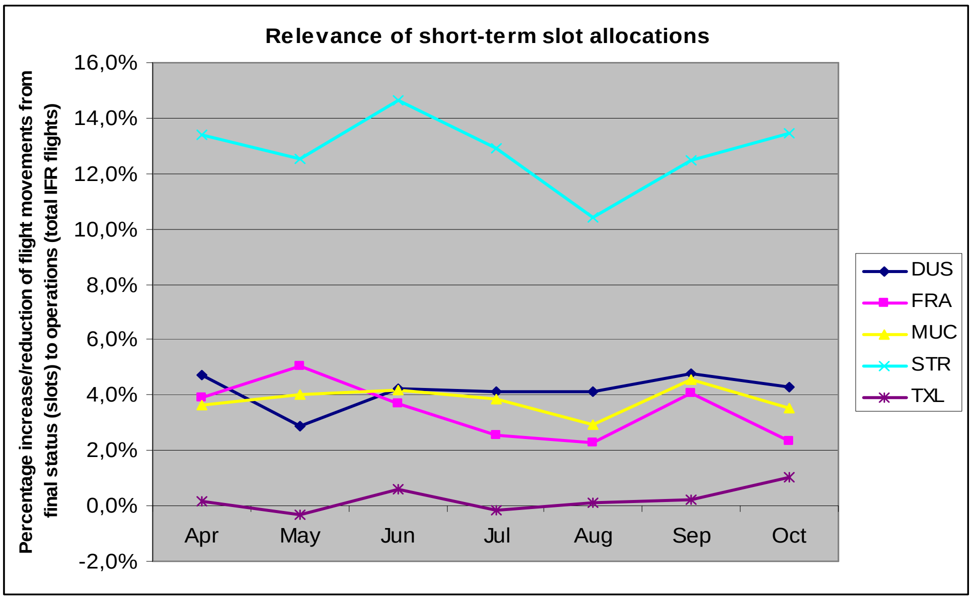


Figure 33: Percentage difference between final status slots and IFR flights operated

The level of exceedance varies between the relevant airports. While at TXL the number of no shows is nearly equal to the number of operated IFR flights at the final status and thus the percentage difference between the numbers of final status slots and of IFR flights operated is marginal (cp. Figure 33), at STR there are more than 10 % additional flights compared to the final status of slot allocation. DUS, FRA and MUC show an average difference of about 3 % to 5 % between final status slots and IFR flights actually operated. It can be expected that Berlin Tempelhof (THF) being located in the city centre attracts the vast majority of general aviation flights with origin/destination Berlin. Accordingly the number of additional flights at TXL not being slot-scheduled at the final status is limited. In contrast the low capacity utilisation level at STR enables a greater relevance of short-term slot allocation and general aviation traffic volume.

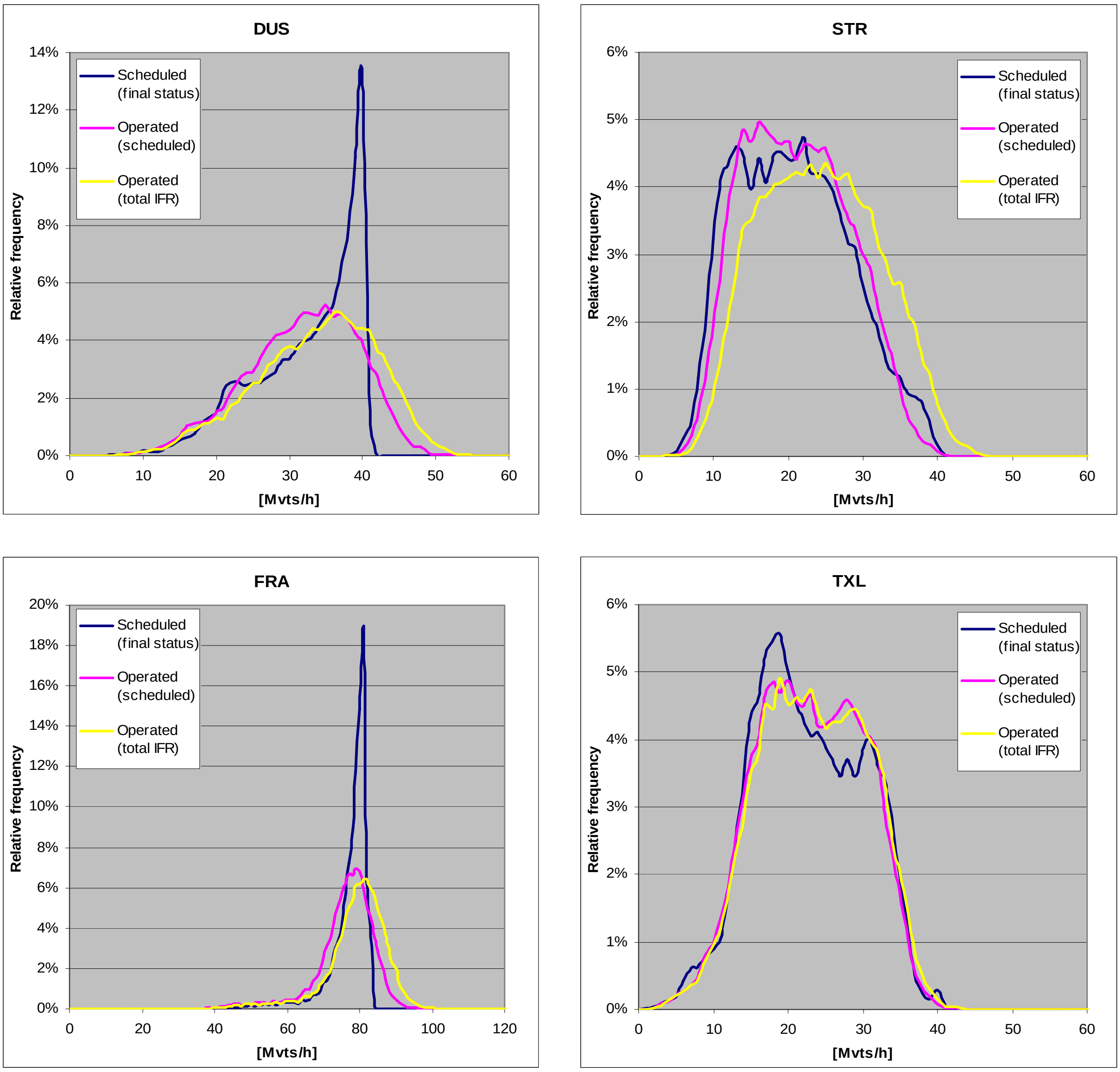
5.2.2 Demand variations: Flight concentration

The airport scheduling result which is the relevant reference programme for the operational activities does not determine the number of daily flights exclusively, but is supposed to control the demand concentration within certain time periods as well. This chapter's analysis focuses on achievable levels of operational demand (flow) variations' predictability as well as control feasibility and thus verifies the operational compliance with accordant scheduling agreements on flight concentration.

With regard to the usage of declared capacity this investigation is relevant in particular as during airport coordination and slot allocation several declared capacity values with different block types and durations are applied to control not only the total number of flight movements, but to impact on the demand concentration as well (cp. chapters 4.2.1 and 4.3.1). Confirmation of different block times' and durations' effectiveness could support their application during scheduling which represents additional restrictions to allocate all declared airport capacity. On the other hand contrary results would question those restrictions' suitability to control and to meter the operational arrival and departure flow.

A particular airport is analysed at the following relevant stages: Final status of airport coordination office's scheduling activities which represent the reference program (demand), and the days of operations to analyse the actual flow. The latter includes a further specification to differentiate between operations which were scheduled at the final status already and all IFR operations. This specification is used in chapter 5.2.1 as well.

Figure 34 depicts the analysis' results at all relevant German coordinated airports. Total movements (take-off time, landing time) within all 60min rolling blocks from 06:00 to 23:00 LT as scheduled at the final status (blue line: demand) are compared to the accordant numbers at the days of operations: Operations as scheduled at the final status (pink line: flow I) and all IFR operations (yellow line: flow II). To demonstrate the relevant behaviour density functions are used as display format. This continuous function depicts the relative frequency the number of movements having a particular value. The sum of all relative frequencies within this function is 1 (=100 %).



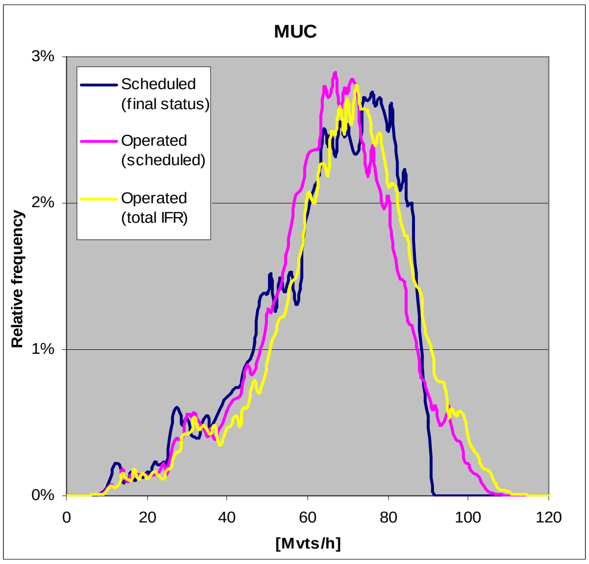


Figure 34: Total movements within all 60min rolling blocks from 06:00 to 23:00 LT - density functions (varying scaling at different airports)

Characterising those graphs, differentiation between heavily loaded airports (DUS, FRA) and moderately utilised ones (MUC, STR, TXL) is expedient. The former feature a distinctive high at the final status of scheduling activities (blue line) which represents the relevant 60min declared capacity (cp. Table 2). While at DUS just under 25 % of all scheduled 60min blocks include 39 (10,4 %) or 40 movements (13,6 %), at FRA about 33 % of all block volumes are comparably close to the declared capacity (80 mvts/h: 14,9 %; 81 mvts/h: 18,7 %). As a consequence the accordant distribution is explicitly asymmetric and the highs represent the graphs' completion from the right widely. By contrast final status' graphs at MUC, STR and TXL are characterised by significantly broader distributions which do not feature that particular highs. STR and TXL show nearly symmetric graphs which cannot be noticed in MUC, because the latter is close to complete congestion many times of the day as well due to this hub airport's peaked demand pattern.

The differentiation between DUS, FRA at the one hand and MUC, STR, TXL at the other hand is continued with regard to the airports' actually operated demand volume. Both operated/scheduled (pink line) and operated/total IFR (yellow line) distributions are significantly broader than the scheduled ones at DUS and FRA. The highs are less distinctive and the graphs feature almost complete symmetry. Accordingly a significant portion of blocks reaches total flow volumes explicitly above relevant declared capacity values. The latter is valid not only at DUS and FRA, but at MUC as well. In contrast the scheduled (final status) and operated (scheduled) distributions are nearly congruent in STR and TXL. At all airports except TXL (almost no short-term traffic, cp. 5.2.1) the operated (total IFR) graph is located to the right of the operated (scheduled) one which results from the higher number of flights included.

The characterisation above focuses on total movements only. To understand possible differing behaviour with regard to solely arrival or departure movements, density functions of arrival and departure movements (60min blocks, 06:00 to 23:00 LT) at FRA and MUC are depicted in Figure 35. Germany's biggest airports were chosen to compare different performances at highly congested airports and moderately congested ones.

Again declared capacity values are more significant barriers during scheduling at the congested airport FRA (blue line). This results in distinctive highs and comparatively narrow distributions. The lower declared arrival capacity is more relevant than the declared departure capacity at FRA which is variable in the course of the day (cp. Table 2). At MUC declared departure and arrival capacity is less relevant than at FRA, but more relevant than the total declared capacity (cp. Figure 34). This results from an unbalanced capacity utilisation in consequence of the Lufthansa/Star Alliance hub's arrival and departure waves (Cp. Figure 9).

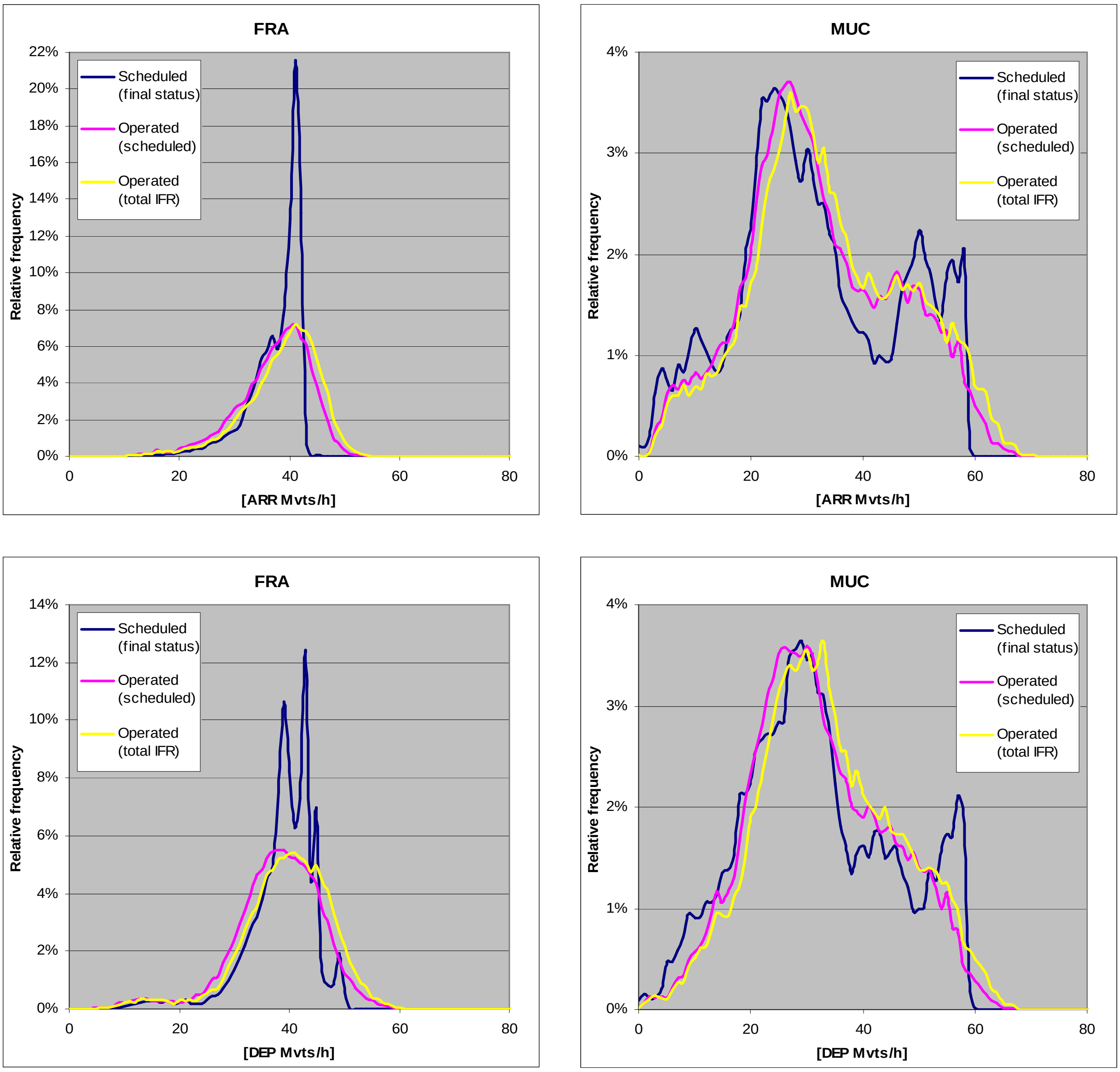


Figure 35: ARR (above) and DEP (below) movements within all 60min rolling blocks from 06:00 to 23:00 LT at FRA and MUC – density functions (varying scaling at different airports)

With regard to the scheduling agreements' realisation at the days of operations above-mentioned total movements' characteristics are as well confirmed for solely arrival and departure movements. At highly congested airports distributions of flow volumes flatten and a significant number of blocks features flow volumes exceeding the declared capacity. In contrast the operated graphs (scheduled/total IFR) follow the scheduling reference more completely at MUC, but flatten in the constrained area around 59 arrival/departure movements. Actual movements exceed scheduling agreements significantly as well.

For a discussion on applicability and suitability of flight concentration limitations in the form of declared capacity values to control and to meter arrival and departure flows, Figure 36 depicts two airports with (FRA) and without (MUC) applied 30min restrictions on total movements. This limitation's relevance does not achieve the one of the 60min declared capacity at FRA. Accordingly the scheduling's final status distribution is broader and more symmetric than the 60min total movements one (cp. blue lines in Figure 34 and Figure 36). The accordant distribution at MUC is significantly broader even and does not feature a distinctive high.

With regard to the operational performance operated/scheduled and operated/total IFR graphs follow the scheduling reference at MUC closely but with regard to highly utilised blocks the curves shift to the right and thus a significant number reaches 30min blocks exceeding the scheduling agreements. High compliance with the scheduling reference corresponds to the afore-mentioned behaviour of airports with no capacity shortage. In contrast distributions describing the relative frequency of demand volumes during operations at FRA flatten slightly, they broaden to the right and thus a significant number of 30min blocks features demand volumes exceeding the scheduling limits.

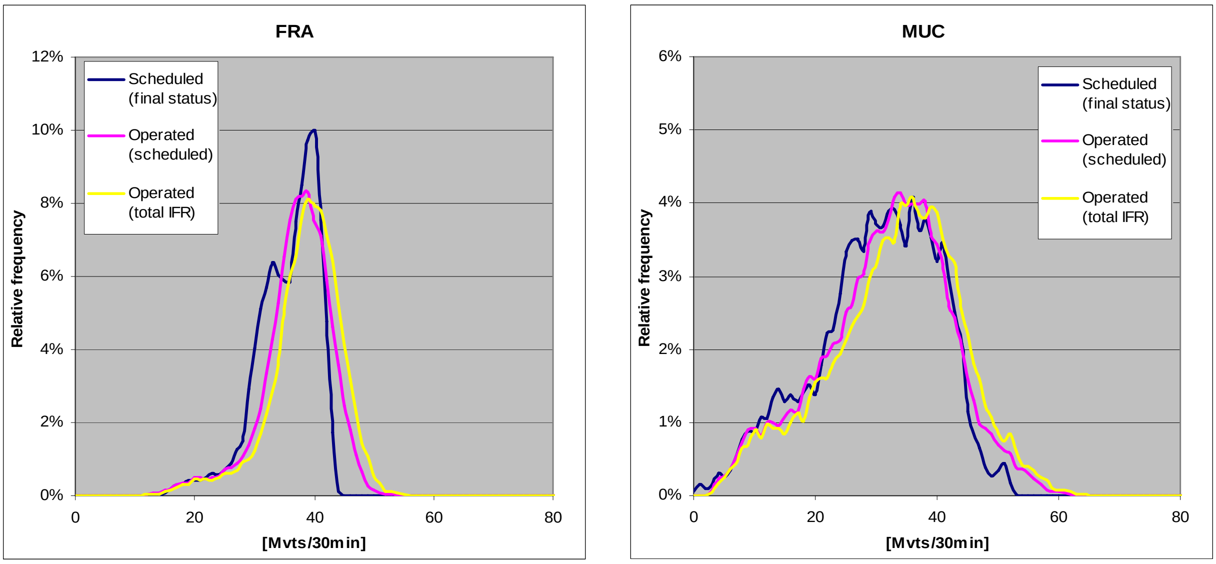


Figure 36: Total movements within all 30min rolling blocks from 06:00 to 23:00 LT at FRA and MUC – density functions (varying scaling at different airports)

The dimension of operational exceedance of agreed maxima (Mvts/30min) appears comparable at MUC and FRA (cp. Figure 36). With the maximum number of actual movements per block period thus depending on scheduling agreements at airports with and without application of flight concentration limitations obviously, it can be assumed that the latter can be used as scheduling measure to control actual flows effectively. Because this investigation's expressiveness is limited – the impact of the application of 30min declared capacity values on operational flow volumes yet cannot be verified. Applicability and suitability of flight concentration limitations in the form of declared capacity values (30min/10min) thus can still be questioned.

The analysis on scheduling restrictions' effectivity to control flows has to be expanded and deepened in the future. All different types (rolling/static) and lengths (10/30/60min) of blocks' impact on operational performance have to be included, thus the applicability to use accordant scheduling restrictions can be evaluated. With regard to the investigations at hand, it can be assumed that varying block lengths can be used to control an airport's operational flight concentration. Accordingly the implementation of scheduling restrictions seems to be justified, although it might result in non-optimal utilisation of the declared capacity due to additional parallel limits. Those results' verification with statistical significance cannot be achieved here.

5.2.3 Verification of scheduling standard taxi times

Slot allocation at German coordinated airports is based on runway times (cp. chapter 3.2). To derive runway times from slot-related on block/off block times, standard taxi times are used. Within chapter 5.2.3 the scheduling taxi time defaults are verified by determining actual taxi times based on CODA data. According to CODA data coverage at relevant airports, the following investigation includes about 65 % of total IFR movements. Precise CODA data coverage rates for each airport separately are depicted in Figure 31.

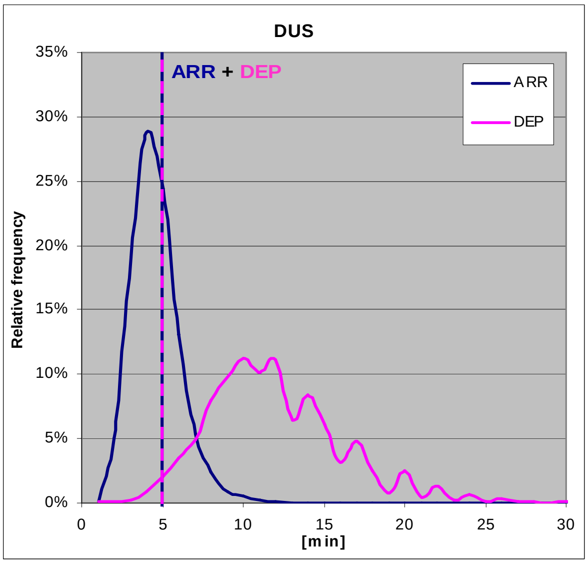
With only one arrival and one departure fixed taxi time default being used for scheduling purposes at each airport, actual taxi times are computed and analysed. Table 11 includes a comparison of scheduling defaults and average actual values. To asses the distribution of actual taxi times' density functions, arrival and departure taxi times at each relevant airport are compared to accordant fixed standard taxi times in Figure 37.

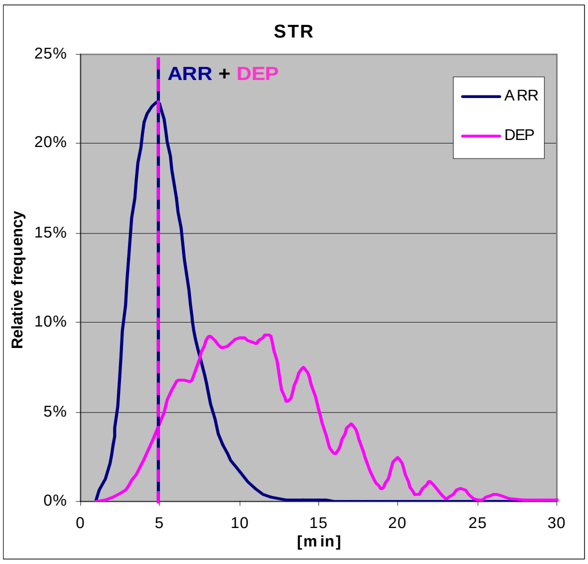
	Scheduling defaults [min]		Average actual values (CODA) [min]	
	ARR	DEP	ARR	DEP
DUS	05:00	05:00	04:26	11:44
FRA	05:00	10:00	06:47	13:19
MUC	05:00	10:00	05:07	13:32
STR	05:00	05:00	05:08	10:59
TXL	05:00	05:00	04:11	10:02

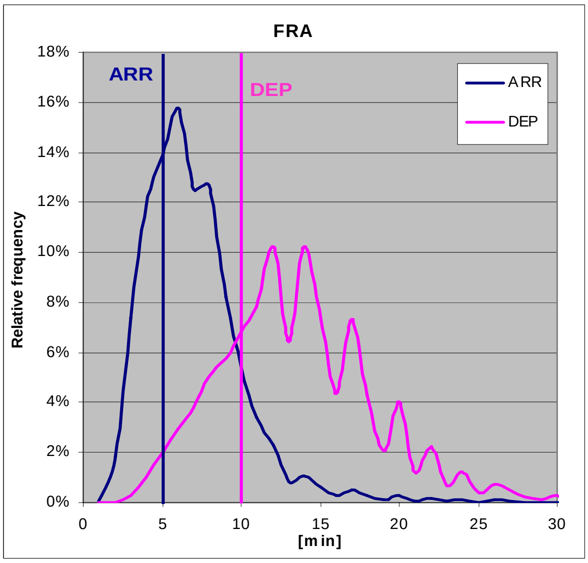
Table 11: Comparison of taxi times - scheduling defaults vs. average actual values (CODA)

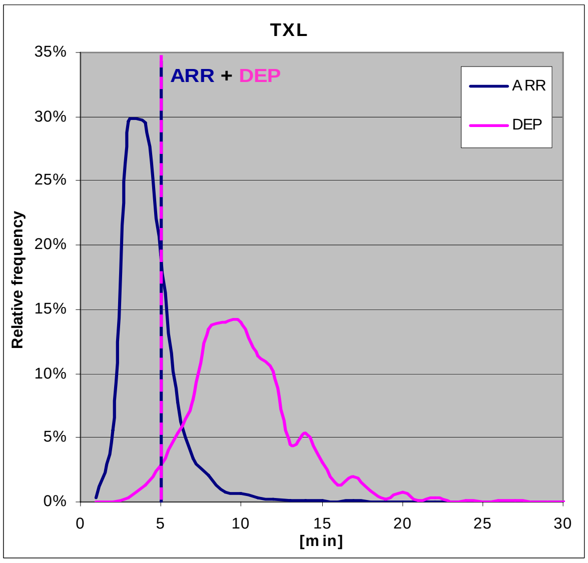
Except MUC and FRA (standard departure taxi time = 10 minutes) all airports' standard arrival and departure taxi time is 5 minutes. Average actual taxi times (CODA) feature significant differences between arrival and departure taxi times. While arrival taxi times vary from 4 (TXL) to 7 (FRA) minutes, departure taxi times are between 10 (TXL) and 13:30 (MUC) minutes. Accordingly arrival scheduling defaults comply with average actual values sufficiently, but standard departure taxi times deviate from actual CODA times significantly.

The graphs of accordant distributions (density functions) confirm those conclusions. Actual arrival taxi times show tight distributions (blue line), relevant standard taxi times are close to the maximum of each density function. In contrast departure scheduling defaults underestimate actual taxi times, accordant values vary from the density functions' maxima significantly. Distributions of CODA departure taxi times feature distinctive statistical spreads which might result from the inclusion of (departure) queuing times. The latter cast the preliminary fixing of one single standard value into doubt in general.









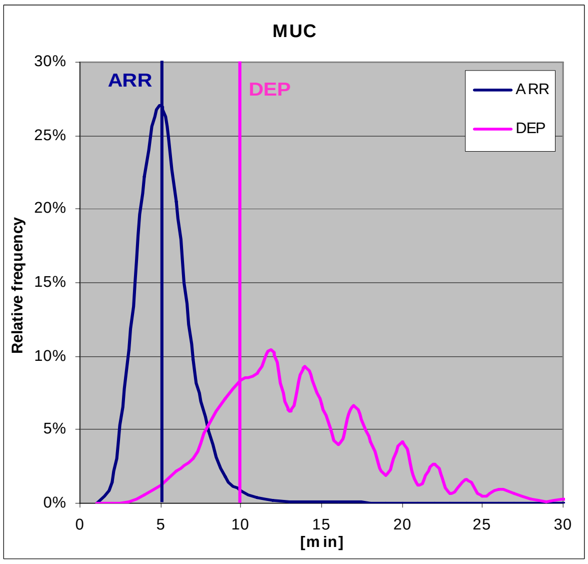


Figure 37: Actual taxi times' (CODA) density functions vs. scheduling standard taxi times defaults (ARR + DEP) (varying scaling at different airports)

With regard to arrival slots scheduling assumptions to calculate runway times seem to be adequate. Departure standard taxi times vary from actual CODA times significantly. To decide about the suitability of possible adjustments, knowledge of taxi times' composition (taxiing, waiting in departure queue) is required. Adjusted standard taxi times' impact on slot demand's compliance with declared capacity values and thus possible simplification and improvements with regard to slot allocation and capacity utilisation have yet to be analysed. To avoid declared capacity compliance conflicts (with regards to historic slots in particular) adjustments to standard taxi times should be conducted in combination with an uprating of declared capacity values.

6 Résumé

This paper highlights both inefficiencies and optimisation potentials concerning the usage of declared capacity at coordinated German airports in summer 2005 schedule season. Relevant conclusions are deduced from an extensive analysis on available data representing the sequence of strategic airport scheduling and the realisation of agreed schedules at the days of operations.

Declared capacity values are defined by up to 9 different restrictions (arrival/departure/total movements, block type rolling/static, block length 10/30/60min). Depending on the airlines' slot demand coordinated German airports' declared capacity is utilised at the coordination office's initial slot allocation date variably. Due to required parallel compliance with all different coordination parameters, and also due to both an unbalanced slot demand and the need to allocate slot pairs (arrival and departure), complete capacity utilisation at the initial slot allocation cannot be reached at any coordinated German airport.

From the initial allocation to the defined final status of the coordination office's activities capacity utilisation decreases at all relevant airports. The return of slots cannot be compensated by newly allocated ones completely – within the study at hand this scheduling inefficiency is quantified. Decline is more significant at less congested airports and during non-congested periods, but even at most constrained FRA capacity utilisation drops about 2 % which represents more than 6000 slots between 06:00 and 23:00 LT in the summer 2005 schedule season. A considerable number of slots is returned after the official slot return date which means a contravention of the current framework. The loss of capacity utilisation at coordinated German airports forms a major type of inefficient performance during slot allocation processes.

Drivers to the non-optimal utilisation of declared capacity at the final status of coordination office's activities are differentiated by the following categories: Lack of local slot demand, local airport reasons and airline network reasons. While the lack of local slot demand to compensate slot returns is out of scope of this analysis on scheduling inefficiencies, local airport reasons include the current slot allocation framework's impact on capacity utilisation. While the current framework is appropriate for the seasonal allocation of scarce infrastructure rights of use, strict compliance with it has to be enforced effectively. Strict adherence to the slot return day causes availability of unwanted slots at an early stage which is an essential precondition for successful repeated allocation. Airline network reasons for non-optimal capacity utilisation result from the need to adapt the internal network planning to local slot availability and vice versa. Operational (need to combine slot pairs at suitable times) and commercial (financial interests, low bookings, business strategy) reasons for slot returns and for non-compensation of slot-returns are differentiated.

A coordinated schedule as agreed at the final status of the coordination office's activities represents a certain reference program for the day-to-day operations. Within this study's part 2 operational adherence to scheduling agreements is verified with regard to total demand figures and limitations of demand concentration. Additionally actual taxi times are compared to default values as applied during scheduling processes to calculate runway times. German coordinated airports feature no show rates (flights being scheduled at the final status but not operated) of between 1 % and 3 % on average. At all airports except TXL this rate is over-compensated by short-term slot requests for e.g. ferry flights, general aviation, military etc. With regard to the limitation of flight concentration the actual performance varies from scheduling agreements significantly. A considerable portion of time periods even shows substantial exceedance of the number of flight movements as agreed during scheduling. Actual taxi times differ from scheduling presumptions for departure flights in particular.

Including all flight cancellations being inevitably due to weather, technical reasons etc., no shows seems to be negligible with regard to inefficient utilisation of declared capacity. This is confirmed by the over-compensation of no shows due to additional flights at short notice. With regard to preliminary results on flight concentration as scheduled and as operated one might assume that control of flows using particular scheduling restrictions (different declared capacity block types and lengths) can be effectively. Additional analysis is required to validate those conclusions.

Fields of study for continuative research result from the matching of scheduling and operational data in particular. The latter was accomplished in spite of significant data inconsistency. The accordant approach is to be used to analyse scheduling decisions' impact on the operational performance in detail. At this feasibility to control and to meter flows using adequate scheduling restrictions is at the centre of interest. Besides the connection between scheduling and operations additional research is required to provide effective solutions for achieving the optimal utilisation of declared capacity within scheduling and slot allocation processes.

7 References

[1] ACI (Ed.): Study on the use of airport capacity. An ACI Europe study. Brussels 2004

[2] Commission of the European Communities: Commission Staff Working Document: Commercial slot allocation mechanisms in the context of a further revision of Council Regulation (EEC) 95/93. Brussels 2004

[3] ECAC [Ed.]: Outcome of study on slot allocation procedures. Report of Task Force. Paris 2005

[4] Council Regulation (EEC) No 95/93 of 18 January 1993 on common rules for the allocation of slots at Community airports Official journal NO. L 014, 22/01/1993

[5] IATA (Ed.): Worldwide Scheduling Guidelines. Montreal 2004

[6] National Economic Research Associates (Ed.): Study to assess the effects of different slot allocation schemes. London 2004

[7] Performance Review Commission [Ed.]: “Report on Punctuality Drivers at Major European Airports”. Report prepared by the Performance Review Unit. Brussels 2005