Virtual Institute

Airport Planning and Management

Synopsis of Capacity Management and Analysis in Air and Rail Traffic

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1 Introduction

Within the scope of political discussion on regulation and liberalisation of transport markets in Germany and Europe, drawing comparisons between different transportation systems became part of the ongoing debate. To benefit from meaningful comparisons in terms of capacity management and analysis, effective comparability between transportation systems is required. Such comparability exists between air and rail traffic which both are transportation systems with scheduled operations. And thus interesting similarities can be noticed: Planning and scheduling of available network capacity precede the day-to-day operations, and still severe capacity scarcity appears in particular parts of the networks. These similarities allow the reciprocal adoption and finally the use of methodologies, procedures and models of capacity management and analysis. A detailed analysis of both transportation systems' scheduling and operations displays relevant differences as well which disagree with an injudicious and precipitous transfer of modelling theories.

Capacity research for air and rail traffic is in the centre of interest of the activities at the Virtual Institute "Airport Planning and Management" of the RWTH Aachen University (Department of Airport and Air Transportation Research; Chair of Railway Engineering and Transport Economics) and the German Aerospace Centre DLR (Air Transport and Airport Research; Institute of Flight Guidance). The integration of railway and aviation sciences into the research activities is supposed to allow the reciprocal utilisation of capacity models, performance and quality criteria for both carriers as well as to enable the use of synergy. This interdisciplinary approach requires the availability of a detailed synoptic description of capacity management and analysis in air and rail traffic which includes major similarities but relevant differences as well. Results of the synopsis form the basis for subsequent researches being conducted for both transportation systems separately.

The paper on hand focuses on the aforementioned synopsis but includes some preliminary results of the ongoing research in the field of airport scheduling also which were encouraged by conclusions from the synopsis. To provide relevant fundamentals, relevant process levels (scheduling/ planning, operations) and their temporal classification at transportation systems with scheduled operations are described at the beginning. According to this scheme scheduling and operations in air and rail traffic are summarised separately. This paper's main focus is the synoptic investigation of capacity management and analysis. While the latter concentrates on relevant fundamentals of capacity determination and of quality of service/ performance evaluation, capacity management includes – besides scheduling and operations of air and rail traffic – the modelling of network infrastructure and of aircraft/ vehicle movements. Being based on the synopsis' results which state a significant disregard of the strategic planning phase in air traffic sciences, ongoing research in the field of air transportation amongst others focuses on the strategic airport scheduling and slot allocation. The paper on hand is completed by an introduction into the current project's scope and objectives as well as by some preliminary results of the analysis.

2 Synopsis of capacity management and analysis

Research at the Virtual Institute “Airport Planning and Management” focuses on questions of modelling, performance and quality criteria as well as on the practical application of models for air and rail traffic as transportation systems with scheduled operations. The integration of railway and aviation sciences into the research activities allows the comparison of methodologies and theories of both carriers. This leads to a certain benefit for the project due to the use of synergy.

Against the background of the interdisciplinary approach of the institute’s current research, a synopsis of capacity related issues for air and rail traffic was elaborated initially. This synopsis is composed of two main parts: A comparison of relevant process levels (strategic/ (pre-)tactical/ operational planning, operations) in air and rail transportation within the first part; a synopsis of capacity theory (including modelling, performance and quality criteria, methodology for capacity determination, Level-of-Service concepts) for both carriers as second part.

On the basis of the synopsis major similarities of air and rail traffic become apparent. Infrastructure networks comprise of links and nodes which are tracks and stations or airspace and airports. In accordance with the available but often scarce infrastructure capacity the bigger part of operations are scheduled tightly.

2.1 Process levels: Scheduling and operations

Because of the limited infrastructure capacity both carriers require a schedule for temporal order and spatial separation of the transportation units. Thus planning/ scheduling phases precede operations at transportation systems with scheduled operations. The different phases of planning can be distinguished with regard to the planning horizon on the one hand, and with regard to the different opportunities of action on the other hand. The strategic planning is a long-term coordination which results in the creation of a schedule. Tactical measures are based on the results of strategic planning, the latter will be analysed and evaluated and thus necessary modification and specification are decided and implemented. Short-term operational planning is part of the realisation at the day of operations. Control and guidance of operations is part of the operational planning. This pattern (strategic, tactical, operational planning) is shown in Figure 1 and maintained in the following chapters which include a separate description of planning and operations for air and rail traffic.

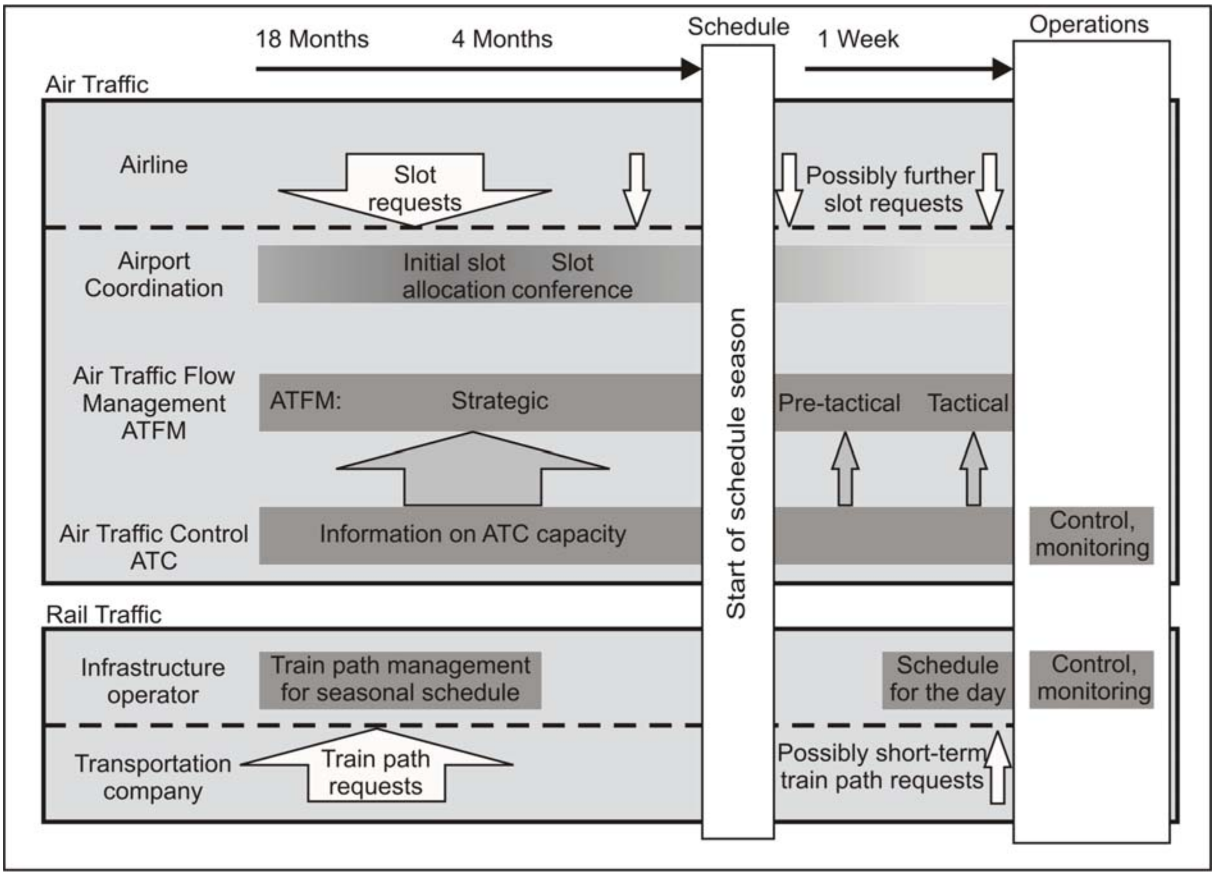


Figure 1: Process levels in air and rail traffic

2.1.1 Air traffic: Scheduling and operations

This chapter deals with the main processes and instruments of air transportation's process levels scheduling and operations. With regard to the chronology of the single events, scheduling focuses on (long-term) strategic and pre-tactical measures, while operations consider all (short-term) tactical and operational activities [Men93]. As to the infrastructure operators the involved parties can be classified in accordance to the link-node-structure of the air transport network: While besides airport operators the national airport coordinator is relevant for the airports in particular, planning and operations for the Europe-wide airspace is dominated by the EUROCONTROL department CFMU (Central Flow Management Unit). In addition the local air traffic control (ATC) influences on planning and operations of both airports and airspace. With respect to infrastructure users, aircraft operators and thus airlines in particular are the only parties involved [Prc05].

Within the strategic planning of the airport utilization the biannual allocation of airport usage rights in the form of airport slots is the major process. In the run-up to this the airport authority declares its scheduling capacity (declared capacity). The determination of the declared capacity means a fixing of the seasonal airport infrastructure capacity at an early stage. It is based on analysis involving a large amount of data and – despite of different approaches – should consider all relevant technical and political/environmental capacity related aspects. An airport's declared capacity (number of arrival/departure/total flight movements over some period) limits the number of slots available for allocation. It tries to maximise the use of available airport capacity while keeping delays at locally acceptable levels [Prc05].

The following slot allocation in the EU and thus in Germany is based on Council Regulation 95/93 [Eu93]. 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”. The slot time designates the time when the aircraft goes off block (departure slot) or on block (arrival slot) and thus corresponds to the published airline schedule.

The time for airline slot requests ends about 5 months before the semi-annual (winter/ summer) schedule season starts. Afterwards the slot allocation activities by the national airport coordinator begin. Requested slots can be allocated as requested or – in periods of excess slot demand – can be allocated but retimed (slot alternative) or can even be rejected completely. This is decided by using administrative priority criteria as stated in Article 8 of the Council 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. 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 a new entrant at that specific airport [Eu93].

Airport coordination continues after the initial allocation as well. Council Regulation 95/93 allows for various ways to fine tune schedules by airlines. Returning, retiming, transferring (between parent and subsidiary company), swapping and (late) requesting slots are possible ways to adjust schedules. The worldwide IATA Schedules Conference is a major opportunity to negotiate slots allocated initially. All ways of possible schedules adjustments may continue not only until the season starts but also until the operations [Iat04].

To some extent simultaneously but managed independently, the (long-term) strategic and (short-term) pre-tactical planning processes of the Europe-wide en-route/airspace capacity take place in the form of en-route communities (CFMU, Air Navigation Service Providers) ATFM (Air Traffic Flow Management) [CfmES]. Strategic ATFM capacity planning is based on the precedent season’s post operations analysis and traffic forecast. This states a macroscopic approach which does not consider single flights but focuses on traffic flows. Possible imbalance between available en-route capacity and expected traffic demand are detected and adequate measures and restrictions are formulated. Pre-tactical ATFM within the last week before operations means a more precise planning than the strategic one. It is based on an increasing number of available ATC flight plans and thus the anticipation of precise traffic flows allows the determination of an ATFM daily plan for the next day of operations [Cfm02].

With the ATFM daily plans release the process of strategic and pre-tactical planning ends and the phase of operations starts. With regard to the airports, slot allocation by the airport coordinator stops as well about 24 hours in advance of operations, any shot-term slot requests, returns and adjustments are managed by the operational airport slot department itself. During operations the (strategic and pre-tactical) airport and en-route planning requires further specification and precision. CFMU's tactical ATFM is based on the monitoring of available capacity and actual traffic. Due to the information included in ATC flight plans, details on flight times, routes, flight levels and speeds are available for the purpose of tactical ATFM. Planning of the en-route capacity's utilization can be specified. Possible tactical ATFM measures are short-term re-routeing, level capping and allocation of ATFM slots. The latter allows the metering of traffic flows due to forced delays at the departure airport already (ground holding) [Cfm03].

Air traffic controllers are responsible for control, monitoring and guidance of aircraft movements during operations. Active cooperation of aircraft pilots is inevitable here since verbal communication is the only means of correspondence. Besides those measures to guarantee required separation of aircraft, controllers decide on traffic organisation and coordination. The determination of flight levels, of routes and of the precise sequence of aircraft is within the controllers' field of responsibility. By ad-hoc decisions they complete the imprecise and fragmentary previous planning of aircraft flight movements. Controllers' activities during operations are based on "first-come-first-served"-strategy [Men93].

2.1.2 Rail traffic: Scheduling and operations

Also for the rail traffic the allocation of limited capacity is required during the strategic planning for a certain timetable period. The railway companies have to plan the circulation of their trains and to formulate the train path requests for the annual schedule. For this the train path management is necessary which coordinates the train path requests. The significant instrument for the train path management is the train path, which is defined as *„that part of the track capacity of an operator of the rail track system which is necessary so that a train can run at a particular time between two points"* [EIBV05].

It is the planned local and temporal occupancy of the infrastructure through a train from a station over the track to another station. The construction and the graphical illustration result from blocking time graphs (Figure 3) in the time-space-diagram. A block section is defined by signals in which maximal one train can be located. The occupancy of the block section is the blocking time (Figure 2) with the components running time, approaching time, clearing time, switching times and reaction time. The variable times include infrastructural constraints, like the signalling and train protection system and parameters of the trains (length, speed and speedup).

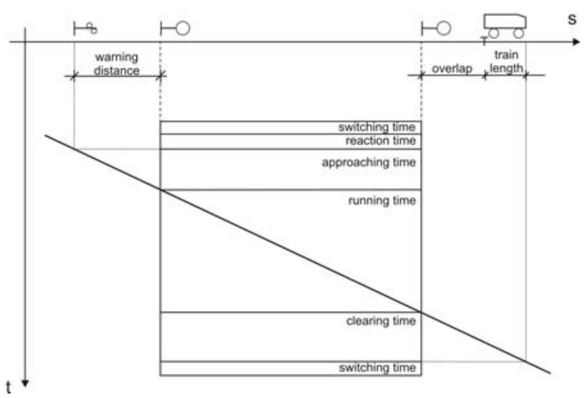


Figure 2: blocking time

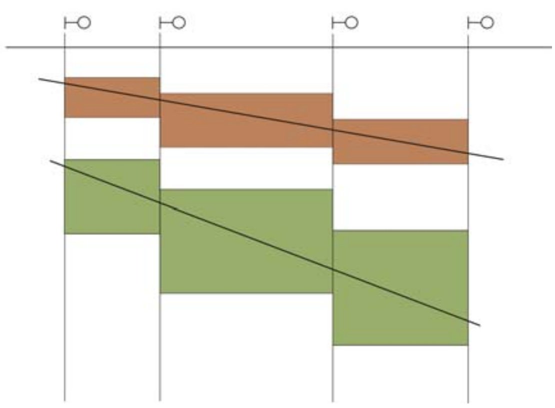


Figure 3: blocking time graph

Based on these requests for train paths the infrastructure manager coordinates and constructs a conflict free schedule [R402]. Conflicts can arise if requests for train paths overlap. The infrastructure manager has to solve them by achieving an amicable resolution. Is this not possible he decides corresponding to the lawful priorities by giving priorities for transnational or periodical traffic. Are these priorities equal, the higher fee for the train path decides. If nothing else can be realised the ceiling price method is used. [EIBV05]. Thereby the infrastructure manager has to warrant a discrimination free access to the infrastructure for all railway companies [AEG05]. Additional to the annual train path requests a framework agreement for 5 years can be concluded. So the railway company has the right to get a train path for period of time with the advantage of planning reliability [2001/14/EG]. But this possibility complicates the scheduling.

The train path management ends 17 weeks before the schedule period. The schedule maintains until the day of operation, achieves an unrestricted realisability and will only be supplemented with short-term train paths.

During the operation the signalling and train protection system ensure a safe operation and the necessary distance between the trains. This track controlled transportation system transfers information from the signals to the locomotive driver. He has to react and can not operate self-contained. So the schedule can be implemented. Though dispatchers are necessary. For unplanned incidents (e.g. vehicle or infrastructure losses) they decide on matters to reach the planned schedule and a high punctuality.

2.2 Synopsis of capacity management

2.2.1 Modelling of the infrastructure

The existence of an infrastructure network is the basis for the realisation of planning and operation of transportation systems. For both carriers a node-link-model represents the infrastructure network. In air traffic, airports represent the nodes and the en-route airspace the links. Equivalent to this, rail traffic features stations as nodes and lines as links. Besides this macroscopic perception, microscopic models can be used to model the infrastructure of network nodes in particular. Thus with regard to rail traffic, switches form the nodes and lines in-between the according links, while accordingly an airport featuring a runway system, taxiways, aircraft stands and possible intersections can be modelled by a microscopic node-link-model.

2.2.2 Modelling of the aircraft/ vehicle movements

The modelling of the infrastructure network enables a comparison of the different degree of freedom to move aircraft/ vehicles in air and rail traffic. Variations are constrained in rail traffic because the links are one-dimensional. With regard to the opportunities to move aircraft, air traffic shows a major change between en-route and TMA (terminal manoeuvring area). While the en-route airspace is three-dimensional, air traffic changes to a univariant system (“single-file”) within the TMA. Thus routes become one-dimensional, and the degree of freedom is comparable to the one seen in rail traffic [NeO03].

To specify movements of vehicles/aircraft in the infrastructure network the mathematical model “trajectory” is employed. A trajectory describes the position with regard to time and location as well as the exact movements of trains and aircraft over the time. Contrary to the one-dimensional movement in the direction of travel in rail traffic, air traffic features vertical and lateral aircraft motions additionally. To illustrate the infrastructure capacity consumption, trajectories can be used as well. For this, trajectories have to be encased by envelopes. Regarding rail traffic, those envelopes represent blocking time graphs. In air traffic a trajectory describing an aircraft movement is encased with a band of possible envelopes to consider the required horizontal and vertical separation.

2.2.3 Use of capacity, slot/ train path

The use of trajectories and related envelopes makes the consumption of limited but required infrastructure capacity clear. Thus early planning processes are required to allocate limited resources for both transportation systems. Within train path management and airport coordination as major processes during the strategic planning phase, the use of capacity during operations is forecasted and coordinated. To allocate available infrastructure capacity early, comparable planning instruments are used in air and rail traffic: Airport slots and train paths represent the occupancy of capacity and allow an early estimation of capacity consumption during later operations. Train paths integrate network links and nodes and are based on comprehensive and conflict free trajectories. Thus the complete train run including stations and lines is covered. On-the-minute train paths are determined transparently and reproducibly following fixed rules. Considerations of detailed parameters describing infrastructure configuration and driving dynamics of vehicles is compulsory. In contrast to that airport slots only mean imprecise planning for the network nodes. With regard to complete aircraft movements, capacity usage planning based on the use of airport slots is fragmentary and solely covers start and end points of a flight movement. Any network effect is achieved by the airline matching the slot pairs internally to include the airports of origin and destination. Additionally major capacity related parameters (e.g. aircraft wake vortex category) are not considered at all. The comparison of slots and train paths is shown in Table 1.

(Airport-)Slot	Train Path
Planning of airport capacity	Planning of line and station capacity
Covering the nodes of the infrastructure network and thus start and end point of a flight movement only	Covering nodes and links of the infrastructure network and thus a complete train run
Individual, airline internal matching of a slot pair including the airports of origin and destination	Transparent, reproducible determination of train paths following fixed rules
Imprecision with regard to the planning of arrival / departure times by using 10-min-slot-windows	Minimal on-the-minute planning precision
No compulsory consideration of important capacity related parameters (e.g. aircraft wake vortex category)	Compulsory consideration of detailed parameters describing infrastructure configuration and driving dynamics of vehicles (e.g. pitch, brake/acceleration force)

Table 1: Comparison of slots and train paths

So the results of airport coordination and train path management differ significantly: On the one hand there is a train schedule which actually is realisable during operations, on the other hand there is a flight schedule as a rough pattern only which needs additional detailing and specification during (pre-) tactical and operational planning processes.

Besides airport slots as planning instruments during the strategic processes of airport slot allocation, air traffic uses ATFM slots within the tactical air traffic flow management (ATFM). By including the en-route airspace planning of aircraft movements both become more precise and complete and with it the forecast of network capacity consumption as well. The ATFM slot, referring to an aircraft´s take-off run, considers the complete flight movement until landing at the airport of destination. The start point (= ATFM slot time) represents the beginning of one possible trajectory for the whole flight movement. The usage of ATFM slots during tactical ATFM air traffic planning includes network links and nodes (airports and en-route airspace) and thus approximates to rail traffic planning based on train paths. But by contrast ATFM slot's precision with regard to times stays vague - although it has improved significantly during tactical ATFM - which results from the use of 15 minutes slot windows [Cfm04]. Compared to the analogue planning in rail traffic, air traffic planning of network capacity consumption features deficits regarding completeness and precision even when considering improvements due to the use of ATFM slots. Differences between the transportation systems with regard to the early forecast of anticipated aircraft/vehicle movements using the instruments train path and (airport/ ATFM) slot, have an impact on the complete course of planning and operations.

2.2.4 Strategic scheduling processes

Airport coordination and train path management are the major processes of both carriers' strategic planning. Using aforementioned planning instruments slot and train path limited infrastructure capacity is allocated. The limited availability of capacity might cause isochronal requests by transportation companies which are mutually exclusive: Demand exceeds available capacity temporarily at least (excess demand). Both, rail traffic and air traffic, address those strategic conflicts of capacity allocation and usage by using certain priority rules [Iat04]. With regard to airport coordination grandfather rights are the most important priority regulation. Granting historical precedence to slots that had been used in the previous season regularly, grandfather rights are comparable to train path management's framework agreements. The latter grant train path precedence for multiple consecutive seasons as well, but do not focus on single train paths but on a certain temporal bandwidth in which one train path can be placed. Thus during both carriers' strategic planning phases the current priority rules approve historical precedence for the allocation of limited infrastructure capacity.

Schedules as results of train path management and airport coordination differ with regard to planning precision and completeness. This impacts on the operations significantly. A train schedule is an exact and conflict free in advance planning of all train runs. At the day of operations this train schedule is completely realisable in theory. Additional short-term tactical and operational planning is needed in the case of external influences only causing deviation from schedule. By contrast an air traffic schedule (timetable) does not represent a precise planning and preparation of operational activities. Being based on airport slots which do not cover the complete network and feature a certain temporal imprecision (slot window), an air traffic schedule is a rough coordination only. This results from the scheduling's sole focus on airports as network nodes, its continuous amendments, temporal imprecision, missing operational bindingness and the disregard of aircraft performance characteristics. Airport coordination as air traffic's strategic planning process does not aim at a precise scheduling equivalent to the train path management's results which considers conflict free coordination of every single train run. Thus pre-tactical and tactical planning measures (ATFM) are much more important than according activities in rail traffic. ATFM achieves additional precision with regard to the times, but – even more important – completes the planning scope by considering network links and nodes. At that time, close to or during operations, air traffic planning arrives at a level of precision and completeness that rail traffic has seen during train path management months before. And even now the latter is more advanced due to the planning of conflict free vehicle sequencing which – with regard to air traffic – is not part of tactical ATFM but of operational ATC activities. The comparison of airport coordination and train path management is shown in Table 2.

Airport Coordination	Train Path Management
Fixed seasonal declared capacity as input parameter	Data covering driving dynamics and infrastructure configuration as input parameters
Approximate demand regulation and coordination at airports; planning of airport capacity	Precise arrangement of train path requests; conflict free coordination
Result: Schedule for passenger information and as approximate pattern for operations	Result: Schedule for passenger information; precise planning and preparation of operations, completely realisable at the day of operation
Solution of scheduling conflicts by priority regulation (grandfather rights in particular)	Solution of scheduling conflicts by discussion normally
No financial aspects	If no agreement by discussions: "Maximum price procedure" possible

Table 2: Comparison of airport coordination and train path management

2.2.5 Operations

Various influences – outside and inside – cause deviation from schedule and thus unscheduled operations. Target specifications from different planning phases (strategic, tactical, operational) cannot be met – variations occur in the form of operational, non-scheduled delays. Being less susceptible to outside influences like weather for instance, rail traffic shows higher probabilities to comply with the given schedule during operations. This can be seen as one major reason for the more complete and more precise rail traffic scheduling in contrast to comparable processes in air traffic.

If there are no outside influences causing deviation from target specifications and thus reactionary delays, rail traffic schedule's completeness and exactness allow its one-to-one realisation without any additional planning activities or decisions. By contrast the air traffic strategic and tactical scheduling requires additional short-term decisions during operations even if operations run according to schedule. The previous scheduling is completed and specified. Sequencing of aircraft, flight levels and routes are determined finally by ad-hoc decisions.

In practice operations feature deviation from scheduling at both traffic systems air and rail traffic: Planned trajectories have to be modified with regard to time mainly and position occasionally. While air traffic procedures to handle such unscheduled traffic do not change, or do change marginally, only compared to procedures to handle traffic according to schedule, rail traffic requires ad-hoc decisions of control centres' dispatchers only if there is unscheduled traffic. Thus operational activities in rail traffic vary depending on the traffic being scheduled or unscheduled, while air traffic operational procedures do not differ in both cases significantly.

Dispatchers' short-term activities aim to bring back operations to previous scheduling by determining modified ad-hoc scheduling. Being comparable to air traffic controllers' responsibilities, dispatchers do not join in if there are operations according to schedule only. By contrast air traffic controllers have to complete and specify the vague previous scheduling in real-time. Thus dispatchers' and controllers' activities mean an operational reallocation of the authorisation to use the given infrastructure as assigned during previous (strategic and tactical) scheduling phases.

Used strategies for this operational rescheduling vary between the traffic systems. While rail traffic dispatchers comply with strict priority rules which grant precedence to superior trains (e.g. fast long-distance passenger trains), air traffic controllers apply the "first-come-first-served" policy. This proves the minor relevance of air traffic strategic scheduling once again. A comparison of operations in air and rail traffic is shown in Table 3.

Operations: Air Traffic	Operations: Rail Traffic
Previous planning requires short-term specification and precision by controller's ad-hoc-decisions	Precise planning available: Schedule can be realised completely without any further specification required
Operational procedures independent from the operations being as scheduled or being out of schedule (e.g. variations due to delays)	Only in the case of operations being out of schedule: Disposition from the control centre: Revision, modification and adaptation of previous planning / schedule of operations
Controllers use „First-come-first-served"-strategy	Disposition uses priority-regulation-strategy to return to scheduled operations as quickly as possible
⇒ Operational reallocation of previous planning phase's authorisation to use the infrastructure	

Table 3: Comparison of air and rail traffic

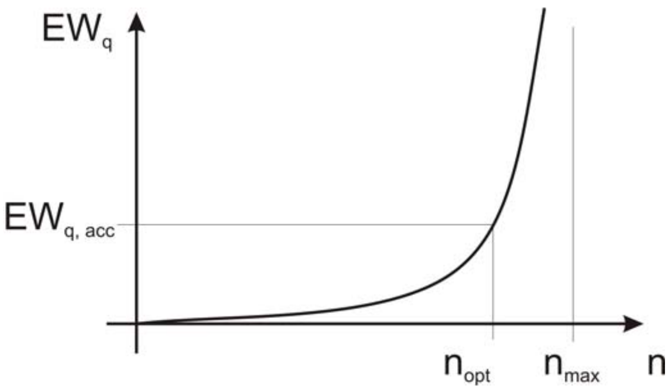
2.3 Synopsis of capacity analysis

2.3.1 Fundamentals

In general the term capacity describes the processing capability of a service facility over some period. With certain components of transportation systems being considered as a service facility, here capacity means the capability to satisfy demand for the transportation of persons, goods or information according to quantity and traffic service and in compliance with a desired quality of service (e.g. cost effectiveness, safety, quickness, punctuality). Thus to determine and quantify capacity as a correlation of an adequate performance parameter a suitable quality criterion is required. For capacity analysis of air and rail traffic systems, performance usually is specified as the number of transportation units over some period (e.g. flight movements per hour, train runs per day), while queue length or the average or total delay within the period under consideration can be seen as common quality criteria [NeO03].

Air and rail traffic capacity analysis differentiate between several measures of capacity, from which the two most common ones in terms of transportation sciences are described in the following. Saturation capacity (or maximum throughput capacity, n_{max}) of a certain component of a transportation system means the number of transportation units that can be processed in compliance with all relevant safety regulations and additional specific conditions under which operations are conducted. For a service facility to realise its saturation capacity of a continuous transportation unit demand is compulsory, while there is no reference made to any quality of service requirements. In other words, saturation capacity might relate to an infinite queue length or waiting time (delay).

This characteristic of n_{max}, the absence of any reference to quality of service requirements, has motivated the formulation of the second commonly used measure of capacity: Practical capacity (or nominal capacity, n_{opt}). In contrast to saturation capacity, practical capacity implies a congestion limitation within a facility which can be expressed by the queue length or the average/total amount of waiting time. Thus the specification of an acceptable threshold of quality of service precedes the definition of the practical capacity. The determination of an acceptable quality threshold should depend on an optimum economic benefit from the perspectives of both the system user (airline, train company) and the system operator (airport, track operator). The selection of a particular threshold value requires a reasonable agreement on a facility's acceptable level of congestion (waiting time/delay, queue length) based on all parties' interest. The important relationship between demand, waiting time, saturation capacity and practical capacity is illustrated in Figure 4 (capacity curve) [Hor94].



EW_q ... Expected waiting time (total or average): Quality criterion
$EW_{q,acc}$ ... Acceptable expected waiting time (total or average)
n …Demand (No of flight movements, train runs): Performance parameter
n_{max} …Saturation capacity
n_{opt} …Practical capacity

Figure 4: Capacity function

Measures of capacity as described above can be used in air and rail traffic sciences in different ways. With regard to rail traffic, a capacity analysis can be conducted for both the scheduling process and the operations. The evaluation of the scheduling process as part of the strategic planning phase (train path management) is carried out by determining the so called schedule capacity. Schedule capacity means the maximum number of train paths that can be planned for the upcoming schedule season. Its corresponding quality criterion is the scheduled waiting time which results from a possible train path's retiming due to an allocation conflict with another train path during the train path management. Correspondingly a capacity analysis for the operations is based on the determination of the operational capacity. The operational capacity describes the number of train runs that can be conducted on a track during a certain period under consideration. The related quality criterion is the reactionary/ secondary delay which is a train run's operational deviation from its planned trajectory. Such delay is generated from multiple external and internal effects. To clarify its differentiation towards scheduled delays, reactionary/secondary delays can be designated as non-scheduled delays as well.

In contrast to the usual proceeding in rail traffic sciences, at present capacity analysis in air transportation sciences focus on the operations only [Wen99]. Although the scheduling capacity or declared capacity exists, this means nothing but an early agreed fixing of the operational capacity for the purpose of limiting the number of slots to be allocated for the upcoming season. Scheduling capacity in aviation is no measure to evaluate the strategic planning phase and the scheduling/slot allocation process itself, but its determination is based on the operational performance during precedent seasons. Accordingly there is no quality criterion in aviation comparable to scheduled delays in rail traffic sciences. As mentioned before, capacity analysis in aviation rather includes the operations and thus focuses on the operational capacity only. Its corresponding quality criteria are primary and reactionary delays. Comparable to the occurrence of (non-scheduled) railway delays, delays in aviation mean a deviation from planned times resulting from multiple external and internal effects (e.g. weather, airline, airport, ATFM delay).

2.3.2 Capacity determination and influencing factors

Figure 4 shows a capacity curve and thus the important relationship between demand, expected waiting time, saturation capacity and practical capacity. To determine this capacity curve, in general the following three main methodologies can be distinguished [Jan00]:

- empiricism
- analytics
- simulation

These methodologies are used for the capacity curve determination of both air and rail traffic facilities. Although a synoptic investigation into common capacity models and capacity determination methodologies is fruitful and allows important conclusions, due to the different objectives this paper focusing on it is not included here.

The capacity of air and rail traffic facilities depends on various influencing factors which have to be considered when determining capacity using analytical models or simulation. These factors can be classified into several groups including, but not limited to, the following [Hor94]:

- environmental conditions
- demand
- infrastructure

While environmental conditions are negligible with regard to rail traffic, due to heavy weather sensitiveness (wind, visibility, rain) they show a major impact on the actual capacity of air traffic facilities. Demand characteristics are relevant for both traffic systems including size, speed, brake power and homogeneity of trains and aircraft as transportation units. As to physical configuration, technical equipment and usage strategy of traffic facilities effects on air and rail traffic capacity, infrastructure is comparable important for both carriers.

2.3.3 Quality of service

With the interrelation between performance parameter (e.g. train runs/flight movements over some period) and quality criterion (e.g. average delay) being determined for certain air or rail traffic facilities, the quality of service can be evaluated. The assessment of the quality of air and rail traffic services can be carried out by using different levels of service. Being based on the more sophisticated level-of-service-concept as included in the U.S. Highway Capacity Manual for road traffic, in its simplest form, this method uses a certain threshold to distinguish between acceptable and non-acceptable quality of service. This chapter focuses on the current procedures to benchmark traffic facilities' quality of service while maintaining the synoptic approach of the paper on hand.

The quality of both air and rail traffic services can be evaluated by the quality criterion punctuality. Punctuality in operations is measured by determining the deviation of a service's actual arrival or departure time from its scheduled arrival or departure time. For designating a passenger flight movement or train run as punctual or unpunctual, the traffic systems feature different thresholds. While passenger train runs feature punctuality if they arrive or depart within 5 minutes from their scheduled times, a flight movement usually is considered being punctual if the deviation from its scheduled time is no larger than 15 minutes. These thresholds are used commonly, but others might be applied as well [Prc05].

Measuring punctuality in operations shows one major difference between air and rail traffic. With regard to passenger train runs, deviation from scheduled times appears in the form of delay nearly completely. Both arrivals and departures ahead of scheduled times are practically impossible. Featuring major – positive and negative – deviation from scheduled times cargo trains are the only exception from this (for the latter the aforementioned punctuality threshold is not valid at all). In contrast to that, a reasonable proportion of flight movements – passenger flight movements as well – arrive ahead of scheduled time, long-haul flights in particular. As there are almost no flights departing ahead of time, the fact of premature arrivals detects the existence of serious buffer times within most scheduled block times. For this reason the significance of punctuality measurement based on scheduled block times to evaluate the quality of service of air traffic operations is limited [Jan00].

Besides those measures to evaluate the quality of single services in operations, air and rail traffic capacity sciences use the – average or total – expected waiting time (delay) or any value deducible from that to assess the quality of service. According to the availability of a schedule capacity and thus of a performance measurement for the scheduling phase, rail traffic does not only focus on the quality of service during operations, but on the quality of service during scheduling as well. The evaluation of the scheduling performance is based on the quality criterion scheduled delay (and thus scheduled queuing length by conversion). A certain threshold is defined as acceptable queuing length during scheduling. This threshold depends on the proportion of long distance passenger trains.

In contrast to that air traffic's common approaches to evaluate the quality of service do not consider the scheduling and thus assessing the quality of service during strategic planning processes (airport slot allocation) using a systematic analytical procedure is not usual at the moment.

Concerning the assessment of the operational quality of services, the methodology in railway sciences is quite similar to the proceeding to evaluate the scheduling performance. Using the quality criterion reactionary/non-scheduled delay, the relevant threshold is defined as acceptable queuing length during operations which again depends on the proportion of long-distance passenger trains. Compared to the scheduling performance operations feature greater demands on quality which results from the higher significance of reactionary delays.

To determine the operational performance of an airport runway system at an acceptable quality of service, aviation sciences usually use the average expected waiting time (delay) per flight movement during operations. While accepted thresholds vary from 2 to 10 minutes/ flight movement, 4 minutes average delay per flight movement is used most commonly.

2.3.4 Conclusions from the synopsis

The synoptic investigation covering capacity management and analysis in air and rail traffic clarifies major similarities, but detects relevant differences between the transportation systems as well. While the latter result from technical system discrepancy, historical and political structures as well as the varying area of validity of the majority of results (national/ European/Worldwide), significant similarities between the transportation systems are based on the identical classification as traffic systems with scheduled operations. Altogether the interdisciplinary approach for research activities within the Virtual Institute is confirmed. Precise knowledge of parallels and differences between the transportation systems is used to detect fields of interest for continuative projects addressing capacity research for air and rail traffic separately. The Virtual Institute’s current research work on the airport scheduling phase which was encouraged by the synopsis’ results is presented exemplarily. [GrK05]

As one of the synopsis’ most important conclusions a significant disregard of the strategic planning phase in air traffic sciences is stated which is confirmed by previous scientific publication. Current procedures of air transportation capacity and performance analysis in particular concentrate on the day-to-day operations primarily. Within the synopsis the different approach with regard to strategic planning and scheduling for rail traffic is clarified. This phase’s systematic consideration and analysis results in the determination of a rail traffic scheduling performance which uses “scheduled delays” as relevant performance criterion. At the moment any analogous procedure approaching the scheduling phase’s performance analytically or measuring and evaluating any unaccomodated or retimed demand is unknown within aviation sciences. For this reason the current research work focuses on the airport scheduling and slot allocation. Scope and objectives as well as some preliminary results are described in chapter 3.

3 Strategic scheduling in air traffic

Besides the conclusions from the rail/air traffic synopsis on hand (see above), the meaning of the scheduling phase has been realised within the aviation community in recent years. While the majority of available studies and reports focuses on the economic and financial disadvantages of current procedures and thus proposes alternatives [Dot01] [Ner04], some publications include primary approaches to assess the air transportation scheduling performance [Aci04] [Eca05]. A close relation between scheduling and operations is stated in EUROCONTROL Performance Review Unit's "Report on Punctuality Drivers to European Airports" wherein the drivers to air transportation punctuality are broken down into the scheduling of air transportation operations, the operational performance before the aircraft goes off-block and the operational performance after the aircraft goes off-block [Prc05].

For those reasons the Virtual Institute "Airport Planning and Management" was encouraged to focus on the scheduling of air transportation operations. The project on hand is derived from the rail/air traffic synopsis but is justified by the actual needs of the aviation community as well. To confine the field of investigation within the broad area of air transportation scheduling, the current analysis concentrates on airport scheduling and slot allocation only. It does not consider internal airline planning (business plan, draft schedule, planning of resources) or airspace capacity planning (strategic, pre-tactical, tactical air traffic flow management) which both are part of the air transportation scheduling phase as well. In addition the declared airport capacity is used as an input parameter within this investigation, thus the post operations analysis of determining the upcoming season's declared capacity at a given quality of service is out of scope also.

It is this project's objective to allow an evaluation of an airport's scheduling performance. This requires the determination and formulation of one or more adequate airport scheduling performance criteria. Within this investigation the scheduling phase's impact on the operations is considered. Based on a detailed analysis of all relevant processes a model of the airport slot allocation is supposed to be developed to allow the estimation and prediction of the course of airport scheduling procedures. At the moment two main focuses of the investigation are the loss of capacity utilisation during scheduling (scheduling inefficiency) on the one hand and the predictability during scheduling on the other hand.

Currently the aforementioned work is at an early stage and thus data analysis is still in progress. This chapter introduces the current analysis on the airport scheduling procedures and includes some preliminary results. While the investigation on the airport capacity utilisation already includes 5 coordinated German airports, the analysis on the predictability during scheduling focuses on Düsseldorf airport only.

3.1 Part 1: Capacity utilisation

3.1.1 Available data, input parameters

The analysis is based on the airport slot allocation data for summer 2005 season as provided by the German slot coordination office (FHKD). 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

The slot allocation's complete course of events from the initial request up to the final status of coordination activities including all possible options for action is illustrated in Figure 5.

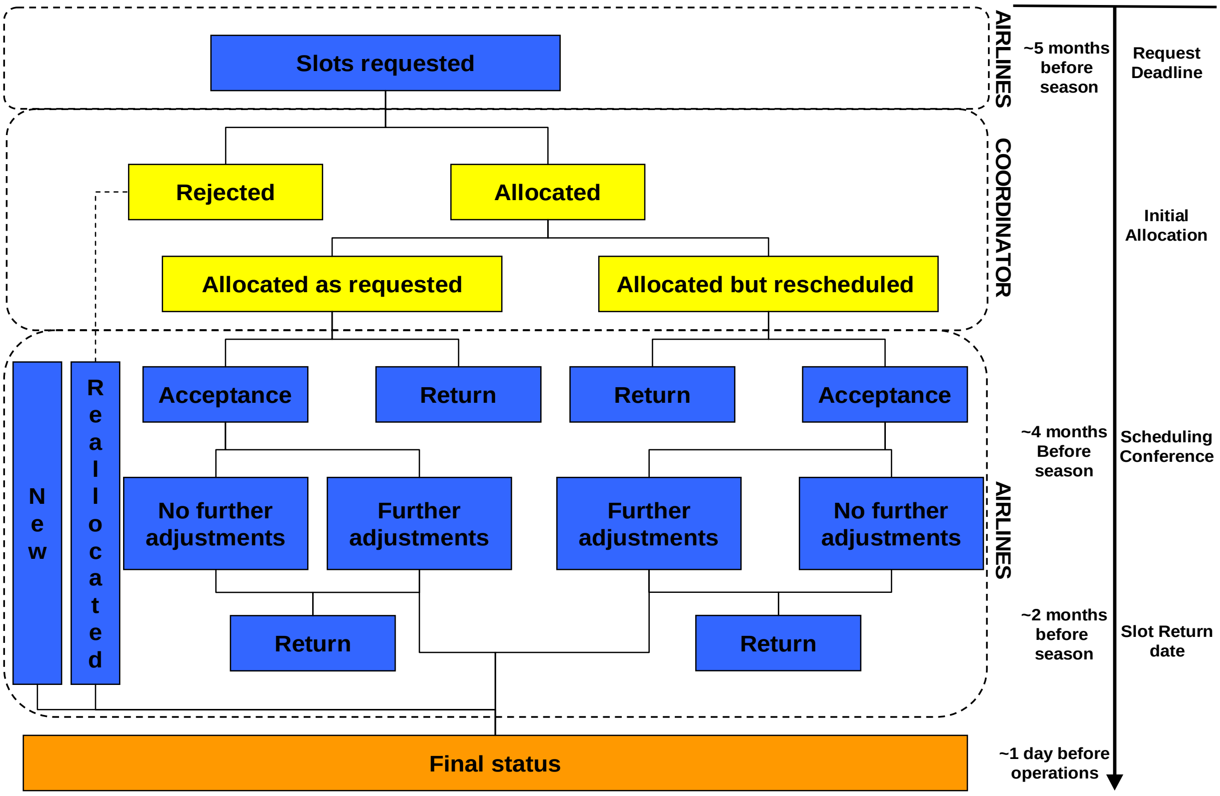


Figure 5: Slot Allocation Procedures from initial request to final status

Due to the dataset's weekly update, the final status of coordination activities 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.

In detail each planned flight movement is specified by the relevant airports (final/origin, previous/next), flight number, scheduled block times, days of service, aircraft type and market segment. Available slot allocation data including all planned flight movements at German coordinated airports allows a complete reproduction of the available demand at each stage of the coordination process.

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 values are used as published by the German airport coordination office.

3.1.2 Proceeding

Available slot allocation data is transformed into a daily schedule for each coordinated airport. Thus a planning status representing the planned demand is available for each airport slot allocation processes' key moment. Using given declared capacity values this planned demand allows the computation of a level of planned capacity utilisation for each relevant stage of the coordination process. Knowledge about 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 objective the complete slot allocation process can be reproduced including a precise determination of number, proportion and type of returned, new, retimed and reallocated slots.

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 additionally. Certain precedence to operations of less noisy aircraft 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 local time). This excludes night curfew restrictions' impact on the analysis' results as far as possible.

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. All coordinated airports in Germany feature a similar structure of declared capacity values, usually a mixing of different types and different durations 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 (30 min, 10 min) or a specification of arrival/departure flights (ARR/DEP) might be possible. Declared capacity values might vary depending 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.

For airport coordination in Germany the aforementioned 10 minutes intervals are used as basis for the coordination process. The number of scheduled flights and thus allocated slots usually has to comply with up to 3 different declared capacity values (10 min / 30 min / 60 min). While the 10 minutes declared capacity matches the 10 minutes coordination unit (flights are scheduled in 5 minutes steps but summed up in 10 minutes coordination units) and thus can be applied as *static* blocks, for the 30 (60) minutes declared capacity 3 (6) adjacent coordination units are summed up. This 30 (60) minutes interval is then shifted by 10 minutes intervals. Accordingly declared capacity of 30 (60) minutes is applied as *rolling* blocks.

3.1.3 Results

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 requested initially, FRA is the only airport featuring nearly constant excess demand throughout all season days (weekdays and weekend) and all times of the day. Thus about 67 % of all rolling 60-min-blocks (mixed movements) within the period under investigation are overloaded, when considering any declared capacity (arrival, departure, mixed), this value increases to about 90 % of all available block periods.

With regard to all slots available, DUS features even higher excess demand than FRA for summer 2005 schedule period. But this excess demand concentrates on very congested peak days/hours, a significant difference between weekdays and weekend can be noticed and thus the proportion of overloaded blocks is less than in FRA. In terms of daily demand pattern, MUC, STR and TXL show a similar significant difference between weekdays and weekend. But with the total capacity utilisation being lower and with less 60-min-blocks being overloaded, periods of excess demand are limited to few peak hours. A comparing summary of demand characteristics at German coordinated airports is illustrated in Figure 6 and Figure 7.

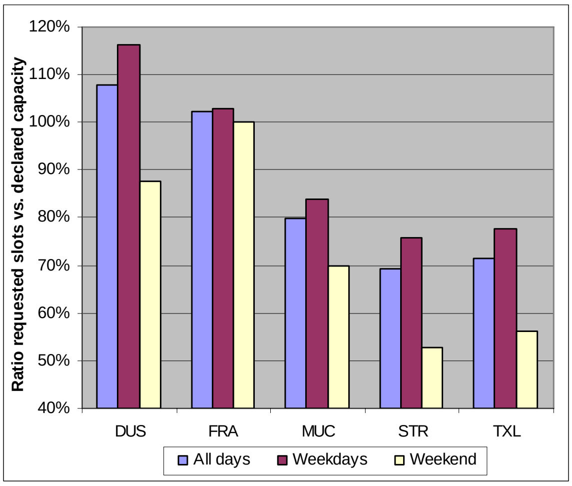


Figure 6: Capacity utilisation at the initial request (all days/weekdays/weekend)

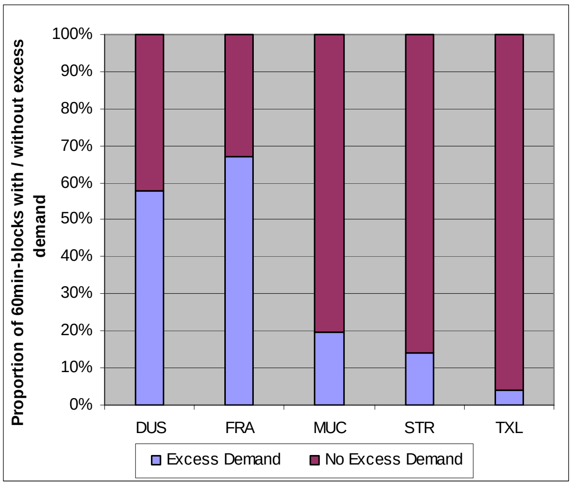


Figure 7: Proportion of rolling 60-min-blocks with/without excess demand

Initial slot requests are processed by the coordinator and finally lead to the initial slot allocation. 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 which leads to a slot time proposal different from the requested one (compare Figure 5). The latter requires a reasonable number of slots still available at the initial request to reschedule flights. At airports with demand excess throughout the day retiming is hardly ever possible.

According to this the summer 2005 schedule season's initial slot allocation proceeds at German coordinated airports. With DUS and FRA featuring excess demand throughout the day, a large number of slots are rejected at these airports because there are no reasonable options available to reschedule these slots. 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 to that, 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. The performance at the initial slot allocation is illustrated in Figure 8 and Figure 9.

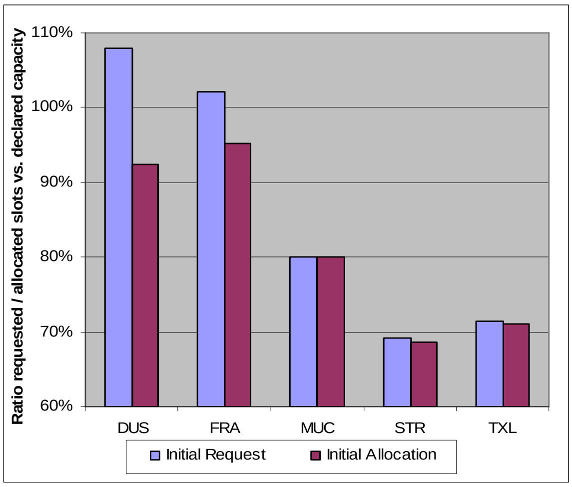


Figure 8: Capacity utilisation at initial request and initial allocation

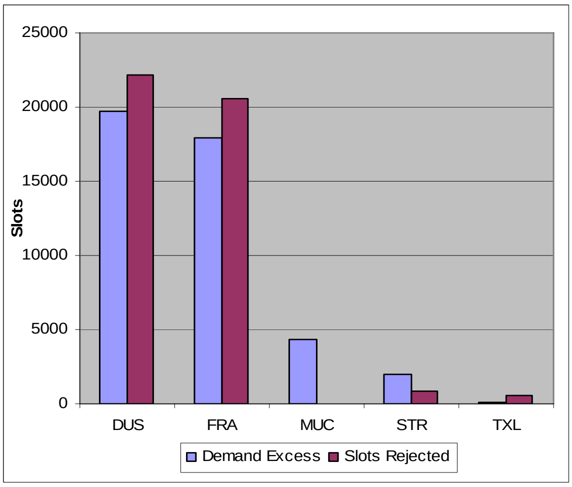


Figure 9: Number of slots rejected compared to number of slots in periods with excess demand

The investigation on hand covers the whole slot allocation process from the initial request up to a final status of coordination activities as defined in chapter 3.1.1. With regard to the utilisation of available (declared) capacity, Figure 10 shows its status at each key moment of the slot allocation process (Initial request, initial allocation, post conference, slot return date, final status). Figure 10 is based on average values of all season's rolling 60-min-blocks and differentiates between blocks with excess demand (ED – solid lines) and with no excess demand (nED – dashed lines).

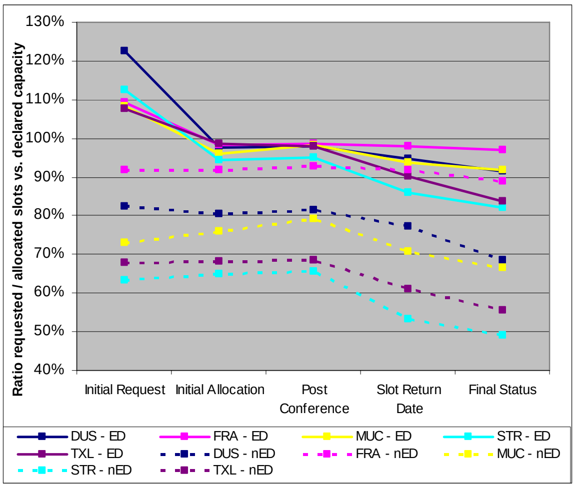


Figure 10: Capacity utilisation (rolling 60-min-blocks with (ED) / without (nED) excess demand) at slot allocation key moments

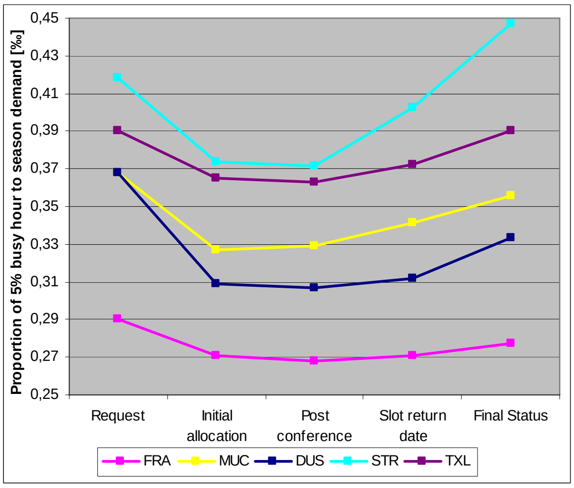


Figure 11: Demand peak level at slot allocation key moments

To comply with the declared 60 min capacity (mixed movements), capacity utilisation in blocks with excess demand is shortened to 100 % or below at the initial allocation. Due to the necessity to allocate slot pairs (arrival and departure) which are linked by a reasonable turnaround time, the coordinator usually does not achieve 100 % capacity utilisation. High capacity utilisation in FRA (> 90 %) even in no-overload periods clarifies the stability of slot demand. 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). For all blocks the situation improves slightly at the post conference status which obviously results from successful schedule negotiations and adjustments at the conference.

Starting at the post conference status capacity utilisation decreases at all relevant airports until the slot return date and further on up to the final status of coordination activities. The number of returned slots cannot be replaced by new or reallocated slots. This loss of capacity utilisation concerns blocks both with excess demand and without overload, although the latter are affected more intensively (dashed lines). Less overloaded airports (STR, TXL) feature a higher percentage of returned slots after the post conference status, while the highly utilised capacity in FRA sees minor changes only. This conclusion it confirmed by an investigation of the demand peak level at the different key moments of the slot allocation process (Figure 11). Within the analysis on hand the indicator for the demand peak level is defined as the 5 % busy hour demand's proportion of the total seasonal demand [‰].

Demand peak levels decrease at all airports from the initial request to the initial allocation. Slots causing demand tops (which are above declared capacity values) are either rejected (mainly DUS, FRA) or retimed to less utilised periods (STR, TXL, MUC). Thus demand curves feature more stability and constancy. Highly utilised FRA shows a significant lower level than the other airports. While the demand peak levels remain nearly constant or even improve at the post conference status (due to the filling of available gaps), from that time on it rebounds to dimensions which are near the starting value at the initial request. Airlines seem to concentrate on most interesting peak hours of the day finally, thus the demand pattern is less constant but features some real peaks again. This results from the return of slots and the loss of capacity utilisation.

The loss of capacity utilisation might be one important parameter to measure an airport's scheduling performance. Within this investigation the loss of capacity utilisation is defined as the percentage reduction of the utilisation of the declared capacity from the initial allocation to the final status of coordination activities within a certain period. This loss of capacity utilisation develops if the number of returned slots exceeds the number of new or reallocated slots. As far as the return of slots is conducted before the slot return date, it complies with the relevant Council Regulation Nr. 95/93 [Eu93]. All additional slot returns, from the slot return date until the final status, violate the current rules. An illustration of the loss of capacity utilisation is shown in Figure 12.

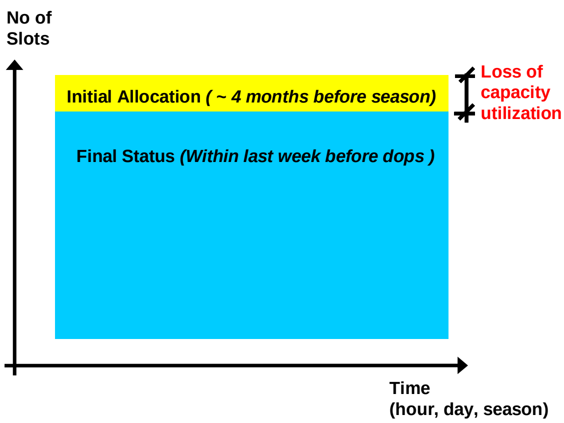


Figure 12: Definition of "loss of capacity utilisation"

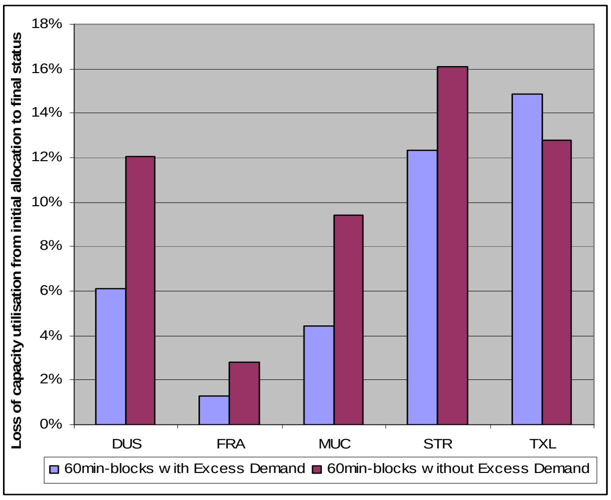


Figure 13: Loss of capacity utilisation (rolling 60-min-blocks)

With regard to the airport scheduling performance, the loss of capacity utilisation should be weighted differently for periods with/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 at the initial allocation a certain number of slots have been rejected or retimed at least, the given declared capacity is not utilised at the end of the coordination activities completely. With regard to German coordinated airports, up to about 15 % of allocated slots are returned and cannot be reallocated (Figure 13). The loss of capacity utilisation worsens in periods with no overload and shows minor severity at utilised airports and during periods with excess demand in particular (DUS, FRA, MUC).

3.2 Part 2: Predictability during scheduling phase

3.2.1 Available data, input parameters

The analysis on the predictability during the scheduling phase uses the results of the precedent investigation on the capacity utilisation as input parameter. Thus the period under investigation is the summer 2005 scheduling period again. Additionally cooperation with Eurocontrol's PRU (Performance Review Unit) allows the usage of CFMU data. CFMU data covers all IFR flights at relevant German airports and specifies amongst others scheduled and calculated block, take-off and landing times. "Calculated" means: As computed on the basis of ATC information by the CFMU internal system TACT. The availability of CFMU data allows the matching of airport scheduling and airport operations. Current status of the investigation includes relevant data for Düsseldorf airport only.

3.2.2 Proceedings

A major challenge within this part of the project is the linking of available slot data and relevant CFMU data. This is required to analyse the scheduling phase's impact on the operations and thus to evaluate the level of predictability achievable during the strategic airport slot allocation processes.

For about 95 % of all flight movements at Düsseldorf airport, the use of developed tools allows an automated linking of slot allocation data and CFMU data using flight numbers as adequate interface. The remaining 5 % require manual data processing. This mainly results from short-term changes of flight numbers or from subsidiary and lease airlines operating services on behalf of actual slot holders.

The approach to analyse the predictability during scheduling is at an early stage and not stable yet. The investigation includes two preliminary main focuses at the moment:

1. A comparison of the scheduling phase's result (final status as defined above) and the actual traffic at the day of operations (abbr.: dops) based on the total number of flight movements.
2. The compliance with scheduled declared capacity values at the dops and the dimension of variations from the input as agreed during scheduling.

3.2.3 Results

The comparison of the total number of flight movements scheduled at the final status and operated at the dops allows an estimation of the proportion of no-shows (flight movements scheduled but not operated) and of short-term slot allocation (flight movements not scheduled at the final status but operated and thus scheduled between final status and operations). Within this investigation the scheduling status at the final status is considered as reference basis (= 100 %).

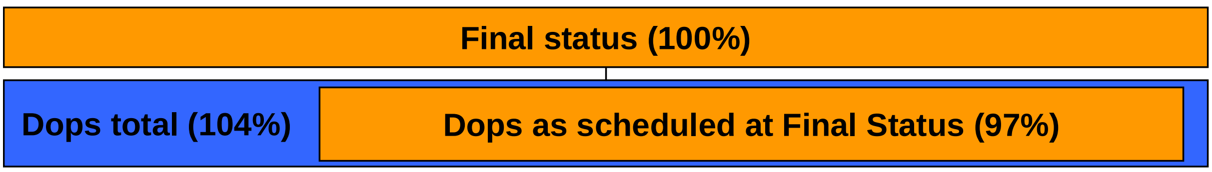


Figure 14: Actual traffic (as scheduled/total) at the days of operations (dops) compared to schedule at final status

Figure 14 illustrates the according results for summer 2005 scheduling season at Düsseldorf airport. With regard to the final status of scheduling activities, only 97 % of all slots being allocated at that moment have been operated at the dops which means a fall in capacity utilisation of another 3 %. But this considers flights only that had been scheduled at the final status. With regard to all IFR flights operated at the dops, Düsseldorf airport features a 4 % traffic increase compared to the scheduling/slot allocation at the final status. This results from short-term slot allocation which includes amongst others mainly private flights, taxi/charter flights, transfer flights and some rescheduled commercial passenger flights. Those flights over-compensate the number of no-shows at Düsseldorf airport in summer 2005 scheduling season. Considering the results of this project's part 1 on the capacity utilisation, still the loss of capacity during scheduling cannot be recuperated.

Scheduling phase smoothens and de-peaks the initial slot demand by complying with declared capacity values (60 min, possibly 30 min, 10 min) which requires the cutting of demand peaks and – if possible – the rescheduling of flights to less utilised periods (compare chapter 3.1.3). It is the main focus within this part of the analysis to check the sustainability of this demand smoothing during operations and thus approach the predictability during scheduling.

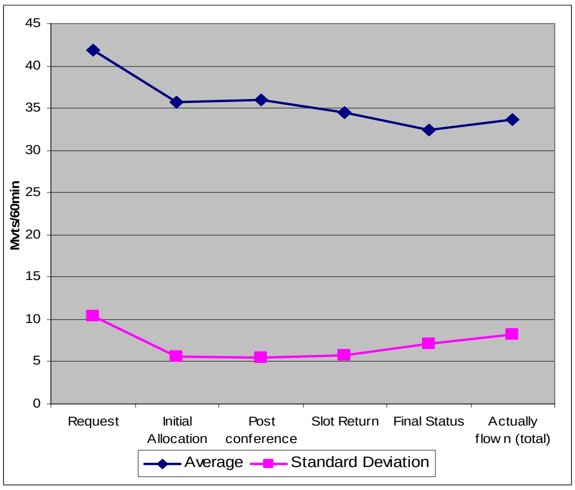


Figure 15: Average number of hourly movements (rolling 60-min-blocks) and according standard deviation at slot allocation key moments and days of operations (all IFR traffic)

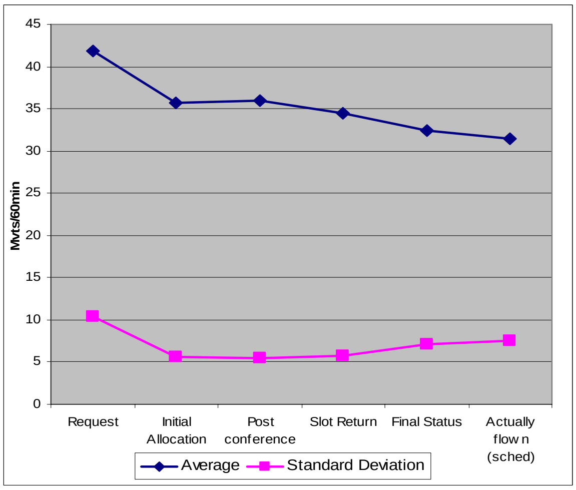


Figure 16: Average number of hourly movements (rolling 60-min-blocks) and according standard deviation at slot allocation key moments and days of operations (traffic as scheduled at final status only)

Figure 15 and Figure 16 illustrate the total season's average number of flight movements (arrival and departure flights) per all rolling 60-min-blocks at Düsseldorf airport as well as the according standard deviation. Values at the key moments initial request, initial allocation, post conference, slot return date and final status refer to the scheduling phase and thus are identical in both figures. While the "Actually flown (total)" value in Figure 15 includes all IFR flights (as scheduled at the final status and short-term slot allocation), Figure 16 considers only those flights that have been scheduled at the final status ("Actually flown (sched)"). According to the results illustrated in Figure 14, the average number of movements per 60 minutes increases for all flights compared to the final status, while it falls for scheduled flights only during operations. In either case the associated standard deviation increases – for all flights slightly more than for scheduled flights (at final status) only. This supports the assumption that the demand smoothing achieved during scheduling cannot be maintained during operations.

To evaluate this behaviour with regard to the scheduling performance and predictability, the current analysis has to be extended and specified. Within the investigations' next stage an inclusion of all coordinated German airports is intended which will allow a comparing assessment.

4 Conclusions

The Virtual Institute's interdisciplinary approach to address capacity research for air and rail traffic is confirmed by the results of the synopsis of capacity management and analysis. The precise description of major similarities and differences between the two traffic systems can be used as basis for the ongoing separate researches and thus allows the use of synergy within these works. Additionally with the synopsis relevant fields of study have been detected and the continuative work within the Virtual Institute was encouraged.

As one of the major conclusions a certain disregard of strategic scheduling and slot allocation within air traffic capacity sciences became obvious. While railway sciences analyse the scheduling phase analytically and thus a scheduling performance is determined using "scheduled waiting time/ delay" as performance criterion, there is no according methodology with regard to air traffic scheduling. Any common standardised analytical approach to measure and evaluate airport capacity planning processes is missing at the moment. In addition being encouraged by the aviation community's realisation of the scheduling phase's major impact on the operational performance, within its ongoing researches the Virtual Institute amongst others focuses on the air traffic's strategic scheduling and slot allocation.

Incorporating the declared airport capacity as input parameter, the current project includes all slot allocation's relevant stages (initial slot request, initial slot allocation, slot conference, slot return date, season start) and reaches up to the realisation of the coordinated schedule during day-to-day operations. With regard to summer 2005 schedule season at German coordinated airports these processes are analysed precisely. Based on the investigation's results it is intended to model the slot allocation process and thus to allow a prediction of its progression finally. Via development and formulation of adequate performance and quality parameters evaluation of the strategic scheduling phase can be accomplished.

Primary results as described in chapter 3 confirm the scheduling's relevance regarding the utilisation of scarce airport capacity. The loss of capacity utilisation between initial slot allocation and days of operations represents scheduling inefficiencies during periods of initial excess demand in particular. Despite obvious scarcity a certain proportion of airport capacity is not used at the days of operations. Different German coordinated airports are affected by the loss of capacity utilisation during scheduling differently. From aviation community's and in particular airport's perspective the loss of capacity utilisation plays a decisive role for the evaluation of the scheduling phase and thus it is in the centre of further investigations.

Besides the decrease in capacity utilisation current research includes the level of predictability achievable during scheduling. The matching of scheduling data and operational data allows estimating the variability of demand during operations compared to what has been agreed during scheduling. The use of the level of predictability to measure and evaluate the scheduling performance depends on the results of further investigations. At the moment there are only preliminary results available covering Düsseldorf airport, anticipated analysis with regard to predictability will include all German coordinated airports.

Additional investigation of scheduling data will focus on the rejection and rescheduling of requested slots as well. With a certain amount of slots being allocated but rescheduled by the coordinator, it is assumed that scheduled block times possibly include a kind of "scheduled delays" which resemble scheduled delays as used as performance criterion during railway scheduling. Scheduled delays represent a slot time deviation from its initially requested time during scheduling already. A major impact on the day-to-day operational performance can be expected. It is this project's objective as well to approach scheduled delays in air traffic and to evaluate its suitability to be used as performance criterion for airport scheduling processes.

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