

Capacity analysis of airport slot planning and air traffic demand

A study on the bunching effect in the Dutch airspace

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Capacity analysis of airport slot planning and air traffic demand

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Thesis

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Abstract

Schiphol Airport was in 2017 the airport with the biggest inbound ATFM delay of all major airports in Europe. One of the reasons causing the inbound ATFM delay is the 'bunching' problem at the border of the EHFIRAM. The objective of this research is to determine if the encountered planned bunches at the -3-hour planning phase has a relationship with the airport slot planning. This research focusses on the airport slot declaration and the planned demand based on the last filed flight plans, covering a period from the 25th of October 2017 till the 27th of October 2018. The analysis is conducted using a quantitative research method and contains 254,000 arriving flights in both winter and summer season. The analysis determines to which extent bunching and overdemand occur in the airport slot declaration, and at the border of the EHFIRAM. The results reveal that bunching and overdemand already exists within the airport slot declaration and is caused by the skewness within the airport slot-brackets. The analyses render similar patterns in which overdemand occurs within the time-brackets. The subsequent relationship between the airport slot planning and air traffic demand is around 48%, within the assumptions and limitations of the research. This means that 48% of the flights which are planned in a period with overdemand within the airport slot allocation, also tend to arrive in a period with overdemand at the border of the EHFIRAM.

Keywords: Airport ATFM delay, Inbound traffic, Airport Capacity, Flight plan, Schedule buffers, Air Traffic Flow, Airspace Capacity.

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List of Abbreviations

A

AAS	Amsterdam Airport Schiphol
ACNL	Airport Coordination Netherlands
AOs	Airplane Operators
ATM	Air Traffic Management
ATFM	Air Traffic Flow Management
ATS	Air Traffic Service
AUAS	Amsterdam University of Applied Sciences

C

CFMU	Centralized Flow Management Unit
CISS	Central Information System Schiphol
CoE	Centre of Excellence

E

EIBT	Estimated In-block Time
EOBT	Estimated Off-block Time

F

FIR	Flight Information Region
FIFO	First in - First Out
FPL	Filled Flight Plan

I

IAF	Initial Approach Fix
IATA	International Aviation Transportation Association
ILS	Instrument Landing System

K

KDC	Knowledge & Development Centre
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L

LVNL	Luchtverkeersleiding Nederland
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O

OTP	On-time performance
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P

PRIO	Priority
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S

SIBT	Scheduled In-block Time
SOBT	Scheduled Off-block Time

T

TMA	Terminal Movement Area
-----	------------------------

Definitions of terms

B

Bunch

Short period (i.e. from 5 till maximum 20 to 30 minutes), in which the traffic demand is higher than in periods around it.

Bunching

Accumulation of air traffic within a period from 5 till maximum 20 to 30 minutes, in which the traffic demand is higher than in the periods around it.

E

EHFIRAM

Partition of the Dutch airspace, used to regulate air traffic arriving and departing Amsterdam Schiphol Airport

O

Overdemand

Period in which the traffic demand is higher than the declared capacity.

S

Structural overdemand

More than half (i.e. 50%) of the time in a season or year the term overdemand is applicable on the same place and the same period of the day.

Skewness within slot brackets

Airport slots are disproportionately distributed within the slot bracket. This could be on the left side, in the middle or on the right side of the slot bracket.

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Summary

In 2017, Schiphol Airport was the airport with the biggest inbound ATFM delay of all major airports in Europe. One of the reasons causing the ATFM delay is the uneven distribution of air traffic demand within the -3-hour planning phase. Flights tend to arrive in accumulated chunks. This problem is also referred as to ‘bunching’. A bunch is a short period (i.e. from 5 minutes till maximum 20 to 30 minutes), in which the traffic demand is higher than in periods around it (according to LVNL). In most of the cases, bunching is combined with overdemand. ATFM delays are assigned to flights which are waiting for departure to Schiphol at their outstations. This results in reactionary delay and is very hard to recover due to the limit of 500,000 airplane movements per year at Schiphol airport, which is almost reached. Therefore, it is important to use the available capacity as efficient as possible. Schiphol airport differs from the other major airports in Europe (i.e. London Heathrow, Frankfurt Main, Paris Charles de Gaulle). The airport slots are allocated within 20-minute slot brackets, where at the other Major airport the capacity is declared per 10- or even 5-minutes. Therefore, thought is that the airport slot declaration has something to do with the encountered bunches at the FIR border.

The objective of the research was to investigate if the encountered bunches in the -3-hour planning phase at the border of the Dutch FIR has a relationship with the airport slot planning. This objective resulted in the following main research question:


What is the relationship between airport slot planning and air traffic demand, and what options are there to minimise the bunching effect in the Dutch airspace?

The research was conducted using quantitative research methods by analysing the declared airport slot capacity and the entry times from the EHFIRAM. The data is gathered from season Winter 2017 and Summer 2018, which covers a period from the 25th of October 2017 till the 27th of October 2018. This time frame comes closest to the limited capacity situation which is experienced at the moment. In the analysis, only arriving flights are taken into account. The research steps focused on the magnitude and frequency in which bunching and overdemand occurs within the airport slot allocation and at the border of the FIR. Heatmaps are used to render the extent of the overdemand. Thereafter, the research continued determining to what extent flights in a peak of airport slots are relatable to flights in a peak of overdemand at the border of the FIR.

The analyses revealed that bunching and overdemand already exists within the slot planning when reviewed per 20 minutes- rolling per 10 minutes. The bunching and overdemand is caused by the skewness within the static 20-minute slot-brackets. The allocated airport slots in the slot-brackets are not evenly distributed. Which means, when reviewed per 20 minutes – rolling 10 minutes, the intermediate time-brackets experience overdemand in sometimes extreme measures. Table 1 below represents the average number of declared airport slots in S18, divided into 10 minutes. The intermediate time-bracket from 06:30 till 06:50 is experiencing overdemand of 7 airport slots, assumed that the capacity of 23 slots is maintained.

Table 1: Average number of declared airport slots in S18 per 10 minutes.

Slot-bracket	06:00	06:20	06:40	07:00	07:20
	9/14	9/14	16/6	14/8	7/4


 06:30 – 06:50: **30** slots

The research concludes that around 48% of the flights are planned in a bunch with overdemand within the airport slot allocation also appear in a bunch with overdemand at the EHFIRAM border. Whereat the skewness within the slot allocation the main reason is of the overdemand in the slot allocation. However, it should be noted that the research was built on several assumptions and limitations, which could influence the results of the analyses. The capacity of the slot declaration and FIR have influence into what extent overdemand occurs. Besides that, the rounding in which flight occur in particular time-brackets was not taken into account. No particular proceedings have been applied to solve this problem.

Although this research delivered a solid base of information to the fact that the airport slot declaration has something to do with the bunching and overdemand at the border of the Dutch airspace, more research is necessary in order to deliver a firm relationship. The following most important recommendations resulted from this research:

- More, in depth, research into the relationship during the inbound peaks, whereat the fluctuating capacity has less influence on the results.
- A thorough research into the possibilities and consequences of dissolving skewness within the slot brackets.

1 Introduction

Amsterdam Schiphol Airport is a level 3 coordinated airport, which means that the amount of air traffic movements is restricted due to capacity reasons. This capacity restriction requires a slot coordinator to determine which airline can operate to Schiphol Airport and when. Every season, summer or winter, the slot coordinator provides airlines with slots. At Schiphol Airport, these slots are provided on a 20-minute basis, issued per 5 minutes. This means an airline should plan its arrival within these 20 minutes in its flight schedule. A global planning is made to ensure demand and capacity meet each other. The declared capacity is determined every year by Airport Coordination the Netherlands (ACNL), in close corporation with Air traffic control the Netherlands (LVNL) and Schiphol Airport, depending on airspace, runway and gate capacity. Schiphol Airport is different, compared with other level 3 coordinated airports. Where at Schiphol the capacity is declared per 20 minutes, the capacity at other airports is declared per 10-, or even 5-minutes.

The flow controller at LVNL makes approximately three hours in advance a tactical planning of the airspace at LVNL, dependent on the provisional flight plans handed in by the Airplane Operators (AOs) and local weather. If every AO would adhere to their allocated slot, an even spread and smooth air traffic flow should be established. If not, ATFM delays are assigned to flights which are still waiting for departure to Schiphol at their outstation. If flights are already en-route, they will be slowed down, vectored through the Dutch airspace or even assigned to fly holding patterns.

Given is, that Schiphol Airport the biggest inbound ATFM delays generates from all the major airports in Europe. In 2017 Schiphol Airport generated 13.8% of all airport arrival ATFM delay in the European network (Eurocontrol, 2018). Aerodrome Capacity and Disruptions are a significant portion of the total average airport delays generated in 2017 (Figure 1).

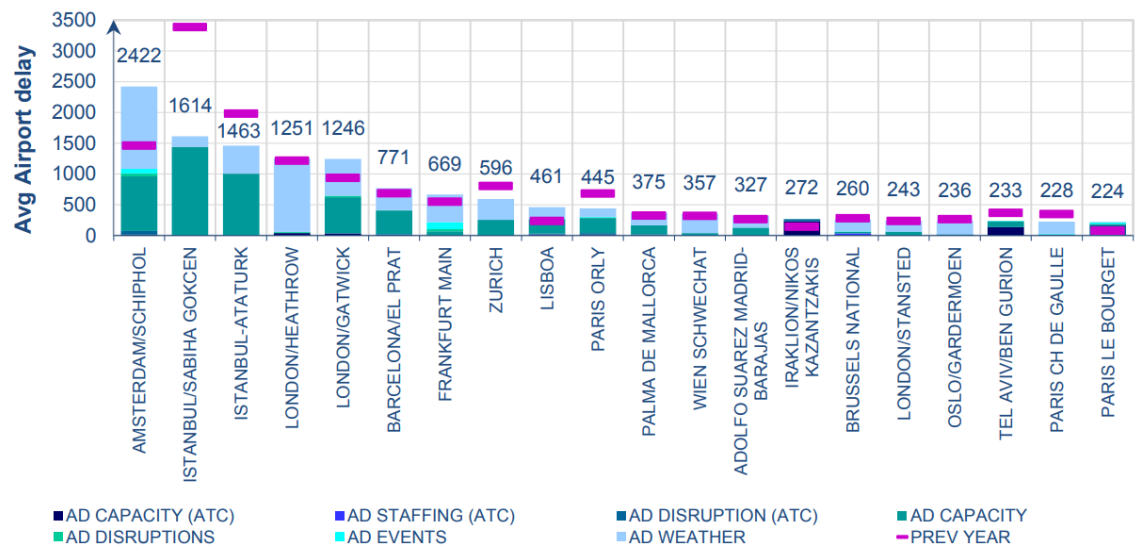


Figure 1: Top 20 airport delay locations during 2017, (Eurocontrol, 2018).

No research has been done regarding the bunching in relation with the airport slot declaration at Schiphol Airport. However, this research is part of more extensive research, initiated by the LVNL, into the factors causing structural overdemand during peak periods which result in Airport ATFM delays. In the research the following organisations are participating; LVNL, KLM, Schiphol Airport, ACNL, easyJet, Martinair Cargo, the Ministry of Infrastructure and Water management and the KDC, opening in two participating graduate researchers.

1.1 Problem statement

Experiences from the air traffic controllers and flow controllers at LVNL tell that in certain periods of the day, especially during peak hours, flights arrive in accumulated chunks instead of an even distribution. This results in a too crowded Dutch airspace during peak hours, and flights are assigned to be vectored through the airspace, fly holding patterns or even assigned an ATFM slot delay, waiting for an available spot at the runway or airport. This appearance is not favourable, and there should be an even distribution of air traffic instead of the accumulation. This is referred to as 'Bunching' and could result in overdemand.

1.2 Research objectives

The participating stakeholders of this conducted research want to determine if the encountered planned bunches at the border of the Dutch airspace has a relationship with the airport slot declaration. Data analysis should yield insight into the magnitude and frequency in which bunching and overdemand occur.

1.3 Research relevance

LVNL seeks to counter the increased delays and wants to improve its performance. By making capacity management one of its priorities LVNL wants to increase its capacity by system development, make better use of existing but latent capacity and improve capacity planning to balance demand and capacity. This research will support LVNL to create insight into the bunching problem and will investigate the possible relationship of airport slot planning in the existing bunches at the EHFIRAM border.

Bunching has a significant influence on the plan stability of Schiphol Airport. Operational aspects e.g. gate planning, security lanes, check-in counters and terminal occupation are based on the planned demand of flights which will arrive at Schiphol. If bunching occurs in this planning, those operational aspects are incorrectly planned, and no plan stability will be achieved.

Concerning the limited airport and airspace capacity, it is crucial to create more insight into the existing problems and find new ways to use the available capacity as efficiently as possible.

1.4 Research questions

The main research question is:

What is the relationship between airport slot planning and air traffic demand, and what options are there to minimise the bunching effect in the Dutch airspace?

It is essential to realise what the impact of the bunching effect is before a clear relationship can be defined. What is the magnitude and what is the frequency in which bunching occurs? Do the flights in peaks in slots also appear in peaks in demand at the EHFIRAM border?

The objectives stated above are translated into the following sub-questions (SQ) used to answer the main research question:

- SQ1. What is the frequency and magnitude in which bunching and overdemand occur in the airport slot allocation?
- SQ2. What is the frequency and magnitude in which bunching and overdemand occur in the tactical planning phase at the border of the EHFIRAM?
- SQ3. To what extent are flights in a peak of airport slots relatable to flights in a peak of overdemand at the border of the EHFIRAM?

Background questions are used to help answer the sub-questions and understand the theory behind the analyses. The background questions are stated below:

- 1. How does the Dutch ATM system look like for arriving flights into Schiphol airport?
- 2. How does the airport slot system work at Schiphol Airport?
- 3. What is the role of schedule buffers in the bunching problem?
- 4. What factors does influence the arrival time at Schiphol Airport?

1.5 Research scope

The goal of the research is to examine a possible cause of the bunching problem in the tactical planning phase (approx. 3 hours before arrival). Only arriving flights at Schiphol are used for the analysis. Flights arriving at regional airports (Rotterdam, Eindhoven, Maastricht, Groningen) are not taken into account. No departures are considered in this research. When counting bunching, it means planned bunching which is already visible before (most) airplanes are in the air.

The analysis is based on data collected from season Winter 2017 and Summer 2018, which covers a period from the 25th of October 2017 till the 27th of October 2018 and 254,000 flights. This period covers both a winter season, which is quieter, and a summer season, which is very busy. By this way it can be measured if bunches and overdemand do occur in a greater extent during the busy summer season.

This research will only focus on the total demand at the border of the Dutch airspace. The questions why flights are arriving in bunches and why flights do not arrive in their allocated airport slot is accommodated into the thesis research of Marc Riebeek (Riebeek, 2019).

1.6 Assumptions, Limitations, and Delimitations

Because the tactical planning at LVNL is based on the last filed flight plan data, this data is used in the analysis as well. To ensure the other data sets which are used match the flight plan data, assumptions, limitations and delimitations have been made.

The process of matching the different datasets resulted in a loss of data. In the dataset from Schiphol which includes the airport slot data and flight schedules and the entry times of the EHFIRAM, some flights could not be matched. Data which fails to match during the data collection is not used in the analysis. However, this does not result in a big loss of data, since the data is containing enough flights to be usable.

SQ3 exists of data which is adjusted by adding and subtracting existing schedule buffers, delays and flight-time. The schedule buffers are determined by using Scheduled Off-Block Times (SOBT) and the Estimated In-Block Times (EIBT). The dataset existing the SOBTs provided by the airlines is created months before the season started. Potential amendments of the flight schedule are therefore not taken into account. Consequently, some flights do not match the

data-sets used in the analysis. The EIBT provided on the flight plan is not realistic and is based on a straight flight path directly from the point of entry to Schiphol. The EIBT used in the determination of the Schedule buffer is created by adding an average time from the 5 sectors to the runway.

The average times are based on historical data collected from 2017. The runway usage is stated for 18R (Polderbaan) because this runway has the longest taxi-time to the gate (average taxi time of 12 minutes). Appendix III provides the average lead times of the FIR. LVNL uses the standard times for their analysis. Therefore, it encourages the choice of using average times in the analysis of this research.

1.7 Thesis structure

The thesis is structured around the sub-questions in the same order as stated in this chapter. Chapter 2 will represent the methodology and design of the research. Important information to understand the research is stated in the Literature review in Chapter 3. In Chapter 4 and 5, the determination of magnitude and frequency of respectively bunching in airport slot planning and air traffic demand and are shown. Subsequently, the last research question is analysed in Chapter 6. Finally, the research findings, conclusions and recommendations are stated in each Chapter 7, 8 and 9.

2 Methodology and data

The methods used during the research are quantitative, which include data analyses. The main research question of the research can be answered using the research process described in this chapter. At first, the design of the research is presented, following the data collection and the sample sizes of the different datasets. At last, the analysis methods of the different sub-questions are explained.

2.1 Research Design

The analysis is entirely based on quantitative research for the three sub questions. Figure 2 provides the research process (from left to right), which is based on the sub questions stated in Chapter 1.

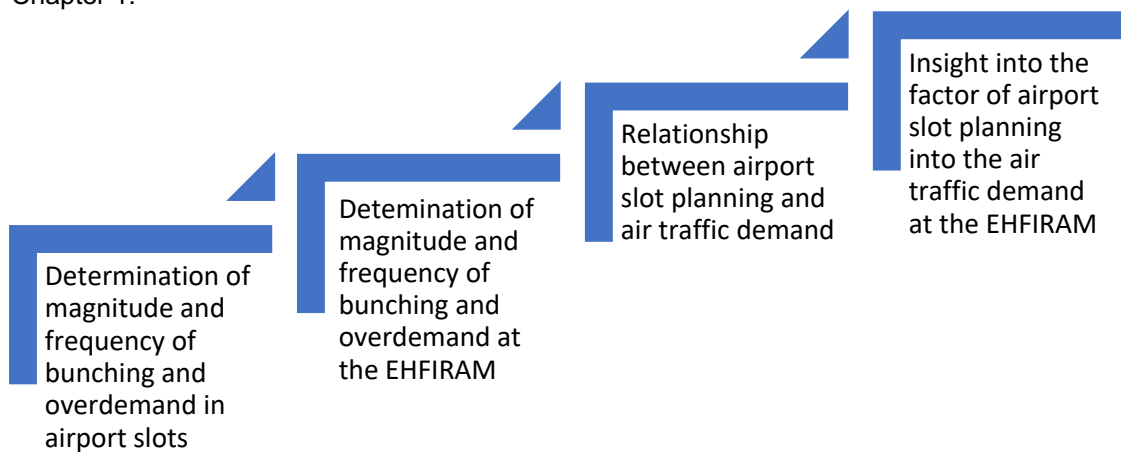


Figure 2: Research process

The first step of the research is to determine the magnitude and frequency in which bunching and overdemand exist in the airport slot planning. The quantitative analysis is done using slot data retrieved from AAS. This data consists of flight schedules, combined with the allocated airport slot and is collected from CISS (Central Information System Schiphol)⁴. The allocated slot information is originating from ACNL and is shared with AAS. Using bar graphs and heatmaps the problem of bunching and overdemand is visualised. First with time-brackets as stated in the slot declaration, and afterwards per 20-minutes, rolling 10 minutes. This is done to reveal the skewness within the slot declaration.

If the magnitude and frequency of bunching and overdemand is determined in the airport slot declaration, it is needed to determine the extent in which bunching and overdemand exist at the border of the EHFIRAM. The data used for the analysis of SQ2 is collected from NEST⁵. NEST is used for airspace structure design and development, capacity planning and post operations analysis. It is also commonly used for ad-hoc studies within the ANSPs. NEST can process large quantities of data gathered from multiple years in history (EUROCONTROL, 2012). The specific data collected from NEST which is used in the analyses are the entry-times of the Dutch Airspace (EHFIRAM) from flights arriving at Schiphol Airport. Also, the Sector-entries in which sector (1, 2, 3, 4 or 5) the airplanes entered the EHFIRAM is used. Making use of the same bar graphs and heatmaps as in SQ1, the visualisation of bunching and overdemand is performed.

When the magnitudes and frequencies of bunching and overdemand in both the airport slot planning and at the border of the EHFIRA are known, the relationship can be determined. This is done using a quantitative research method. The data used in SQ3 is consisting of schedule Off-Block times (SOBTs) gathered by LVNL.

⁴ CISS is a system used at Schiphol airport in which airlines and ground handlers provide information about scheduled flights.

⁵ NEST is a tool developed by Eurocontrol and used by the Network Manager and local ANSPs.

2.2 Sample and data manipulations

As discussed in the previous sub-chapter, three datasets are used in this research. To help understand the datasets, the sample sizes are stated below.

2.2.1 Slot data

For SQ1, the sample data is provided by AAS. AAS created a dataset including all arriving flights into Schiphol from season W17 and S18 (27.10.2017 – 25.10.2018). In this dataset flight schedules and airport slots are matched. The sample sizes stated in table 3 and 4 represents the dataset from AAS. Due to the complexity to match the last 2,500 flights and slots, around 50 flights are double matched. This is a tiny part of the total sample size and therefore neglectable. The data matching is performed by the airport capacity department of Amsterdam Airport Schiphol (AAS). Flights and airport slots which could not be matched are so-called NO-OPS and NO-RECS, whereby NO-OPS are airport slots without a matched flight and NO-RECS are a flight without an airport slot. The NO-OPS slot data is used in the data analysis of SQ1 because these airport slots are actually issued within the capacity declaration.

Tabel 2: Sample size of W17 dataset AAS.

W17 (27.10.2017 – 25.03.2018)	# flights	# Arrivals
Matched flights and airport slots	91,953	91,953
NO-OPS	1,065	1,065
NO-RECS	2,097	
Sample size		93,018

Tabel 3: Sample size of S18 dataset AAS.

S18 (26.03.2018 – 25.10.2018)	# flights	# Arrivals
Matched flights and airport slots	159,514	159,514
NO-OPS	1,277	1,277
NO-RECS	3,462	
Sample size		160,791

2.2.1 NEST data

The sample data used in SQ2 consist of two datasets comprising all arrivals into Schiphol from season Winter 2017 (W17) and Summer 2018 (S18) (27.10.2017 – 25.10.2018). The dataset containing the entry times is already filtered in NEST for arrivals into Schiphol. Almost 254,000 arrivals are included in this sample. The dataset consisting the sector entries, contains almost 640,000 flights crossing the Dutch Flight Information Region (FIR). This dataset contains flights which are of no interest to the research because it focusses on flights which are planning to cross the EHFIRAM border in the -3-hour planning phase. These are flights include police flights, coastguard flights, medical emergency flights, domestic flights and passing air traffic. Filtering of the data is conducted manually, since the concerning flights are well indicated. After filtering, the sample sizes stated in table 1 and 2 represent the data used in the analysis.

Tabel 4: Sample size of W17 dataset NEST.

W17 (27.10.2017 – 25.03.2018)	# flights Before filter	# Arrivals After filter
Entry-times	92,943	92,943
Sector-entry	229,362	92,881
matched flights (sample size)		92,857

Tabel 5: Sample size of S18 dataset NEST.

S18 (26.03.2018 – 25.10.2018)	# flight Before filter	# Arrivals After filter
Entry-times	160,610	160,610
Sector-entry	410,580	160,546
matched flights (sample size)		160,489

2.2.2 Schedule Off-Block Time data

The data consisting the schedule off-block times is provided by the airlines in an early stage of planning. The consequence is that the airline schedules sometimes do not match the schedule dataset of AAS because the changes in the flight schedule are not communicated to LVNL. Table 4 and 5 provides the sample sizes of W17 and S18.

Tabel 6: Sample size of W17 dataset SOBT.

W17 (27.10.2017 – 25.03.2018)	# flights	# Arrivals
Matched flights and airport slots	-	93,018
Sample size	-	86,922

Tabel 7: Sample size of S18 dataset SOBT.

S18 (26.03.2018 – 25.10.2018)	# flights	# Arrivals
Matched flights and airport slots	-	160,791
Sample size	-	148,755

2.3 Data Analysis

The data analysis is divided into three parts related to the sub-questions.

2.3.1 Bunching in slots

- i. **Per day.** The first step in the analysis is to visualise the bunching and overdemand by day. Do bunching and overdemand occur in the airport slot declaration on a daily basis? The following formula (1) is used to create the data which visualises the overdemand and bunching.

$$N_{Airport\ slots} = ((Bracket_start \leq Slot_time(UTC) < Bracket_end) \equiv Slot_date) \tag{1}$$

The formula counts the number of flights in which the slot time is equal or larger than the start of the bracket (for example 08:20), smaller than the end of the bracket (08:40) and equal to the date selected. The graphs created represent a quiet day in the winter (February 20, 2018) and a busy day in the summer (June 19, 2018).

- ii. **Per season.** Step two is the visualisation of overdemand and bunching on a larger scale. This is achieved using a heatmap which is based on the magnitude of overdemand per slot bracket of every day in the season. The heatmap is based on the formula (2) below.

$$N_{Airport\ slots} = (((Bracket_{start} \leq Slot_{time(UTC)} < Bracket_{end}) \equiv Slot_{date}) - Capacity) \tag{2}$$

The heatmap indicates in which bracket overdemand occurs. The dates of the season are displayed on the vertical side of the map. The slot brackets are displayed on the horizontal side. The heatmap is created using Python. The script can be found in appendix I.

- iii. **Magnitude and frequency.** The results of the heatmap are used afterwards to define the magnitude and frequency in which bunching and overdemand occur in the slot declaration. Translated into the following parameters:
 - The average demand relative to the slot capacity
 - The frequency in which overdemand occurs.

Subsequent of the analysis per slot bracket, the brackets per 20 minutes – rolling 10 minutes is analysed. Time brackets of 20 minutes are moving every 10 minutes. This method visualises the potential skewness in slot brackets. Figure 3 below visualise the method. The adjacent time brackets overlap each other by 10 minutes.

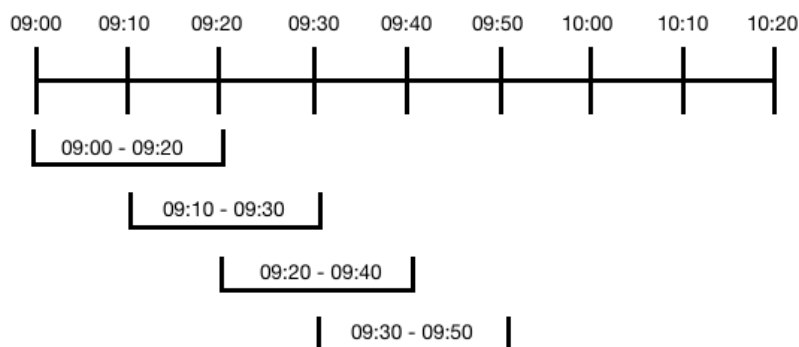


Figure 3: Visualisation of the rolling 20-minute method.

2.3.2 Bunching and overdemand in air traffic demand

The analysis of bunching and overdemand in air traffic demand is conducted per 20 minutes – rolling 10 minutes and with the same methodology as the airport slot analysis. Therefore, the same formulas are used.

- i. **Per day.** The first step in the analysis is to visualise the bunching and overdemand by day. Do bunching and overdemand occur on a daily basis? The formula (3) below is used to creating the data which visualises the overdemand and bunching.

$$N_{Flights} = ((Bracket_{start} \leq Entry_{time(UTC)} < Bracket_{end}) \equiv Slot_{date}) \tag{3}$$

The formula is counting the number of flights in which the entry time is equal or larger than the start of the bracket (for example 08:20), smaller than the end of the bracket (08:40) and equal to the date selected.

- ii. **Per season.** Step two is the visualisation of overdemand and bunching on a larger scale. This is achieved by using a heatmap which is based on the magnitude of overdemand per slot bracket of every day in the season. The heatmap is based on the formula (4) below.

$$N_{Flights} = (((Bracket_{start} \leq Entry_{time(UTC)} < Bracket_{end}) \equiv Slot_{date}) - Capacity) \tag{4}$$

The heatmap indicates in which bracket overdemand occurs. The dates of the season are displayed on the vertical side of the map; The slot brackets are displayed on the horizontal side.

- iii. **Magnitude and frequency.** The results of the heatmap are afterwards used to define the magnitude and frequency in which bunching and overdemand occur in the slot declaration. This results in the following parameters:
- The average demand relative to the slot capacity;
 - The frequency in which overdemand occurs.

2.3.3 Relationship between overdemand in airport slot planning and air traffic demand

The relationship between overdemand in airport slot planning and air traffic demand is determined by indicating which flights are planned in a bunch in the airport slot planning and in the -3-hour planning phase.

The determination of the relationship uses the result of the analysis of the airport slot declaration and air traffic demand. The heatmaps of the slot declaration per 20 minutes - rolling 10 minutes - and air traffic demand per 20 minutes – rolling 10 minutes - are used to assign flights to time-brackets which encounter overdemand. The method used is equivalent for the airport slots and flight demand and discussed below:

- (1) The first step is to assign a time-bracket to each flight in both datasets. The time brackets are assigned per 10 minutes and named from 1 to 144.
- (2) Next, the individual flights are matched with the brackets in the heatmap to determine if a flight is planned in a time-bracket with overdemand. This is performed using a matrix lookup function in Microsoft Excel based on the date of the flight and the bracket number assigned in step (1).
- (3) Subsequent, the flights which are planned in a time-bracket with overdemand are labelled and counted.
- (4) The number of flights which are planned in a period with overdemand in the airport slot declaration is the reference for the calculation of the percentage of relationship. The percentage of match is calculated with formula (5).

$$Percentage_{match} = \frac{N_{flights\ in\ overdemand\ EHFIRAM}}{N_{flight\ in\ overdemand\ airport\ slots}} \times 100\% \quad (5)$$

To ensure the analysis is conducted a correct way, a control analysis is created. The objective of the control analysis is to eliminate all variable factors which affect the arrival time at Schiphol, and therefore the demand sequence at the EHFIRAM border.

If the initial relationship is determined in a correct way, every subsequent scenario should yield a larger relationship between overdemand in airport slot planning and demand. This is obvious, because the entry times are peeled off and getting closer to match the scheduled arrival times. Eventually a 100% match should be accomplished.

The control analysis consists of four different scenarios. Using the initial dataset with entry-times of the EHFIRAM, the entry times are modified by eliminating the variable factors in the flight plans, which are causing differences in flight times throughout the flight. The variable factors modified in the analysis are Schedule-buffer time (1), Delay (2) and lead-time from the EHFIRAM to the gate (3). The three factors create three different scenarios which are analysed in the same way as the previous conducted analyses of the airport slots and demand at the EHFIRAM.

Scenario 4 stated below is the initial data of the entry times at the EHFIRAM and is therefore included in the process. The four (4) scenarios are explained below:

Scenario 4: The initial scenario (4) is the original dataset consisting the entry-times of the EHFIRAM. This scenario is identical to the -3-hour tactical planning as experienced by the duty managers of LVNL. This scenario consists of a realistic schedule buffer, delay and flight time.

Scenario 3: The next scenario consists of a dataset without schedule buffers. Including, realistic delay and realistic flight time. The modification is realised by eliminating the schedule buffers in the flight plan block time of the flights. The schedule buffer is determined by subtracting the delta between EIBT and EOBT from the delta between SIBT and SOBT. The entry times of scenario 3 are determined by applying the following formula (6):

$$Entrytime_{scenario3} = Entrytime_{initial} + ((SIBT - SOBT) - (EIBT - EOBT)) \quad (6)$$

Scenario 2: The dataset of scenario 2 consist of entry times without schedule buffers, without delay and realistic flight times. The delay is also eliminated from the entry time. The delay is stated as EOBT minus SOBT. The following formula (7) is used to calculate the entry times of scenario 2:

$$Entrytime_{scenario2} = (Entrytime_{initial} + (Schedule\ buffer)) - (EOBT - SOBT) \quad (7)$$

Scenario 1: The last scenario eliminates the last variable factor from the dataset. The flight time throughout the FIR. This is done using the formula (8) below. The variety is eliminated by using an equal flight time from EHFIRAM entry to the gate. This time is determined using the historic lead-times of the Dutch FIR, with landing on Runway 18R and taxi-time of 12 minutes to the gate. Appendix 3 includes the historical lead times. The time used in the analysis is the average lead-time, which is 35 minutes.

$$Entrytime_{scenario3} = ((Entrytime_{initial} + (Schedule\ buffer)) - (Delay)) - 35\ min \quad (8)$$

3 Information behind the research methodology

This chapter presents information about the subjects regarding the research. To help understand the problem definition and way of thinking, the arrival process of LVNL, the airport slot system at Schiphol, Schedule buffers and operational milestones are explained. Furthermore, relevant research about the problem is summarised.

3.1 Dutch ATM system

Every country has his own Air Traffic Management (ATM) provider with all different system handling the air traffic visiting their airspace or Flight Information Region (FIR). The Amsterdam FIR covers the airspace over the Netherlands and extends for a large part over the North Sea. In the Amsterdam FIR both LVNL and the Royal Netherlands Air Force are responsible for providing ATM services.

Figure 3 represent partition of the Dutch Airspace. The airspace is divided into 5 sectors named clockwise 1 to 5 and are regulated by LVNL. The Royal Netherlands Air Force is responsible for the military controlled parts of the FIR, north of sector 1 and 5, east of sector 1 and 4 and south of sector 2 and 3. These sectors and military parts of the airspace are controlled by one or multiple air traffic controllers located at Schiphol-East. In the middle of the sectors is laying the Terminal Movement Area (TMA). Airplanes flying in this region are under control of the approach controllers and air traffic controllers in the air traffic towers at Schiphol airport.

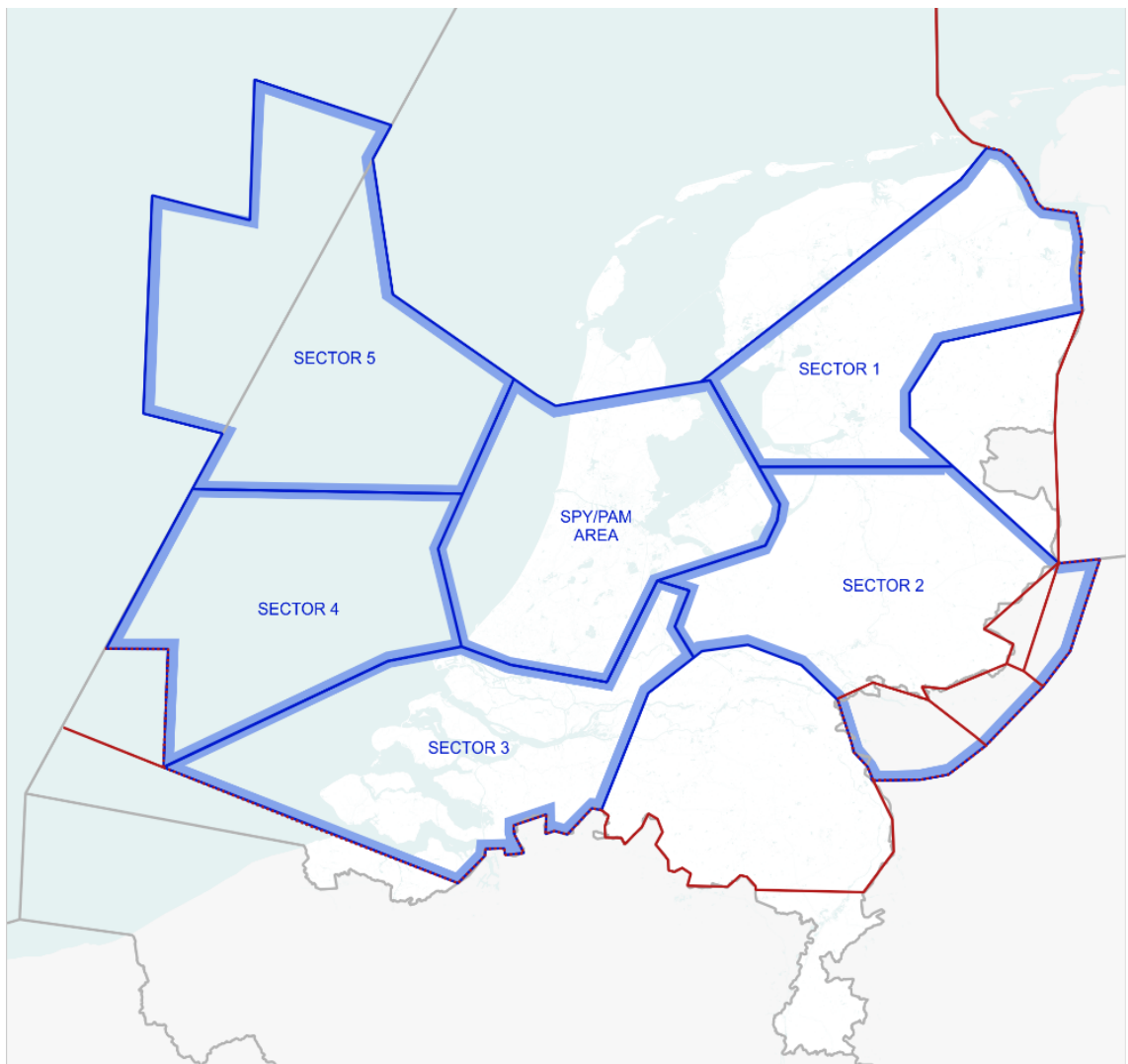


Figure 4: Sectors of the EHFIRAM.

The airplane arriving at the sectors are guided to the TMA prior arriving at Schiphol. To maintain a structured air traffic flow, three Initial Approach Fixes (IAFs) are created whereat the airplane are handed over to the approach controllers in the TMA. These IAFs are ARTIP, RIVER and SUGOL. ARTIP aggregates traffic from sector 1 and 2, RIVER from sector 3 and SUGOL from sector 4 and 5. Figure 4 represents the IAFs of the Amsterdam FIR.

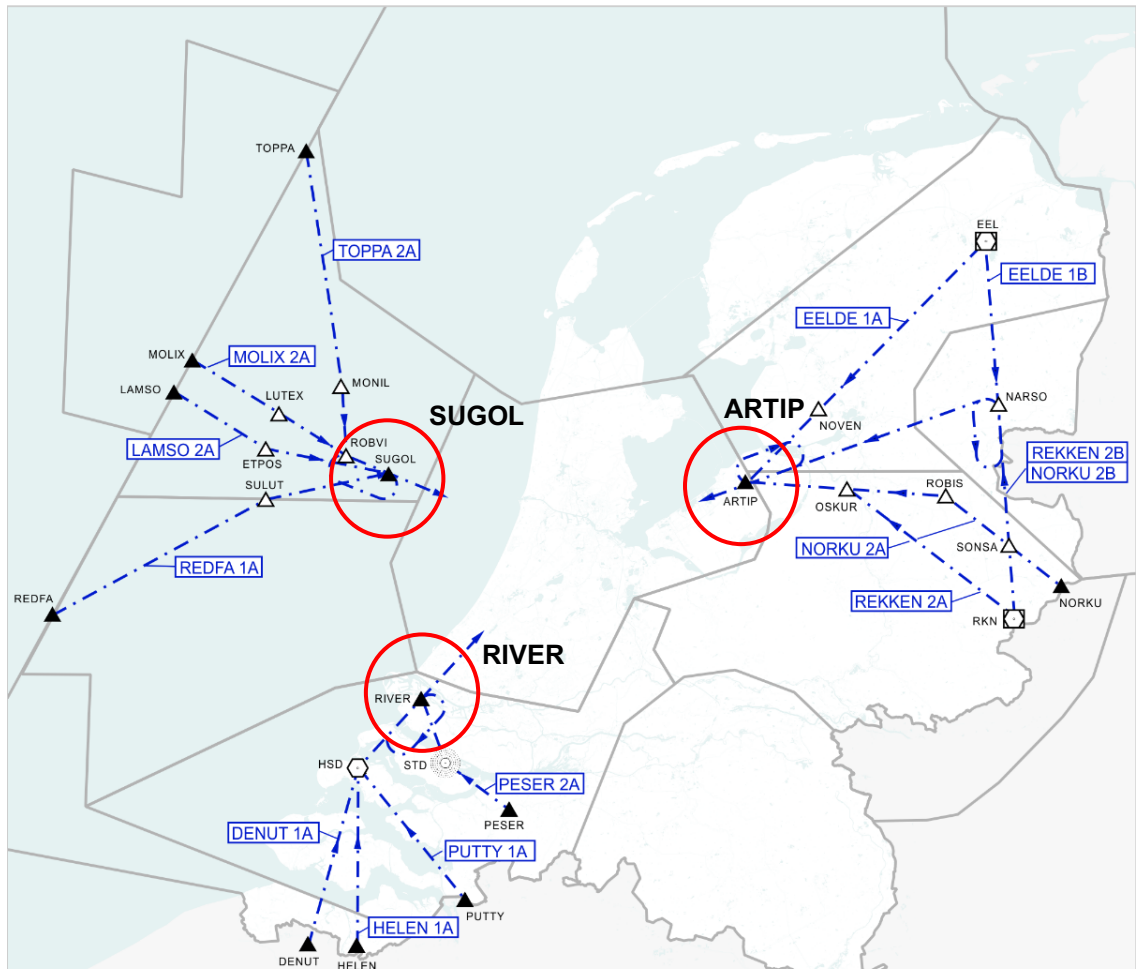


Figure 5: Initial approach fixes (IAFs) of the EHFIRAM

Within the TMA airplanes are guided to the active runway(s) through directions given by the approach controller (vectoring). The approach controller is responsible for lining up the airplane on the Instrument Landing System (ILS) of the active runway, When the airplanes are established on the ILS, the airplanes are handed over to the tower controllers. They give the airplane clearance to land.

The sectors of the Amsterdam FIR are capacity limited. During inbound and outbound peaks, the capacity differs. The capacity of the FIR for inbound and outbound traffic is stated in QRC 63 (Appendix II and III).

3.2 Slot allocation process at Schiphol Airport

The International Air Transport Association (IATA) has three levels for airport coordination (IATA, 2018). Coordination means the allocation of limited airport capacity to airlines and other operators to ensure a stable and smooth air traffic flow and maximise the efficient use of airports infrastructure. IATA states that airport coordination is not a solution to the fundamental problem of a lack of airport capacity (IATA, 2018). Coordination should be seen as an interim solution to manage congested airport infrastructure until a long-term solution of expanding airport capacity is implemented. The three airport levels are:

- **Level 1** airports are non-coordinated airports. The airports have no capacity constraints and is able to meet the demand of airlines and airplane operators at all time.
- **Level 2** airports are schedule facilitated, which means they have potential congestion during some periods in a day/week/season. This congestion can be solved by scheduling the flights arriving at the airport.
- **Level 3** airports are fully coordinated. The airports exceeding the capacity due to excessive demand and no solution can be expected in short time. At these airports a slot coordinator will allocate the airport slots to airlines and other airplane operators.

When particular airports are congested or the runway cannot deal with the demand, an airport is assigned as a level 3 coordinated airport. Since Schiphol Airport is a level 3 coordinated airport, the capacity is limited and coordinated by a slot coordinator. (IATA, 2018). In the Netherlands, Airport Coordination Netherlands (ACNL) provides the slots. ACNL determines when and which airline can operate at Schiphol airport in order to make sure the available capacity is used in the most optimal way and the air traffic flow is distributed as well as possible. The goal of the slot coordinator is to manage the declared capacity of the airport.

The declared capacity of Schiphol airport is determined by LVNL and Schiphol airport. The capacity is based on environmental (i.e. noise limitations) and operational capacity (i.e. runways, terminals and air traffic management). The declared capacity is given by the maximum number of airplane movements that the airport can handle within a timespan (Vû, 2016). This time span is called a bracket and each possible bracket is called a slot. ACNL declares the capacity on basis of 20-minute slot-brackets. This means that within the 20 minutes a maximum number of airport slots can be issued to the airlines and operators. The capacity is adapted to the inbound and outbound peaks. During inbound peaks 23 slots are available per 20 minutes and in the outbound peaks 12 slots are available to be issued. In Appendix IV and V, the declared slot capacity of W17 and S18 is stated.

3.3 Block hours in aviation

When an airline or airplane operator receive an airport-slot form the slot coordinator, the flight schedule will be determined. In theory, the flight schedule should always match the allocated airport slots (Ivanov, Netjasov, & Jovanović, 2016). In practice, this is not always the case. (Riebeek, 2019). Flight scheduling is a difficult process and depends on airplane imitations, predictable weather conditions, minimum connection times and crew-based limitations (Simmons, 2012).

After the flight schedules are finalised, the airlines communicate their flight schedules to the airport and ground handler. This is done by communicating the Schedule In-Block Time (SIBT) and Schedule Off-Block Time (SOBT). The SIBT is the time an airplane is scheduled to arrive at its first parking position (Eurocontrol, 2015) and the SOBT is the time and airplane is scheduled to depart from its parking position (Eurocontrol, 2015).

At the day of operation, a provision flight plan is created by the airline. The flight plan provides specified information, relative to an intended flight or portion of a flight of an airplane (Eurocontrol, 2015). Just for departure (Approx. 3 hours before) the flight plan is filed to Eurocontrol. This filed flight plan (FPL) is defined as filed with an ATS unit by the pilot or a designated representative, without any subsequent changes (Eurocontrol, 2015). In the FPL, the Estimated Off-Block Time (EOBT) and Estimated In-Block Time (EIBT) are stated. The EOBT is the estimated time at which the airplane will commence movement for departure. The EIBT is stated as the time the airplane is estimated to arrive at the gate (In blocks).

The EIBT includes the estimated taxi time from the active runway to the gate. Together, the SOBT and SIBT form the scheduled block time of a flight (SIBT minus SOBT). The schedule block time represents the time presented on the tickets of the passengers. The EOBT and EIBT form the flight plan block time (EIBT minus EOBT). The Flight plan block time is usually shorter than the schedule block time. The difference is the schedule buffer.

3.4 Schedule buffers

Due to the growth of the aviation industry in the past years, the airline market has become more competitive. This increased the importance of optimal flight schedules to maintain and increase high revenue and market shares. To achieve this, airplanes need to be flying as much as possible, resulting in minimal ground time. Often, this results in a stressed system with a low ability to recover from delays (Forsberg, 2016). To cover the potential delay, airlines schedule extra time into their flight schedule.

4 Bunching and overdemand in airport slots

The analysis of the bunching in slots is arranged into two perspectives. Per slot bracket, as defined in the Airport Slot Declaration (Airport Coordination Netherlands, 2018), and per 20 minutes - rolling 10 minutes. The analysis is performed to witness if bunching already exists in the declared slot declaration. The results will answer sub-question 1: “What is the frequency and magnitude in which bunching and overdemand occur in the airport slot declaration?”

4.1 Bunching and overdemand in airport slots per slot bracket

The declared slot capacity of W17 and S18 are stated in Appendix IV and V respectively. The A logical step into the analysis is to investigate whether the declared airport slots do not exceed the declared capacity.

4.1.1 Bunching and overdemand in airport slots per slot bracket/per day

In figure 6 and 7, the visualisation of bunching and overdemand at February 20th and June 19th is stated respectively. These dates represent a quiet and busy day in season W17 and S18 respectively. The visualisation per day is used as a first step in the analysis to create a clear view on the problem.

To indicate if a slot bracket is experiencing overdemand, the declared slot capacity is projected on the background of the graphs. If the allocated airport slots exceed the declared slot capacity, overdemand occurs, which is not acceptable within the airport slot allocation. The formula (1)⁶ as described in Chapter 2.5 is applied to value the number of declared airport slots per slot bracket.

Figure 6 exhibits the visualisation of allocated airport slots at February 20th. The bar graph reflects the number of allocated airport slots per slot bracket. The number of declared airport slots and the declared slot capacity is stated above the bars of the brackets which stand out in the figure. Multiple brackets are meeting the 23 available airport slots. The figure also reveals there are also slot brackets which are not full. There are clearly no signs of overdemand⁷ within the declared slot brackets. The number of allocated airport slots remain within the slot declaration at any time on this day. However, when refer to the definition of bunching⁸, bunching does occur during the day (reference A).

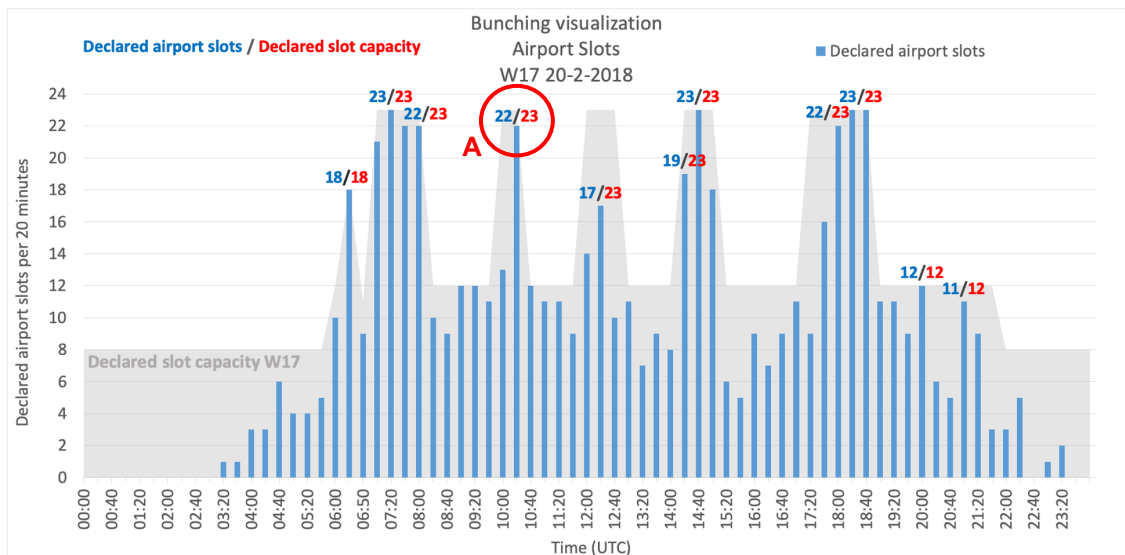


Figure 6: Bunching & Overdemand visualisation of airport slots at February 20, 2018 (W17).

⁶ $N_{Airport\ slots} = ((Bracket_start \leq Slot_time(UTC) < Bracket_end) \equiv Slot_date)$

⁷ Period in which the traffic demand is higher than the declared capacity.

⁸ Short period (i.e. from 5 till maximum 20 to 30 minutes), in which the traffic demand is higher than in periods around it.

Figure 7 exhibits the visualisation of June 19, 2018, which is representative for S18. Compared with February 20, 2017 (Figure 6), the capacity during the inbound peaks is (almost) fully used. Reference **B** displays almost full slot brackets. The allocated airport slots in the slot brackets have reached the declared airport slot capacity. The surrounding brackets are also full. In practice, this will limit the feasibility to recover for delays or disruptions in air traffic flow. Just as February 20, 2018, no overdemand is experienced during this day while bunching does occur in some slot brackets. (reference **C**). Although bunching does occur, it is not noticeable because of the small magnitude and well below the declared slot capacity.

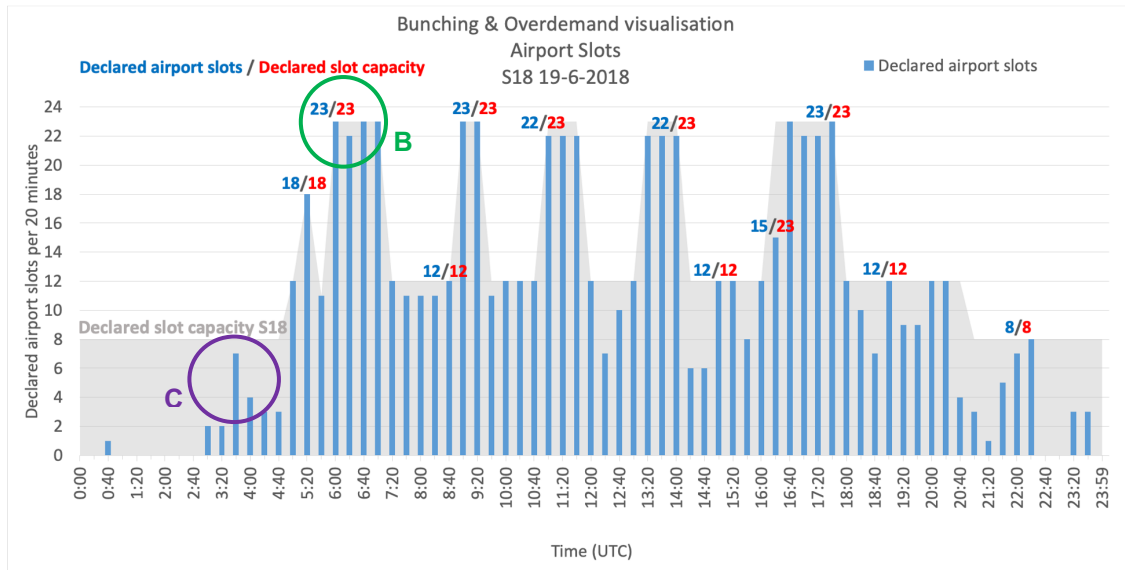


Figure 7: Bunching & Overdemand visualisation of airport slots at June 19, 2018 (S18).

4.1.2 Magnitude and frequency of overdemand in airport slots

The analysis in the overhead paragraph is the basis of the analysis of magnitude and frequency in which overdemand and bunching occurs. Formula (2)⁹, as described in chapter 2.5, values the number of allocated airport slots relative to the declared slot capacity. The results of the formula make it possible to reveal the slot brackets which are experiencing overdemand in the season (W17 and S18).

The analysis of bunching and overdemand in airport slots per declared slot bracket does not reveal a significant magnitude and frequency of overdemand. The airport slots are allocated in a correct way in most of the time. The next step in the analysis is to reveal the potential skewness within the declared airport slot brackets. This is done by analysing the data per 20 minutes – rolling 10 minutes.

⁹ $N_{Airport\ slots} = (((Bracket_{start} \leq Slot_{time(UTC)} < Bracket_{end}) \equiv Slot_{date}) - Capacity)$

4.2 Bunching and overdemand in airport slots per 20 minutes - rolling 10 minutes

The analysis in Paragraph 4.1 is conducted per consecutive slot bracket. But what happens when the analysis is done per 20 minutes – rolling 10 minutes? By this way, the skewness within the slot brackets is revealed and the magnitude and frequency in which overdemand occurs outside the declared slot brackets is determined.

Because of the rolling 20 minutes, the capacity of the brackets between the transition of inbound and outbound peaks does not match the actual capacity at that moment. This will project an unrealistic image of the magnitude and frequency of overdemand in the particular time brackets. To minimise the effect of this problem, the capacity during the transition of 10 minutes is interpolated with the capacity of the adjacent slot brackets. By this way the intermediate time brackets of 10 minutes show a fictional capacity that has to be included into the analysis.

4.2.1 Bunching and overdemand in airport slots per 20 minutes – rolling 10 minutes/per day

Formula (1)¹⁰, as described in chapter 2.5, is used to process the data of February 20, 2018 and June 19, 2018. In figure 8 and 9 respectively the results are projected. Again, the analysis per day is done as a first step to create a clear view of the problem. In the background of the graphs, the fictional slot capacity is projected, since the declared slot capacity does not match the analysed time brackets. Any bar which exceeds the slot capacity, is not favourable. The number of declared airport slots and the slot capacity is projected above the time brackets which stand out in the figure.

Bunches and overdemand are clearly visible in figure 8, which represents the allocated airport slots at February 20th in W17. The amount of flights per 20 minutes – rolling 10 minutes, does exceed the fictional slot capacity in multiple time-brackets per day. Reference E point out two time-brackets with overdemand and bunching. The worst time bracket is from 07:30 – 07:50. In this time bracket 31 airport slots are declared, whilst the slot capacity is only 23 slots during the inbound peak. Overdemand does occur in multiple time-brackets on this day.

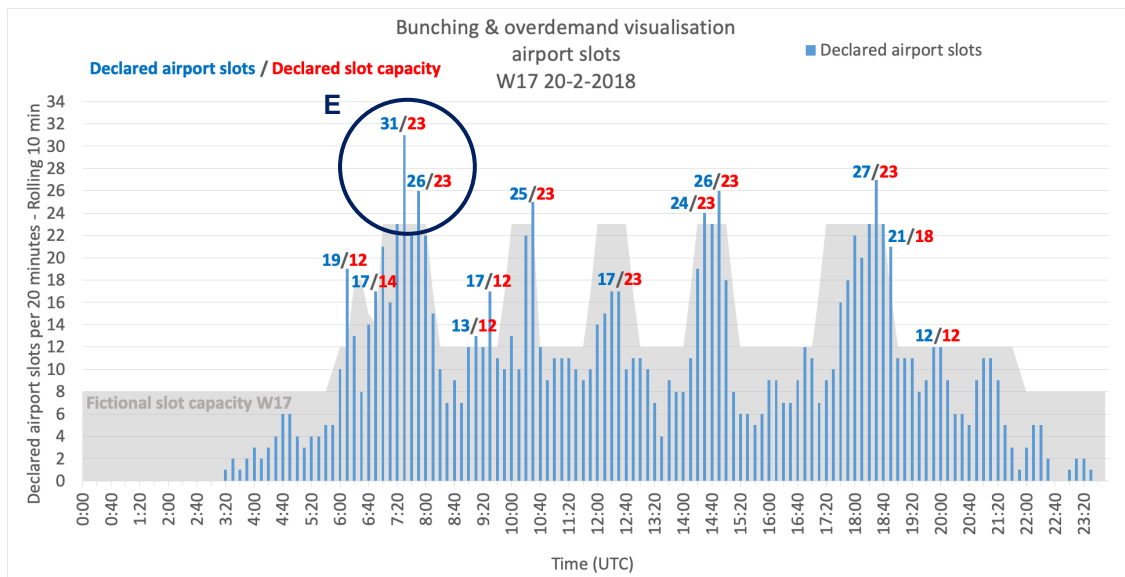


Figure 8: Bunching & Overdemand visualisation airport slots at February 20, 2018 (W17).

¹⁰ $N_{Airport\ slots} = ((Bracket_start \leq Slot_time(UTC) < Bracket_end) \equiv Slot_date)$

Figure 9 reveals bunching and overdemand at June 19th, reviewed per 20 minutes – rolling 10 minutes. Overdemand is present in every inbound peak at this day. The number of declared airport slots does exceed the capacity in a very large extent.

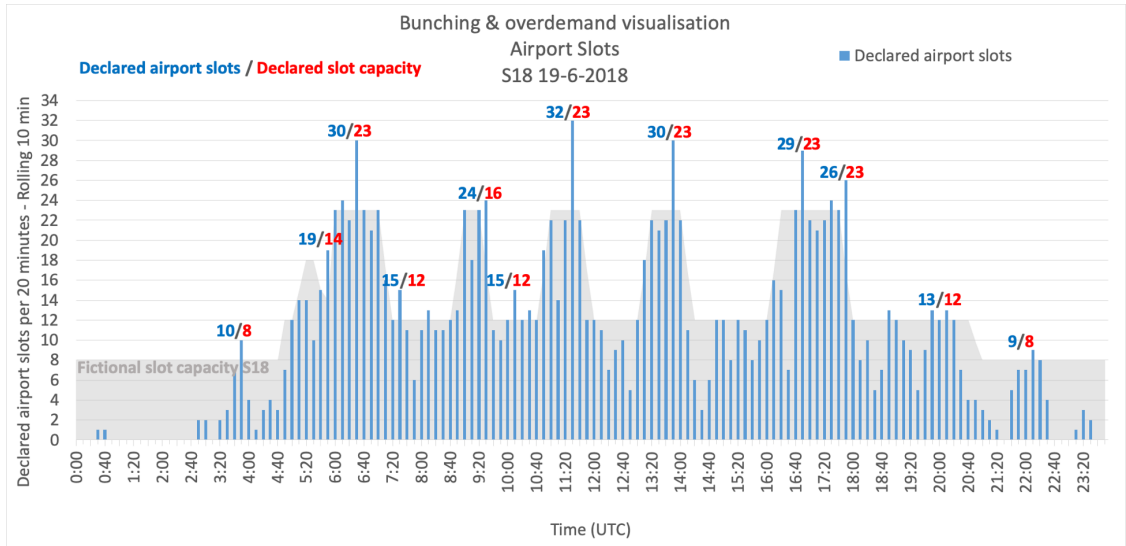


Figure 9: Bunching visualization airport slots at June 19, 2018 (S18).

The visualisation per day reveals the bunching and overdemand at two days, which are representative for W17 and S18. To determine to what extent bunching and overdemand occurs in both season W17 and S18, the analysis is expanded on seasonal basis in the next paragraphs, to investigate whether the overdemand and bunching are structural existing.

4.2.2 Magnitude and frequency of overdemand in airport slots

Formula (2)¹¹, as described in chapter 2.5, determines the number of declared airport slots relative to the fictional capacity. This results in an insight into what extent overdemand occurs per time bracket per season. The results are processed into a heatmap to visualise and give value to the results of formula (2).

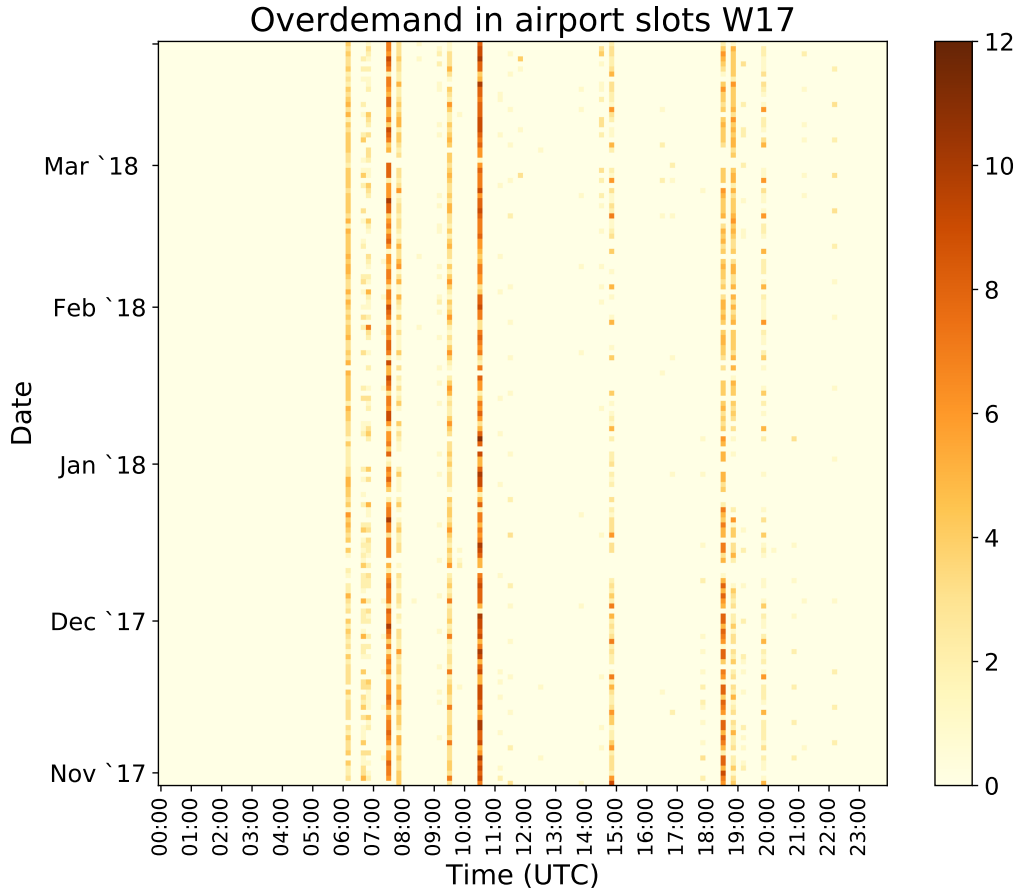


Figure 10: Heatmap overdemand in airport slots W17.

The heatmap of W17 in Figure 10 above, visualises the time-brackets which encounter overdemand in the season. The vertical axis represents the date in the season and the horizontal axis represents the time per 20 minutes – rolling 10 minutes. The time brackets per day which encounter overdemand are highlighted, ascending from small to large extent. Whereat red is a very large extent of overdemand and off-white a small extent of overdemand. In multiple time-brackets during this season, the structural overdemand is clearly visible. In particular the time brackets in the morning are experiencing overdemand to a large extent.

¹¹ $N_{Airport\ slots} = (((Bracket_{start} \leq Slot_{time(UTC)} < Bracket_{end}) \equiv Slot_{date}) - Capacity)$

Figure 11 below translates the results of the heatmap in figure 10 into the frequency and magnitude in which overdemand arises. The blue bars in the graph reveal the percentage of days with overdemand in the season per time bracket and is stated in the right side of the figure. The red line represents the average demand relative to the fictional slot capacity and is stated on the left side of the figure.

Time brackets, diffused over the day, encounter overdemand in more than 50 percent of the season (Reference **F**). The large blue bars reflect the time brackets highlighted in the heatmap in Figure 10. The average magnitude of overdemand in those time brackets is significant. The bracket which is experiencing overdemand the most frequent (07:30 - 07:50) has an average overdemand of six slots. The heatmap in Figure 10 shows there are outliers of 12 slots overdemand in that specific bracket.

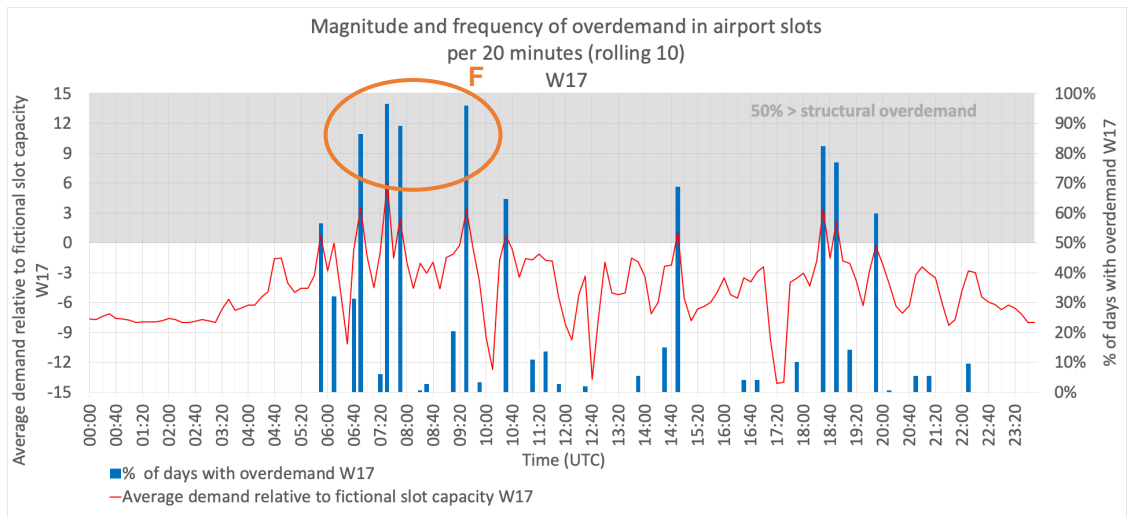


Figure 11: Frequency of overdemand in airport slots per 20 minutes – rolling 10 minutes in W17.

The results of the analysis of S18 are displayed in Figure 12. The overdemand experienced in S18 is diffused over more time brackets. The overdemand is larger in S18 compared to W17. More time-brackets experiencing overdemand and the overdemand is experienced in a larger extent.

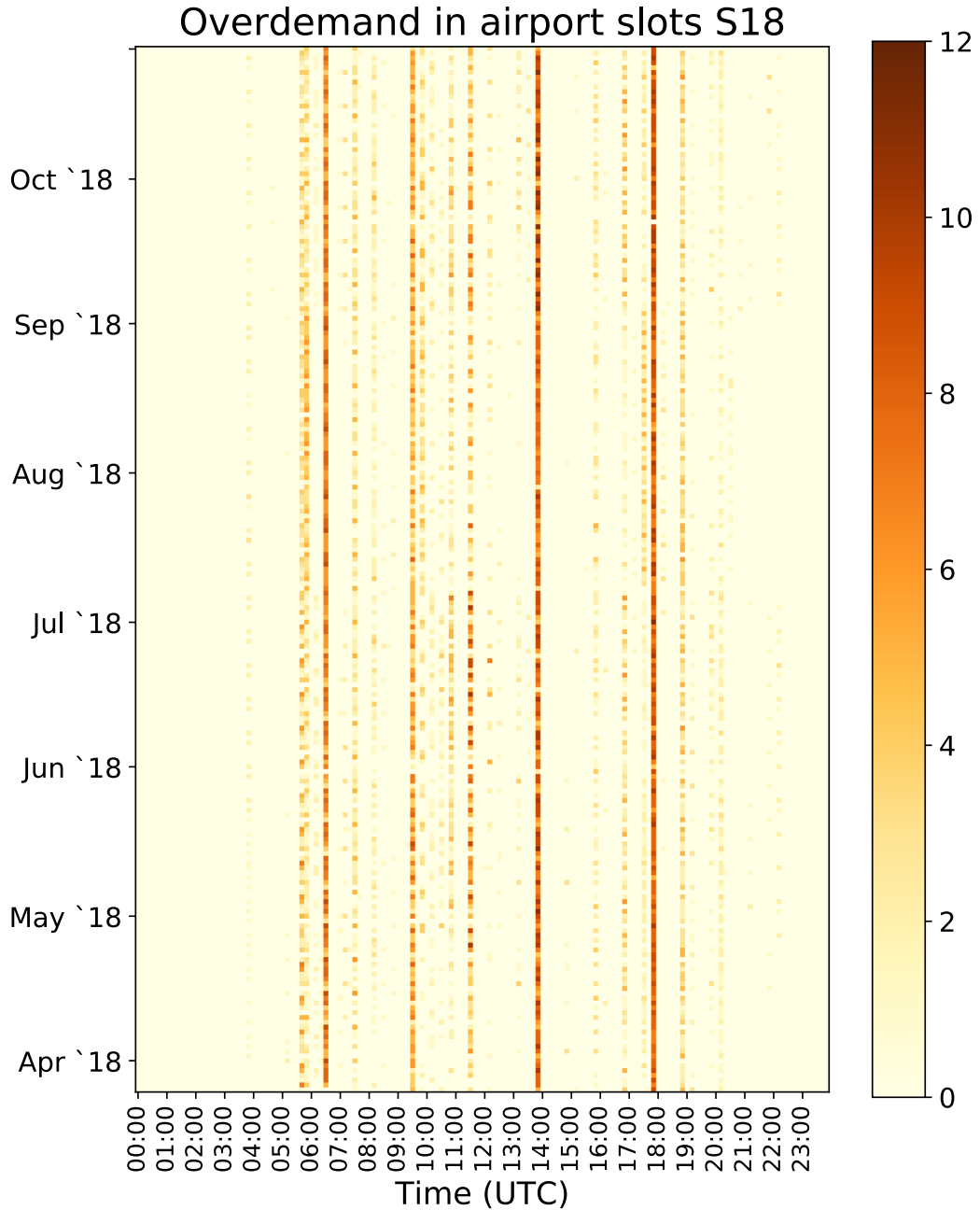


Figure 12: Heatmap overdemand in airport slots S18.

Figure 13 translates the result of the heatmap into the frequency and average magnitude in which overdemand arises per time bracket per season. Three time-brackets are experiencing overdemand in every day of the season (Reference H). The red line in the figure represents the average overdemand experienced in that time bracket. The average overdemand in S18 exceeds the nominal capacity in more time-brackets and with a larger average extend compared to W17. And two time brackets have an average overdemand of 8 airport slots. In the heatmap in Figure 12 outliers of 12 slots overdemand can be mentioned.

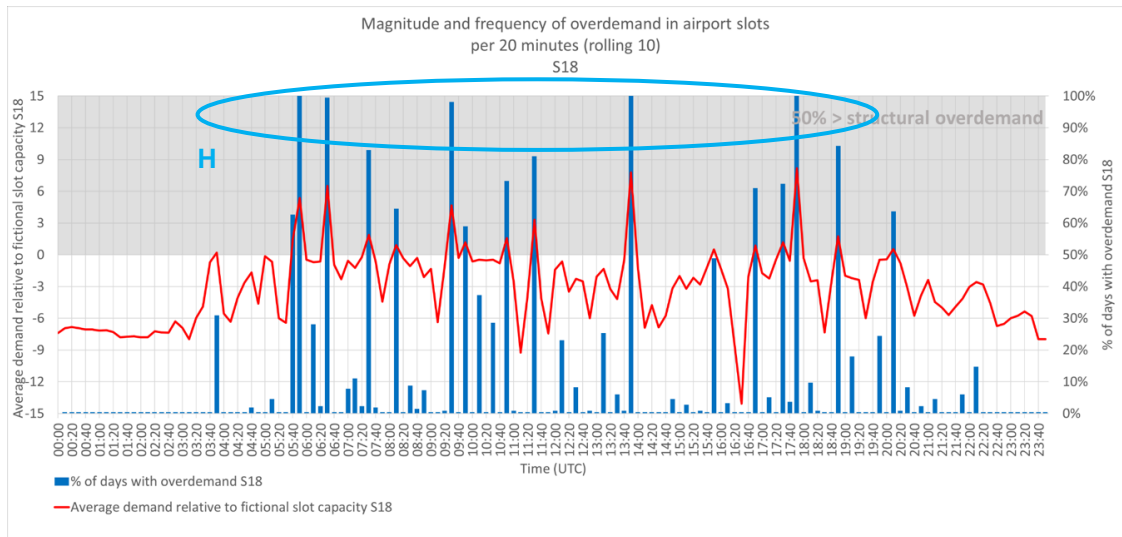


Figure 13: Magnitude and frequency of overdemand in airport slots per 20 minutes – rolling 10 minutes in S18.

The overall analysis of the airport slot allocation reveals no worth mentioning overdemand and bunching. The airport slots are neat distributed within the airport slot declaration. However, when reviewed per 20 minutes – rolling 10 minutes, overdemand and bunching arises within the slot allocation. In some cases, the overdemand is exists into a very large extent.

The subsequent step of the research is to determine into what extent bunching and overdemand occurs at the border of the EHFIRAM. Which reflects to the second sub question: “What is the frequency and magnitude in which bunching and overdemand occur in the tactical planning phase at the border of the EHFIRAM?”

5 Bunching and overdemand in air traffic demand

The analysis of the demand at the EHFIRAM is conducted with the same methodology as the analysis of the airport slot declaration. To indicate if bunching and overdemand occur on a daily basis, the visualisation per day is conducted. To indicate to what extent bunching and overdemand occur at the EHFIRAM, the analysis per season is conducted. The goal of this chapter is to answer the second sub question: “What is the frequency and magnitude in which bunching and overdemand occur in the tactical planning phase at the border of the EHFIRAM?”

5.1 Bunching and overdemand at the EHFIRAM per 20 minutes – rolling 10 minutes

The nominal FIR capacity, which is used in the analysis, is stated in QRC 63 (Appendix II and III). The FIR capacity is regulated per 20 minutes and per hour. During the inbound-peaks 23 flights are allowed to enter the FIR. Outbound- and off-peaks allow 12 flight to enter the FIR. In the night the capacity is stated at 8 flights per 20 minutes. At every turn, the maximum number of flights which are allowed to enter the FIR is stated at 68 per hour. A demand above the stated capacity results in regulations, in order to make sure the maximum available capacity is maintained. The rolling 20-minute method, as discussed in Chapter 5 is applied; Therefore, an interpolated capacity is used in the intermediate time-brackets.

5.1.1 Bunching and overdemand at the EHFIRAM per day

The planned demand, experienced approximately 3 hours in advance at the EHFIRAM at February 20, 2018 (representable for W17), is projected in graph 9. The data in the graph, is gathered using formula (3)¹² as described in Chapter 2.

In Figure 14, reference I, the demand is exceeding the capacity in a very large extent. 35 flights are expected to arrive within this 20-minute time bracket. Bunching and overdemand occur in several time brackets during the day. Most frequent in the first and last inbound peak.

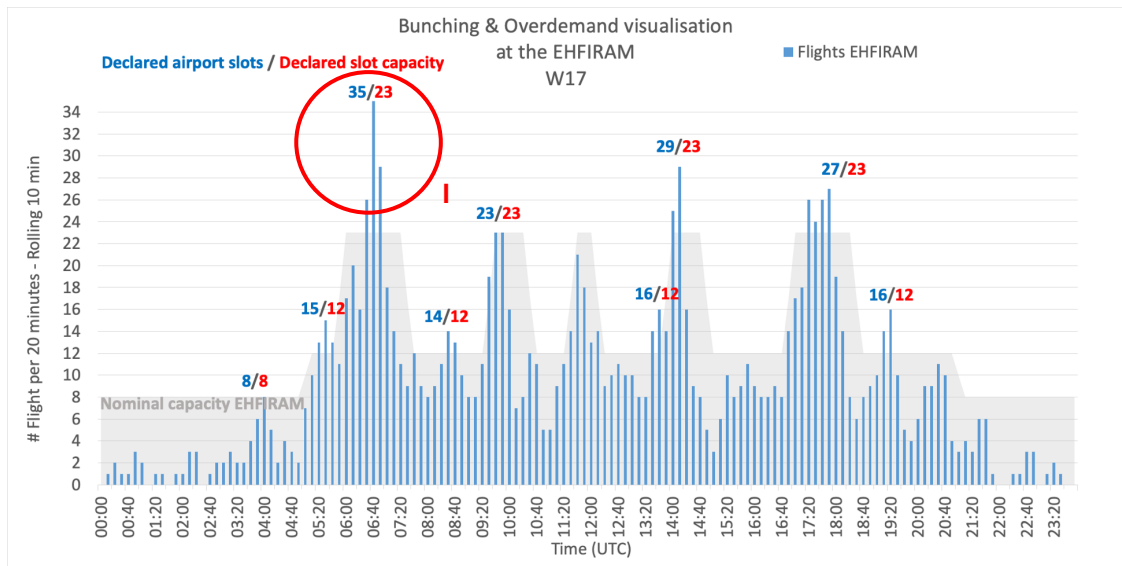


Figure 14: Bunching visualisation EHFIRAM. February 20, 2018 (W17).

¹² $N_{Flights} = ((Bracket_{start} \leq Entry_{time(UTC)} < Bracket_{end}) \equiv Slot_{date})$

Figure 15 represents the planned demand at June 19, 2018 (representable for S18). Clearly visible are the brackets with overdemand during the first (reference J) and fifth inbound peak (reference K). When the flow controller at LVNL encounter the situation in Figure 15, he will contact the network manager at Eurocontrol. As a result, ATFM delays will limit the airplanes entering the FIR. Reference L highlights a time bracket with overdemand in between the inbound peaks.

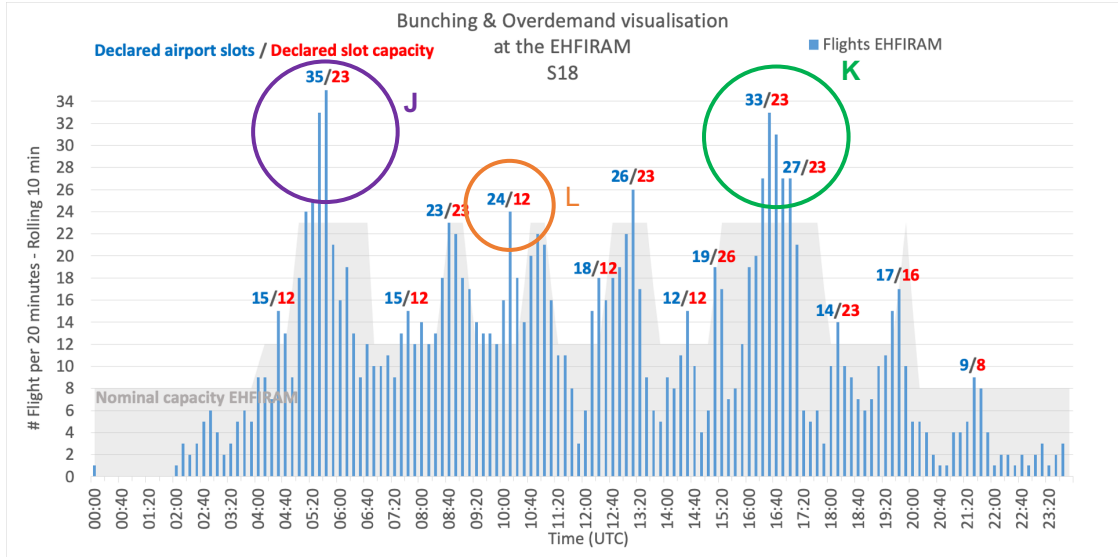


Figure 15: Bunching visualisation EHFIRAM. June 19th, 2018 (S18).

5.2 Magnitude and frequency of overdemand at the EHFIRAM

The heatmap in Figure 16 visualises the results of formula (4)¹³ for W17. Several time-brackets in season W17 are showing structural periods with overdemand in the tactical planning phase. The time-brackets between 06:00 and 07:00 stand out in the figure, the overdemand is the largest during this period of time.

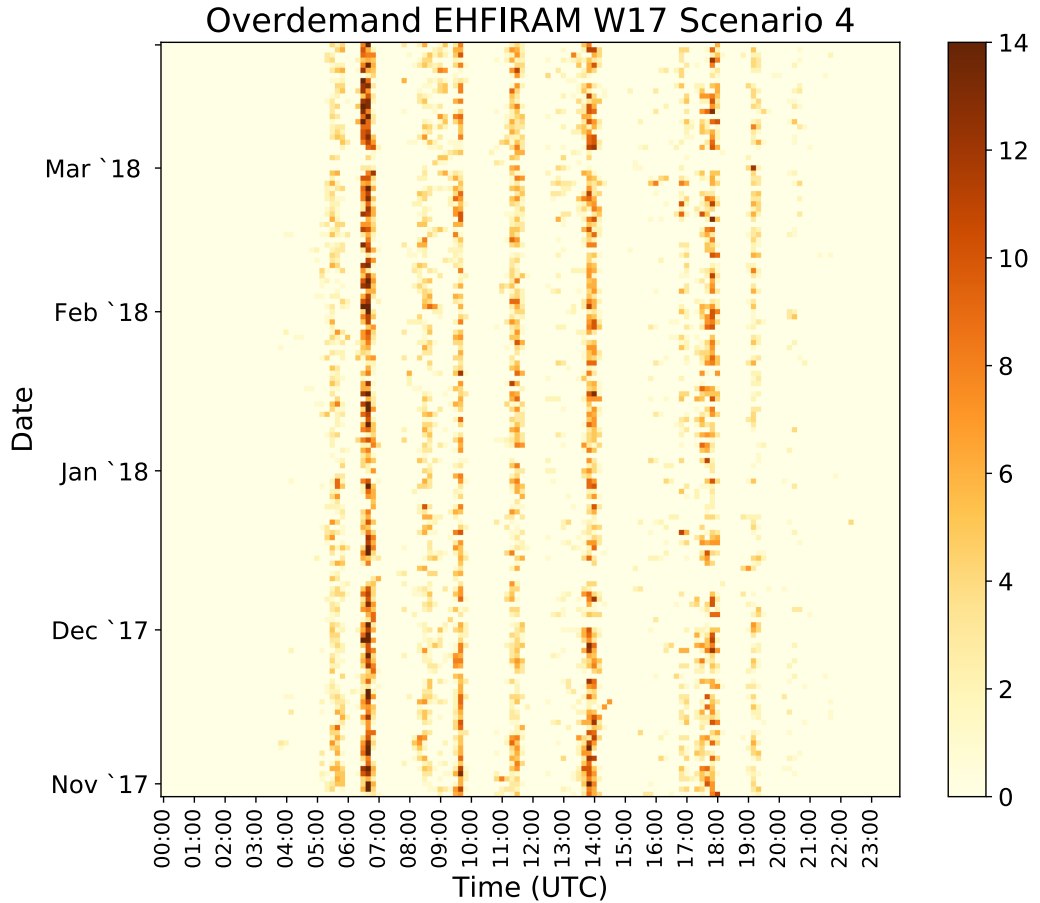


Figure 16: Overdemand EHFIRAM W17.

¹³ $N_{Flights} = (((Bracket_{start} \leq Entry_{time(UTC)} < Bracket_{end}) \equiv Slot_{date}) - Capacity)$

Figure 17 reflects the results of the heatmap in Figure 16. The blue bars represent the frequency in which overdemand does occur in that specific time bracket and is stated in the right side of the figure. The red line represents the average magnitude of overdemand in the time brackets. The values are stated on the left side of the figure. The structural overdemand is significant. In reference **M**, the magnitude of the average overdemand of time brackets is between six and nine flights.

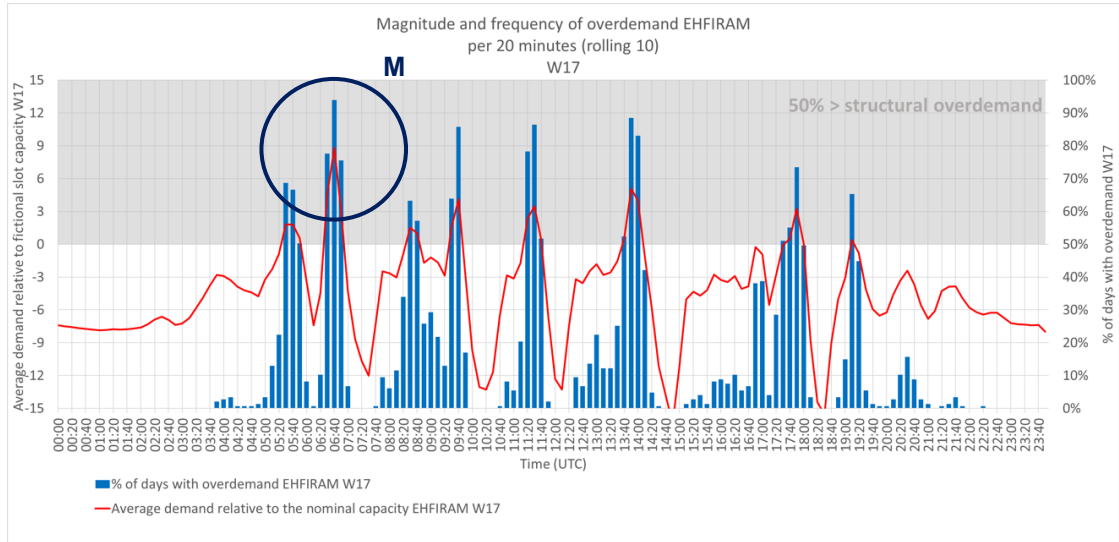


Figure 17: Magnitude and frequency of overdemand at the EHFIRAM per 20 minutes – rolling 10 minutes in W17.

Figure 15 represents the overdemand in S18. The number of time-brackets which experience overdemand is larger compared to W17. The time-brackets between 05:00 - 06:00 and 16:00 - 17:00 stand out. These periods reveal the most frequent and largest periods with overdemand.

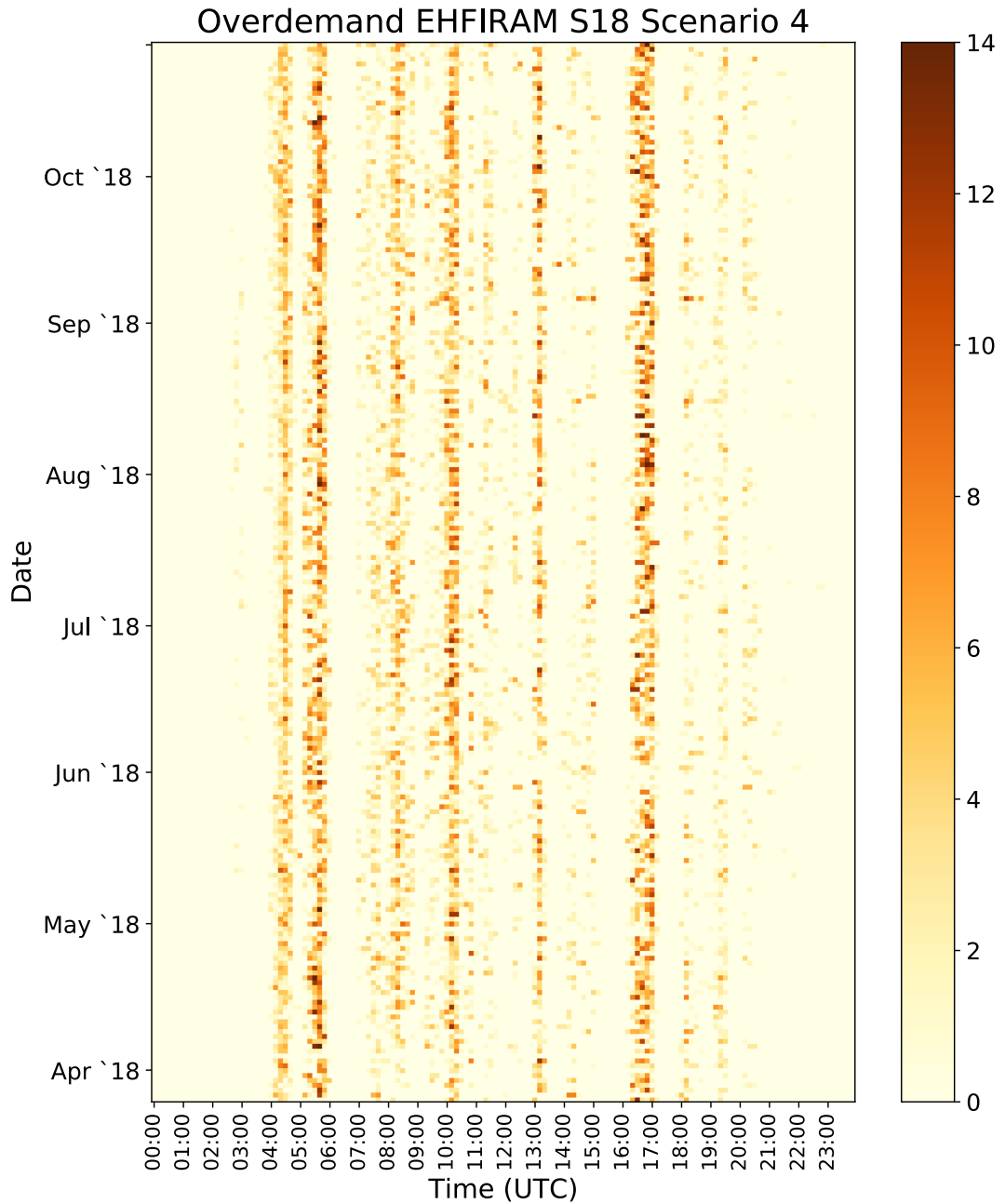


Figure 18: Overdemand EHFIRAM S18.

Figure 19 visualise the results from the heatmap in Figure 18. The blue bars represent the frequency in which overdemand occurs and belongs to the right side of the figure. The extent in which overdemand occurs is displayed by the red line. The values are stated on the left side of the figure. The extend in which overdemand occurs is very large. Almost every time-bracket is experiencing overdemand multiple days in the season.

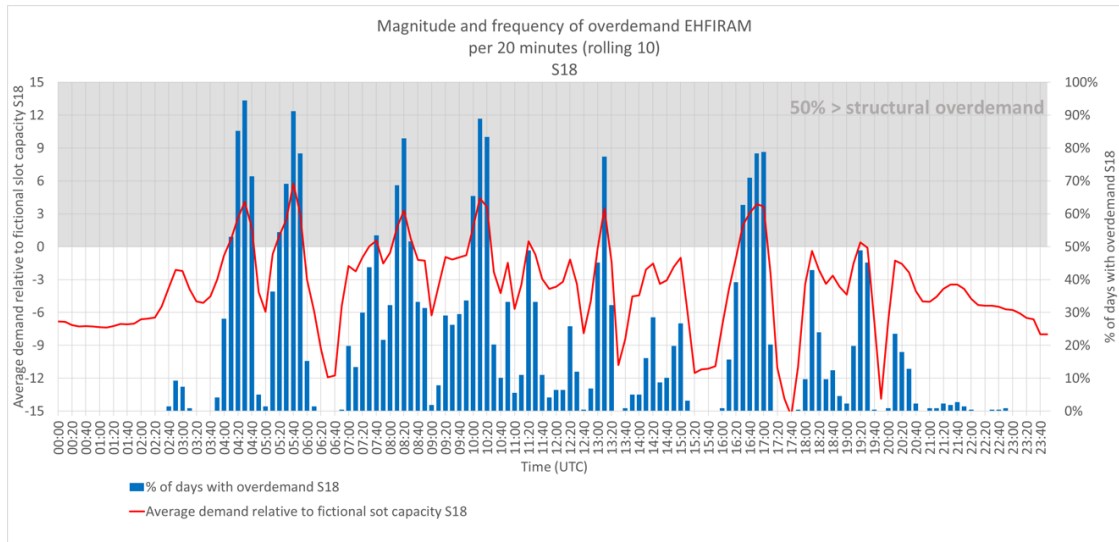


Figure 19: Magnitude and frequency of overdemand at the EHFIRAM per 20 minutes – rolling 10 minutes in S18.

The analysis of the entry-times at the border of the EHFIRAM revealed the extent in which bunching and overdemand exists in the -3-hour planning phase. The analysis of both the airport slot allocation and at the border of the EHFIRAM reveal bunching and overdemand in significant extent. The subsequent step is therefore to determine the relationship between the bunches and overdemand in the slot allocation and the -3-hour planning phase.

6 Relationship between slot planning and air traffic demand

Since overdemand already exists in the airport slot planning and in the -3-hour planning phase at the EHFIRAM, the last research question can be answered: To what extent are flights in a peak with overdemand at the border of the EHFIRAM relatable to flights in a peak of overdemand in airport slots?

6.1 Relation between overdemand at the EHFIRAM and airport slots

The relationship shown in graph 13 is determined following the methodology explained in chapter 2.3.3. The graph is divided per month. The average relationship over W17 and S18 is 48%. This means that 48% of the flights which are planned in a time-bracket with overdemand in the airport slot planning, are also planned in a time-bracket which is experiencing overdemand at the EHFIRAM.

Clearly visible is the difference between W17 and S18, whereby W17 is showing a larger relationship (54%) compared to S18 (42%). Also, the dip in December stands out.

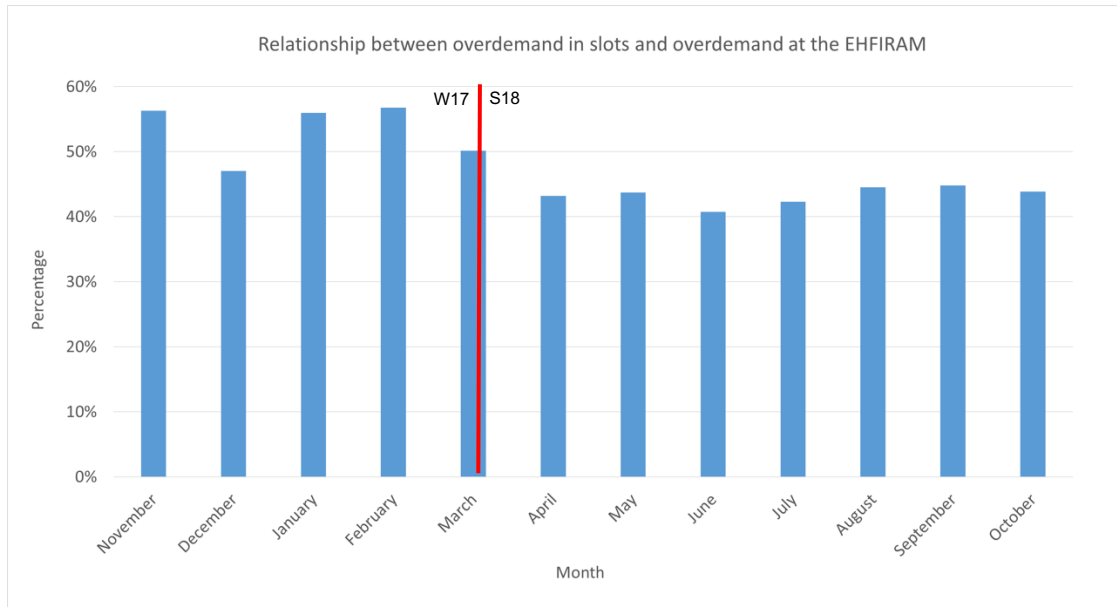


Figure 20: Relationship between overdemand in airport slots and at the EHFIRAM.¹⁴

¹⁴ October consists of 27 days, instead of the full month. This is due to the change of season (resp. from S18 to W18) and data.

6.2 Control analysis ‘Relationship between slot planning and air traffic demand’

As discussed in Chapter 2.3.3, a control analysis is applied to make sure the previous determined relationship is properly substantiated. The reasoning behind is to eliminate the variable factors which can influence the arrival time at the airport. Therefore 4 scenarios are created. Each scenario eliminates one variable factor. Scenario 4 is the original data containing the arrival time of the flight plan. Scenario 3 eliminates the schedule buffers built-in by the airlines. Scenario 2 eliminates the delay sustained in the flight plan. The last scenario manipulates the flight time within the Dutch FIR. A standard flight time is used whereby the variable flight time (which is dependent on the Dutch Air traffic controllers) is eliminated. If the analysis is conducted correctly, the relationship between the airport slot planning and scenario 1 should yield 100%.

Graph 14 represents the relationships of the four scenarios. Scenario 4 is identical to the relationship stated in chapter 6.1. The relationship of scenario 3 is, contrary to what was hypothesised, slightly compared with scenario 4. Scenario 2 renders a larger percentage. The influence of schedule buffers (scenario 3) is larger in W17, referred to the difference between the blue and the grey bar. The bars differ more from each other, compared to S18. The influence of flight time in the Dutch FIR has by far the biggest influence on the feasibility of the flight schedules referring to scenario 1. The relationship almost reaches the 100%.

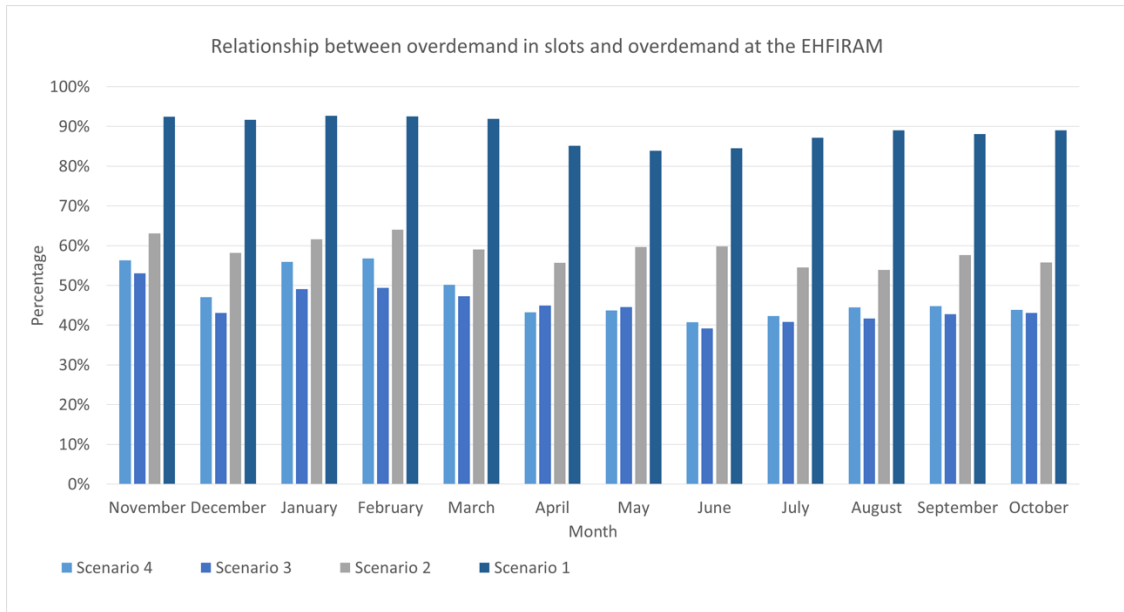


Figure 21: Relationship between overdemand in airport slots and at the EHFIRAM for the 4 scenarios.¹⁵

¹⁵ October consists of 27 days, instead of the full month. This is due to the change of season (resp. from S18 to W18) and data.

7 Research findings

During the analysis, several situations came to light. The objective of this chapter is to explain and understand those situations based on literature, existing knowledge and further research of the data.

The first research question, which is answered in Chapter 4, is: **“What is the frequency and magnitude in which bunching and overdemand occur in the airport slot allocation?”** The analysis of the declared airport slot data in both W17 and S18 (chapter 4.1) revealed respectively 10 and 51 slot-brackets in the whole season with overdemand. Although these numbers might not be very high, the airport slot declarations should never exceed the airport slot capacity as declared by ACNL (Airport Coordination Netherlands, 2018). Zooming in into the concerning slot-brackets resulted into the following findings:

- In W17, two of the 10 concerning slot-brackets can be explained. Two cargo flights with an airport slot in the same bracket, were not scheduled in those brackets. Regarding their flight schedules, they should arrive one hour earlier. Also, an empty airport slot was declared. No flight number nor destination was assigned to this slot.
- In S18, some General Aviation flights were granted a double airport slot. This is possible due to the fact that the airport slot requests are processed manually. Together with the fact that the operators update their flights a couple of times, makes it error sensitive (Riebeek, 2019).

In total 24 of the concerning 61 slot-brackets can be explained with the above-mentioned findings, two out of 10 in W17 and 22 out of 51 in S18. Nevertheless, the remaining slot-brackets with overdemand cannot yet be explained.

The results of the analysis of the declared airport slot data per 20 minutes – rolling 10 minutes (chapter 4.2), reveals structural overdemand in several time-brackets in both season W17 and S18. Further investigation into the allocated airport slots indicates skewness within the airport slot declaration. Table 6 presents the average number of declared airport slots between 06:00 and 07:20 in S18. The capacity during this period is 23 slots per 20 minutes. The results of dividing the 20-minute brackets in 10-minute brackets is visible e.g. between 06:20 and 06:40, in the first 10 minutes 9 airport slots are declared and in the other 10 minutes 14 airport slots. Initially, this is not an issue if it is recurring in every second half of the 20-minute brackets. However, when the skewness in the adjacent slot bracket occurs in the first half of the bracket, and the rolling 10-minute method is applied, overdemand is experienced in a, for sometimes, significant large extent. In the case of table 8: overdemand of 7 airport slots is experienced between 06:30 and 06:50.

Tabel 8: Average number of declared airport slots in S18 per 10 minutes.

Slot-bracket (UTC)	06:00	06:20	06:40	07:00	07:20
	9/14	9/14	16/6	14/8	7/4

06:30 – 06:50: 30 slots

When the declaration of airport slots will be more even distributed, the skewness and therefore the overdemand of time-brackets will disappear.

“What is the frequency and magnitude in which bunching and overdemand occur at the border of the EHFIRAM?” is the second research question answered during the research. The analysis of the air traffic demand at the EHFIRAM revealed, like in the slot declaration, structural overdemand in multiple time-brackets over the day. At first sight, referring to the heatmaps of both analyses, a slight relationship is visible. The time-brackets which are experiencing overdemand seems to occur in the same periods in both analyses (flight-time from the EHFIRAM to the gate included) and are showing the same pattern. Both heatmaps of the slot declaration and air traffic demand in W17 and S18 are presented in respectively figure 10 and figure 11 below.

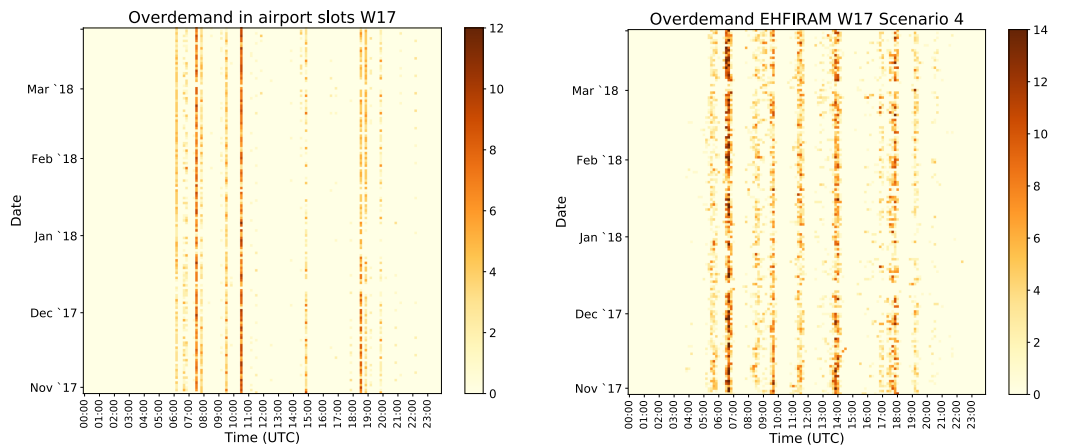


Figure 22: Overdemand in airport slots and at the EHFIRAM in W17

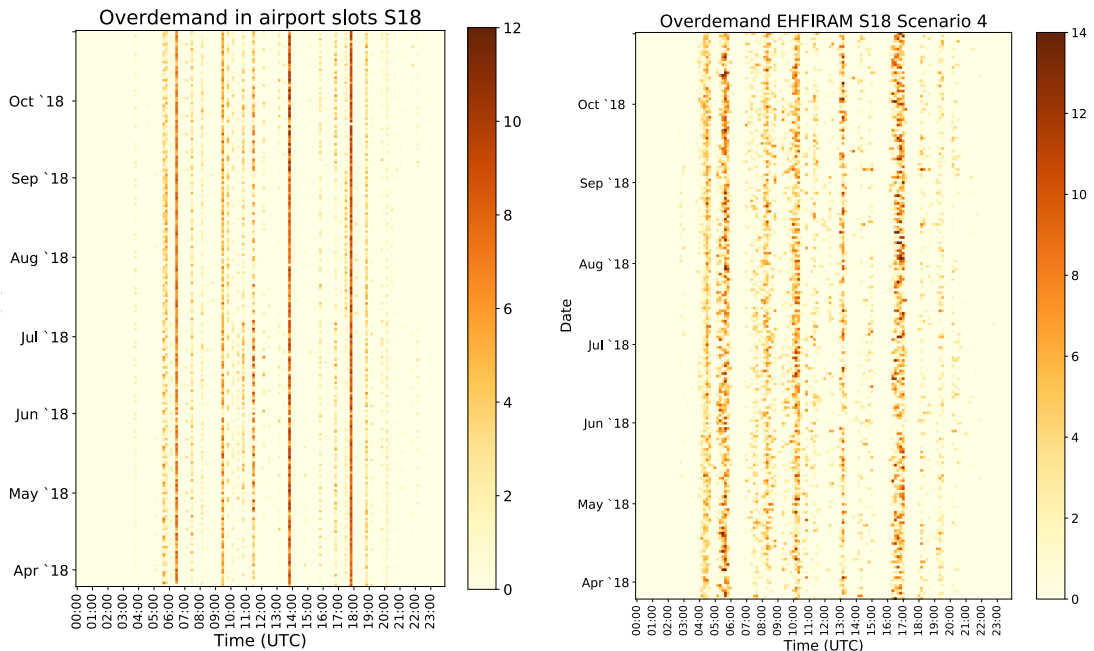


Figure 23: Overdemand in airport slots and at the EHFIRAM in S18.

In Chapter 6 the third, and last, research question is answered. “**To what extent are flights in a peak of airport slots relatable to flights in a peak with overdemand at the border of the EHFIRAM?**”. The relationship between the planning phases is 48%, within the scope and the assumptions of the research. In other words, 48% of the flights planned in a period with overdemand in the airport slot allocation, are also planned in a period with overdemand at the EHFIRAM. The 52% which could not be explained by the airport slot planning is the result of the other variables of a flight schedule: influence of schedule buffers in the flight schedule, the delay in the flight plan and the difference in flight-time in the Dutch FIR.

The relationship differs between W17 and S18. The reason for this could be the different amount of flights during these months. S18 is more crowded (160.000 inbound flights) compared to W17 (93.000 inbound flights). Another assertion could be the difference in schedule buffer size. The schedule buffers built in the schedule of the airlines to intercept delays and adhere to the schedule arrival times are larger during the winter than during the summer. This can be explained by the extra time built in the schedules, due to the potential de-icing operation. De-icing takes extra time on the ground and causes (extra) delays (Riebeek, 2019). The results of the validation analysis of scenario 3 (entry-times without schedule buffer) indicate an overall smaller decrease in relationship between the airport slot planning and demand at the EHFIRAM compared to the other scenarios. The decrease in W17 is larger than in S18, which indicates influence of schedule buffers is larger in W17 compared to S18.

The overall findings of the research result that bunching overdemand does exist within the airport slot allocation. This is mainly caused by the skewness within the slot brackets. Subsequent, the analysis of the entry times of the flight plan reveals a similar pattern in overdemand during the day. This reinforced the idea that overdemand in the -3-hour planning phase has a relationship with the airport slot planning. The determined relationship in the last sub-question revealed that 48% of the flights that are planned in a period with overdemand in the airport slot planning, also is planned to arrive in a period with overdemand in the -3-hour planning phase.

8 Discussion

The research is established using several assumptions and limitations which could influence the overall analyses results. In this section, the decisions that are taken per sub question are reconsidered and further explained. At last, the limitations and interpretation of the conducted research are reviewed.

The capacity used in the analyses for the sub questions, shifts from inbound to outbound peaks, in which the capacity differs in both modes. To intercept the problem of the intermediate time-brackets between two modes a mean capacity is used. However, while this is a proper method to use, it does not reflect the actual capacity at that moment and could therefore influence the results.

The first sub question is: ***“What is the frequency and magnitude in which bunching and overdemand occur in the airport slot allocation?”*** In order to answer this question, a quantitative research method is used. Data is provided by AAS. The dataset is containing the scheduled arrival times at Schiphol, collected from CISS and the slot data provided by ACNL. To allocate a slot time to the scheduled arrivals, the datasets are merged by AAS using different iterations based on arrival times, origin, date and time. Due to the complexity of the last 6 iterations, used to match around 4.000 schedules and slots, around 50 flights could be double matched. It is not sure, but these flights could cause the overdemand in the airport slot declaration.

The analysis model created for both sub question 1 and 2 is divided per 20 minutes – rolling 10 minutes. By this way, skewness within the brackets is visible, but the time brackets do overlap each other by 10 minutes. This means that every flight does appear in two adjacent time-brackets. Therefore, the time-brackets need to be reviewed per individual bracket.

The second sub question is: ***“What is the frequency and magnitude in which bunching and overdemand occur at the border of the EHFIRAM?”*** This sub question is answered using the same model as sub question 1 but uses a different dataset. The dataset is based on two separate datasets. One containing the entry-times of the EHFIRAM and one containing the sector in which the flight arrived in the FIR. Combining those datasets resulted in a loss of around 300 flights over season W17 and S18.

In the research plan, research into the development of bunching and overdemand within the Dutch airspace was discussed. However, due to the availability of data and assumptions that have been made, the results were not supportive enough to give a clear explanation of the development of bunching and overdemand in the Dutch airspace.

The last sub question is: ***“To what extent are flights in a peak of airport slots relatable to flights in a peak of overdemand at the border of the EHFIRAM?”*** The control analysis of sub question three faces a couple of difficulties. The different scenarios created and reviewed are based on the Scheduled Off-Block Time (SOBT), Scheduled In-Block Time (SIBT), Estimated Off-Block Time (EOBT) and Estimated In-Block Time (EIBT). The SOBT and EIBT are not directly available in the datasets. Therefore, the EIBT is calculated using average lead times of the Dutch FIR. The average time from entering the FIR to the gate is added to the entry time. For this the assumption is made that every flight landed at runway 18R and the taxi time to the gate is always 12 minutes. It is very difficult to use the complex runway system of Schiphol in the analysis. This does influence the result of the analysis. The other difficulty is the absence of the SOBT in the datasets. Therefore, the SOBT is merged using a self-gathered dataset created by LVNL. The disadvantage of this dataset is that it is created months in advance before the season has started. The changes airlines made in their flight schedule are not taken into account and therefore, the merging of the dataset was very difficult. This results in a data loss of 7%.

The results of the control analysis of scenario 1 should yield a relationship of 100%. However, the analysis showed an overall relationship of 89%. The explanation of the difference is as follows: To determine the schedule buffer in block-times of the flights, the Schedule Off-block time (SOBT) is used. The sample size of the dataset providing the SOBTs is explained in chapter

2.4.3. 92% of the available Flight plan data is left, after matching the SOBT with the slot data and flight plan data. Therefore, 7% of the available data cannot be used.

The data created in scenario 1, is equal to the Schedule In-block Time (SIBT). Since the SIBT do not match the declared airport slot data by around 3% (Riebeek, 2019), the relationship cannot be greater than 97%. The remaining 1% is relatable to the number of NO-OPS airport slots, which are slots that are not used in the operation.

There is no margin taken into account within the determination in which time-bracket a flight is arriving. It is possible that flights are missing the time-bracket by a couple of seconds. This could also influence the outcome of the research.

The overall interpretation of the research lead to the conclusion this research delivered a solid base of information to the fact that the airport slot declaration has something to do with the bunching and overdemand at the border of the Dutch airspace. However, due to the limitations and assumptions made, the results of the research required more support in order to be used in the sector research. The sector already started with further in-depth analysis based on the results gathered from this research.

If the research is conducted using other, more complex analyses, the precise relationship between the bunching and overdemand in the two planning phases could be determined. More detailed recommendations are stated in Chapter 10.

9 Conclusions

This research aimed to provide insights into the problem of bunching and overdemand which is experienced at the border of the Dutch FIR. The conclusions found during the research are used to answer the main research question:

“What is the relationship between airport slot planning and air traffic demand, and what options are there to minimise the bunching effect in the Dutch airspace?”

In order to determine the relationship between the airport slot planning and air traffic demand, the extent in which bunching and overdemand is experienced is defined with the first research question: ***“What is the frequency and magnitude in which bunching and overdemand occur in the airport slot allocation?”***. At first the airport slot declaration is analysed to identify if bunching and overdemand already exists within the airport slot allocation. On basis of the quantitative analysis, bunching and overdemand do not exist conform the airport slot declaration. However, bunching and overdemand become visible when the airport slot declaration is reviewed per 20 minutes – rolling 10 minutes. Structural overdemand is experienced within multiple intermediate time brackets of the declared slot-brackets. The presence of overdemand is caused by the uneven distribution of airport slots within the declared airport slot-brackets.

Overdemand does exist within the airport slot allocation. The second research question: ***“What is the frequency and magnitude in which bunching and overdemand occur at the border of the EHFIRAM?”*** is used to determine the extent in which bunching and overdemand is experienced at the border of the EHFIRAM. By using the same quantitative analysis method as the airport slot allocation, the analysis revealed like in the airport slot declaration, structural overdemand in multiple time brackets over the day. At first sight, both analyses are showing a slight relationship: the time brackets which are experiencing overdemand are showing the same pattern in occurrence.

Now it is clear that both the airport slot allocation and air traffic demand experience overdemand and bunching, the question remaining is: ***“To what extent are flights in a peak of airport slots relatable to flights in a peak of overdemand at the border of the EHFIRAM?”***. Do flights which are planned in a time-bracket with overdemand in the airport slot declaration, also appear to plan to arrive in a time-bracket with overdemand at the border of the EHFIRAM? The question is answered using a quantitative analysis method. The analysis showed an overall relationship of 48%. This means that 48% of the flights are both planned in a period of overdemand in the airport slot declaration as well in the -3- hour planning phase based in the last filed flight plan.

The relationship between airport slot planning and air traffic demand is, keeping the assumptions and limitations of the research in mind, 48%. The overdemand at the EHFIRAM should decrease with around 48% when the skewness in the airport slot declaration is dissolved. Schedule buffers, flight-time in the FIR and excessive delay causes the remaining 52% of the flights not to arrive in their assigned airport slot bracket. When these factors, especially flight-time and schedule buffers, are better predictable the influence of the airport slot planning will make Schiphol Airport great again,

Altogether, more research is needed before a thorough relationship can be concluded. The assumptions and limitations made during the research have too much influence on the results in order to state a hard relationship between the two planning phases. Important issues such as the capacity and runway usage need to be determined in such a way, their influence on the outcome of the research is acceptable.

10 Recommendations

The following recommendations aim to provide possibilities to reduce the airport ATFM delay at Schiphol and motivate to conduct further research into the bunching problem.

The results of the first sub question: “**To what extent does bunching and overdemand occur in the airport slot planning?**”, showed that bunching and overdemand in the airport slot declaration occur due to the skewness within the declared slot brackets. Knowing that the relationship between the airport slot declaration and air traffic demand is 48%, means that if the skewness is dissolved overdemand should decrease with around 48%.

The first recommendation is therefore to perform a thorough research into the possibilities and consequences of dissolving the skewness within the slot brackets. This is possible in multiple ways:

- Maintaining the current slot system whereat a more even spread distribution of the airport slots is established;
- Investigate whether the current slot system is outdated and not suitable for the amount of flights in combination with the layout and system of the Dutch airspace. Other level 3 coordinated airports coordinate their slot declaration based on 10 or 5 minutes. This results in possibly more distributed airport slots.

Maintaining the current slot system is the most obvious choice, because it is a very difficult and time-consuming process to change the whole airport slot planning. Dissolving the skewness within the declared slot brackets is much easier task. However, the slot coordinator at ACNL must take the historical slot rights into account. This means that operators may keep their slot of the past season when the operator followed the 80% OTP rule. This could be a problem, when dissolving the skewness.

Dissolving the skewness by implementing 10- or 5-minute slot brackets could preserve the even distribution within the brackets. Nevertheless, skewness is still possible then. However, this would not to the same extent as the situation now but smaller.

The benchmark research, performed in the sector research, under the major level 3 coordinated airports in Europe should yield more information about the smaller slot-brackets in relation with the air traffic demand at the local FIR boundaries. The results of the benchmark could be of great value for the research whether further research is needed or unnecessary. If bunching and overdemand does not exist at those airports, the slot brackets might be necessary to amend.

The analysis of the second sub question: “**To what extent does bunching and overdemand occur at the border of the EHFIRAM?**” The intention was to investigate what the gradient of overdemand and bunching is throughout the Dutch FIR. However, due the limitations and assumptions made, the analysis at the different locations in the FIR resulted in unreliable values. This could be valuable information to decrease the amount of regulations, if the overdemand decreases within the FIR. Recommended is to conduct a more specific research into the gradient of overdemand and bunching throughout the FIR.

The assumptions made in the scenarios of sub question 3: “**To what extent are flights in a peak of airport slots relatable to flights in a peak of overdemand at the border of the EHFIRAM?**”, do not reflect a realistic view of the flight- and taxi-times of the flight arriving at Schiphol. The scenarios give a global picture of the influence of the factors. However, the assumption made distort the actual fluctuation of the flight- and taxi-times. More detailed research, including more fluctuating flight- and taxi-times, is recommended to give the relationship between airport slot planning and air traffic demand a more thorough support. This is a more detailed and mathematical analysis.

To neglect the capacity issues discussed in the discussion, research on only the inbound peak is recommended. The fluctuating capacity is not an issue anymore and does not affect the results in which bunching and overdemand occurs. Also, the determination of the last sub question is recommended to be executed on time-bracket level, instead of based on the filed flight plans. To do so, the margin in which airplanes arrive in particular brackets does not influence the results of the research.

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Capacity analysis of airport slot planning and air traffic demand

A study on the bunching effect in the Dutch airspace

Appendices

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Appendix I Reflection

The reflection of the conducted research follows the STARR (Situation, Task, Action, Result and Reflection) method. The most informative situations during my period at the KDC are discussed in this Appendix. At first my educational reflection on my professional skills during the research is discussed. Afterwards, my experiences with the SCRUM method and Sprint reviews are discussed.

Professional skills

During the conducted research, a quantitative research method was used. This required a lot of data-analysis skills to be used. The research subject is more operations orientated than engineering. However, together with my professional experiences and the gained analysis skills at the university, I was able to manage the research and brought it to a successful conclusion.

Situation

The first instance of the research was to investigate the gradient of bunching within the Dutch Airspace. After developing the used model in the analysis, the data which I modulated seemed not to reflect a realistic view of the situation within the Dutch Airspace. The assumptions I had to make, made it not to be realistic and therefore useless in the analysis.

Task

This forced me to adapt to the situation and chose a different path. During a weekly meeting with the department we discussed several options. This was a difficult and time-consuming task. I think during this period of my research I learned the most on personal and professional level. This requires a strong mindset and motivation. The department struggled with the goal of the research and multiple mindsets were discovered amongst the department-members. I think this situation is very common in the professional field. The situation asked to be very precise in my explanations and assumption.

Action

Keeping everyone in line was a difficult task, especially because the department-members are very specialised on this subject. I tried to understand every individual member. Extra meetings were scheduled, and I was forced to understand their different research methods. Due to this, I became comfortable with a new programming language: Python. I scheduled a meeting with a programmer at LVNL and he taught me the basic steps.

Result

Eventually I translated the heatmaps into Python script and I think it raises the level of my report. The heatmaps are now better readable than before and I have learned a new skill which I can use in my further career.

Reflection

At first, the situation was very stressful for me. The initial research steps could not be conducted, and I was forced to change everything. Although this is common during research in general, it was very confronting. I could have reacted earlier if I was familiar with the situation. If I will face a similar situation in the future, I think I can react much faster and more straight forward because I know what to expect and how to react.

SCRUM/Sprints

Project management is very important and one of the most difficult parts. To maintain the progress of the research at the KDC, two-weekly scrum sessions and a two-monthly sprint reviews were scheduled.

Situation

Two times a week, on Monday and Thursday a scrum session was planned. During this session every graduate student at the KDC was forced to set goals for the week and goals before the following scrum session. We also got advice to tackle any potential problems.

Task

Every two weeks a sprint session was scheduled. During this session we were able to pitch our progress to the KDC stakeholders and ask them for advice. They were also giving advice on further research during the project.

Action

To keep track of the project and keep a clear overview, SCRUM boards were used. On the SCRUM board the process of the research is visualised. The steps required to answer the research and background questions are broken down to ensure a focused approach of each question. The goal was to only work on one step at the time. Once a step was completed and accepted by the stakeholders during the sprint review, the task was removed from the board.

Result

For me, the SCRUM method was not an effective way to keep structure to the research. Together with the planned meeting within the department and within the sector, I 'lost' almost two days per week by organizing and preparing presentations for all different stakeholders. This was not favourable for the progress of the research.

Reflection

The SCRUM method was not working for me. Although I understand the principles of the method, I think it is not working out in the way they expect it to do. I think SCRUM is very useful in group projects when working on the same project. This was not the case with our projects. They differed too much from each other to be productive. However, I gained experience in project management and keeping the stakeholders updated.

Appendix II QRC 63 Winter 2017

Richtlijn TFV EHFIRAM



Piektijden winter 2017

EHFIRAM-tijden (UTC)				Veldtijden (UTC)
Inbound peak	Outbound peak	Off-peak	Night	
		0510 – 0540		0530 – 0600
	0540 – 0600			0600 – 0620
0600 – 0740				0620 – 0800
		0740 – 0800		0800 – 0820
	0800 – 0940			0820 – 1000
0940 – 1040				1000 – 1100
	1040 – 1140			1100 – 1200
1140 – 1220				1200 – 1240
		1220 – 1300		1240 – 1320
	1300 – 1400			1320 – 1420
1400 – 1500				1420 – 1520
	1500 – 1600			1520 – 1620
		1600 – 1700		1620 – 1720
1700 – 1840				1720 – 1900
		1840 – 1900		1900 – 1920
	1900 – 2040			1920 – 2100
		2040 – 2110		2100 – 2130
			2110 – 0510	2130 – 0530

Inbound peak

- Doel: maximaal 68 inbound vluchten per uur.
- Monitoring value: 65 per uur voor de 1^e, 2^e, 3^e en 4^e inbound peak
68 per uur voor de 5^e inbound peak
- Regulatie/Monitoring: eerst verkeersstromen via stacks proberen te beperken, anders reguleren op 65 per uur (EHFIRAM):
 - bij structureel¹ aanbod van 68 of meer per uur; of
 - bij structureel¹ aanbod van 24 of meer per 20 minuten.
- Als een regulatie voor EHFIRAM wordt ingesteld bij een aanbod > 68, vul dan op het formulier 'ATFCM measures' regulation cause 'Aerodrome Capacity' en ANM remark 'High Demand' in.

¹ Structureel: 2 staven of meer

Inbounds tijdens outbound peak

- Doel: maximaal 38 inbound vluchten per uur.
- Regulatie op 35 per uur:
 - bij structureel¹ aanbod van 38 of meer per uur; of
 - bij structureel¹ aanbod van 13 of meer per 20 minuten.
- Als een regulatie voor EHFIRAM wordt ingesteld bij een aanbod > 38, vul dan op het formulier 'ATFCM measures' regulation cause 'Aerodrome Capacity' en ANM remark 'High Demand' in.

¹ Structureel: 2 staven of meer

Appendix III QRC 63 Summer 2018

Richtlijn TFV EHFIRAM



Piektijden zomer 2018

EHFIRAM-tijden (UTC)				Veldtijden (UTC)
Inbound peak	Outbound peak	Off-peak	Night	
		0410 – 0440		0430 – 0500
	0440 – 0500			0500 – 0520
0500 – 0700				0520 – 0720
	0700 – 0840			0720 – 0900
0840 – 0920				0900 – 0940
	0920 – 1040			0940 – 1100
1040 – 1120				1100 – 1140
	1120 – 1240			1140 – 1300
1240 – 1350				1300 – 1410
	1350 – 1520			1410 – 1540
1520 – 1800				1540 – 1820
	1800 – 1950			1820 – 2010
1950 – 2010				2010 – 2030
			2010 – 0410	2030 – 0430

Inbound peak

- Doel: maximaal 68 inbound vluchten per uur.
- Monitoring value: 65 per uur voor de 1^e, 2^e, 3^e en 4^e inbound peak
68 per uur voor de 5^e inbound peak
65 per uur voor de 6^e inbound peak
- Regulatie/Monitoring: eerst verkeersstromen via stacks proberen te beperken, anders reguleren op 65 per uur (EHFIRAM):
 - bij structureel¹ aanbod van 68 of meer per uur; of
 - bij structureel¹ aanbod van 24 of meer per 20 minuten.
- Als een regulatie voor EHFIRAM wordt ingesteld bij een aanbod > 68, vul dan op het formulier 'ATFCM measures' regulation cause 'Aerodrome Capacity' en ANM remark 'High Demand' in.

¹ Structureel: 2 staven of meer

Inbounds tijdens outbound peak

- Doel: maximaal 38 inbound vluchten per uur.
- Regulatie op 35 per uur:
 - bij structureel¹ aanbod van 38 of meer per uur; of
 - bij structureel¹ aanbod van 13 of meer per 20 minuten.
- Als een regulatie voor EHFIRAM wordt ingesteld bij een aanbod > 38, vul dan op het formulier 'ATFCM measures' regulation cause 'Aerodrome Capacity' en ANM remark 'High Demand' in.

¹ Structureel: 2 staven of meer

Appendix IV Declared slot capacity Schiphol Winter 2017

Capacity declaration Amsterdam Airport Schiphol; winter 2017/2018

Environmental capacity; available number of slots for Commercial Aviation

The number of slots available for landing and take-off operations of Commercial Aviation during the winter season 2017/2018 (October 29, 2017 through March 24, 2018; 21 weeks) is specified in the table below. For the winter season, local time equals UTC + 1 hour.

*Available number of slots for Commercial Aviation; winter season 2017/2018
(October 29, 2017 through March 24, 2018)*

	Total number of departures and arrivals	Number of night departures and arrivals
Planning limit (slots)	185,000	10,735

The following definitions apply:

- Commercial Aviation:** Flights performed by an air carrier, providing scheduled flights, programmed charters or ad hoc flights which are open for individual bookings for passengers and/or freight and/or mail, including positioning flights which are directly linked to the operation of these flights.
- General Aviation:** All aviation except commercial aviation. Including but not limited to business aviation, air taxi operations and technical flights.
- Night departure slot:** Departure slot in the period 22:40 – 06:59 LT (21:40 – 05:59 UTC)
- Night arrival slot:** Arrival slot in the period 23:00 – 07:19 LT (22:00 – 06:19 UTC)
- Night slot:** Either a night departure slot or a night arrival slot
- Night movement:** Departure or arrival with a runway time in the period 23:00 – 06:59 LT (22:00 – 05:59 UTC)
- Planning limit:** Total number of slots available for allocation provided that all applicable requirements are met, as determined by the slot coordinator.

The numbers of slots as specified in the above table are based on (i) the upcoming legally binding maximum of 500,000 aircraft movements in Commercial Aviation during an operational year (1st November through 31st October), of which no more than 32,000 are night movements and (ii) the regulation adopted by the state secretary on carrying out an experiment with the limit of 32,000 night movements during operational year 2018.

Nominal operational runway capacity

For slot allocation purposes for both Commercial and General Aviation, the operational runway capacity for the winter season 2017/2018 has been determined as follows:

ATM mode ¹	Possible within period from – to (UTC)	Nominal capacity per hour		Nominal capacity per 20 minutes	
		IFR Arrivals	IFR Departures	IFR Arrivals	IFR Departures
Day; departure peak mode (S)	06:00 – 20:39	36	74	12	25
Day; arrival peak mode (L)	06:00 – 20:39	68	38	23	13
Day; off peak mode (O)	05:00 - 05:39	24	30	8	10
	05:40 - 05:59	24	40	8	14
	06:00 - 21:39	36	40	12	14
	21:40 – 21:59	36	25	12	9
Night mode (N)	22:00 - 04:59	24	25	8	9

Coordination of runway capacity will be based on

- Constraints for 20 minutes periods, and
- For periods of equal ATM mode with a minimum duration of one hour – constraints on rolling hours, i.e. each 60 minute interval that occurs within that ATM mode, with a stepsize of 20 minutes, will have a constraint on capacity.

Additional requirements:

- Arrival and departure peak modes should not overlap.
- Each arrival peak mode period shall be separated from a preceding departure peak mode period by an off peak mode period. Between the first departure and arrival peak, the duration of this off peak mode period should be at least 30 minutes. The duration of this off peak mode period between any other departure and arrival peak shall be at least 20 minutes.
- Each departure and arrival peak mode shall have a minimal duration of 40 minutes, except for the first peak mode at 05:00 UTC, which has a minimal duration of 20 minutes.
- Slots should be requested and will be allocated per 5 minutes.

In the bracket list, that forms integral part of this declaration, the number of available arrival and departure slots for any 20 minute interval and per rolling hour is shown. This capacity depends on the operational runway capacity for the different ATM modes and the agreed peak- and off-peak times for the day period and should meet the mentioned additional requirements. The bracket list for the twenty-four hours period, in accordance with the above table, is specified in Attachment 1.

The bracket list will be endorsed together with this capacity declaration.

¹ Departure peak mode: one runway is used for landings, two runways for take-offs. Day arrival and departure procedures are applied.
 Arrival peak mode: two runways are used for landings, one runway for take-offs. Day arrival and departure procedures are applied.
 Off peak mode: one runway is used for landings, one runway for take-offs. Day arrival and departure procedures are applied.
 Night mode: one runway is used for landings, one runway for take-offs. Night arrival and departure procedures are applied.

Attachment 1: Bracket list winter 2017/2018

Time from [UTC]	Time to [UTC]	# Arrivals	# Departures	# Rolling hour Arr	# Rolling hour Dep
0:00	0:15	8	9	-	-
0:20	0:35	8	9	-	-
0:40	0:55	8	9	24	25
1:00	1:15	8	9		
1:20	1:35	8	9		
1:40	1:55	8	9		
2:00	2:15	8	9		
2:20	2:35	8	9		
2:40	2:55	8	9		
3:00	3:15	8	9		
3:20	3:35	8	9		
3:40	3:55	8	9		
4:00	4:15	8	9		
4:20	4:35	8	9		
4:40	4:55	8	9		
5:00	5:15	8	10	-	-
5:20	5:35	8	10	-	-
5:40	5:55	8	14	-	-
6:00	6:15	12	25	-	-
6:20	6:45	18	20	-	-
6:50	6:55	11	6	-	-
7:00	7:15	23	13	68	38
7:20	7:35	23	13		
7:40	7:55	23	13		
8:00	8:15	23	13		
8:20	8:35	12	25	36	74
8:40	8:55	12	25		
9:00	9:15	12	25		
9:20	9:35	12	25		
9:40	9:55	12	14	-	-
10:00	10:15	23	13	-	-
10:20	10:35	23	13	-	-
10:40	10:55	12	25	36	74
11:00	11:15	12	25		
11:20	11:35	12	25		
11:40	11:55	12	14	-	-
12:00	12:15	23	13	68	38
12:20	12:35	23	13		
12:40	12:55	23	13		
13:00	13:15	12	25	36	74

13:20	13:35	12	25		
13:40	13:55	12	25		
14:00	14:15	12	14	-	-
14:20	14:35	23	13		
14:40	14:55	23	13	68	38
15:00	15:15	23	13		
15:20	15:35	12	25		
15:40	15:55	12	25		
16:00	16:15	12	25	36	74
16:20	16:35	12	25		
16:40	16:55	12	25		
17:00	17:15	12	14	-	-
17:20	17:35	23	13		
17:40	17:55	23	13		
18:00	18:15	23	13	68	38
18:20	18:35	23	13		
18:40	18:55	23	13		
19:00	19:15	12	25		
19:20	19:35	12	25		
19:40	19:55	12	25	36	74
20:00	20:15	12	25		
20:20	20:35	12	25		
20:40	20:55	12	14		
21:00	21:15	12	14	36	40
21:20	21:35	12	14		
21:40	21:55	12	9	-	-
22:00	22:15	8	9		
22:20	22:35	8	9	24	25
22:40	22:55	8	9		
23:00	23:15	8	9		
23:20	23:35	8	9	-	-
23:40	23:55	8	9	-	-

This bracket list winter 2017/2018 resembles the available slots per 20 minutes and per rolling hour, in accordance with the underlying capacity declaration winter 2017/2018 and the current distribution of historical slots. Alternations to the bracket list winter 2017/2018 are possible, provided that it is in accordance with the declaration. The bracket list winter 2017/2018 is part of the declaration. No changes to the bracket list are possible after the endorsement of the final version of this capacity declaration, which will be at least seven days before the IATA Initial Submission Date.

Note that due to technical limitations rolling hours containing the transition to the next day cannot be defined. Therefore only 20 minutes capacities are defined for 23:20-0:40 hours local time.

Appendix V Declared slot capacity Schiphol Summer 2018

Capacity declaration Amsterdam Airport Schiphol; summer 2018

Environmental capacity; available number of slots for Commercial Aviation

The number of slots available for landing and take-off operations of Commercial Aviation during the summer season 2018 (March 25, 2018 through October 27, 2018; 31 weeks) is specified in the table below. For the summer season, local time equals UTC + 2 hours.

*Available number of slots and movements for Commercial Aviation; summer season 2018
(March 25, 2018 through October 27, 2018)*

	Total number of departures and arrivals	Number of night departures and arrivals
Movements	313,740	22,000
Planning limit (slots)	313,740	23,219

The following definitions apply:

- Commercial Aviation:** Flights performed by an air carrier, providing scheduled flights, programmed charters or ad hoc flights which are open for individual bookings for passengers and/or freight and/or mail, including positioning flights which are directly linked to the operation of these flights.
- General Aviation:** All aviation except commercial aviation. Including but not limited to business aviation, air taxi operations and technical flights.
- Night departure slot:** Departure slot in the period 22:40 – 06:59 LT (20:40 – 04:59 UTC)
Night arrival slot: Arrival slot in the period 23:00 – 07:19 LT (21:00 – 05:19 UTC)
Night slot: Either a night departure slot or a night arrival slot
Night movement: Departure or arrival with a runway time in the period 23:00 – 06:59 LT (21:00 – 04:59 UTC)
- Planning limit:** Total number of slots available for allocation provided that all applicable requirements are met, as determined by the slot coordinator.

The numbers of slots and movements as specified in the above table are based on (i) the upcoming legally binding maximum of 500,000 aircraft movements in Commercial Aviation during an operational year (1st November through 31st October), of which no more than 32,000 are night movements and on the (ii) "Tijdelijke regeling van de Staatssecretaris van Infrastructuur en Milieu, van 8 mei 2017, nr. IENM/BSK-2017/107529, houdende vaststelling van vervangende grenswaarden voor de geluidbelasting in de handhavingspunten passend bij een maximum aantal vliegbewegingen handelsverkeer in de nacht van 32.000 voor het gebruiksjaar 2018 op de luchthaven Schiphol (Tijdelijke regeling volumeplafond nachtvluchten Schiphol)."

Nominal operational runway capacity

For slot allocation purposes for both Commercial and General Aviation, the operational runway capacity for the summer season 2018 has been determined as follows:

ATM mode ¹	Possible within period from – to (UTC)	Nominal capacity per hour		Nominal capacity per 20 minutes	
		IFR Arrivals	IFR Departures	IFR Arrivals	IFR Departures
Day; departure peak mode (S)	05:00 – 19:39	36	74	12	25
Day; arrival peak mode (L)	05:00 – 19:39	68	38	23	13
Day; off peak mode (O)	04:00 - 04:39	24	30	8	10
	04:40 - 04:59	24	40	8	14
	05:00 - 20:39	36	40	12	14
	20:40 – 20:59	36	25	12	9
Night mode (N)	21:00 - 03:59	24	25	8	9

Coordination of runway capacity will be based on

- Constraints for 20 minutes periods, and
- For periods of equal ATM mode with a minimum duration of one hour – constraints on rolling hours, i.e. each 60 minute interval that occurs within that ATM mode, with a stepsize of 20 minutes, will have a constraint on capacity.

Additional requirements:

- Arrival and departure peak modes should not overlap.
- Each arrival peak mode period shall be separated from a preceding departure peak mode period by an off peak mode period. Between the first departure and arrival peak, the duration of this off peak mode period should be at least 30 minutes. The duration of this off peak mode period between any other departure and arrival peak shall be at least 20 minutes.
- Each departure and arrival peak mode shall have a minimal duration of 40 minutes, except for the first peak mode at 05:00 UTC, which has a minimal duration of 20 minutes.
- Slots should be requested and will be allocated per 5 minutes.

¹ Departure peak mode: one runway is used for landings, two runways for take-offs. Day arrival and departure procedures are applied.
 Arrival peak mode: two runways are used for landings, one runway for take-offs. Day arrival and departure procedures are applied.
 Off peak mode: one runway is used for landings, one runway for take-offs. Day arrival and departure procedures are applied.
 Night mode: one runway is used for landings, one runway for take-offs. Night arrival and departure procedures are applied.

In the bracket list, that forms integral part of this declaration, the number of available arrival and departure slots for any 20 minute interval and per rolling hour is shown. This capacity depends on the operational runway capacity for the different ATM modes and the agreed peak- and off-peak times for the day period and should meet the mentioned additional requirements. The bracket list for the twenty-four hours period, in accordance with the above table, is specified in Attachment 1.

The bracket list will be endorsed together with this capacity declaration.

Additional requirements and conditions

1. This declaration for summer 2018 is based on a total assumed number of 185,000 movements (Commercial Aviation only) during the winter season 2017/2018 (October 29, 2017 through March 24, 2018, 21 weeks), in accordance with the capacity declaration for winter 2017/2018. If the actual number of movements in said period is less than 185,000, Schiphol will decide, taking into account the input received from the OSO-parties in August 2017, whether the unused capacity will be added to the planning limit of 313,740 slots for summer 2018. The manner and to which degree unused capacity from winter 2017/2018 will be transferred will be determined by Schiphol in the third week of February 2018. The actual transfer, if any, will take place after the 24th of March 2018.

In relation to the transfer of night capacity, the following applies: The declaration for summer 2018 is based on a total number of 10,735 night slots (Commercial Aviation only) during winter 2017/2018 (October 29, 2017 through March 24, 2018, 21 weeks), in accordance with the capacity declaration for winter 2017/2018. If the number of night movements in said period is less than 10,000 movements, the difference will be added to the planning limit of 23,219 night slots for summer 2018.

2. Based on the legally binding noise limits "Lnight" in the legislation mentioned above, a target of 32,000 actual night movements (Commercial Aviation only) during the operational year 2018 should be taken into account for the allocation of night slots.
3. It is noted that for the purpose of the above provision, night slots imply departure slots in the bracket 22:40 – 06:59 LT (winter 21:40 – 05:59 UTC; summer 20:40 – 04:59 UTC) and arrival slots in the bracket 23:00 – 07:19 LT (winter 22:00 – 06:19 UTC; summer 21:00 – 05:19 UTC).

Explanatory remarks

1. It is noted that operational year 2018 should be considered a transition period prior to adoption of the new legislation. Procedures and policies, especially regarding night slots and night movements, may be revised for future capacity declarations.
2. Some supplemental information which is relevant for operators planning operations at Amsterdam Airport Schiphol is provided in Attachment 2.

Attachment 1: Bracket list summer 2018

Time from [UTC]	Time to [UTC]	# Arrivals	# Departures	# Rolling hour Arr	# Rolling hour Dep
0:00	0:15	8	9	-	-
0:20	0:35	8	9	-	-
0:40	0:55	8	9		
1:00	1:15	8	9		
1:20	1:35	8	9		
1:40	1:55	8	9		
2:00	2:15	8	9	24	25
2:20	2:35	8	9		
2:40	2:55	8	9		
3:00	3:15	8	9		
3:20	3:35	8	9		
3:40	3:55	8	9		
4:00	4:15	8	10	-	-
4:20	4:35	8	10	-	-
4:40	4:55	8	14	-	-
5:00	5:15	12	25	-	-
5:20	5:45	18	20	-	-
5:50	5:55	11	6	-	-
6:00	6:15	23	13		
6:20	6:35	23	13	68	38
6:40	6:55	23	13		
7:00	7:15	23	13		
7:20	7:35	12	25		
7:40	7:55	12	25	36	74
8:00	8:15	12	25		
8:20	8:35	12	25		
8:40	8:55	12	14	-	-
9:00	9:15	23	13	-	-
9:20	9:35	23	13	-	-
9:40	9:55	12	25		
10:00	10:15	12	25	36	74
10:20	10:35	12	25		
10:40	10:55	12	14	-	-
11:00	11:15	23	13		
11:20	11:35	23	13	68	38
11:40	11:55	23	13		

12:00	12:15	12	25		
12:20	12:35	12	25	36	74
12:40	12:55	12	25		
13:00	13:15	12	14	-	-
13:20	13:35	23	13		
13:40	13:55	23	13	68	38
14:00	14:15	23	13		
14:20	14:35	12	25		
14:40	14:55	12	25		
15:00	15:15	12	25	36	74
15:20	15:35	12	25		
15:40	15:55	12	25		
16:00	16:15	12	14	-	-
16:20	16:35	23	13		
16:40	16:55	23	13		
17:00	17:15	23	13	68	38
17:20	17:35	23	13		
17:40	17:55	23	13		
18:00	18:15	12	25		
18:20	18:35	12	25		
18:40	18:55	12	25	36	74
19:00	19:15	12	25		
19:20	19:35	12	25		
19:40	19:55	12	14		
20:00	20:15	12	14	36	40
20:20	20:35	12	14		
20:40	20:55	12	9	-	-
21:00	21:15	8	9		
21:20	21:35	8	9		
21:40	21:55	8	9		
22:00	22:15	8	9	24	25
22:20	22:35	8	9		
22:40	22:55	8	9		
23:00	23:15	8	9		
23:20	23:35	8	9	-	-
23:40	23:55	8	9	-	-

This bracket list summer 2018 resembles the available slots per 20 minutes and per rolling hour, in accordance with the underlying capacity declaration summer 2018 and the current distribution of historical slots. Alternations to the bracket list summer 2018 are possible, provided that it is in accordance with the declaration. The bracket list summer 2018 is part of the declaration. No changes to the bracket list are possible after the endorsement of the final version of this capacity declaration, which will be at least seven days before the IATA Initial Submission Date.

Note that due to technical limitations rolling hours containing the transition to the next day cannot be defined. Therefore only 20 minutes capacities are defined for 23:20-0:40 hours UTC.

Appendix VI Python script heatmap

```

%% Importeren
import pandas as pd
import matplotlib.pyplot as plt

slotsw17= pd.read_csv("Slots W17.csv" , sep=';', header=0, index_col='Date')
demandw174= pd.read_csv("Demand EHFIRAM 4 W17.csv" , sep=';', header=0, index_col='Date')
demandw173= pd.read_csv("Demand EHFIRAM 3 W17.csv" , sep=';', header=0, index_col='Date')
demandw172= pd.read_csv("Demand EHFIRAM 2 W17.csv" , sep=';', header=0, index_col='Date')
demandw171= pd.read_csv("Demand EHFIRAM 1 W17.csv" , sep=';', header=0, index_col='Date')

slotss18= pd.read_csv("Slots S18.csv" , sep=';', header=0, index_col='Date')
demands184= pd.read_csv("Demand EHFIRAM 4 S18.csv" , sep=';', header=0, index_col='Date')
demands183= pd.read_csv("Demand EHFIRAM 3 S18.csv" , sep=';', header=0, index_col='Date')
demands182= pd.read_csv("Demand EHFIRAM 2 S18.csv" , sep=';', header=0, index_col='Date')
demands181= pd.read_csv("Demand EHFIRAM 1 S18.csv" , sep=';', header=0, index_col='Date')

font = {'family' : 'normal',
        'weight' : 'normal',
        'size' : 16}

plt.rc('font', **font)

plt.rc('xtick', labelsiz=12)
plt.rc('ytick', labelsiz=14)

%% Airport Slots W17
slotsw17.index = pd.to_datetime(slotsw17.index, format='%d-%m-%y')
plt.figure(figsize=(10,8))
figslots17=plt.imshow(slotsw17, cmap='YlOrBr', interpolation='nearest', vmin=0, vmax=12)

l1 = pd.to_datetime(slotsw17.index).month
l2 = pd.to_datetime(slotsw17.columns).hour
x = pd.Series(l2).drop_duplicates()
y = pd.Series(l1).drop_duplicates()

plt.xticks(x.index,('00:00', '01:00', '02:00', '03:00', '04:00', '05:00', '06:00', '07:00', '08:00', '09:00', '10:00',
'11:00', '12:00', '13:00', '14:00', '15:00', '16:00', '17:00', '18:00', '19:00', '20:00', '21:00', '22:00', '23:00'),
rotation=90)
plt.yticks(y.index,("Mar `18", 'Feb `18', 'Jan `18', 'Dec `17', 'Nov `17'))
plt.colorbar()
plt.xlabel("Time (UTC)")
plt.ylabel("Date")
plt.title("Overdemand in airport slots W17")
plt.savefig('slotsw17.svg', dpi=1200)
plt.show()

%% Demand EHFIRAM 4 W17
demandw174.index = pd.to_datetime(demandw174.index, format='%d-%m-%y')
plt.figure(figsize=(10,8))
figdemandw174=plt.imshow(demandw174, cmap='YlOrBr', interpolation='nearest', vmin=0, vmax=14)

l3 = pd.to_datetime(demandw174.index).month
l4 = pd.to_datetime(demandw174.columns).hour
x = pd.Series(l4).drop_duplicates()
y = pd.Series(l3).drop_duplicates()
plt.xticks(x.index,('00:00', '01:00', '02:00', '03:00', '04:00', '05:00', '06:00', '07:00', '08:00', '09:00', '10:00',
'11:00', '12:00', '13:00', '14:00', '15:00', '16:00', '17:00', '18:00', '19:00', '20:00', '21:00', '22:00', '23:00'),
rotation=90)
plt.yticks(y.index,("Mar `18", 'Feb `18', 'Jan `18', 'Dec `17', 'Nov `17'))

```

```
plt.colorbar()
plt.xlabel("Time (UTC)")
plt.ylabel("Date")
plt.title("Overdemand EHFIRAM W17 Scenario 4")
plt.savefig('demandEHFIRAMw174.svg', dpi=1200)
plt.show()

### Demand EHFIRAM 3 W17
demandw173.index = pd.to_datetime(demandw173.index, format='%d-%m-%y')
plt.figure(figsize=(10,8))
figdemandw173=plt.imshow(demandw173, cmap='YlOrBr', interpolation='nearest', vmin=0, vmax=14)

l5 = pd.to_datetime(demandw173.index).month
l6 = pd.to_datetime(demandw173.columns).hour
x = pd.Series(l6).drop_duplicates()
y = pd.Series(l5).drop_duplicates()
plt.xticks(x.index,('00:00', '01:00', '02:00', '03:00', '04:00', '05:00', '06:00', '07:00', '08:00', '09:00', '10:00',
'11:00', '12:00', '13:00', '14:00', '15:00', '16:00', '17:00', '18:00', '19:00', '20:00', '21:00', '22:00', '23:00'),
rotation=90)
plt.yticks(y.index,("Mar `18", 'Feb `18', 'Jan `18', 'Dec `17', 'Nov `17'))

plt.colorbar()
plt.xlabel("Time (UTC)")
plt.ylabel("Date")
plt.title("Overdemand EHFIRAM W17 Scenario 3")
plt.savefig('demandEHFIRAMw173.svg', dpi=1200)
plt.show()

### Demand EHFIRAM 2 W17
demandw172.index = pd.to_datetime(demandw172.index, format='%d-%m-%y')
plt.figure(figsize=(10,8))
figdemandw172=plt.imshow(demandw172, cmap='YlOrBr', interpolation='nearest', vmin=0, vmax=14)

l7 = pd.to_datetime(demandw172.index).month
l8 = pd.to_datetime(demandw172.columns).hour
x = pd.Series(l8).drop_duplicates()
y = pd.Series(l7).drop_duplicates()
plt.xticks(x.index,('00:00', '01:00', '02:00', '03:00', '04:00', '05:00', '06:00', '07:00', '08:00', '09:00', '10:00',
'11:00', '12:00', '13:00', '14:00', '15:00', '16:00', '17:00', '18:00', '19:00', '20:00', '21:00', '22:00', '23:00'),
rotation=90)
plt.yticks(y.index,("Mar `18", 'Feb `18', 'Jan `18', 'Dec `17', 'Nov `17'))

plt.colorbar()
plt.xlabel("Time (UTC)")
plt.ylabel("Date")
plt.title("Overdemand EHFIRAM W17 Scenario 2")
plt.savefig('demandEHFIRAMw172.svg', dpi=1200)
plt.show()

### Demand EHFIRAM 1 W17
demandw171.index = pd.to_datetime(demandw171.index, format='%d-%m-%y')
plt.figure(figsize=(10,8))
figdemandw171=plt.imshow(demandw171, cmap='YlOrBr', interpolation='nearest', vmin=0, vmax=14)

l9 = pd.to_datetime(demandw171.index).month
l10 = pd.to_datetime(demandw171.columns).hour
x = pd.Series(l10).drop_duplicates()
y = pd.Series(l9).drop_duplicates()
plt.xticks(x.index,('00:00', '01:00', '02:00', '03:00', '04:00', '05:00', '06:00', '07:00', '08:00', '09:00', '10:00',
'11:00', '12:00', '13:00', '14:00', '15:00', '16:00', '17:00', '18:00', '19:00', '20:00', '21:00', '22:00', '23:00'),
rotation=90)
plt.yticks(y.index,("Mar `18", 'Feb `18', 'Jan `18', 'Dec `17', 'Nov `17'))
```

```
plt.colorbar()
plt.xlabel("Time (UTC)")
plt.ylabel("Date")
plt.title("Overdemand EHFIRAM W17 Scenario 1")
plt.savefig('demandEHFIRAMw171.svg', dpi=1200)
plt.show()

### Airport Slots S18
slotss18.index = pd.to_datetime(slotss18.index, format='%d-%m-%y')
plt.figure(figsize=(10,11.7))
figslotss18=plt.imshow(slotss18, cmap='YlOrBr', interpolation='nearest', vmin=0, vmax=12)

l11 = pd.to_datetime(slotss18.index).month
l12 = pd.to_datetime(slotss18.columns).hour
x = pd.Series(l12).drop_duplicates()
y = pd.Series(l11).drop_duplicates()

plt.xticks(x.index,('00:00', '01:00', '02:00', '03:00', '04:00', '05:00', '06:00', '07:00', '08:00', '09:00', '10:00',
'11:00', '12:00', '13:00', '14:00', '15:00', '16:00', '17:00', '18:00', '19:00', '20:00', '21:00', '22:00', '23:00'),
rotation=90)
plt.yticks(y.index,(" 'Oct `18 `", 'Sep `18 `', 'Aug `18 `', 'Jul `18 `', 'Jun `18 `', 'May `18 `', 'Apr `18 `'))
plt.colorbar()
plt.xlabel("Time (UTC)")
plt.ylabel("Date")
plt.title("Overdemand in airport slots S18")
plt.savefig('slotss18.svg', dpi=1200)
plt.show()

### Demand EHFIRAM 4 S18
demands184.index = pd.to_datetime(demands184.index, format='%d-%m-%y')
plt.figure(figsize=(10,11.7))
figdemands184=plt.imshow(demands184, cmap='YlOrBr', interpolation='nearest', vmin=0, vmax=14)

l13 = pd.to_datetime(demands184.index).month
l14 = pd.to_datetime(demands184.columns).hour
x = pd.Series(l14).drop_duplicates()
y = pd.Series(l13).drop_duplicates()
plt.xticks(x.index,('00:00', '01:00', '02:00', '03:00', '04:00', '05:00', '06:00', '07:00', '08:00', '09:00', '10:00',
'11:00', '12:00', '13:00', '14:00', '15:00', '16:00', '17:00', '18:00', '19:00', '20:00', '21:00', '22:00', '23:00'),
rotation=90)
plt.yticks(y.index,(" 'Oct `18 `", 'Sep `18 `', 'Aug `18 `', 'Jul `18 `', 'Jun `18 `', 'May `18 `', 'Apr `18 `'))

plt.colorbar()
plt.xlabel("Time (UTC)")
plt.ylabel("Date")
plt.title("Overdemand EHFIRAM S18 Scenario 4")
plt.savefig('demandEHFIRAMs184.svg', dpi=1200)
plt.show()

### Demand EHFIRAM 3 S18
demands183.index = pd.to_datetime(demands183.index, format='%d-%m-%y')
plt.figure(figsize=(10,11.7))
figdemands183=plt.imshow(demands183, cmap='YlOrBr', interpolation='nearest', vmin=0, vmax=14)

l15 = pd.to_datetime(demands183.index).month
l16 = pd.to_datetime(demands183.columns).hour
x = pd.Series(l16).drop_duplicates()
y = pd.Series(l15).drop_duplicates()
plt.xticks(x.index,('00:00', '01:00', '02:00', '03:00', '04:00', '05:00', '06:00', '07:00', '08:00', '09:00', '10:00',
'11:00', '12:00', '13:00', '14:00', '15:00', '16:00', '17:00', '18:00', '19:00', '20:00', '21:00', '22:00', '23:00'),
rotation=90)
plt.yticks(y.index,(" 'Oct `18 `", 'Sep `18 `', 'Aug `18 `', 'Jul `18 `', 'Jun `18 `', 'May `18 `', 'Apr `18 `'))
```

```
plt.colorbar()
plt.xlabel("Time (UTC)")
plt.ylabel("Date")
plt.title("Overdemand EHFIRAM S18 Scenario 3")
plt.savefig('demandEHFIRAMs183.svg', dpi=1200)
plt.show()
```

```
### Demand EHFIRAM 2 S18
demands182.index = pd.to_datetime(demands182.index, format='%d-%m-%y')
plt.figure(figsize=(10,11.7))
figdemands182=plt.imshow(demands182, cmap='YlOrBr', interpolation='nearest', vmin=0, vmax=14)
```

```
l17 = pd.to_datetime(demands182.index).month
l18 = pd.to_datetime(demands182.columns).hour
x = pd.Series(l18).drop_duplicates()
y = pd.Series(l17).drop_duplicates()
plt.xticks(x.index,('00:00', '01:00', '02:00', '03:00', '04:00', '05:00', '06:00', '07:00', '08:00', '09:00', '10:00',
'11:00', '12:00', '13:00', '14:00', '15:00', '16:00', '17:00', '18:00', '19:00', '20:00', '21:00', '22:00', '23:00'),
rotation=90)
plt.yticks(y.index,(" 'Oct `18 ' , 'Sep `18', 'Aug `18', 'Jul `18', 'Jun `18', 'May `18', 'Apr `18'))
```

```
plt.colorbar()
```

```
plt.xlabel("Time (UTC)")
plt.ylabel("Date")
plt.title("Overdemand EHFIRAM S18 Scenario 2")
plt.savefig('demandEHFIRAMs182.svg', dpi=1200)
plt.show()
```

```
### Demand EHFIRAM 1 S18
demands181.index = pd.to_datetime(demands181.index, format='%d-%m-%y')
plt.figure(figsize=(10,11.7))
figdemands181=plt.imshow(demands181, cmap='YlOrBr', interpolation='nearest', vmin=0, vmax=14)
```

```
l9 = pd.to_datetime(demands181.index).month
l10 = pd.to_datetime(demands181.columns).hour
x = pd.Series(l10).drop_duplicates()
y = pd.Series(l9).drop_duplicates()
plt.xticks(x.index,('00:00', '01:00', '02:00', '03:00', '04:00', '05:00', '06:00', '07:00', '08:00', '09:00', '10:00',
'11:00', '12:00', '13:00', '14:00', '15:00', '16:00', '17:00', '18:00', '19:00', '20:00', '21:00', '22:00', '23:00'),
rotation=90)
plt.yticks(y.index,(" 'Oct `18 ' , 'Sep `18', 'Aug `18', 'Jul `18', 'Jun `18', 'May `18', 'Apr `18'))
```

```
plt.colorbar()
plt.xlabel("Time (UTC)")
plt.ylabel("Date")
plt.title("Overdemand EHFIRAM S18 Scenario 1")
plt.savefig('demandEHFIRAMs181.svg', dpi=1200)
plt.show()
```

Appendix VII Historical lead-times of the Dutch FIR

Table 9: Historical lead-times of the Dutch FIR.

RWY 18R	EIBT	RWY	TMA
EHSECT1	00:37	00:25	00:12
EHSECT2	00:37	00:25	00:13
EHSECT3	00:35	00:23	00:10
EHSECT4	00:33	00:21	00:11
EHSECT5	00:33	00:21	00:10