Robust model for operational stand and gate planning Schiphol

Danuta Käller

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D.I.W.A. Käller

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Thesis committee:	Prof. Dr. R. Curran,	TU Delft, ATO, Chair
	ir. P. C. Roling,	TU Delft, ATO, supervisor
	ir. G. A. Mercado Velasco,	To70, supervisor
	Dr. ir. J. Ellerbroek,	TU Delft, C&S, external examiner

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Preface

"Tout objectif sans plan n'est qu'un souhait"
- Antoine de Saint-Exupéry

In other words: a goal without a plan is just a wish. True words by the French pilot and writer of amongst others 'Le Petit Prince', Antoine de Saint-Exupéry, and very fitting as a quote covering this thesis work. It fits the subject of this thesis, in which the ideal of mitigating stand and gate changes and omitting corresponding delays is to be achieved by the creation of a robust stand and gate allocation plan. A challenging goal, as a hub airport such as Schiphol has long reached its stand capacity and experiences stand changes due to allocation plans that have little room for delay. Furthermore, the quote fits the goal of delivering this report to you, the reader, as one of the last bits of a long-stretched plan that consisted of carrying out this research from the project proposal and the literature review up to the moment I present and defend this work on 15 March 2019. It means that a goal needs a plan if it needs to be more than a whim or an idea, but it also shows that a wish can be realised if carried out with a certain motivation, perseverance and a great deal of organisation. I am proud to say that my wish of becoming an Aerospace Engineer is nearly solidified, which is the result of falling and rising, and most definitely of not losing track of this goal. During my thesis project, I learned a great deal on operations optimisation and on the ins and outs of capacity issues at an airport, and I hope this initial research on individual buffer time optimisation will grow into an effective solution to current airport capacity problems.

Of course, reaching this point would not have been possible without the support and experience of the people that have been involved in this thesis project. They have inherently been part of the 'plan' that has led to this day, and for that, I want to express my sincere gratitude. First of all, I want to put a spotlight on my supervisors and helpful guides, Paul Roling and Gustavo Mercado. Paul, the moment I walked into your office to discuss the possibilities of a graduation project under your wing, you have been perpetual enthousiastic. You have been the perfect supervisor by supporting my every decision, but also by being critical when necessary. All meetings have been a great and motivational boost to execute my research. Gustavo, thank you so much for your insights that you so patiently shared from the beginning of my research. Often you listened so sincerely that you even seemed to understand my questions before I finished to formulate them in detail. Your willingness to help out, even in the frantic last week before your long-planned Christmas holiday, has really been a great support. I am also very grateful to Gergely Földes, my contact at BEONTRA, the German company developing integrated traffic, capacity and revenue planning software for infrastructure providers of which I used parts to formulate my Stand and Gate Allocation model. Gergely, thank you for all the time you spent in providing helpful advice and insights on the use of BEONTRA's Stand and Gate Planning tool. The trip to Karlsruhe has been very informative and I am very grateful for the opportunity of having been able to use the BEONTRA features. Last, I want to thank my colleagues at To70 for their hospitality, their support, and of course for facilitating my graduation project.

Deep gratitude also needs to be expressed to a few people that have been invaluable throughout the journey of turning my wish into an achievable goal. Dear Mom, thank you so much for your unstoppable belief in me and your care, even though you went through so much the last years yourself. It made this thesis period a tensive one with your surgery and the aftermath: I do hope everything goes for the better now. Dear Hans, I am so grateful for you being in my life: with your unfaltering support, your love and your great sense of humor, the achievement of acquiring the Master's degree is as much yours as it is my own. Thank you for being the greatest buddy I could wish for during this adventure! Dear Rogier, if it wasn't for you, my research project would have taken a dreadful turn: thank you so much for all the help when my hard disk broke down, and even more for sharing your unrivalled wisdom regarding programming. Dear Henriëtte, thank you for helping me to realise the cover page: it is the perfect finishing touch on this work. All in all, it has been an unforgettable pleasure to work towards the finalisation of my time as a student with all the dear and helpful people around me. Thank you, dear reader, for taking an interest in my work!

Danuta Käller
Delft, 24 February 2019

Summary

The purpose of this graduation thesis is to investigate the effects of individually established buffer times, based on historical delay data, on the robustness of an operational stand allocation schedule. With an operational schedule, the one-day-ahead schedule for aircraft-to-stand-allocation is meant. As air traffic travel numbers increase every year, airports have to adapt to cope with corresponding capacity issues. These issues are also experienced at Amsterdam Airport Schiphol, where it is estimated that 40% of the flights undergo a minimum of one changed stand in comparison with the operational schedule due to congestions. By optimising stand allocation and incorporating buffer times that are customised for each flight, based on common delay data, optimal use can be made of the resources at an airport. Efficient use of resources then resolves congestions and increases robustness. With robustness, the ability of an allocation schedule to absorb delays is meant. In order to meet the purpose of this thesis, the following research question needs to be answered: "is it possible to increase the robustness of a model for operational stand and gate allocation at Amsterdam Airport Schiphol by optimising buffer times and covering all allocation rules and procedures?"

To this end, an optimisation model for stand and gate allocation for Schiphol is created in BEONTRA software. In this model, business allocation procedures are combined with allocation restrictions. The flight schedule of Monday 16 July 2018, to be used as input for the model, as well as information on the allocation rules and the structure of Schiphol, are provided by aviation consultancy firm To70. In order to investigate the influence of increasing buffer times on allocation results, the buffer times are first uniformly increased from 0 to 20 minutes in steps of 5 minutes. Due to their own nature of operation, low-cost flights remain to have a fixed buffer time of 10 minutes. What stands out, is that with an increasing buffer time, the number of unallocated flights increases. More specifically, the number of unallocated widebody (WIBO) aircraft grows between 6:00 and 14:00, while the number of unallocated narrowbody (NABO) aircraft grows between 19:00 and 21:00. An analysis of the ground movements and the corresponding stand requirements for the flight schedule for 16 July 2018 shows that in these time periods, indeed peaks in the demand for stands of these aircraft types are present, for which at the higher buffer times, the number of contact stands is exceeded.

Next, the buffer times are optimised by grouping delay data of recorded delays in the summer period of 2017. Groups are made according to two scenarios: scenario 1 groups flights based on arrival or departure, on WIBO or NABO, on border control status, and on one of four time periods during the day. Scenario 2 is hybrid and groups flights based on arrival or departure, on airline, on origin or destination, and on one of four time periods during the day. Groups need to contain more than 500 flights in order to obtain an individual buffer time, otherwise a flight is assigned to a fitting scenario 1-group. For each group in both scenarios, an empirical delay distribution is acquired by grouping the corresponding delays in bins that are rounded to the nearest multiple of five. Buffer times are then determined for four different cases for each scenario: the goal is to set a buffer time that would, together with the stand occupancy time, cover respectively 60%, 70%, 80%, and 90% of the flights in the empirical delay distributions. The buffer times respectively increase per subscenario, as well as the number of unallocated flights for the corresponding allocation schedules. These schedules are assessed on several Key Performance Indicators (KPIs) and compared to the baseline allocation schedules with respectively a fixed buffer time of 0 and 20 minutes.

The allocation schedules are assessed on the following KPIs:

- Percentage of unallocated movements with regard to scheduled movements
- Average stand utilisation per allocated movement
- Percentage of tow movements with regard to allocated movements
- Pier Service Level, or the percentage of contact handled passenger flight movements with regard to total allocated passenger movements
- Average clash probability per allocated movement
- Percentage of stand changes with regard to allocation schedule after simulation in fast-time simulation programme AirTOp

- Average total delay per executed movement, as obtained from simulations in AirTOp
- Average stand delay per executed movement, as obtained from simulations in AirTOp

Regarding the 0-minute buffer time schedule: it performs worst in terms of the set KPIs, except for the percentage of unallocated flights and the clash probability per movement. The latter can be explained by the fact that idle times between flights are substantially small and the total clash probability is divided over more movements. Regarding the 20-minute buffer time schedule: it performs similarly to the optimised subscenario 1 - 80% and 90%, which are schedules for which the mean, the median and the mode are approximately 20 minutes. Furthermore, the increase of buffer times proves to have a positive influence on the increase in the stand utilisation per allocated movement; on the increase in Pier Service Level (PSL) of WIBO aircraft; on the decrease in average clash probability per allocated movement, based on recorded flight delay data; and on the decrease in stand change percentage. Regarding the stand change percentage: all allocation schedules result in a stand change percentage of less than the mentioned estimation of 40%. An interesting result is obtained for the delay data: the standard deviations and the standard errors of the mean for the delay data indicate that the results of the averages for scenarios with low buffer times are less accurate than the results of the averages for scenarios with large buffer times. For the scenarios 1 - 80% and 90%, and 2 - 80% and 90%, and the scenario using a buffer time of 20 minutes, it can be stated with more confidence that delay values are relatively low, and that the corresponding allocation schedules are more robust with regard to absorbing delays. Overall, scenario 1 provides better results than scenario 2, of which 1 - 80% and 90% provide results similar to the 20 minute-buffer time schedule. Scenario 1 - 80% and 90% perform better in terms of WIBO PSL, however.

In answer to the research question, it is not possible to compare the operational allocation schedule results from this research to actual operational schedules. However, the estimation of 40% stand changes is not exceeded by the optimised allocation schedules. Furthermore, in contrast to the known allocation procedures of Schiphol, the schedules created for this thesis do incorporate all allocation rules. It appears that grouping and optimising buffer times in time blocks for certain flights has a positive impact on KPIs that indicate robustness, and is similar to a schedule for which the theoretical buffer time of 20 minutes is used. The KPIs that indicate robustness here are the average clash probability per movement, as well as the average delay and stand delay per movement. As this theoretical buffer time of 20 minutes is often diminished in practice, it shows that it is of value to vary buffer times during the day for the optimisation of resources and operations at an airport, as well as to implement business rules into the model in order to provide a practical and operational plan that needs little to none manual adjustments. With regard to the resource optimisation, the scenarios with the largest optimised buffer times generate the best results in terms of WIBO PSLs.

In summary, optimising buffer times shows positive results in terms of robustness measuring KPIs. Together with a model that includes all allocation rules and procedures, optimised buffer times show great potential to improve the robustness of an allocation schedule and, with that, improve airport operations. Therefore, follow-up research is highly recommended. A substantiated answer to the research question can be provided if the modelled allocation schedule results are compared to actual allocations at Amsterdam Airport Schiphol on 16 July 2018. Therefore, it is recommended to compare the research results to actual allocation data by focussing on tactical scheduling. Furthermore, it could be of positive contribution to use more historical delay data in order to compute more accurate clash probabilities and individually optimised buffer times. The influences of more specification details regarding the buffer times can then be investigated, such as narrowing the time periods down to an hour during peak hours. Also, the influence of grouping buffer times for other airports, and the corresponding influence of airport structures on these groups and their results could be investigated. Buffer times could also be optimised for the winter period. A challenging, additional requirement is one of de-icing and the corresponding implementation of de-icing activities in the SGA model, as well as the potential influences of harsh weather conditions and corresponding delay outliers. Last, an interesting topic would be to research the influence of buffer time optimisation as part of the SGA problem, integrated with other airport ground management operations, being the runway allocation and scheduling, and the aircraft ground movement.

Contents

Glossary

Acronyms

A	Arrival
AAS	Amsterdam Airport Schiphol
AMS	IATA code for Amsterdam Airport Schiphol
ATM	Air Traffic Management
Avg	Average
a/c	Aircraft
B&B	Branch and Bound (algorithm)
B&C	Branch and Cut (algorithm)
BCS	Border Control Status
BT	Buffer Time
C	Contact or connected (stand). In case of flight types, 'C' denotes a passenger, charter flight
CISS	Central Information System Schiphol
D	Departure. In case of the header 'O/D', destination is meant
EHAM	Europe Holland Amsterdam: ICAO code for Amsterdam Airport Schiphol
EU	European Union
F	Flight type denoting scheduled cargo/mail flight
GMS	Gate Management Software
H	Heavy aircraft; Wake Turbulence Category
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
ILP	Integer Linear Programming
J	Flight type denoting scheduled passenger flight
KPI	Key Performance Indicator
L	Light aircraft; Wake Turbulence Category
LP	Linear Programming
LVNL	Luchtverkeersleiding Nederland
M	Medium aircraft; Wake Turbulence Category
MARS	Multiple Apron Ramp System
MILP	Mixed Integer Linear Programming
NABO	Narrowbody
NP	Non-deterministic Polynomial-time
NS_scr	Non-Schengen screened
NS_uns	Non-Schengen unscreened
O	Origin
P	Flight type denoting non-revenue positioning flight
Pax	Passengers
Pos.	Positioning stand
Prob	Probability
PSL	Pier Service Level
R	Remote (stand)
RASAS	Regulation Aircraft Stand Allocation Schiphol
S	Superheavy aircraft; Wake Turbulence Category
Scen	Scenario
SCH	Schengen
scr	Screened (Non-Schengen)
SE	Standard Error
SESAR	Single European Sky Air Traffic Management (ATM) Research

SGA	Stand and Gate Allocation
STA	Scheduled Time of Arrival
STD	Scheduled Time of Departure
STDEV	Standard Deviation
TAT	Turnaround Time
uns	Unscreened (Non-Schengen)
WIBO	Widebody
WTC	Wake Turbulence Category

Terms

BEONTRA Scenario Planning tool	Integrated airport-planning tool, covering prediction on both long- and short-term basis
Bin	Interval used in histogram or distribution plot, of which the width is based on a fixed time duration, for example
Block time	The time an aircraft takes from pushing back from the stand at the airport of origin to the time of arrival at the stand of the destination airport
Branching variable	Chosen integer-restricted variable that has a non-integer value in the optimal solution for the Linear Programming (LP) relaxation
Buffer time	Time that a stand or a gate is not in use in order absorb early arriving or delayed flights. Theoretically set to 20 minutes at Amsterdam Airport Schiphol
Bussed gate	Gate that enables passenger transfers by bus to remote stands
Contact handling	Pier (served) handling or handling of a passenger aircraft at a contact stand
Contact stand	Stand that is connected to a gate through an air bridge or by a short-distance walk. Can be used for handling of passenger aircraft only
Dynamic model	Time-dependent model
Dual-hub system	Cooperation system of two hub airports in order to offer more destinations by en-route transfers in one of the two airports
Dual status	Flight, stand or pier status denoting the ability to receive multiple border control statuses
Flight	An arrival and the corresponding departure of one aircraft
Flight movement	See movement
Flight number	Registration number of an aircraft for a specific flight movement, containing the airline code as well
Gate	Terminal area that is designated for passenger embarking and disembarking, linked to a contact stand through an air bridge or by a short-distance walk, or to a remote stand through a bus connection
Gurobi	Optimisation software package
Holding area	Buffer parking position(s) for aircraft, on which flights can wait in case of early arrivals or delays until their designated stand becomes available
Hub-and-spoke network	Network in which there is one airport that receives flights from smaller airports in order to distribute in a more efficient manner: WIBO flights are fed by passengers from arrived NABO flights, and WIBO flight passengers are further distributed to their destinations by NABO flights
IBM ILOG CPLEX Optimization Studio	Also referred to as CPLEX. Optimisation software package
Incumbent	Best integer solution, providing the lowest objective function value at that moment, in the search of a Branch and Bound (B&B) algorithm
Movement	Either an arrival or a departure

Multiple time slot model	Model in which the allocation of flights is considered within multiple time slots, meaning that several, subsequent flights can be assigned to each stand
Narrowbody (aircraft)	Single-aisle aircraft. At Schiphol, narrowbody (NABO) aircraft include aircraft size categories 1 up to 4
Non-preemptive	In the case of Stand and Gate Allocation (SGA) procedures, this strategy implies that a stand is only to be released when the arrived aircraft leaves the stand
Non-Schengen screened	Border control status denoting countries within Europe or countries that have similar border control security requirements as European countries. Passengers travelling from a Non-Schengen screened country to Schiphol require a light security check
Non-Schengen unscreened	Border control status denoting passengers travelling from countries for which additional security checks apply
Operational phase	Part of the Stand and Gate Allocation (SGA) procedure, in which one-day-ahead information on flight changes are taken into account and adapted in the seasonal allocation schedule
Pier (served) handling	Contact handling or handling of a passenger aircraft at a contact stand
Positioning flight	Flight movement of a passenger aircraft, carrying no passengers, in order to position an aircraft at another airport
Preemptive	In the case of Stand and Gate Allocation (SGA) procedures, this strategy implies that a stand that has been assigned to an aircraft can be released if the aircraft has a delay
Relaxation	Simplification of a Mixed Integer Linear Programming problem by removing the integrality restrictions, making it a Linear Programming (LP) problem
Remote handling	Handling of an aircraft at a stand that is not connected directly to a gate. In case of passenger aircraft, passengers are transferred to or from a gate by bus. Non-passenger aircraft are handled at a remote stand only
Remote stand	Stand that is not connected directly to a gate; can be used for both passenger as well as non-passenger aircraft handling
Robustness	The ability of, in this case, an allocation schedule to absorb delays and last-minute alterations
Schengen	Border control status denoting countries from the Schengen area. The Schengen agreement is a set of rules that regulate and abolish the need for border controls between participating countries. Schengen countries are all European Union (EU) member states, excluding Ireland, the United Kingdom, Romania, Bulgaria, Croatia, and Cyprus. Switzerland, Liechtenstein, and Norway are not part of the EU, but they do participate in the Schengen agreement. Furthermore, San Marino, the Vatican City, and Monaco have open borders with neighbouring Schengen countries and can be entered with a Schengen visa
Seasonal phase	Part of the Stand and Gate Allocation (SGA) procedure, in which the time slot allocation schedule, or flight schedule, is used to establish an initial SGA schedule
Stand	Pier-connected or remote parking position for aircraft at an airport, which can vary in size and aircraft handling features
Single time slot model	Model in which the allocation of a batch of flights is considered within one given time slot, meaning that only one flight can be assigned to each stand
Static model	Time-independent model
Swing stand	Dual status stand; stand that can receive both Schengen as well as Non-Schengen flights

Tactical phase	Part of the Stand and Gate Allocation (SGA) procedure, in which the operational allocation schedule is adapted according to (last-minute) changes on the day of operation
Time slot	Period of time in which flights are granted the right to land or take-off, and, correspondingly, are considered for allocation
Tow	Repositioning movement of an aircraft from one stand to another. For long-term parking, a tow can be conducted to an intermediate, long-term parking position; for short-term parking, a tow needs to be conducted for a flight that changes flight type or border control status and for which its initial stand is no longer suited
Towing	Conducting a tow
Turnaround	Flight; an arrival and the corresponding departure of one aircraft and the corresponding, intermediate tows
Turnaround time	The moment of touch-down of a flight up to the moment of take-off, including amongst others taxiing, passenger (dis)embarking, cleaning, and refuelling
Widebody (aircraft)	Twin-aisle aircraft. At Schiphol, widebody (WIBO) aircraft include aircraft size categories 5 up to 9

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1 Introduction

With air traffic travel numbers increasing every year, airports have to adapt in order to cope with capacity change. According to the International Air Transport Association (IATA) [35], the growth in air travel increased more than 7% in 2017 compared to 2016, and the Single European Sky Air Traffic Management Research (SESAR) [34] project expects European traffic to increase from 9.5 million flights in 2012 to 14.4 million in 2035. With a flight, an arrival and the corresponding departure of one aircraft is denoted. To keep subsequent congestions and delays to a minimum, airport resources should be used as efficiently as possible. For that purpose, airport ground management operations should be optimised. These operations include three main problems: runway allocation and scheduling, the ground movement of aircraft, and the aircraft to stand assignment and scheduling. According to Dorndorf et al. [23] and Marinelli et al. [44], the latter is one of the most important and most complicated airport management topics, providing room for improvement and optimisation, and being an interesting and challenging subject for corresponding research.

The purpose of Stand and Gate Allocation (SGA) is to allocate aircraft to appropriate airport stands and gates in a way that planned arrival and departure times of flights can be realised. This process needs to happen without blocking other flights and with as little costly, intermediate repositioning movements, 'towing', as possible. Stands and gates are defined as follows: stands are the pier-connected and remote parking positions for aircraft at an airport, which can vary in size and aircraft handling features. Gates are terminal areas that are designated for passenger embarking and disembarking. Gates can be linked directly to a contact stand through an air bridge, or indirectly to a remote stand through a bus connection that transports passengers between the gate and the stand.

The SGA procedure consists of three phases: the seasonal phase, which consists of the baseline SGA planning for either Summer or Winter season, based on the flight schedule; the operational phase, which is a version of the seasonal planning, in which the one-day-ahead information on flight changes is taken into account; and the tactical phase, which consists of the reallocation and rescheduling on the day of operation in the case of unforeseen congestions and delays. However, in case these congestions and delays could be predicted, and the operational schedule would be able to absorb these deviations, reallocation and rescheduling on the day of operation would not be necessary. In that case, the operational schedule would be robust enough to exclude the need for the tactical phase. With 'robust', it is meant that the schedule is able to withstand last-minute changes. An effective way of implementing robustness is by increasing the times that stands are not in use in order to absorb early arriving or delayed flights, the 'buffer times'. In doing so, a trade-off needs to be made between increasing buffer times and, correspondingly, increasing robustness; and a smaller capacity to handle aircraft.

This research is about the realisation of a robust operational schedule, for which it is looked into this trade-off. In doing so, the objective is to answer the following research question:

"Is it possible to increase the robustness of a model for operational stand and gate allocation at Amsterdam Airport Schiphol by optimising buffer times and covering all allocation rules and procedures?"

In order to provide a substantiated answer, the following sub-research questions apply:

- What are the relevant criteria and objectives to create a model for operational stand and gate allocation in general and how do these apply to Schiphol?
- Are there methods of adapting buffer times in such a fashion that they can be implemented into the stand and gate allocation model?
- What are suitable Key Performance Indicators (KPIs) to assess an allocation schedule on robustness and aircraft handling capacity?

For the purpose of finding optimal buffer times, historical data on planned and actual flight arrivals and departures is used in order to gather information on the most common schedule deviations. With this information, for each flight an individually optimised buffer time can be calculated. Together with common allocation rules as practised by gate planners, so-called 'business rules', the optimal buffer times need to be implemented in an SGA model and tested to evaluate the ability of the schedule to absorb deviations. To build a realistic model and use actual data for optimisation and validation purposes, a robust operational SGA schedule is created for Dutch mainport Amsterdam Airport Schiphol. Serving more than 68 million passengers in 2017, Schiphol is the third busiest international hub airport in Europe in terms of total passenger numbers [5][1], and therefore a challenging subject to be used as input and test area for the SGA model. In order to answer the main research question, use is made of the expertise and data from To70 Aviation Consultants on Schiphol and SGA procedures; of the BEONTRA Scenario Planning tool, which has Gurobi optimisation software implemented to solve Mixed Integer Linear Programming (MILP) models; and the fast-time airport simulation programme Air Traffic Optimisation (AirTOp) for the testing of the SGA schedule.

This thesis report on robust operational stand and gate planning describes the background and challenges of the SGA problem, and discusses the optimised SGA model configuration and results. In order to describe what has been researched and how this project fits into the wider subject area, Chapter 2 discusses SGA planning in literature. Chapter 3 describes the SGA planning specifications, regulations, and challenges at Amsterdam Airport Schiphol. Chapter 4 describes the working principles and configuration of the SGA model. In Chapter 5, an analysis with the expected capacity bottlenecks is given of the input flight schedule, as well as an analysis of the allocation model results for varying buffer times. This is followed by a description of the individual buffer time optimisation and the corresponding model configuration in Chapter 6. The results of the testing of the corresponding allocation schedules testing in terms of clash probability and in AirTOp are described in Chapter 7. Next, the discussion, the conclusions, and the recommendations are given in Chapter 8. The report is concluded by the bibliography and the appendices.

2

Overview of robust stand and gate Allocation in literature

As has been discussed in the preceding project plan and proposal [37] and literature review [36], a change in the flight schedule can cause a snowball effect of severe congestions in the complex environment of packed airport operations if not handled well. The operations directly influenced by a change in the SGA schedule are the ground handling operations. These include passenger embarking and disembarking, loading cargo, restocking catering supplies, cleaning, refuelling, and baggage handling. Hence, the more efficient the SGA, the more efficient the ground services are handled, the lower the roll-on effect of possible flight delays; the higher the passenger satisfaction; the more efficient the use of airport facilities; and the lower the operating costs. Therefore, SGA planning is a challenging area from which many benefits can be achieved.

Not surprisingly, the SGA problem has been the subject of optimisation research for more than four decades. In 1974, Steuart [56] researched the efficiency of stand positions in SGA with a simple stochastic model, after which the subject gained interest due to the growth in air traffic numbers [35][34], and the corresponding congestion rates at airports. Several solutions have been developed since, of which an extensive survey is given by Bouras et al. [11]. In this chapter, a classification of SGA models is given in Section 2.1; the common model formulations are given in 2.2; an overview of the common constraints is given in 2.3; the corresponding solution methods are given in 2.4, and a description of robustness influencing factors in literature is given in 2.5.

2.1. Classification of the Stand and Gate Allocation problem

The SGA problem essentially is the assignment of flights to available and appropriate parking positions, in which several constraints such as aircraft size are taken into account. The aim of the SGA is to assign all scheduled flights to fitting parking positions and to be able to plan and perform all necessary ground handling activities within the time that the gate and stand are assigned to the flight. As described in Chapter 1, the gate is the terminal position assigned to a flight in case of passenger handling, whereas the stand is the parking position of the aircraft. However, in case the term 'stand' is used throughout this chapter, a corresponding stand and gate combination is meant for passenger flights. In the case that 1000 flight movements a day need to be assigned to 100 stands with each different characteristics, the process includes 100,000 decision variables that require an extensive and detailed model in order to find an optimal solution. In this section, the different classification types of SGA as treated in literature are discussed.

A first classification can be made into single or multiple time slot models, according to Dorndorf et al. [23]. With a time slot, the period of time is meant in which arriving and departing aircraft are considered for allocation. In single time slot models, the allocation of a batch of flights is considered within one given time slot, meaning that only one flight can be assigned to each stand per time slot. In multiple time slot models, the allocation of flights is considered within multiple time slots. As the width of the time slots has an influence on the problem size and the stand utilisation, the width of these time slots has to be determined with caution.

Next, the assignment methods are evaluated by Cheng [14]. Aircraft can be assigned to stands in a sequential manner, in which one aircraft at a time is assigned to a stand, based on time of arrival. The sequential method is easy to implement, but it does not look into other factors. For example, it may be more efficient to assign a later arrived aircraft carrying mostly transfer passengers that need to be able to catch their transfer flight, prior to an aircraft with mostly passengers that have reached their destination. Furthermore, there is the parallel assignment, in which all flights and all stands are considered simultaneously. Therefore, more factors can be considered, but for large airports, this could cause combinatorial problems. Last, there is the problem-oriented group assignment, in which flights are grouped together that have, for example, a certain number of transfer passengers aboard. Next, they are assigned in sequence of their arrival time. This method is problem-specific and does not consider other, non-predefined factors.

Regarding these assignment methods, Narciso & Piera [46] add another one. They state that when a terminal is considered, the corresponding stands can be organised in modules. This allows grouping with regard to, for example, the requirements of an airline. Two assignment policies are suggested: the previously mentioned sequential method, and the distributed method. In the sequential method, a module is assigned to a time slot. In that case, all stands in that module have to be used for allocation before moving to another module. In the distributed method, all flights are distributed in a sequential manner to alternating modules. For example, if a terminal has four piers and each pier is a module, the first arriving flight is assigned to a stand at pier 1, the second flight is assigned to pier 2, etc.; whereas in the sequential assignment, all stands at pier 1 are allocated to the first batch of incoming flights before moving on to the next module.

Another classification distinction that is made by Narciso & Piera [46] is between preemptive and non-preemptive SGA strategies. In the case of a preemptive SGA strategy, a stand that has been assigned to an aircraft can be released if that aircraft has a delay. The strategy considers the reassignment of a stand to maximise its utilisation. In the case of a non-preemptive SGA strategy, however, the stand is released only when the assigned aircraft leaves the stand. The stand remains idle and reserved for the assigned aircraft: in case of a delay, the delayed aircraft does not gain any additional delay, but chances are that the subsequent aircraft that is assigned to that stand does.

Furthermore, models of the SGA problem can be classified into static and dynamic models, according to Cheng et al. [13]. While a static model is time-independent and has therefore no internal memory, a dynamic model is time-dependent and does have internal memory. Deken [15] further makes the distinction between robust and stochastic dynamic models. Dynamic models that are stochastic assume that the uncertainty has a probabilistic nature, which is the case for models with objectives regarding flight delays and stand conflicts; dynamic models that are robust assume that the uncertainty is rather deterministic and set-based, which is the case for models with objectives regarding buffer times.

Regarding objectives, Dorndorf et al. [23] make the distinction between passenger- and airport-oriented objectives. Where the first type considers objectives such as passenger walking distance and baggage carrying distance; the second type considers stand preferences and number of towing operations. Bouras et al. [11] make a similar distinction, but refer to the passenger-oriented objectives as airline-oriented ones. In other words: objectives can either be focused on airport efficiency and costs, or on service and convenience for customers, being either airline or passenger. More on the different kinds of objectives as treated in literature is given in Section 2.3.

In conclusion, a robust operational SGA model for a large hub airport such as Schiphol would be created as a multiple time slot model, as the turnaround time of a flight could exceed the single time slot duration. This can have an influence on the allocation in other time slots as well. Furthermore, a problem-oriented assignment method should be used: some flights have a higher allocation priority, such as widebody (WIBO) aircraft, or flights that need additional security, as these flights can only be assigned to specific stands. Regarding assignment strategies, it is specified in the Regulation Aircraft Stand Allocation Schiphol (RASAS) [3] when a stand is to be released. In practice, however, it might depend on the flight's priority whether the stand will be released or not: flights with higher allocation priority might need to stay assigned to their preassigned stand, due to the stand specifications. Delayed flights with less priority might be reallocated to another stand or to a remote spot in order to release their initially assigned stand. Regarding the model of this research, it has to be dynamic in order to take into account the uncertainties of the flight schedule. The operational model will be based on the deterministic case in which it is assumed that the flights occur in the predefined period of the given flight schedule. Last, the objective will be a combination of airport- and customer-oriented factors: the goal is to make the planning as robust as possible in terms of airport-oriented factors, but some of these factors have an influence on customer satisfaction as well, such as on-time performance.

2.2. Mathematical Stand and Gate Allocation problem model formulations

The optimisation problem of allocating flights to stands can be expressed as a set of mathematical relations. These relations involve a to be optimised objective function and a set of constraints, of which common ones in stand planning are given in Section 2.3. If the mathematical relations are linear, the model is linear; if the relations are non-linear, the model is non-linear. Bouras et al. [11] evaluate some model formulations, such as the integer, binary integer, mixed integer linear or non-linear models, and the binary or mixed binary quadratic model. Some models in literature have been formulated as combinatorial optimisation problems, such as the Quadratic Assignment Problem, the Clique Partitioning Problem, the scheduling problem, and the robust optimisation problem.

An integer programming problem uses integer variables. Often the term refers to Integer Linear Programming (ILP), in which the objective function and the constraints are linear. As evaluated by Bouras et al. [11], ILP is used by Lim et al. [40] to develop a model for optimising SGA's and cargo handling costs, solved using the Insert Move heuristic, the Interval Exchange Move heuristic, and Greedy algorithm; and a model for minimising the passenger walking distance, solved using IBM ILOG CPLEX Optimization Studio, an optimisation software package. Also Diepen et al. [18][16] formulate the SGA problem as an ILP model, minimising the deviations in arrival and departure time, and solved using column generation.

In the special case of binary integer linear programming, unknowns are binary. Tang et al. [57] formulate the SGA problem as a binary ILP to develop a stand reassignment framework and a systematic computerised tool to minimise the passenger walking distance, solved using a Branch and Bound (B&B) algorithm. Kumar & Bierlaire [38] present a model that maximises the idle stand time, minimises the cost of towing an aircraft with a long turnaround, and minimises overall costs that include penalisation for not assigning preferred stands to specific turnaround flights, solved using an optimisation solver programme. Mangoubi & Mathaisel [42] and Yan et al. [64] both minimise the passenger walking distance, respectively solved using Column Generation and Greedy algorithms. However, according to Cheng [14], the computing time of the model by Mangoubi & Mathaisel [42] would increase very fast with an increasing number of aircraft: as they applied mathematical programming through the parallel assignment, in which multiple flights are considered simultaneously for allocation, the expansion in flights to be considered would naturally increase the computational time. Vanderstraeten & Bergeron [60] minimise the number of off-stand events, solved using the newly developed "Affectation Directe des Avions aux Portes" heuristic. Bihr [7] minimises the passenger walking distance, solved using the primal-dual simplex algorithm.

In comparison with ILP, Mixed Integer Linear Programming (MILP) models use both integer and continuous or non-discrete variables. Şeker & Noyan [53] minimise the number of conflicts and the total semideviation between idle time and buffer time, solved using Tabu Search algorithms. Where an idle time is random, being the time period between two subsequent flights that a stand is not used; the buffer time is fixed, being the lower bound on each idle time value. Bolat [8] minimises the range of idle times, solved using a B&B algorithm and a heuristic Branch and Cut (B&C). Bolat [10] also presents a framework for the SGA problem that transforms non-linear binary models into an equivalent linear binary model with the objective of minimising the range or the variance of the idle times, solved using a Genetic algorithm. The framework consists of five mathematical models, where two of the five models were formulated as Mixed Integer Linear Programming and the others as Mixed Integer Non-Linear Programming. Regarding Mixed Integer Non-Linear Programming, Li [39] minimises the number of stand conflicts, solved using CPLEX.

In general, the MILP problem is of the following form:

minimise $Z = \mathbf{c}^{\mathrm{T}}\mathbf{x}$

subject to $A\mathbf{x} = \mathbf{b}$

$\mathbf{x} \geq 0$ (some values of $\mathbf{x}$ must be integer values (integrality constraints))

First, to simplify the problem, the integrality restrictions are removed. This 'relaxation' makes it a Linear Programming (LP) problem. Solving LP relaxations provides the basis for the subsequent branching, bounding and fathoming procedures. The solution of this LP relaxation is optimal if it satisfies all integrality restrictions, but in general, one needs to proceed with branching first: an integer-restricted variable, the 'branching variable', is chosen that has a non-integer value in the optimal solution for the LP relaxation; e.g. $x = 3.4$. Next, the problem is divided into two subproblems by specifying two ranges of values for x, using the integer values closest to the solution: in this case, $x \leq 3$ and $x \geq 4$.

The LP relaxation is then solved for both these values. If the solution satisfies the integrality constraints in the original MILP problem, a feasible solution is found. In that case, the branching variable or node will not be further branched: the node is 'fathomed'. Fathoming of a node is also done when the node did not provide a feasible solution. The best integer solution in the search, in this case providing the lowest objective function value at that moment, is called the 'incumbent'. With this incumbent, an upper bound is acquired for the optimal solution of the MILP problem. In further search iterations, the solution providing the lowest objective function value is compared to the upper bound. If this value is below the upper bound, it is the new incumbent, or lower bound. If the lower bound equals the upper bound, an optimal solution has been found [33][31].

Apart from linear programming, the SGA problem can be modelled using quadratic programming. Zheng et al. [65] formulate the SGA problem as a mixed binary quadratic programme, minimising the idle time variance, solved using a Tabu Search algorithm. Bolat [9] also uses mixed binary quadratic programming to minimise the variance of idle times, solved using a B&B algorithm, and he proposes a single pass heuristic and heuristic B&B for solving the model. Xu & Bailey [62] minimise the passenger connection time, solved using a B&B algorithm. Ding et al. [21][20] present a binary quadratic programming model for the overconstrained SGA problem to minimise the number of unassigned flights, solved using a Greedy algorithm and improved using Tabu Search. Using the same case study, Ding et al. [22] improve the with a Greedy algorithm obtained solution with Simulated Annealing and a hybrid of Simulated Annealing and Tabu Search.

As mentioned, some models are formulated as combinatorial optimisation problems, such as the Quadratic Assignment Problem. Drexl & Nikulin [26] use this formulation to minimise the passenger walking distance, to maximise the SGA preferences, and to minimise the number of unassigned flights. The problem is solved using Pareto Simulated Annealing. Li [39] formulates the SGA problem as a parallel machines scheduling problem that is solved using dynamic scheduling for the large problems and B&B for the smaller problems. Dorndorf et al. [25] use a Clique Partitioning Problem model and solve it using a heuristic approach that was developed by Dorndorf and Pesch. Maharjan & Matis [41] formulate the SGA problem as a binary integer multi-commodity network flow model to minimise the fuel burn cost of aircraft taxi by type and expected passenger discomfort for tight connections as a function of inter-stand distance and connection time. The model was written and solutions were obtained using an AMPL/CPLEX 11.2 package. Another combinatorial optimisation formulation is formulated by Diepen et al. [17]. They present a new ILP formulation for the SGA problem, maximising the idle times, that after relaxation is solved using Column Generation.

For this research, it is preferred to keep the model linear. As this makes it less complex, there is no need to use heuristics or combinations of heuristics and use can be made of an existing optimisation solver, such as CPLEX or Gurobi, another optimisation software package. As the model for this research will use both integer as well as non-integer variables, the model will be of the MILP type.

2.3. Overview of Stand and Gate Allocation objectives and constraints

As a model needs to illustrate an actual problem, the objectives and constraints that reflect the real world need to be accurate and detailed enough to provide an appropriate and satisfactory solution, i.e. a solution that would work as appropriate and satisfactory in the real world as in theory. Some model aspects can be contradictory, however. In SGA models, often several objectives have to be satisfied simultaneously and several constraints need to be met. The challenge is to create such a combination of those objectives and constraints that will satisfy the preferences of the user and that will still provide an appropriate solution. Some common objectives and constraints that are used in SGA models are listed by Neuman [47] and Dorndorf et al. [23], and are described in this section. More on the objectives and constraints that will be used in the model of this research is specified in Section 3.3.

The two constraints that are included in all SGA models are:

1. Each flight should be allocated to one stand;
2. A stand can have at most one flight assigned to it at a time.

Other typical constraints depend on the preferences of the user, of which some commonly used ones are as follows:

- Time gap constraint – A variable is introduced in the objective function to maximise the time gap between two consecutive flights at a stand in order to absorb potential delays. Used amongst others by Bolat [9];
- Time window constraint – The time window, or, the time that a flight stays at an airport including a margin in order to absorb potential delays, is included in the objective function to ensure that a flight lands and departs within the specified time window. Used amongst others by Lim et al. [40];
- Fixed minimum buffer time constraint – These fixed times give a flight time to arrive early or to clear the stand at departure. Used amongst others by Kumar & Bierlaire [38];
- Push-back constraint – Similar to the fixed minimum buffer time constraint, as it also adds additional time to clear the stand, but in this case, it is introduced only to those cases where push-back conflicts in the stand area can arise. Used amongst others by Kumar & Bierlaire [38];
- Shadowing constraint – In case a stand cannot be used when another one is used, e.g. when two small stands together can either host two smaller aircraft or one aircraft of a large size, this constraint is included in order to block the other stand usage. Used amongst others by Dorndorf et al. [23] and Nikulin & Drexl [26];
- Stand feature constraint – Constraints that hold stand characteristics, such as stand size or security level, have to be included to match flights to fitting stands. Used amongst others by Dorndorf et al. [23][24] and Diepen et al. [18][16];
- Towing constraint – When a flight stays a specified long time at an airport, it might be more efficient to intermediately tow it away to a remote stand to make place for another flight at that stand. Used amongst others by Dorndorf et al. [23][24], Diepen et al. [18][16], and Kumar & Bierlaire [38];
- Passenger walking distance constraint – A variable is introduced in the objective function that has to be minimised in order to have transfer passengers walk a minimum distance between two consecutive flights and their assigned stands. Used amongst others by Cheng [14], Lim et al. [40], and Xu & Bailey [62];
- Preceding/following constraint – Indicates that a flight can have at most one preceding or following flight at the same stand. Used amongst others by Lim et al. [40] and Xu & Bailey [62].

Since the SGA problem is a multi-objective one, it is solved by combining the objectives into one function with penalising weights. The SGA's are then determined by minimising this function. The corresponding penalties or weights are based on the preferences of the user. Some commonly used objectives in stand planning are as follows:

- Minimisation of the absolute deviation from the originally planned schedule. Used amongst others by Dorndorf et al. [23][25], Cheng [14], and Nikulin & Drexl [26];
- Maximisation of the flight to stand preferences. Used amongst others by Dorndorf et al. [23][25][24], and Nikulin & Drexl [26];
- Maximisation of the idle times. Used amongst others by Diepen et al. [18][16], Bolat [9], and Dorndorf et al. [25][24]. Bolat [9] minimises the variance of idle times at the stand, while Diepen et al. [18][16] maximise a weighted sum of the gap durations;
- Minimisation of waiting time for a flight to be allocated to a stand, in case there are more flights than stands. Used amongst others by Cheng [14], and Lim et al. [40];
- Minimisation of the number of remotely allocated flights, meaning that flights are preferably allocated to contact stands. In that case, transport of passengers by bus is also minimised. Used amongst others by Cheng [14], Diepen et al. [18], Ding et al. [20][22], Nikulin & Drexl [26], and Dorndorf et al. [25];
- Minimisation of the number of stand conflicts between flights. Used amongst others by Xu & Bailey [62] and Ding et al. [20];
- Minimisation of the number of towing operations. Towing operation numbers are often minimised in literature, as towings are seen as additional, costly movements that could cause conflicts. Used amongst others by Dorndorf et al. [23][25][24] and Nikulin & Drexl [26].
- Minimisation of the total passenger walking distance, sometimes combined with the minimisation of the baggage carrying distance, is an extensively researched objective in literature due to its complexity as an NP hard problem. Minimising walking distances might make the difference for passengers to be in time for their transfer flight. In contrast, airports would actually prefer passengers to walk around more in order to spend more time and money in the airport shops. This objective is often researched theoretically only, as in practice, data on transfer passenger numbers are not accessible to the public.

2.4. Solution methods for Stand and Gate Allocation planning

The SGA problem can be solved with an expert system approach, based on human experience, or by optimisation. Optimisation involves using an exact or a heuristic approach. In case the problem is linear or can be rewritten into a linear problem, it is preferable to use an exact algorithm. This generates an exact optimum and can be solved using an optimisation solver programme, such as CPLEX or Gurobi.

According to Neuman [47], exact enumeration methods return the best solution after having considered every possible one. However, when the problem size or the complexity increases, the computational time increases as well. There are exact methods that eliminate parts of the search space beforehand to reduce the computational time in such cases: an example is the Branch and Bound (B&B) algorithm, in which all solutions form branches of a tree, in which the best branch-route is obtained by discarding branches that can not improve the known solution.

Another example is the Branch and Cut (B&C) algorithm, that uses the same search principle as the B&B, except that it adds a cutting-plane method. This method refines a feasible set by means of linear inequalities, or cuts. The B&C algorithm is used in most optimisation solvers, such as CPLEX and Gurobi. Both B&B and B&C can provide exact solutions, but they have problems with symmetrical solution branches: if two branches lead to the same objective, they are equivalent and no branch can be discarded. In the SGA problem, this could happen if two stands have the same characteristics and allocation would lead to the same costs. This problem can be resolved by implementing symmetry breaking constraints, however.

However, when the SGA problem is formulated as a quadratic or a Non-deterministic Polynomial-time hard (NP-hard) problem, which is the case when interrelations such as the gate-to-gate walking distance are taken into account in case of transfers, the complexity increases exponentially with the problem size. In order to keep computational time to a minimum, a heuristic approach is then preferred. Heuristics evaluate alternative steps and approximate an optimal solution based on available information at each branching step. A heuristic that is extensively used to solve the SGA problem is the Greedy algorithm, which chooses the best solution available at the current stage of the search. It takes into account the local optimum for each stage, based on previous choices, but no future choices are considered: hence, the solution might not be globally optimal, as stated by Neuman [47].

As described by Ghazouani et al. [28], other heuristics that are used are based on ranking, such as the First Unused Stand and Gate Assignment and the Most Unused Stand and Gate Assignment approaches. The first sorts flights by their arrival time and the stands by their numbers, which are based on their level of convenience in terms of available air bridges and passenger walking distances. When a flight arrives, it is assigned to the first available stand with the highest ranking in the stand number sequence, as done by Hamzawi [32]. The Most Unused Stand and Gate Assignment sorts the stands in ascending order of their occupancy frequency, in which an arriving flight is assigned to the most occupied stand that is available. Another sequencing heuristic is presented by Mangoubi & Mathaisel [42]: here, flights are sorted according to the number of passengers aboard.

In the case of solving large or complex problems, approximating a solution using a heuristic is faster than using an exact approach. According to Cheng [14], the downsides to the use of heuristics, however, are that they are often problem-specific, and that they employ intensification over diversification. The problem with intensification is that promising solution areas are explored rather than non-promising regions, which could mean that approximations are poor and that the solution search process gets stuck at a local optimum instead of finding a global one.

In that case, there is the alternative of general, strategic search methods called metaheuristics. All different metaheuristics have their different specifications, mainly based on their dynamic balance between diversification and intensification. Metaheuristics guide subordinate heuristics in local search spaces to provide an optimal approximation. According to Hillier [33], metaheuristics are ideal to solve large and complicated problems, such as combinatorial optimisation problems, that cannot be solved by exact algorithms. The most common techniques that are used in SGA literature are the Genetic algorithm, Tabu Search, Simulated Annealing, and hybrid methods. These approaches are more extensively described by Hillier [33]. Some novel metaheuristic methods are in the field of swarm intelligence: Marinelli et al. [44][43] proposed a solution method through Bee Colony optimisation.

In short, Genetic algorithms use a set of solutions that evolve towards better solutions, based on iterative, natural selection. Tabu Search considers non-improving solution branches in its search process to double-check if there is a better local optimum in case it has found one already. It uses 'Tabus' to avoid backtracks on the next iterations. Simulated Annealing also accepts worse solutions on occasion. The algorithm generates a random trial point, after which it is iteratively shifted within bounds. Selecting the optimal option of the old and new trial point, the algorithm stops when the average change between the shifted points is smaller than a predefined number. Next, a hybrid algorithm often is a combination of the Tabu Search and Simulated Annealing. Last, in Bee Colony optimisation, the number of bees simulates the number of optional solutions. The 'employed bee' searches for these solutions and the 'onlooker bee' evaluates the quality, after which the best solution is selected.

Another solution method to solve the SGA problem is the use of expert systems. According to Goodall [30], an expert system, rule-based decision management system, or knowledge-based system is a computer system that imitates a decision-making process of an expert. These systems do not use mathematical models, but a knowledge base: this is a set of if-then rules based on human expert experience. According to Cheng [14], advantages of the use of this system are that human expertise on a specific problem is used; that it is ea-sier to respond to unknown or special cases; and that the system can continuously be improved. Downsides are that the system cannot perform as efficiently as human experts, as the system often represents only a small part of an expertise domain; that the process of comparing all if-then rules is time-consuming; and that the pure knowledge-based system is not suited to solve the numerical multi-objective optimisation problem in an efficient manner.

For the SGA problem of this research, an exact method is preferred. As the aim is to build a robust model, the exact method gives the most problem-unspecific freedom. Use can be made of an existing optimisation solver, and as the aim is to keep the problem linear, no significant problems are expected regarding a long computational time. As an optimal solution in a multi-objective environment is to be provided, a numerical method would be preferred to an expert system. Although use is made of human experts to gather allocation decisions, it is expected these rules can be implemented in the mathematical model without a problem.

2.5. Factors of influence in robust Stand and Gate Allocation

Any airport needs to deal with the difficulty of allocating flights to suitable stands; meeting specified, often multiple objectives; and not crossing the specified constraints. Where the baseline schedule should theoretically be sufficient for an efficient and satisfactory stand schedule, unforeseen changes to the flight schedule bring the need for reallocation. According to Buitendijk [12], it is estimated that, at Amsterdam Airport Schiphol, 40% of the flights undergo a minimum of one changed stand in comparison with the operational schedule. Furthermore, 20% of the passengers have to go to a gate that differs from the gate as indicated on their boar-ding pass due to a reallocation. As schedule alterations and corresponding stand and gate changes can create a snowball effect of congestions and delays, it is important that an SGA schedule takes into account that alterations in flight arrival and departure times might occur. In other words, solving the SGA problem for an airport for practical purposes must happen in a robust fashion.

In Section 2.1, it has been discussed what classifications there are to specify the SGA problem. Regarding the model of this research, it should be dynamic in order to take into account the mentioned uncertainties of the flight schedule. Furthermore, it should be based on the deterministic case in which it is assumed that the flights occur in the predefined period of the given flight schedule. Robustness is then established by optimising buffer times by basing them on historical delay data of the summer period in 2017. Per airline and per route it can then be determined what the distribution of early arrivals and delays is. From these values, one can establish what the optimal buffer time would be to cover a specific percentage of recorded flights.

In literature, robust deterministic models mainly focus on the buffer and idle time concepts. Mangoubi & Mathaisel [42] were among the first to look into robust SGA modelling and to propose the use of fixed buffer times between two continuous flights to absorb schedule deviations; Hassounah & Steuart [59] also state that the use of buffer times can have a mitigating effect on the impact of flight delays: both do not perform research on the length of those buffer times, however. Yan et al. [63] evaluate the effects of stochastic flight delays and the use of flexible buffer times, but their framework cannot do a cross-factor analysis of the effect of stochastic flight delays on various flexible buffer times simultaneously.

Bolat [8][9] has done research on the uniform distribution of idle times and on the minimisation of the range and variance of the idle times. The first research resulted in unwanted long idle times at the start and end of the schedule, and the second turned the SGA problem into an NP-hard problem. Diepen et al. [18][17] maximised the idle time and solved the problem in two phases. In the first phase, a basic SGA schedule is created, and in the second, gate planners provide an optimal solution using their expert knowledge. However, as this research needs to lead to an operational, robust SGA plan for which little to none adjustments have to be made, the influence on robustness of individually optimised buffer times will be analysed.

Little information is available on the influence of towing operations on the robustness, especially combined with the optimised buffer times. By towing an aircraft from a contact stand to a remote stand, after which it is towed back prior to departure, it is made possible to use a contact stand intermediately. However, it adds more costs, as well as more operations that may cause congestions in case of a delay. Immediate towing to a remote stand may also cause passenger discomfort, due to the added transportation distance by bus. Therefore, the minimisation of towing is the only objective regarding towing that has been researched, amongst others by Dorndorf et al. [23][25][24], and by Nikulin & Drexl [26].

As towing might actually be a valuable solution to congested flight schedules, its influence on the stand utilisation is an interesting research subject. Especially when towing happens intermediately for flights with long turnaround times, causing no discomfort to passengers, and when the costs of towing are less than the costs of delays. Therefore, this research encourages towing operations when possible and according to Schiphol towing rules.

3

Illustration of Stand and Gate planning at Amsterdam Airport Schiphol

Amsterdam Airport Schiphol is the third busiest international hub airport in terms of total passenger numbers in Europe [1]. It has six runways, one terminal, and seven piers. The terminal is divided into three halls, and soon, an extra pier will be added. The general layout is given in Figure 3.1, in which five of the six runways can be seen (the last runway, 18R/36L or the 'Polderbaan', is located to the northwest with regard to this figure); pier B, C, D, E, F, G, and H are located at the centre, surrounded by the A and B aprons; the D, E, and G buffers; the P, J and Y platforms; the R apron, which is primarily meant for cargo flights, but is also used for remote parking of passenger flights; and the P holding area, on which flights can wait in case of early arrivals or delays until their designated stand becomes available. To the east of the centre, general aviation stands are located at the K, L, an M apron. Across the 'Kaagbaan', the S apron is located, where cargo flights are parked. The runways are given in more detail in Figure 3.2.

As one of the largest economic drivers in The Netherlands [51], it is important that Schiphol invests in future growth to maintain these positions. The building of the new pier A has already started southwest of pier B, at the location of the B apron, and is to be finished in 2019. A new terminal with one departure hall is planned to be built and finished in 2023 [50]. However, apart from adding new and costly buildings, growth can be achieved by optimising the current airport ground management. As stated in Chapter 1, a challenging ground management operation is SGA. In this chapter, it is listed what the current stand specifications are at Schiphol in Section 3.1; after which the current SGA planning process is discussed in 3.2; followed by the allocation regulations in 3.3. Next, SGA at other European hub airports is discussed in 3.4; concluded by Section 3.5 on the areas of improvement with regard to SGA planning at Schiphol.

3.1. Characteristics of stands and gates at Amsterdam Airport Schiphol

It has been published in the NRC newspaper [52] and by the Airports Council International [1] that in 2017, Schiphol processed 496,747 flight movements. These movements, 1,361 daily on average, are directed to and from the current seven piers with 96 contact stands [4], and to and from 139 remote stands that require transportation to and from the stand by bus. All these stands and their specifications are given in Appendix A. It has to be noted that not all of the 139 remote stands are meant for commercial flights, but also for cargo, being twenty-one stands, and general aviation, being fifty-one stands. Each pier and stand has different capabilities and depending on the specifications of the flight, such as aircraft size or origin and destination of passengers, flights either need to be redirected or would prefer to be redirected to a certain stand.

With regard to the size of aircraft and stands, there are nine size categories used at Schiphol: category 1 up to 4 for narrowbody (NABO) or single-aisle aircraft, and category 5 up to 9 for widebody (WIBO) or twin-aisle aircraft. Category 9 is the Airbus A380 and has two contact stand possibilities at Schiphol: stand E-18 and G-09. With regard to International Civil Aviation Organisation (ICAO) standards, size category 1 corresponds with ICAO size category A and B; category 2, 3, and 4 correspond with ICAO category C; category 5 and 6 correspond with category D; 7 and 8 correspond with category E; and 9 corresponds with category F.

Figure 3.1: General layout of Amsterdam Airport Schiphol aprons and piers (modified from source: OpenStreetMap [49])

Based on the information as presented in Appendix A, the size characteristics are given in Table 3.1, in which the maximum fuselage length and wingspan are given for the corresponding size category. It has to be taken into account that rounding assumptions are made: in case a stand is given the category '6-', which means that it can host category 6 aircraft except for one or more category 6 aircraft; for convenience, it is assumed that it can host any category 6 aircraft, however. Similar for the category '6+', which means that a stand can host all category 6 aircraft and one or more aircraft from a higher category: here, it is assumed that it can only host category 6 aircraft. Most allocation regulations are given in the Regulation Aircraft Stand Allocation Schiphol (RASAS) [3], and current SGA plans are made on the basis of these regulations. More on these regulations is given in Section 3.3.

Table 3.1: Size category characteristics at Amsterdam Airport Schiphol

Category	Maximum operational length [m]	Maximum wingspan [m]
1	22.00	24.00
2	28.00	29.00
3	37.00	29.00
4	45.00	36.00
5	49.00	44.00
6	55.50	52.00
7	72.00	61.00
8	76.00	65.00
9	77.00	80.00

Figure 3.2: General layout of Amsterdam Airport Schiphol runways (1=Polderbaan, 2=Zwanenburgbaan, 3=Kaagbaan, 4=Aalsmeerbaan, 5=Buitenveldertbaan, 6=Schiphol Oostbaan) (source: Schiphol Jaarverslag 2012 [2])

First, it will be discussed what the characteristics are for the several piers, in which a distinction is made based on legislation. In Europe, travelling within Schengen[1] countries is possible without passport control. Basically, pier B and C are for Schengen flights; pier E, F, and G are for Non-Schengen flights, and pier D and H are, dependent on the gate and stand, for both Schengen and Non-Schengen flights. Future pier A will also be used for both Schengen and Non-Schengen flights. The layout of the current piers and their corresponding stands is given in Figure 3.3, in which pier A will be located southwest of Pier B (this figure still shows the old pier D configuration that was in use before 2014, however).

Departure hall 1 mainly hosts passengers for flights between Schengen countries. It consists of pier B and C, partly of pier D, and in the future of pier A. Pier B has thirteen NABO aircraft stands and pier C has fourteen NABO stands. All stands are category 3 or 4. The new pier A will have eleven NABO stands for flexible use, of which six NABO stands are Multiple Apron Ramp System (MARS) stands and can also be used as three WIBO stands [50].

Departure hall 2 consists of piers D and E. The tuning-fork shaped pier D is a dual status pier and, for that purpose, has two floor levels to efficiently divide passengers of different border control status. It is the largest pier at Schiphol. Non-Schengen stands and their corresponding gates are numbered from D-01 to D-57 and are accessible via the ground floor; Schengen stands and gates are numbered starting from D-59 and are accessible via the upper floor. In total, there are thirty-three stands at the pier and six buffer stands near, varying from category 4 up to 8. Pier D also has two MARS stands: if one of these is in use, the adjacent stand D-51 or D-55 cannot be used. Pier E is for Non-Schengen flights only and has fourteen stands and gates at the terminal and three buffer stands near: they are mainly category 7 and 8. Pier E is home to SkyTeam members that fly to and from the United States (US), such as KLM and Delta Air Lines, but also SkyTeam members that fly to and from Middle Eastern and Asian locations.

[1] Schengen countries are all European Union (EU) member states, excluding Ireland, the United Kingdom, Romania, Bulgaria, Croatia, and Cyprus. Switzerland, Liechtenstein, and Norway are not part of the EU, but they do participate in the Schengen agreement. Furthermore, San Marino, the Vatican City, and Monaco have open borders with neighbouring Schengen countries and can be entered with a Schengen visa.

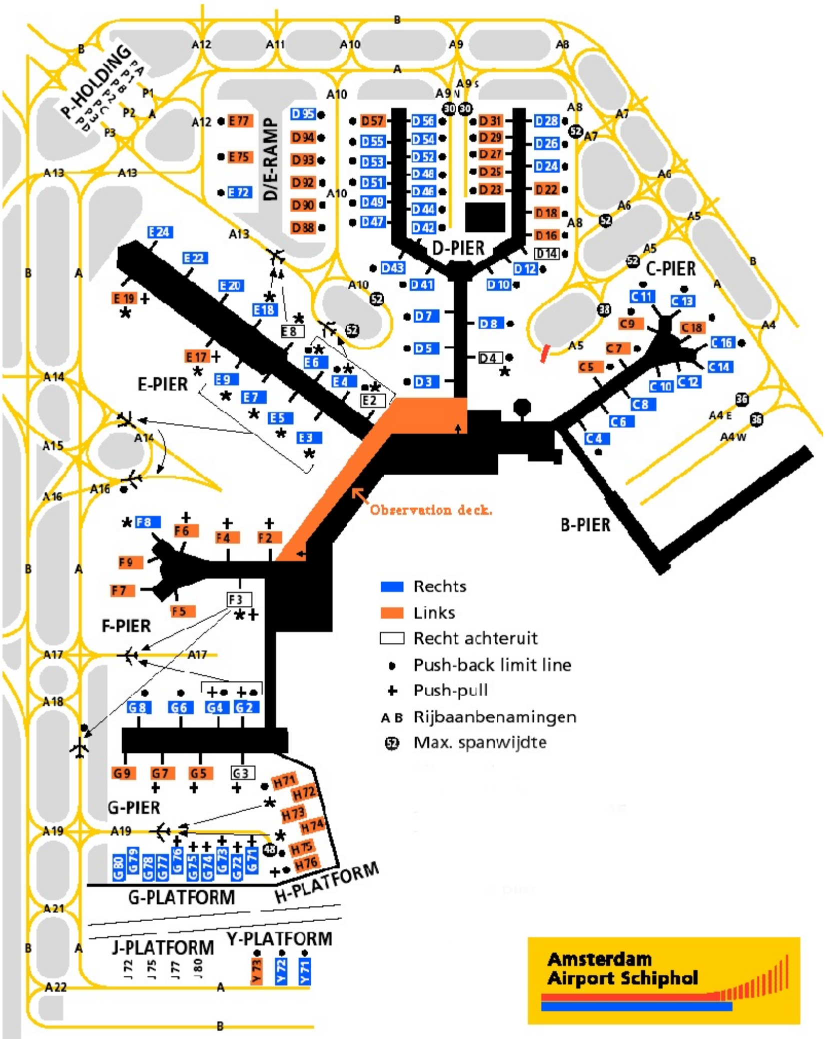

Figure 3.3: Layout of gates and stand positions at Schiphol [58]

Departure hall 3 consists of Non-Schengen pier F and G, and mixed pier H. Same as pier E, pier F is home to SkyTeam members. It consists of seven gates and seven category 8 stands. Pier G mostly hosts flights from and to Asia. It has eight contact stands of category 4 and 8, but also one category 9 contact stand, G-09, from which daily A380s operate for Middle Eastern and Asian airlines. Pier G has three buffer stands near. Furthermore, both pier F and G are Non-Schengen areas. As many Non-Schengen nationalities enter and leave The Netherlands via the G pier, the military police are located close to it. Furthermore, pier H has seven category 4 contact stands and hosts low-cost airlines. The low-cost airlines that fly at Schiphol are easyJet, Norwegian Air, Flybe, Jet2, WOW Air, and Ryanair. To keep the costs at a minimum, these stands have no air bridges and the turnaround time for all flights is mostly 30 minutes or less.

To summarise the specifications, all aprons and piers with their corresponding stands are given in Table 3.2 for stands suited for NABO flights only, and in Table 3.3 for stands suited for WIBO aircraft. It has to be noted that most WIBO stands can receive NABO flights as well. Furthermore, contact stands are related to a border control status, for which Schengen is denoted by 'SCH' in these tables, and Non-Schengen, 'NS'. NS is further subdivided in screened, or 'NS_scr' and unscreened, or 'NS_uns'. At NS_uns stands, additional security can take place, but also NS_scr flights can make use of these stands. At swing stands, denoted by 'Swing', both Schengen as well as Non-Schengen flights can be allocated. Positioning stands, 'Pos.', are remote stands that can receive positioning flights, which are flight movements of a passenger aircraft, carrying no passengers, in order to position an aircraft at another airport.

At remote stands, no border control security takes place: therefore, these stands are preferably not used for passenger handling. Disregardless, capacity issues require remote handling. In order to provide an appropriate security check, remotely handled passengers at the D, E, and G buffer, and at the A, B, J, P, Y, and R apron receive their check after transportation by bus to a bussed gate of the required border control status. Bussed gates are found at contact stand B-15, B-16, B-17, B-27, C-04, C-06, C-08, D-07, D-22, D-23, D-24, D-25, D-27, D-28, D-29, D-48, D-52, D-54, D-56, H-01, or H-02. When all bussed gates are occupied, however, it is not possible to handle passengers remotely, regardless of the availability of remote stands. This is not taken into account, however: remote stands are counted as available stands disregardless.

Furthermore, gates and stands that block other stands when hosting an aircraft of a large size, such as D-57 blocking D-55 when hosting a WIBO aircraft, are still counted; i.e. in the case of D-57 and D-55, D-55 counts as one NABO-stand and D-57 counts as one WIBO-stand. They can be used simultaneously, however, when both stands host a NABO aircraft. Cargo flights are handled fully remote at the R and S apron, of which the R apron also functions as a remote handling apron for passenger flights. The U apron can be used as intermediate tow stand for passenger flights, as well as the L apron for Transavia flights. Aircraft of category 1 and 2 are primarily handled at the A and B apron.

Table 3.2: Available NABO stands, categorised by flight type, contact/remote position, and border control status

<table>
<tr><th colspan="4">NABO stands</th></tr>
<tr><td rowspan="6">Passenger & Positioning stands</td><td rowspan="4">Contact</td><td>SCH</td><td>27</td></tr>
<tr><td>NS_scr</td><td>5</td></tr>
<tr><td>NS_uns</td><td>9</td></tr>
<tr><td>Swing</td><td>16</td></tr>
<tr><td rowspan="2">Remote</td><td>Pax & Pos. handling and towing</td><td>43</td></tr>
<tr><td>Towing only</td><td>3</td></tr>
<tr><td colspan="3">Cargo</td><td>2</td></tr>
</table>

Table 3.3: Available WIBO stands, categorised by flight type, contact/remote position, and border control status

<table>
<tr><th colspan="4">WIBO stands</th></tr>
<tr><td rowspan="6">Passenger & Positioning stands</td><td rowspan="4">Contact</td><td>SCH</td><td>0</td></tr>
<tr><td>NS_scr</td><td>0</td></tr>
<tr><td>NS_uns</td><td>27</td></tr>
<tr><td>Swing</td><td>12</td></tr>
<tr><td rowspan="2">Remote</td><td>Pax & Pos. handling and towing</td><td>29</td></tr>
<tr><td>Towing only</td><td>5</td></tr>
<tr><td colspan="3">Cargo</td><td>19</td></tr>
</table>

A last remark can be made about the ground handling at Schiphol. Ground handling services are provided by several companies at Schiphol, such as KLM Ground Services, Swissport, dnata, FreshPort, Menzies Aviation, and Aviapartner Handling. Each company has contracts with different airlines, hence, each ground handler company is linked to stands or parts of a pier that are linked to the corresponding airline's preference, as is stated as a requirement by Diepen et al. [18][16][17]. Furthermore, when planning the flight to stand allocation, it is taken into account what the origin and destination are of the flight; as well as the size category of the aircraft, as it has to match the size of the gate. The corresponding preferences of the companies that are involved are also taken into account.

3.2. Current allocation process at Amsterdam Airport Schiphol

The information in this section is mainly based on RASAS [3]. As mentioned in the introduction of this chapter, Schiphol is the third busiest European hub airport in terms of total passenger numbers [1] and tries to maintain or even improve this position. For this purpose, it is important to ensure that hub carriers that supply transfer passengers can rely on seamless transfer connections. Therefore, Schiphol uses zone definition for their SGA method: it is pursued to assign flights with the most transfer passengers to stands that are closest to the terminal to reduce the walking distance for transfer passengers. The 'Central Transfer' zone is reserved for airlines carrying the most transfer passengers; the 'Common Use' zone is reserved for airlines that carry less to none transfer passengers. The sizes of these zones are determined for every new season schedule, based on preconditions, policy principles, and flight schedules.

The season schedule is drawn up for every Summer and Winter schedule. The season plan contains a 'best-fit' zoning and allocation plan for all aircraft stands, based on the time slot allocation schedule, which in turn is based on available flight schedules of all airlines. The allocation is done on the sequence of arrival and departure as given in the time slot allocation schedule. Furthermore, the allocation regulations as written in RASAS [3] are used to determine an appropriate SGA plan. For passenger flights, it is important that the number of outbound passengers does not exceed the capacity of the pier gate waiting area. Aircraft falling into a category lower than that of the aircraft stand will only be allocated to these stands in the absence of larger aircraft. This plan, combined with the one-day-ahead flight information that is entered in the Central Information System Schiphol (CISS) by 17:00 in the evening before the day of operation, serves as the base for the operational or one-day-ahead plan.

The operational plan is then determined using the Gate Management Software (GMS). It is hard-coded, which makes it difficult to implement any adjustments. In practice, gate planners primarily use their expert knowledge to make a fitting schedule: especially in the case of the peak periods, gate planners often adjust this operational schedule manually. In order to fit in all scheduled flights, buffer times can be adjusted and diminished from 20 minutes to 15, 10, 5, or even 5 minutes.

For the allocation plan, all flights are assigned to the corresponding zones, based on the allocation regulations. In the event that the capacity of a pier is insufficient in one zone, a pier stand from the other zone is assigned to the concerned flight. If this would not be possible, the aircraft is assigned to a remote stand and transportation of passengers is done by bus. Agreements on preferred use of pier stands can be concluded with airlines or ground handling agents on a seasonal basis, but only if an airline company is able to accommodate at least eight turnaround flights at a single pier stand per 24 hours. Ground handling agents can fight a stand change on the day of operation in order to optimise operational management up to two hours before the arrival of the flight.

3.3. Allocation regulations at Amsterdam Airport Schiphol

The information in this section is mainly based on RASAS [3]. An addition is made on allocation regulations as used in practice, so-called 'business rules', that are given Appendix B. The information will then be used to make a thorough mathematical model to solve the SGA problem for Schiphol in a robust fashion.

It is stated that Schiphol aims to ensure maximum efficiency for the processes, guaranteeing security, improving punctuality, and offering reliable transfer connections, while promoting the effective and efficient use of infrastructure and facilities at the airport. Of course, during the SGA planning procedure, physical restrictions are taken into account: the aircraft and stand categories have to match, and certain technical features need to match as well; e.g. it should be possible to connect the hydrant system. As stated in Section 3.1, also airline preferences should be taken into account. According to RASAS [3], in order of importance, the following allocation regulations apply for airliners:

1. Flights carrying many transfer passengers need to be assigned to the 'Central Transfer' zone. Practically, this means that large aircraft have a higher priority to be allocated close to the terminal and/or close to subsequent flights of large aircraft;

2. Flights carrying few transfer passengers need to be allocated to stands outside of the 'Central Transfer'

zone. However, Schiphol reserves the right to deviate from the zoning system if circumstances do require. Regarding the zoning regulations: they need to be implemented in the objective function as the minimisation of passenger walking distance by prioritising large aircraft positioning close to the terminal;

3. A minimum separation time, or buffer time, of 20 minutes is reserved between two flights: the stand should be cleared and the aircraft ready for departure no later than the scheduled departure time plus 20 minutes. For low-cost flights, a lower separation time of 10 minutes is reserved, due to the flexible allocation method at pier H. At pier H, simply the first available stand is assigned to an incoming flight. The minimum separation time between an aircraft that is being towed to or from the stand and an arriving or departing flight is 10 minutes. This 'time gap or buffer time constraint' is introduced to the objective function to maximise the time gap between two consecutive flights. In practice, however, buffer times are often diminished to 15, 10, 5, or even 0 minutes, especially during peak hours. In practice: the minimum separation time between an aircraft that is being towed from a stand and an aircraft arriving to that stand is 5 minutes;

4. Any delay that lasts beyond scheduled departure time plus 20 minutes means that the stand is released and the aircraft is redirected to a remote stand. Failure to clear a stand as required may result in sanctions. If passengers are not yet on board, passengers are transferred to the aircraft by bus. The gate planning department may decide to make an exception in reallocating a delayed aircraft to a remote stand, however. Here, maximisation of on-time flight allocation or minimisation of delayed flight allocation is taken into account;

5. Passenger flights are preferably directed to pier stands instead of to remote stands, as transportation of passengers by bus is costly and less comfortable for passengers. Hence, gate or contact stand utilisation should be maximised;

6. Flights in a specific category are allocated to a stand of the same category, but in absence of larger aircraft, stands can be allocated to smaller aircraft of a lower category: this is rather a physical constraint than a preference. For passenger flights, the number of outbound passengers must not exceed the capacity of the pier gate waiting area. Hence, matching flight-to-stand categories should be maximised;

7. Flights without passengers are allocated to remote stands. If passenger flights are allocated to remote stands due to capacity shortage at the pier, the following priority in allocation applies:

   (a) Separate incoming flight with the smallest passenger numbers;

   (b) Separate departing flights with the smallest passenger numbers;

   (c) Turnaround flights, with priority being given to flights with the smallest passenger numbers;

   This is also part of the minimum passenger walking distance objective;

8. WIBO aircraft with a turnaround of more than 210 minutes and NABO aircraft with a turnaround time of more than 170 minutes are eligible for intermediate towing to a remote stand. Optimising the towing constraint can lead to maximising the stand utilisation. The following regulations apply:

   (a) In the event of a WIBO towing operation: the minimum stand occupation time is 75 minutes for the inbound and 85 minutes for the outbound flight movement;

   (b) In the event of a NABO towing operation: the minimum stand occupation time is 55 minutes for the inbound and 65 minutes for the outbound flight movement;

   (c) The minimum time frame for intermediate towing is 10 minutes for driving towards and 10 minutes for driving away from the remote stand, with a parking time of 30 minutes;

   (d) Flights with the longest turnaround times are allocated to the farther located remote stands, flights with a smaller turnaround time are allocated to the closer located buffer stands;

   (e) Stand occupation times may exceed the mentioned times, as special circumstances may apply, such as longer boarding procedures or new types of aircraft;

   (f) Flights might be interrupted with a single intermediate towing operation to a different stand, e.g. in case a suitable stand is not yet available at the time of arrival. A minimum turnaround time of 170 minutes applies for WIBO aircraft and 130 minutes for NABO aircraft.

9. Flights contracted with the same handling agent are clustered together, as well as flights operated by the same airline to streamline airline-related processes. In other words: clustering is maximised to increase efficiency;

10. Preferred use of stands by airlines can be discussed in case an airline is able to accommodate at least eight turnaround flights per 24 hours at a single stand. In this case, customer service is maximised, as both airlines, as well as passengers, have a known, expected 'base' to go to/from. Also, airlines can cluster their preferred stands to increase efficiency, hence, clustering is maximised;

11. Regarding dual status flights, i.e. flights from Schengen to Non-Schengen regions and vice versa: if capacity issues require a dual status flight to be allocated to a non-dual status stand, the status of the flight will correspond with the status of the outbound flight. Passengers on the inbound flight are then transported by bus to a bus pick-up point, or bussed gate, in accordance with their border control status. Passengers with the status 'Non-Schengen unscreened' cannot enter the terminal without a security check: as there are few stands with a dual status Non-Schengen unscreened/Schengen, the flight is separated in case the turnaround time allows to do so. In case it is not a low-cost flight, which preferably would be handled at pier H, the arriving flight will then be allocated to pier E, F, or G; the departing flight is allocated to a pier that matches the status of the flight. In case the turnaround time is too short, the flight is allocated to a dual status pier, currently being pier D, reinforced by pier A from 2019 onwards, or to one of the Schengen piers, being pier B and C, and the passengers are transported separately by bus to a bus pick-up point in accordance with their border control status. If no suitable stands are available for a dual status flight, it will be handed fully remote. When a choice has to be made between multiple dual status flights, the flight carrying most outbound passengers has a higher allocation priority. In this case, allocation of flights to contact stands of their border security status is maximised, which is an objective that has not extensively been treated in literature;

12. Preferably, flights on a nightly stopover will be allocated for departure to the same stand as the arrival stand. An intermediate towing operation to a remote stand might be necessary. In this case, customer service is maximised, in which the customers are passengers, ground handlers, and airlines;

13. Flights with identical scheduled arrival/departure times cannot be assigned to adjacent stands, as there might occur push-back conflicts, and to enable handling agents to handle adjacent aircraft successively with the same team. This is a physical constraint, for which the allocation of flights with identical scheduled arrival/departure times should be minimised;

14. In case a remote flight is assigned, a bussed gate for departure and a bus pick-up point for arrival is assigned in the zone with the applicable border status. As the planning of the bus schedule is not within the scope of this research, this regulation is left out of the objective;

15. In case flights change flight data on the day of operation, e.g. aircraft type or arrival time, they are not eligible to reclaim the preassigned stand and they will be moved to another stand if necessary. As has been mentioned in the fourth bullet point: any delay that exceeds the time gap of 20 minutes results in redirection to a remote stand; in this bullet, additional changes are added. Here, scheduled flight allocation is maximised, or, absolute deviation from the originally planned schedule is minimised;

16. In case an arrived flight cannot approach its assigned stand immediately, it is decided to keep the flight either waiting on this stand if it is possible to have the passengers disembark no later than 30 minutes after arrival, which is the landing plus the time to taxi; to assign another stand; or to assign an aircraft stand and a shuttle bus. In other words: passenger or flight-to-stand allocation waiting time should be minimised, or, customer service should be maximised.

As pier H, which is the pier for low-cost flights with short turnaround times, is not taken into account in this research, the corresponding regulations as given in RASAS [3] are not included in this section. Neither are the regulations regarding aprons, such as apron K, which is the apron to which general aviation is allocated. Apart from the regulations as stated by Schiphol, gate planners also use allocation rules based on agreements or expert knowledge: these rules are confidential and are not treated in this report.

In conclusion, the objective of Schiphol is focused on minimisation of connecting times, as Schiphol relies on its position of being an important hub airport for transfer passengers. As it is unknown how many outbound passengers there are on an inbound flight, an estimation is made in the model by giving WIBO aircraft that are probably carrying a large number of transfer passengers, a higher allocation priority. Furthermore, the objective function for the Schiphol gate planning also includes physical constraints; the maximisation of matching border control status allocation; the maximisation of the time gap constraint, including the to be researched buffer times; the maximisation of on-time flight allocation by penalising delayed or changed flights; the maximisation of gate utilisation, amongst which the encouraged towing constraint; the maximisation of customer service, e.g. by clustering of involved companies, or by minimising passenger waiting time. In other words, all objectives that already have been treated in Section 2.3 are also amongst the objectives of Schiphol, the minimisation of tows and the maximisation of matching border control status excluded. An interesting sidenote with regard to the multi-objective environment of Schiphol is that Földes [27] mentions that little research has been done on the SGA problem that tries to satisfy more than three objectives simultaneously.

3.4. Stand and Gate Allocation at other European hub airports

In order to gain understanding of Amsterdam Airport Schiphol and its SGA planning process, it is important to be able to compare it to other significant hub airports in Europe. In this section, some brief remarks are made about other European hub airports. According to the World's Busiest Airport list of CNN [48] and the Airports Council International [1], the first four busiest airports in Europe in terms of passenger numbers respectively are London Heathrow, ranked 7th with 78,047,278 passengers in 2017; Paris Charles de Gaulle, ranked 10th with 69,471,442; Amsterdam Airport Schiphol, ranked 11th with 68,515,425; and Frankfurt Airport, ranked 14th with 64,500,386. All four won a World Airport Award from Skytrax as well [54], respectively ranked 8th, 37th, 12th, and 10th. In terms of aircraft movements in 2017, Schiphol is the leading European airport and ranked 9th in the world with 514,625 movements; followed by Paris, ranked 11th; Heathrow, ranked 12th; and Frankfurt, ranked 13th [1]. All except London Heathrow are in the same time zone: UTC+1; London Heathrow is UTC+0. This means that all four have the arrival and departure peaks at the same time, approximately.

London Heathrow, located in the United Kingdom, is the busiest airport in Europe. It is the busiest airport in terms of passenger numbers [48], of which most passengers are international [1]. It is ranked second in the list of 2017 regarding total international passenger traffic numbers, right after Dubai. Together with five other international airports, it serves the metropolitan area of London. With regard to the other, smaller airports, London Heathrow is the long-distance hub. It is the primary hub for flag carrier British Airways and the primary operating base for Virgin Atlantic. With regard to Schiphol, it has currently two runways and four terminals. The use of multiple terminals has the advantage that total passenger walking distance is minimised more successfully at Heathrow, as passengers have to walk in smaller terminals [61]. Apart from that, London Heathrow can focus more on long-distance flights, as other types of flight are operated from the other London airports. Furthermore, some gates are connected to four stands, whereas Schiphol MARS gates can each serve up to two stands. A more significant difference with regard to Schiphol is that operations are clustered for airlines and alliances rather than into domestic and international routes.

Paris Charles de Gaulle, located in France, is the biggest airport of the five serving the Paris area. Same as for Heathrow regarding the other London area airports, Paris Charles de Gaulle is the long-distance hub for the Paris region. It is the primary hub of flag carrier Air France and other legacy carriers from the Star Alliance, Oneworld, and SkyTeam. Paris Charles de Gaulle forms an efficient dual-hub system with Schiphol, as Schiphol is the primary hub for flag carrier KLM, and as Air France and KLM have merged. Both airports can offer more destinations to passengers and cargo carriers this way by en-route transfers in one of the two cooperating airports. Furthermore, Paris Charles de Gaulle has four runways and three terminals, of which the second terminal is divided into multiple buildings: there is Terminal 1; Terminal 2, including 2A, 2B, 2C, 2D, 2E, 2F, and 2G; and Terminal 3. Paris Charles de Gaulle has several satellite piers and midfield piers, meaning that passenger transportation is done by shuttle buses or trains. The advantages are that there is more space for aircraft movement and handling on the apron, and that similar arrival or departure times at adjacent gates would cause less of a problem.

Frankfurt Airport, located in Germany, is the busiest European airport with regard to international cargo traffic, ranked 8th in the world; and the second busiest European airport with regard to total cargo traffic, ranked 11th in the world, right after Paris Charles de Gaulle [1]. It is the primary hub for the biggest airline in Europe, when combined with its subsidiaries Austrian Airlines, Germanwings, and Swiss Airlines, both in terms of passengers carried, as well as fleet size [29]: Lufthansa. Same as for London Heathrow, operations are also grouped for airlines rather than for routes. Frankfurt has four runways and two passenger terminals, which are connected by a monorail and by bus.

In conclusion, Schiphol differs from other airports by currently operating from one terminal, to which the seven finger piers are connected. In comparison to a decentralised terminal, which is the case for the other three hub airports, overall walking distances in a single terminal are bigger and no terminals can be reserved for airlines or airline alliances, which could adapt all facilities to their requirements in that case. The centralisation of flights leads to more flexible operations, as check-in counters or gates can be shifted more easily [61]. Flights at Schiphol are grouped by flight routes and corresponding border security status instead of by airline and airline alliances, with the benefit to cluster security checks, but with the downside of not always being able to cluster airlines, airline alliances, ground handlers, and all their requirements. In comparison with Heathrow and Frankfurt, Schiphol has the advantages of the dual-hub system by cooperating with Paris Charles de Gaulle.

3.5. Areas for improvement regarding Stand and Gate Allocation at Amsterdam Airport Schiphol

As has been discussed throughout this chapter, Schiphol is an important international hub airport that success fully processed 496,747 flight movements in 2017 [1], being 1,361 daily on average. However, air traffic numbers continue to grow, and in order to maintain or even improve its position as third busiest European airport in terms of passenger numbers [1], Schiphol has to be able to process more flights in a more efficient way. It also has to be able to offer its customers, being both airlines and passengers, on-time performance in flights and gate handling. As stated in Section 2.5, it is estimated that, at Schiphol, 40% of the flights undergo a minimum of one changed gate. Furthermore, 20% of the passengers have to go to a gate that differs from the gate as indicated on their boarding pass due to a reallocated gate [12]. As can be seen, there is still room for improvement by making the operational gate allocation schedule more robust.

One of the most significant problems with the operational schedule is that the Gate Management Software (GMS), the allocation software that Schiphol uses, is hard-coded and adjustments are hard to make. As the objective at Schiphol is to assign all flights, and the constraints are based on RASAS only, gate planners have to make manual adjustments in order to make the theoretical planning that comes out of the software a practical one. For example, according to RASAS, only those WIBO aircraft are towed away that have a turnaround time of more than 210 minutes, but the programme does not take the morning peak into account in which the most WIBO aircraft arrive. This means that in practice all WIBO aircraft have to be towed away in order to allocate all incoming flights in a comfortable way.

Furthermore, gate planners at Schiphol use their expert knowledge about flight routes, as they assume that many flights from the US arrive earlier than planned; that cargo flights are often late; and that some flights from specific origins, such as Aruba and Bonaire, need extra security checks. They might see that a specific flight is better off at a different gate, as the gate planners know that the walking distance for the transfer passengers of which they know are aboard would need to walk less to get to their transfer gate. Some of these expert or business rules are given in Appendix B.

As in the current model not all allocation regulations are implemented, the robust model that is to be the result of this thesis needs to incorporate all written and unwritten regulations that are used in gate allocation at Schiphol. This way, a complete and thorough baseline schedule can be provided that would need few manual adjustments at the start of the day of operation. In contrast to the current allocation tool, the to be created model must have room for adjustment and addition of constraints, and needs to be able to achieve several objectives, such as the minimisation of buffer times, or the minimisation of towing operations. Being more flexible than the GMS gives room for growth and change.

Although a complete allocation regulations-covered baseline schedule needs few manual adjustment at the start of the day of operation, the problem remains that alterations in the flight schedule can occur. For the purpose of the schedule remaining operable, it needs to be able to absorb such alterations. Factors that have an influence on this required robustness are mentioned in Chapter 2: buffer times are able to absorb changes in arrival or departure times of a flight. Time gaps of 20 minutes are already in use at Schiphol, but are not specified for an airline or a flight route. Little research has been done on the optimisation of these time gaps, which is to be done by a statistical analysis of historical flight data of Schiphol. Buitendijk [12] developed a stochastic model, based on updated, actual flight data information, and used it for simulation to test and develop a robust tactical gate allocation model. Use could also be made of historical flight data, however, to estimate the likeliness of a flight of a specific size and border control status, or of a flight flying a specific route for a specific airline being early or late with regard to the scheduled times. Using historical flight delay data to predict changes on the day of operation, the operational schedule could be made robust enough to mitigate most tactical reassignments on the day of operation.

In conclusion, and apart from a contribution to the efficiency of realistic and robust gate planning at the international hub airport Schiphol that contains all allocation rules, the contribution to the body of knowledge consists of the creation of a model in which the buffer times are optimised by using historical delay data. Instead of minimising the number of towing operations, it is encouraged in this research to tow an aircraft when the stand that comes available will be of use. When towing happens intermediately for flights with long turnaround times, causing no discomfort to passengers, and when the costs of towing could be less than the costs of delays, more stand space could be created to allocate more or delayed flights. Making a complete and robust operational gate allocation tool is a unique opportunity in the sense that the resources for this research are promising: flight delay data for Schiphol is available and a model validation is done using fast-time airport simulation software Air Traffic Optimisation (AirTOp).

4

Configuration of Stand and Gate Allocation model in BEONTRA Scenario Planning tool

With the challenges of Stand and Gate Allocation discussed in Chapter 2, and the allocation procedures at Schiphol treated in Chapter 3, an SGA model of Schiphol can now be made. As input to this model, the time slot allocation schedule of week 29 in 2018 is used, which is given in Appendix C. Details on the used time slot allocation schedule can be found in Chapter 5. It has been mentioned already in Section 2.2 that it is highly valued to keep the model linear to reduce complexity and calculation time. Furthermore, as both integer as well as continuous variables need to be used, the model will be of the MILP type. For MILP models, use can be made of an existing optimisation solver: for this research, indirect use is made of the optimisation solver Gurobi, which is integrated into the capacity module of BEONTRA Scenario Planning software. The reason for choosing this tool as well as the working principles are given in Section 4.1. Next, in Section 4.2, an overview is given of the design choices regarding model constraints and limitations.

4.1. Description of BEONTRA Scenario Planning tool

For the purpose of modelling, use is made of BEONTRA Scenario Planning software. BEONTRA Scenario Planning software is an integrated airport-planning tool, covering prediction on both long- and short-term basis. The planning suite delivers scenarios supporting operational and strategic decisions by optimisation, facilitated by Gurobi, and by planning of traffic, capacity, and revenue. As input, historical traffic information or schedules can be used. The exact airport modules of the planning tool are given in Figure 4.1. For the purpose of SGA, an allocation schedule can be acquired by using the BEONTRA system modules ’B Tactical’, covering the schedule-based forecasting area, and ’B Capacity’, covering the capacity planning area. More on these two modules can be found in Subsection 4.1.1. The SGA feature of ’B Capacity’ makes use of Gurobi optimisation solver, which is further described in Subsection 4.1.2.

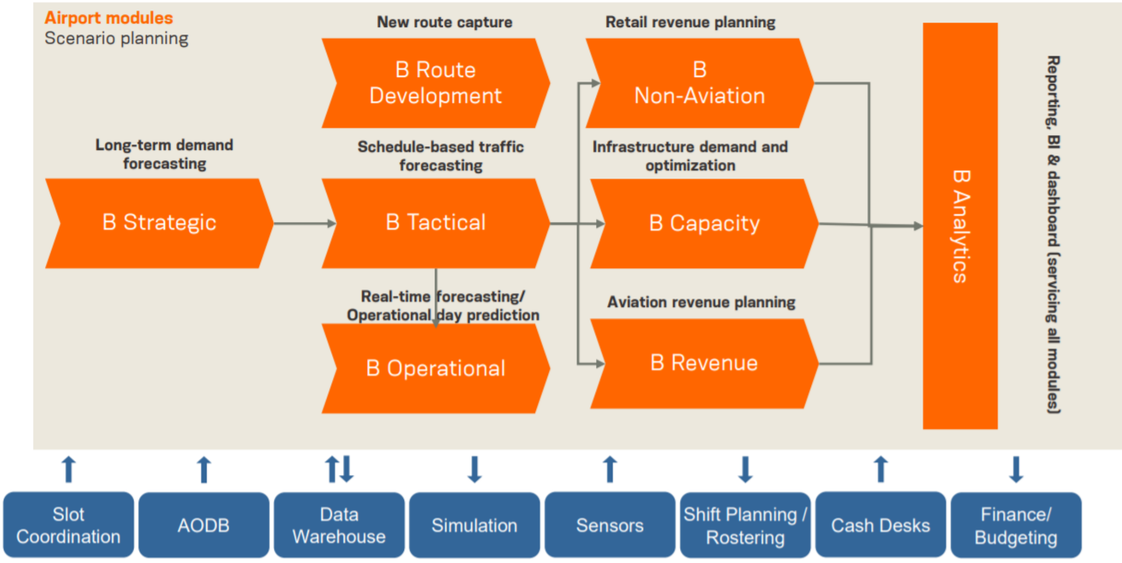

Figure 4.1: Airport modules of BEONTRA Scenario Planning software [19]

The reason to work with the SGA feature of the BEONTRA Scenario Planning tool in this research is because the user is aided in implementing the allocation constraints with visual instructions on infrastructural modelling procedures, physical stand restrictions, and allocation preferences, as is further described in Section 4.2. Furthermore, the BEONTRA products are facilitated by the Gurobi optimiser: according to Hans Mittelmann's MILP Competitive Benchmarks [45], Gurobi is fastest to optimality, on the broadest test set, to feasibility, and to detect infeasibility in comparison to optimisation programmes CBC, CPLEX, GLPK, lpsolve, MATLAB, MIPCL, SAS, SCIP-cpx, SCIP-spx, and XPRESS. An additional benefit is that Gurobi, regardless of its integration in the BEONTRA Scenario Planning software, can be used for free with an academic license.

Besides the fact that the interface is helpful in modelling an SGA problem, using BEONTRA Scenario Planning tool is also of value from a business perspective. By modelling Schiphol in its SGA feature, BEONTRA can gain insight and feedback on an international hub airport case study and how the tool behaves undergoing constraints of an airport for which the capacity module for SGA purposes has not yet been used before. Furthermore, the supportive aviation consultancy of this thesis, To70 Aviation Consultants, can gain insight into the performance of their AirTOp allocation results, compared to the allocation results that are based on a Gurobi optimisation and calculated using a tool that is specialised in scenario planning.

4.1.1. Description of Scenario Planning tool modules 'B Tactical' and 'B Capacity'

The input of the 'B Tactical' module is a flight schedule. In order to implement a flight schedule, it needs to be defined what time period it covers and whether it defines single flight events or periodical ones. For the module to be able to process the schedule, it should at least contain information on the nature of the flight movement, i.e. denoting whether it is an arrival or a departure; and what the type of the flight is, i.e. cargo, passenger, or positioning. Furthermore, the schedule should contain the flight number, carrier code, aircraft type, date and scheduled time of each movement, as well as the linked flight number. Additional information regarding passenger numbers, maximum take-off weight, route specifications or the number of seats can be added as well.

As subsequent output, an analysis of the flight schedule is given: peak periods or peak hours are plotted in a graph and numbers on flight movements per airline or aircraft type are given. An example regarding the flight movements per hour on Monday 16 July on Amsterdam Airport Schiphol, is given in Figure 4.2. It can be observed that a peak of in total 110 flight arrivals and departures takes place around 9:00, and that most seats, based on the aircraft types scheduled at that moment, are handled around 13:00. In conclusion, the 'B Tactical' module provides the possibility to display, analyse and further edit an imported flight schedule.

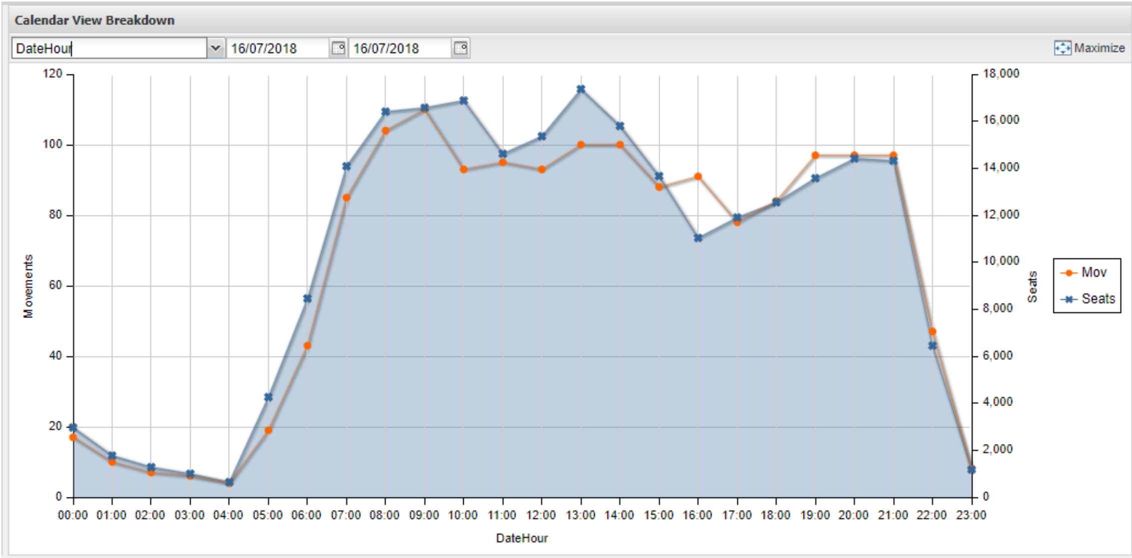

Figure 4.2: Flight movements on 16 July 2018 at Amsterdam Airport Schiphol in 'B Tactical'-module, part of BEONTRA Scenario Planning tool

With all flight movements imported, optimisation or capacity assessment can be performed. First, the analysed flight schedule from 'B Tactical' is linked to the 'B Capacity' module of the BEONTRA Scenario Planning Tool. Then, using data on flight movements, an assessment can be made of the airport capacity; e.g. what the waiting times are at security control with a new scanner system, or the number of passengers per hour arriving at passport control on a certain date. Furthermore, a planning of capacity demand can be made, or an assessment of the airport sizing.

In order to optimise stand and gate usage with the SGA feature in the 'B Capacity' module, the infrastructure of an airport needs to be defined first. The number of terminals, gates, and stands needs to be implemented in the programme, as well as the constraints to which the objective and variables are subject to. For both stands and gates separately, allocation priorities with regard to both airline and airport can be assigned. Furthermore, occupancy times can be established, as well as towing handling schemes. Based on the given infrastructure and the implemented constraints, the programme can run an optimisation calculation. Detailed information on how the SGA feature of the 'B Capacity' module is to be used, is illustrated in Section 4.2.

4.1.2. Description of working principle Gurobi optimisation solver programme

As has been mentioned in the previous subsection, the software tool that is used to design an airport model for Stand and Gate Allocation is the SGA feature of the BEONTRA Scenario Planning 'B Capacity' module. The Gurobi optimisation solver programme is integrated into the BEONTRA Scenario Planning products to facilitate optimisation, and the SGA feature within this module provides an interface to list all information needed by Gurobi. In order to gain understanding of the BEONTRA Stand and Gate Allocation feature, the working principle of Gurobi is addressed in this subsection. Information in this subsection is primarily acquired from the Gurobi website [31] and Hillier [33], Section 12.7.

Gurobi Optimizer is a commercial optimisation solver programme for linear and mixed integer linear programming; and quadratic, quadratically constrained, mixed integer quadratic, and mixed integer quadratically constrained programming. As explained in Section 2.2, MILP problems contain decision variables that are discrete and continuous: in the case of a Stand and Gate Allocation problem, the model will use both integer variables, such as allocation variables that determine whether a stand has a flight assigned to it, as well as continuous variables, such as time or occupancy rates. After loading data, and setting up the MILP model, Gurobi generally solves the problem using a linear- programming based Branch and Bound (B&B) algorithm.

Of course, the objective function and the corresponding costs need to be defined first. This is done by taking into account the preferences; e.g. stand allocation preferences. If airline Z wants to use stand 1 up to 5 at pier X and, most definitely, not stand 1 up to 3 at pier Y, the lowest costs can be assigned for the combination of aircraft of this airline allocated to the stands of its preference at pier X. Then, the highest costs are to be assigned to combinations involving the stands at pier Y. If an allocation combination is not possible at all, a '0' can be assigned to discard that combination. When costs are assigned to all preferences for all combinations of flights and stands, and all constraints are implemented, Gurobi acquires a solution to the objective function by means of the B&B algorithm. In case of the SGA problem, the solution is presented as an allocation schedule, by providing results on when to assign which flight to what stand.

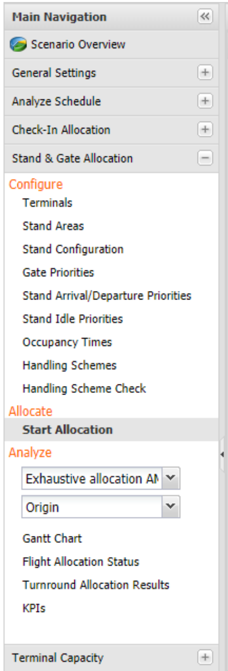

Figure 4.3: Configuration parts of the SGA feature in the 'B Capacity'-module navigation menu, part of BEONTRA Scenario Planning tool

According to to the BEONTRA Scenario Planning 'B Capacity' user guide [6], the cost function in the SGA algorithm in the BEONTRA Scenario Planning tool is based on a strict hierarchy. The four parts of this cost function, in order of importance, are:

1. Unallocated turnarounds should be minimised with the highest priority;
2. The defined handling scheme should be used as much as possible. More on the handling scheme is given in Section 4.2;
3. Preferences for Stand and Gate Allocations should be maximised, but applied only if there are multiple options for stands or gates using one and the same handling scheme;
4. Ranks of the used stand and gate should be maximised, but only if there are multiple options that result in the same objective value regarding the cost function parts defined above. More on ranks is given in Section 4.2.

A formulation of the cost function, to illustrate how the hierarchy works, would look like:

$$TotalCost = Decision_{unallocatedFlights} * C_{unallocatedFlights} + Priority_{handlingscheme} * C_{handlingscheme}$$

$$+ PREFERENCES_{handlingPlan} * C_{preferences} + RANKS_{handlingPlan}$$

Here, 'C' is a constant that assures the strict hierarchy. For example, the first constant, $C_{unallocatedFlights}$, must be a very large number that assures that the costs in case a turnaround is unallocated ($Decision_{unallocatedFlights} = 1$) are always higher than for the worst case of being allocated. In other words: it is preferred to use the worst handling scheme and assign a flight to the stands and gates with the lowest possible preferences and rankings over that flight remaining unallocated. For each passenger-carrying turnaround, a minimum of two resources and a maximum of five, i.e. stands and gates, can be used and rated. This would respectively be the case for a flight undergoing no tows and a flight undergoing two tows. Respectively, one gate and one stand, and three different stands and two gates would need to be evaluated.

4.2. Overview of design choices for Stand and Gate Allocation model

As mentioned in Section 4.1, the SGA feature of the BEONTRA Scenario Planning tool makes use of the Gurobi optimisation problem solver, in which visual and structured help is given for setting up the SGA problem. In this section, a description is given of the working principle of the SGA feature, partly based on the BEONTRA Scenario Planning 'B Capacity' user guide [6]. Furthermore, the steps that are taken to set up the model of Amsterdam Airport Schiphol within this tool are discussed, as well as the details on input and design choices.

The BEONTRA Scenario Planning 'B Capacity' user guide [6] states that the SGA feature consists of two main aspects: the model for resources and preferences, accompanied by Figure 4.4, and the handling concept, accompanied by Figure 4.5. As can be seen in Figure 4.4, the model is set up by definition of the resources for the terminal, the stand and gate areas, as well as for corresponding allocation preferences on an airport- and airline-level. Furthermore, corresponding occupancy times and flight schedule specifications can be defined, that on their turn influence the stand and gate set-up. In Figure 4.5, it can be seen how the model set-up is combined with the handling scheme, which will be discussed later in this section. All possible options are then generated in the handling plan, which is then solved by Gurobi to generate an allocation schedule.

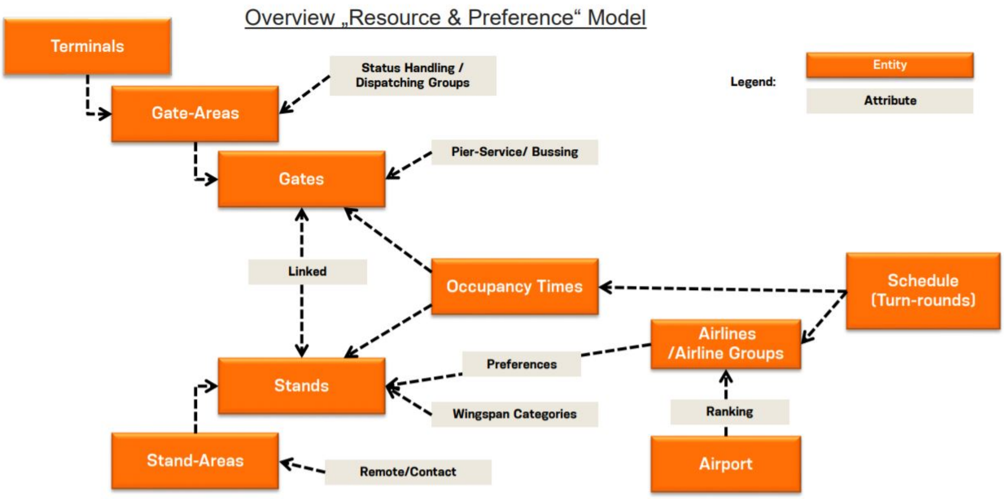

Figure 4.4: Overview of the model for resources and preferences of the BEONTRA Scenario Planning 'B Capacity' module, SGA feature [6]

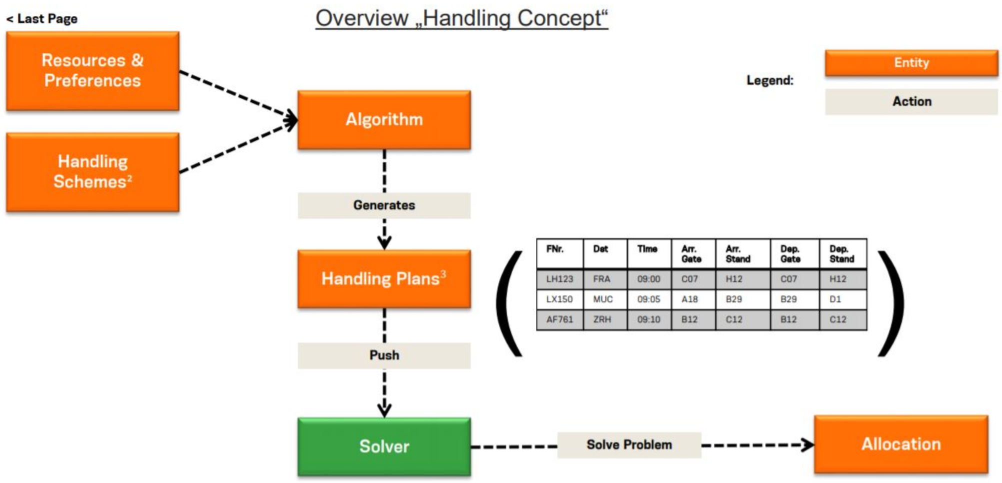

Figure 4.5: Overview of the handling concept of the BEONTRA Scenario Planning 'B Capacity' module, SGA feature [6]

Before moving on to a description of the definition of the resources and the handling scheme, a description of the groups that will help in defining those will be given first. In the 'B Capacity' module, use can be made of the Group Editor. Here, several groups on airlines, destinations, and terminals can be defined to construct a suitable and detailed analysis in the modules later on. An example is the division in WIBO and NABO aircraft type groups, in which all aircraft of the BEONTRA database are assigned to one of the two groups. When Gantt charts showing the allocation schedule are acquired in the BEONTRA Scenario Planning tool, these groups can also be used to filter flights, as is explained later on. The groups as defined for this model are as follows:

- **Border control status** - This group consists of a Schengen subgroup, a Non-Schengen screened one, and a Non-Schengen unscreened group, by assigning all airports of the BEONTRA database to one of each groups. This assignment is done on an airport level, as security standards can differ per airport. This group is used to define hard constraint gate characteristics in the 'Terminals' configuration part of the SGA feature. All SGA feature configuration parts are depicted in Figure 4.3, showing the navigation menu of the 'B Capacity' module;

- **Physical restrictions** - Schiphol distinguishes between nine aircraft size categories, based on fuselage length and wingspan. Since some stands can only receive aircraft of a specific aircraft category, all aircraft types from the BEONTRA database are assigned to the matching size category. As some stands can only receive some aircraft at specific times or of a specific flight type, e.g. cargo or passenger, a triple subdivision is made for all aircraft size categories. The first group contains all non-passenger type aircraft of a certain size. The second contains all passenger type aircraft of that size, but at daytime (between 6:00 and 24:00) only. The third contains all passenger type aircraft of that size at nighttime (between 0:00 and 6:00). This 'Physical restrictions' group is used to define hard constraint stand characteristics in the 'Stand Configuration' part of the SGA feature;

- **Airline preferences** - This group consists of all airlines: allocation preferences that are known per airline, as given in the business rules in Appendix B, are grouped per airline, containing that airline and possibly other subdetails, such as aircraft type or travel destination. This group is used to define gate preferences in the 'Gate Priorities' part of the SGA feature;

- **Preferences on specific routes** - In this group, flights are grouped together per country, or per arrival or departure destination, based on the business rules that define preferences on flight carriers of a certain nationality or from certain airports. This group is used in the 'Stand Arrival/Departure' and in the 'Handling Schemes' part of the SGA feature;

- **Idle time preferences** - In this group, subgroups are made based on preferences of airlines, aircraft sizes, or flight types with regard to their idle parking positions that can be defined later. This group is used in the 'Stand Idle Priorities' part of the SGA feature;

- **WIBO and NABO** - As given as an example earlier, a group is made with two subgroups that contain all WIBO aircraft types and NABO ones, respectively. This group is used in the 'Handling Schemes' part of the SGA feature;

- **WIBO and NABO, low-cost and not low-cost per hour** - Same as above, but with a subdivision in low-cost airlines and non-low-cost airlines. To specify even more detail, this subdivision includes every hour of the day as well. This group is used in the 'Occupancy Times' part of the SGA feature;

- **Blocktime** - In this group, blocktimes are defined that are important for towing. As WIBO aircraft with a turnaround time longer than 210 minutes need to be towed away, subgroups consisting of an 'equal to or more than 210 minutes'-equation and one of 'less than 210 minutes' are added. As NABO aircraft need to be towed away after 170 minutes, subgroups consisting of an 'equal to or more than 170 minutes'-equation and one of 'less than 170 minutes' are added as well. This group is used in the 'Handling Schemes' part of the SGA feature;

- **Passenger, positioning or cargo** - Two subgroups are defined within this group: one containing all passenger-oriented flight types, and one containing all non-passenger-oriented flight types. It is used in the 'Handling Schemes' part of the SGA feature;

- **Flights day- and nighttime** - As there is a difference between SGA at night (0:00-6:00) with regard to at day (6:00-24:00), due to the lack of bus services at night, both day and night hours are defined in two subgroups. This group is used in the 'Handling Schemes' part of the SGA feature.

With the groups defined, the model can be set up in a few steps. First, the number of terminals is set. At Schiphol, the current number of terminals in use is one: the building of the future terminal A is to be finished in 2023 and is therefore not taken into account for this planning. Next, the module differs gates from stands, as explained in Chapter 1: gates are terminal areas that are designated for passenger embarking and disembarking. They can be linked directly to an aircraft stand through an air bridge, or to a bus stop that connects to a remote aircraft stand. Stands are all aircraft parking positions, both contact and remote.

In Figure 4.6 it is defined how many gates there are present per pier part, in which a distinction is made between border control status areas within piers. In the names of the gate areas, it is defined what flights it can handle: 'Schengen' can only manage Schengen arrival and departure; 'Non-Schengen screened' can manage only screened Non-Schengen flights; 'Non-Schengen unscreened' can manage all Non-Schengen flights, both screened as well as unscreened; 'Swing screened' can manage both Schengen and screened Non-Schengen flights; and 'Swing unscreened' can manage all flights. Together with the handling scheme, as is discussed later, this feature covers allocation regulation no. 11 as defined in Section 3.3.

For the gate areas, seven piers with 96 contact gates[1] are covered here. Next, an Excel-file can be exported for the 'Gate Areas' definition: this file is given in Appendix D. As can be seen, a 'True' ('1') is assigned when a border control status applies to a gate area, and a 'False' ('0') is assigned when this is not the case.

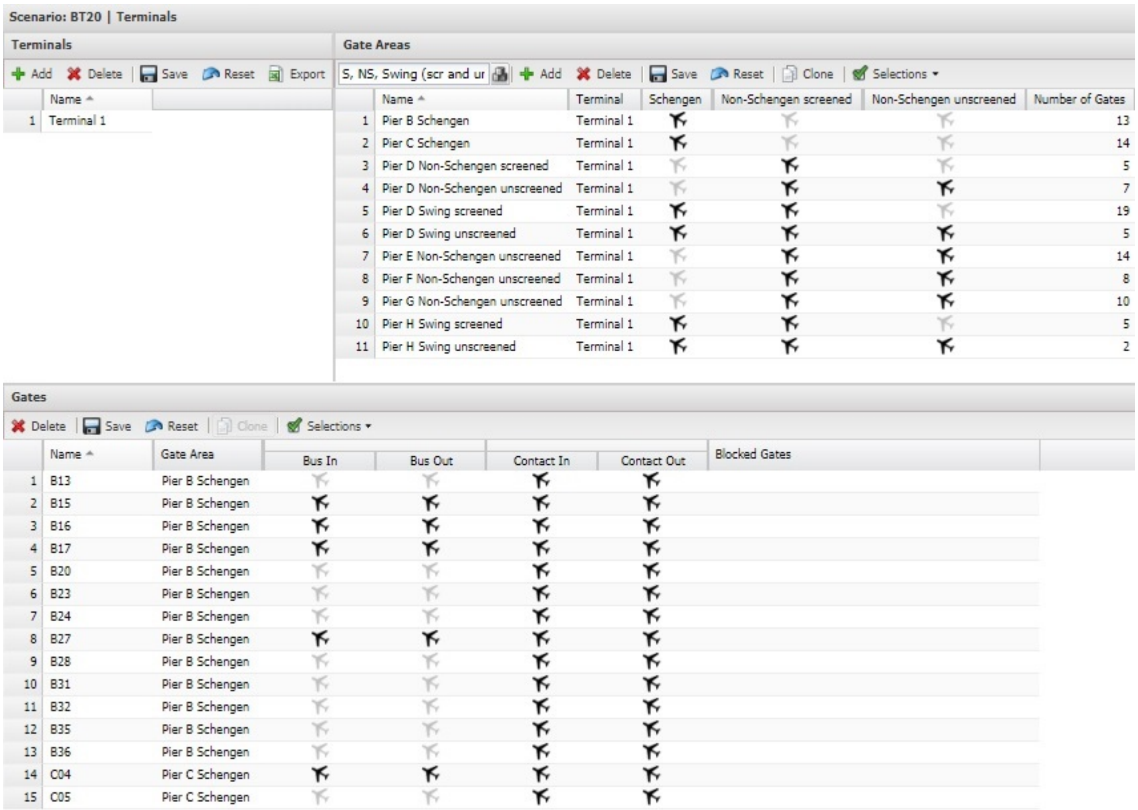

Figure 4.6: 'Terminals' configuration part of SGA feature, part of BEONTRA Scenario Planning tool

In the same menu, it can be specified per gate whether it is a contact gate for arrival flights, departure flights or both; whether it can handle buses; and whether certain gates are blocked when others are in use. Contact gates that also provide access to a bus stop are the following: B-15, B-16, B-17, B-27, C-04, C-06, C-08, D-07, D-22, D-23, D-24, D-25, D-27, D-28, D-29, D-48, D-52, D-54, D-56, H-01, and H02. The stand numbers for these gates are the same. The corresponding, exported Excel-file with data on gate level is given in Appendix D, in which possible combinations are marked with 'True' and impossible ones with 'False'.

[1]This number excludes five gate positions that are additionally defined in the SGA feature of the BEONTRA Scenario Planning tool to define a MARS stand or a gate that blocks another gate when in use.

Scenario: BT20 | Stand Areas

Add | Delete | Save | Reset

	Name	Type	Number of Stan...
1	Alfa Apron	Remote	11
2	Bravo Apron	Remote	26
3	Juliet Ramp	Remote	8
4	Kilo Apron	Remote	32
5	Lima Ramp	Remote	3
6	Mike Ramp	Remote	14
7	November Ramp	Remote	2
8	Papa Platform	Remote	8
9	Pier B Schengen	Contact	13
10	Pier C Schengen	Contact	14
11	Pier D Non-Sch...	Contact	5
12	Pier D Non-Sch...	Contact	7
13	Pier D Swing sc...	Contact	19
14	Pier D Swing un...	Contact	5
15	Pier D buffer	Remote	6
16	Pier E Non-Sche...	Contact	14
17	Pier E buffer	Remote	3
18	Pier F Non-Sche...	Contact	8
19	Pier G Non-Sch...	Contact	10
20	Pier G buffer	Remote	4
21	Pier H Swing sc...	Contact	5
22	Pier H Swing un...	Contact	2
23	Romeo Cargo A...	Remote	10
24	Sierra Cargo Ap...	Remote	11
25	Uniform Ramp	Remote	5
26	Yankee Ramp	Remote	3

Figure 4.7: 'Stand Areas' configuration part of the SGA feature, part of BEONTRA Scenario Planning tool (the numbers correspond to the actual stand numbers, excluding six additional stands defined to cover MARS stands or stands that block other stands when in use)

Next, the stand areas are defined in the 'Stand Areas' configuration part of the SGA feature, as shown in Figure 4.7. All aprons are included for completeness, but some are not used for allocation: apron K is used for general aviation only and no general aviation flights are part of the flight schedule used, hence, no arrivals or departures are planned from this apron. The aprons L, M, N, and U are used for towing purposes only in this model. Furthermore, the P holding apron is not included, as this apron is meant for short waiting times only: i.e. if an assigned stand is not yet ready to receive its follow-up flight. The corresponding, exported Excel-file is given in Appendix D.

The characteristics of the stands are then defined in 'Stand Configuration', for which the 'Physical restrictions'-group is used to define whether a stand can handle non-passenger flights, passenger flights at day, passenger flights at night, or combinations of those. Also, stands can be linked to corresponding gates, and it can be defined what stands are blocked when a specific stand is in use. In summary: the pier stands can receive passenger flights only, both during the day as well as during the night. Buffer stands D, E, and G, and aprons A, B, J, Y, P, and R can only receive passenger flights and only during daytime. Apron R and S can receive non-passenger flights at all times. The corresponding, exported Excel-file, showing 'True' or 'False' at the combinations of size categories and stands, is given in Appendix D. 'Stand Configuration' thus covers, together with the handling scheme, allocation regulations no. 6 and 7 from 3.3.

In the subsequent SGA configuration parts 'Gate Priorities', 'Stand Arrival/Departure priorities', and 'Stand Idle Priorities', the costs are assigned for business rules, also covering allocation regulation no. 9 and 10 from Section 3.3. The respective exported Excel-files with costs per gate and stand are given in Appendix D. Costs can be assigned both on an airline and on an airport level, which influences the 'ranks' as defined in Section 4.1.2. These costs are kept the same, as for this model, airline and airport preferences are assumed to be the same.

In assigning costs to preference-gate and preference-stand combinations, it is taken into account that passen- ger flights are preferably assigned to contact stands and that non-passenger flights are not. With this, allocation regulation no. 5 and 7 (and roughly, discarding the zoning definition, allocation regulation no. 1 and 2) from Section 3.3 are covered. Intermediate towing for long-term parking is conducted to non-contact stands only. In general, the hard constraints regarding border control and aircraft size restrictions are followed.

Preferences are followed as long as the capacity allows it: if a specific combination is not possible, a cost of '0' can be assigned in order to disable a combination.

Next, the 'Occupancy Times' configuration part is defined. In this configuration part, a distinction is made between stand and gate occupancy times; as well as for 'pier served' and 'bussed' handling. These times can be specified for both arrival and departure, resulting in eight different occupancy times. For the same combinations, buffer times can be defined. One needs to assign a predefined group in order to specify the mentioned occupancy and buffer times. As there is a difference between the theoretical buffer times for low-cost and regular airlines; and a difference between WIBO and NABO occupancy times; it is decided to use the 'WIBO and NABO, low-cost and not low-cost per hour'-group.

For the occupancy times of both 'pier served' and 'bussed' stands, and 'pier served' gates, 55 minutes for NABO and 75 minutes for WIBO arrivals is used. For the occupancy times of both 'pier served' and 'bussed stands', and 'pier served' gates, 65 minutes for NABO and 85 minutes for WIBO departures is used. The arrival and departure occupancy times for 'bussed' gates are 20 minutes for NABO and 40 minutes for WIBO. In order to be more flexible in assigning occupancy times, these times can be defined per hour, which has been predefined in the 'WIBO and NABO, low-cost'-group as well. The occupancy times are primarily used to specify the minimum time a flight needs to occupy a stand or gate, before it can be towed away.

For the buffer times, low-cost flights use the prescribed buffer time of 10 minutes; regular flights use a buffer time of either 20, 15, 10, 5, or 0 minutes. The theoretical buffer time of Schiphol is set to 20 minutes, but this number is often lowered in practice. Regarding the influence of the length of buffer times for regular airlines, more is specified in Chapter 5. Regarding the buffer time specification, allocation regulation no. 3 and 4 from Section 3.3 are covered, except that buffer times other than 20 minutes are evaluated as well. After conducting research and calculating individually optimised buffer times, these times can be specified more elaborately. The 'Occupancy Times' export for a buffer time of 20 minutes is given in Appendix D.

Last, the 'Handling Schemes' configuration part is set, in which up to five groups can be used to define the handling scheme for all flights. Here, the groups 'WIBO and NABO', 'Blocktime', 'Passenger, positioning or cargo', 'Flights day- and nighttime', and 'Preferences on specific routes' are used. It is then defined how passengers and aircraft in turnaround flights should be handled, according to the order of appearance of the given handling rules. Basically, it covers allocation regulation no. 7 from Section 3.3 in a manner that it is adjusted to the business allocations.

Handling Schemes by Filter

Add Delete Save Reset

	Arrival Filter					Departure Filter					Passenger Handling		Aircraft Handling			
	WIBO or NABO	Blocktime	Passenger, positioning or cargo	Flights day- and nighttime	Preferences on specific routes	WIBO or NABO	Blocktime	Passenge...	Flights day- and nighttime	Preferences on specific routes	Arrival	Departure	Arrival	Departure	Towing	Priority
1	*	*	Cargo	*	*	*	*	Cargo	*	*	None	None	Remote	Remote	0	1
2	*	*	Cargo	*	*	*	*	Cargo	*	*	None	None	Remote	Remote	1	2
3	*	*	Positioning	*	*	*	*	Positioning	*	*	None	None	Remote	Remote	0	3
4	*	*	Positioning	*	*	*	*	Positioning	*	*	None	None	Remote	Remote	1	4
5	*	*	Passenger	*	*	*	*	Passenger	*	*	Pier Served	Pier Served	Contact	Contact	0	5
6	*	*	Passenger	*	*	*	*	Passenger	*	*	Pier Served	Pier Served	Contact	Contact	0	6
7	*	t>=210	Passenger	*	Arrivals from AUA, BON, CUR, PMB, SXM, CCS, PMV	*	t>=210	Passenger	*	*	Pier Served	Pier Served	Contact	Contact	2	7
8	*	t>=170	Passenger	*	Arrivals from AUA, BON, CUR, PMB, SXM, CCS, PMV	*	t>=170	Passenger	*	*	Pier Served	Pier Served	Contact	Contact	1	8
9	*	t>=170	Passenger	*	Arrivals from AUA, BON, CUR, PMB, SXM, CCS, PMV	*	t>=170	Passenger	*	*	Pier Served	Bussed	Contact	Remote	1	9
10	*	t>=210	Passenger	*	*	*	t>=210	Passenger	*	Departures to US PAX	Pier Served	Pier Served	Contact	Contact	2	10
11	*	t>=170	Passenger	*	*	*	t>=170	Passenger	*	Departures to US PAX	Pier Served	Pier Served	Contact	Contact	1	11
12	*	t>=170	Passenger	*	*	*	t>=170	Passenger	*	Departures to US PAX	Bussed	Pier Served	Remote	Contact	1	12
13	*	t>=170	Passenger	*	*	*	t>=170	Passenger	*	Departures to CDG - DAY	Pier Served	Pier Served	Contact	Contact	2	13
14	*	t>=130	Passenger	*	*	*	t>=130	Passenger	*	Departures to CDG - DAY	Pier Served	Pier Served	Contact	Contact	1	14
15	*	t>=130	Passenger	*	*	*	t>=130	Passenger	*	Departures to CDG - DAY	Bussed	Pier Served	Contact	Contact	1	15
16	*	*	Passenger	*	Arrivals from AUA, BON, CUR, PMB, SXM, CCS, PMV	*	*	Passenger	*	*	Pier Served	Pier Served	Contact	Contact	0	16
17	*	*	Passenger	*	*	*	*	Passenger	*	Departures to US PAX	Pier Served	Pier Served	Contact	Contact	0	17
18	*	*	Passenger	Day - 06:00-23:59	*	*	*	Passenger	Day - 06:00-23:59	*	Bussed	Bussed	Remote	Remote	0	18
19	*	*	Passenger	*	*	*	*	Passenger	*	Departures to CDG - DAY	Pier Served	Pier Served	Contact	Contact	0	19
20	WIBO	t>=210	Passenger	*	*	WIBO	t>=210	Passenger	*	*	Pier Served	Pier Served	Contact	Contact	2	20
21	WIBO	t>=170	Passenger	*	*	WIBO	t>=170	Passenger	*	*	Pier Served	Pier Served	Contact	Contact	1	21
22	WIBO	t>=170	Passenger	*	*	WIBO	t>=170	Passenger	Day - 06:00-23:59	*	Pier Served	Bussed	Contact	Remote	1	22
23	WIBO	t>=170	Passenger	Day - 06:00-23:59	*	WIBO	t>=170	Passenger	*	*	Bussed	Pier Served	Remote	Contact	1	23
24	NABO	t>=170	Passenger	*	*	NABO	t>=170	Passenger	*	*	Pier Served	Pier Served	Contact	Contact	2	24
25	NABO	t>=130	Passenger	*	*	NABO	t>=130	Passenger	*	*	Pier Served	Pier Served	Contact	Contact	1	25
26	NABO	t>=130	Passenger	*	*	NABO	t>=130	Passenger	Day - 06:00-23:59	*	Pier Served	Bussed	Contact	Remote	1	26
27	NABO	t>=130	Passenger	Day - 06:00-23:59	*	NABO	t>=130	Passenger	*	*	Bussed	Pier Served	Remote	Contact	1	27
28	*	t>=130	Passenger	*	*	*	t>=130	Passenger	*	*	Pier Served	Pier Served	Contact	Contact	1	28
29	*	t>=130	Passenger	*	*	*	t>=130	Passenger	Day - 06:00-23:59	*	Pier Served	Bussed	Contact	Remote	1	29
30	*	t>=130	Passenger	Day - 06:00-23:59	*	*	t>=130	Passenger	*	*	Bussed	Pier Served	Remote	Contact	1	30
31	*	t>=130	Passenger	Day - 06:00-23:59	*	*	t>=130	Passenger	Day - 06:00-23:59	*	Bussed	Bussed	Remote	Remote	1	31
32	*	*	Passenger	*	*	*	*	Positioning	*	*	Pier Served	None	Contact	Remote	1	32
33	*	*	Passenger	Day - 06:00-23:59	*	*	*	Positioning	*	*	Bussed	None	Remote	Remote	0	33
34	*	*	Positioning	*	*	*	*	Passenger	*	*	None	Pier Served	Remote	Contact	1	34
35	*	*	Positioning	*	*	*	*	Passenger	Day - 06:00-23:59	*	None	Bussed	Remote	Remote	0	35

Figure 4.8: 'Handling Schemes' configuration part of SGA feature, part of BEONTRA Scenario Planning tool ('*' denotes that all options are included, i.e. that it is applicable to all flights)

As can be seen in Figure 4.8, cargo and pure positioning flights, of which both arrival and departure are a positioning flight, are handled first. Flights that are within these groups need to be handled at a remote stand and can be towed 0 or 1 times. Second, passenger flights are to be handled at a contact stand: this rule is applied twice, to have the programme try this rule twice. Unallocated flights are then handled according to their origin and destination. First, arrival flights from Aruba, Bonaire, and all other origins that require a 100% security check are handled at a contact stand. Second, departures to the US are handled at a contact stand. Next, departures to Paris Charles de Gaulle are handled at a contact stand as well. For all the rules concerning these three flight routes, towing twice or once is possible if the stand occupancy time allows to; the linked flight is preferably handled at a contact stand as well, but can be handled remotely as well. Conducting no tows at all has secondary priority.

If there are still unassigned flight and daytime hours apply, they are preferably handled remotely and without towing; otherwise, the handling scheme follows the rules for towing corresponding to WIBO and NABO occupancy times. WIBO handling has priority over NABO handling, and towing happens preferably to contact stands and only during daytime. Next, handling rules for towing once are applied again to all flights that are left. Last, the flights that change flight type from passenger to positioning and vice versa are handled, in which the positioning arrival or departure is handled remotely; and the linked passenger arrival or departure is handled preferably at a contact stand, and at a remote stand otherwise. The corresponding, exported Excel-file for the handling scheme is given in Appendix D.

The handling rules have taken into account some of the allocation regulations that are mentioned in Section 3.3. Implicitly, it is specified in the handling rules that during nighttime, passenger flights need to be pier served and should not be towed, as specified in allocation regulation no. 12. Furthermore, WIBO aircraft have a higher allocation priority, especially to contact stands, than NABO aircraft. This covers both allocation regulation no. 1 and 2, as well as 5. WIBO Aircraft should be towed away intermediately if their turnaround time exceeds 210 minutes; same for NABO aircraft when their turnaround time exceeds 170 minutes, as specified in allocation regulation no. 8 from Section 3.3. However, when there is no need for towing when the stand demand is low, aircraft may remain on their stand. Regarding allocation regulation no. 14, 15, and 16 from Section 3.3: these are not taken into account, as the first relates to shuttle bus planning, and the latter two regulations relate to reallocation. Both subjects are not considered in this model.

With all required fields defined in the SGA feature of the BEONTRA Scenario Planning tool, an optimal allocation can be calculated. Selecting one specific day of the linked flight schedule as input leads to an allocation of that specific day. With the Amsterdam Airport Schiphol flight schedule of Monday 16 July 2018, being the busiest day of week 29 in terms of flight movement numbers, as input, allocations are retrieved that are discussed in Chapter 5.

5

Evaluation of Stand and Gate Allocation model of Amsterdam Airport Schiphol

With the function, requirements, and layout of Amsterdam Airport Schiphol given in Chapter 3 and the corresponding model configuration described in the Chapter 4, an analysis of the input and the output of the model is given in this chapter. The input for the SGA model is the flight schedule of week 29. More specifically, it is the time slot allocation schedule for week 29, 16 to 22 July 2018, as has been created in November 2017. An excerpt of this flight schedule, showing flights scheduled on Monday 16 July 2018, is given in Appendix C. The analysis of the input schedule is given in Section 5.1.

The aim of this section on schedule analysis is to provide insight into the density and mixture of the flight schedule. For this purpose, Subsection 5.1.1 starts with a description of how this analysis is performed. Next, Subsection 5.1.2 gives the results of the analysis and presents numbers and percentages on flight types, airlines, fleet mix in terms of border control status and size category; the number of turnarounds that would be eligible for one or two tows, according to RASAS [3]; and the stand demand per hour for the busiest day in week 29, being Monday 16 July. With the stand demand per hour, potential allocation bottlenecks can be indicated.

The output of the SGA model is an allocation schedule. As the influence of the buffer time on the output results is important for this research, five different allocation schedules have been created with a respective buffer time of 0, 5, 10, 15, and 20 minutes. These allocation schedules are given in Appendix F. The results are discussed in Section 5.2, and compared to the bottlenecks that are discussed in Section 5.1. The aim of this section is to provide insight into the effects of an increasing buffer time.

5.1. Input analysis of flight schedule of Amsterdam Airport Schiphol for 16 July 2018

The aim of this section on schedule analysis is to provide insight into the density and mixture of the flight schedule. For this purpose, Subsection 5.1.1 starts with a description of how this analysis is performed. Next, Subsection 5.1.2 gives the results of the analysis and presents numbers and percentages on flight types, airlines, fleet mix in terms of border control status and size category; the number of turnarounds that would be eligible for one or two tows, according to RASAS [3]; and the stand demand per hour for the busiest day in week 29, being Monday 16 July. With the stand demand per hour, potential allocation bottlenecks can be indicated.

Before continuing to the analysis, two important remarks about the flight schedule should be taken into account. First, the flight schedule of 16 to 22 July represents a peak week at Schiphol: summertime has a larger throughput of passengers with regard to the winter period, as more leisure passengers pass by due to the holiday period. As stated in Section 3.1, the daily average of flight movements in 2017 was 1,361; the daily average of flight movements in the week of 16 to 22 July 2018 is 1,532. Second, the input schedule is a time slot allocation schedule, created in November 2017. Hence, this schedule is based on the available flight schedules of all airlines a season ahead. One-day-ahead flight cancellations, delays, and alterations are not considered, but for the purpose of setting up and testing a model that includes business rules and individual optimised buffer times, this would have no significant impact.

5.1.1. Description of set-up for flight schedule analysis

To provide insight into the density and mixture of the flight schedule, this subsection describes how the analysis of the flight schedule is performed. The analysis can be done for any schedule that for each flight contains a flight number; the aircraft type and/or aircraft size category; the flight type; the arrival and/or departure time and date, and, in case of a turnaround flight, the linked flight number and/or the turnaround time; and the origin and/or destination, or the corresponding border control status. Furthermore, occupancy times and towing regulations should be known. When towing is an option, stands that handle flights with sufficiently long turnaround times can be used intermediately, increasing the stand usage efficiency.

As mentioned in Chapter 3, the border control status classification for passenger flights at Schiphol consists of Schengen, Non-Schengen screened and Non-Schengen unscreened flights. In case an arrived flight changes its border control status at departure, it would need to change stands as well, in case of pier served handling. Most Non-Schengen stands can handle both screened as well as unscreened Non-Schengen flights, so changing between these statuses would not cause any significant problems. Non-Schengen to Schengen changes could, however, as there are only seven so-called dual status contact stands at Schiphol that are able to handle both status types: five at pier D and two at low-cost pier H. Again, intermediate towing of aircraft proves to be beneficial to handle all flights that change status and cannot remain at the same stand.

Besides the fact that flights can change status, they can change flight type as well. Cargo flights remain cargo flights, but scheduled passenger flights and charter passenger flights can change to positioning flights and the other way around. As positioning flights need to be handled at a remote stand, and passenger flights preferably at a contact stand, such flights should be towed away in case their turnaround time allows it. Therefore, as stand requirements can change during a turnaround due to changing border control status or due to changing flight type, it is important to break a flight apart in several segments. Both the turnaround time and the minimum occupancy times for towing determine the occupancy times at the stands in these segments. Using these times, both the start and the end time of a stand occupancy, also for intermediate tow stands, can be determined.

Therefore, to determine the stand occupancy times and the number of tows, and to take into account flights with changing flight type or border control status, the turnaround duration of each flight is analysed first. Based on the RASAS [3] regulations: if a NABO flight or a WIBO flight respectively has a turnaround time equal to or exceeding 170 or 210 minutes, the flight is labelled as 'long'. The flight is then eligible to be towed twice. If a NABO flight or a WIBO flight respectively has a respective turnaround equal to or exceeding 130, but smaller than 170; or 170, but smaller than 210 minutes; the flight is labelled as 'medium'. The flight is then eligible to be towed once. If the turnaround time is smaller than the mentioned durations, the flight is labelled as 'short'.

Next, the occupancy times of stands can be taken into account. Occupancy times in the case of the 'short' flights equal the duration of their turnaround. The arrival and departure times of a flight are then equal to the stand arrival and departure times. As stated in RASAS [3], occupancy times in the case of the 'long' and 'medium' flights are 55 minutes for NABO and 75 minutes for WIBO at arrival, and 65 minutes for NABO and 85 minutes for WIBO at departure. The time needed to perform a tow movement is set to 10 minutes. Performing this analysis in Microsoft Excel, it can be determined at what time arrival flights with a long or medium turnaround leave their initial stand, being 55 or 75 minutes after arrival. It can also be determined at what time departure flights with a long or medium turnaround time arrive at their departure stand, being 65 or 85 minutes prior to their departure. In between, it can be determined at what time a flight arrives at its intermediate, remote stand: this is 10 minutes after a flight has left its arrival stand. 10 Minutes prior to arriving at its departure stand, it leaves this intermediate stand. Of course, in case of a medium flight, towing only takes place once.

Based on the times as given in the flight schedule, the start and end occupancy times for either an arrival or a departure stand, or for the stand to which a flight is possibly towed away, are now known. Subsequently, one can count cumulatively how many stands of what kind there are needed. For that purpose, flights that would arrive at a stand, either at an arrival stand, at an intermediate or tow stand in case of a long turnaround, or at a departure stand after being towed, get a ’+1’. Flights that depart from a stand, either from an arrival stand for the purpose of towing, from an intermediate or tow stand, or from a departure stand, get a ’-1’.

Furthermore, all movements, being arrivals or departures at stands or tow stands, get a timestamp. The movements can be counted for the right stand type in the period the movement takes place. A further distinction is made between size categories, from category 1 up to 9; between border control status stands, being Schengen, denoted by ’SCH’, Non-Schengen screened, by ’NS_scr’, and Non-Schengen unscreened, by ’NS_uns’; between tow stands that are used intermediately during long turnarounds; and between stands linked to flight type, being passenger, denoted by ’J’ or ’C’, cargo, denoted by ’F’, and positioning, denoted by ’P’.

In Figure 5.1, an excerpt from Appendix E is given. Figure 5.1 shows the stand movements and occupancies from 6:10 to 6:20 on 16 July 2018: all arrivals at a stand are given ’+1’ in the ’Counter’-column; all departures from a stand are given ’-1’ in this column. A ’0’ is given for all movements that are not taken into account: this is the case for all linked flight numbers for short flights, as these are already accounted for for all movements; and for calculated, potential tow movements that do not apply for short turnarounds.

Callsign	Category	WIBO_or_NABO	FlightType	BorderControlStatus_Short	DateAndTime	TATDuration	Operation	Block	Counter	Timestamp
HV5131	4	NABO	J	SCH	16-7-2018 06:10:00	Long	-	-	0	1607180610
HV5517	4	NABO	J	NS_scr	16-7-2018 06:10:00	Long	-	-	0	1607180610
HV5763	4	NABO	J	SCH	16-7-2018 06:10:00	Long	-	-	0	1607180610
HV5131	4	NABO	J	SCH	16-7-2018 06:10:00	Long	-	-	0	1607180610
HV5517	4	NABO	J	NS_scr	16-7-2018 06:10:00	Long	-	-	0	1607180610
HV5763	4	NABO	J	SCH	16-7-2018 06:10:00	Long	-	-	0	1607180610
KL0405	7	WIBO	J	NS_uns	16-7-2018 06:10:00	Long	A_start	On	1	1607180610
MF0811	7	WIBO	J	NS_uns	16-7-2018 06:10:00	Long	A_start	On	1	1607180610
AZ0119	4	NABO	J	SCH	16-7-2018 06:10:00	Long	D_start	On	1	1607180610
BA8450	3	NABO	J	NS_scr	16-7-2018 06:10:00	Long	D_start	On	1	1607180610
KL1597	4	NABO	J	SCH	16-7-2018 06:10:00	Long	D_start	On	1	1607180610
HV6463	4	NABO	J	SCH	16-7-2018 06:10:00	Long	D_end	Off	-1	1607180610
EZY7975	4	NABO	J	SCH	16-7-2018 06:15:00	Long	D_start	On	1	1607180615
KL1791	4	NABO	J	SCH	16-7-2018 06:15:00	Long	D_start	On	1	1607180615
KL1001	4	NABO	J	NS_scr	16-7-2018 06:15:00	Long	D_start	On	1	1607180615
LLX5011	4	NABO	C	SCH	16-7-2018 06:15:00	Long	D_start	On	1	1607180615
AZ0111	4	NABO	J	SCH	16-7-2018 06:15:00	Long	D_start	On	1	1607180615
VY8318	4	NABO	J	SCH	16-7-2018 06:15:00	Long	D_start	On	1	1607180615
EZY7933	4	NABO	J	NS_uns	16-7-2018 06:15:00	Long	D_start	On	1	1607180615
HV6891	4	NABO	J	SCH	16-7-2018 06:15:00	Long	D_start	On	1	1607180615
HV0071	4	NABO	P	SCH	16-7-2018 06:15:00	Long	D_end	Off	-1	1607180615
HV1161	4	NABO	C	SCH	16-7-2018 06:15:00	Long	D_end	Off	-1	1607180615
HV6737	4	NABO	J	SCH	16-7-2018 06:15:00	Long	-	-	0	1607180615
HV5801	4	NABO	J	NS_uns	16-7-2018 06:15:00	Long	-	-	0	1607180615
HV6737	4	NABO	J	SCH	16-7-2018 06:15:00	Long	-	-	0	1607180615
HV5801	4	NABO	J	NS_uns	16-7-2018 06:15:00	Long	-	-	0	1607180615
KL0856	8	WIBO	J	NS_uns	16-7-2018 06:15:00	Long	T_in	On	1	1607180615
HV1520	4	NABO	C	NS_uns	16-7-2018 06:15:00	Long	T_out	Off	-1	1607180615
EK9743	8	WIBO	F	NS_uns	16-7-2018 06:20:00	Long	F_start	On	1	1607180620
EZY1354	4	NABO	J	SCH	16-7-2018 06:20:00	Long	D_start	On	1	1607180620
SK550	4	NABO	J	SCH	16-7-2018 06:20:00	Long	D_end	Off	-1	1607180620
HV5637	4	NABO	J	SCH	16-7-2018 06:20:00	Long	D_end	Off	-1	1607180620
HV6463	4	NABO	J	SCH	16-7-2018 06:20:00	Long	-	-	0	1607180620
HV6463	4	NABO	J	SCH	16-7-2018 06:20:00	Long	-	-	0	1607180620

Figure 5.1: Excel-excerpt showing all stand movements at Schiphol from 6:10 to 6:20 on 16 July 2018

Furthermore, the subscript ’start’ or ’end’ in the ’Operation’-column denotes whether it is the start of the stand movement or the end, respectively. In the ’Operation’-column, ’A’ denotes an arrival and ’D’ a departure as part of a long or medium turnaround that will respectively be succeeded and preceded by a tow, whereas ’B’ denotes a short turnaround, which is not shown in this excerpt, however. Last, ’T_in’ denotes the start of a tow stand occupancy; whereas ’T_out’ denotes the end of it.

To illustrate the described flight movements with an example: a 737-800 scheduled passenger flight, denoted by flight type 'J', is a Non-Schengen screened flight at arrival. It arrives at 8:00 and departs at 11:10 as a Schengen flight. It thus has a turnaround of 190 minutes, which is indicated as a 'long' turnaround in this case: hence, the aircraft is eligible to be towed twice. Being a NABO aircraft, it will remain for 55 minutes at its arrival, Non-Schengen screened stand. Therefore, 'A_start' indicates an addition of '1' in the column corresponding to aircraft size 3 and to border control status NS_scr in the period of 8:00 until 8:55. At 8:55, the stand occupancy duration of the arrival stand has ended, at which point a subtraction of '1' takes place from this column, and the flight departs to a towing stand. As a tow movement will take 10 minutes, the aircraft will arrive at its intermediate stand at 9:05. At the point of this arrival time at the tow stand, indicated by 'T_in', the column corresponding to size 3 and to 'Tow' stands gets an addition of '1'. As it needs to be taken into account that this flight needs to arrive 65 minutes at its departure stand, prior to departure at 11:10, the size 3 'Tow' column keeps the '+1' until 9:55. At that time, 'T_out' takes place, after which the '1' is subtracted from this column again. 10 Minutes later, at 10:05, 'D_start' takes place and the column corresponding to size 3 and to Schengen gets a '+1' until 11:10, indicating 'D_end', after which it is subtracted again.

An excerpt of the actual cumulative list is given in Figure 5.2. From 6:10 to 6:20 on 16 July 2018, all stand movements are given for aircraft categories 3, 4, 7, and 8. All cumulatively listed stand movements for week 29 of 2018 are given in Appendix E. With the cumulative list, the demand for stand types is known. With these numbers, a rough estimate of allocation bottlenecks can be seen already: if the demand for a specific stand type equals or exceeds the number of currently available stands, there will probably be trouble in allocating the corresponding flights.

	3	3						4	4						7	7						8	8					
Timestamp	TOTAL	SCH	NS_scr	NS_uns	Tow	Cargo	Positioning	TOTAL	SCH	NS_scr	NS_uns	Tow	Cargo	Positioning	TOTAL	SCH	NS_scr	NS_uns	Tow	Cargo	Positioning	TOTAL	SCH	NS_scr	NS_uns	Tow	Cargo	Positioning
1607180610	9	8	1	0	0	0	0	32	26	3	1	2	0	1	9	0	5	2	2	0	0	4	0	1	2	0	1	0
1607180610	9	8	1	0	0	0	0	32	26	3	1	2	0	1	9	0	5	2	2	0	0	4	0	1	2	0	1	0
1607180610	9	8	1	0	0	0	0	32	26	3	1	2	0	1	9	0	5	2	2	0	0	4	0	1	2	0	1	0
1607180610	9	8	1	0	0	0	0	32	26	3	1	2	0	1	9	0	5	2	2	0	0	4	0	1	2	0	1	0
1607180610	9	8	1	0	0	0	0	32	26	3	1	2	0	1	9	0	5	2	2	0	0	4	0	1	2	0	1	0
1607180610	9	8	1	0	0	0	0	32	26	3	1	2	0	1	9	0	5	2	2	0	0	4	0	1	2	0	1	0
1607180610	9	8	1	0	0	0	0	32	26	3	1	2	0	1	10	0	5	3	2	0	0	4	0	1	2	0	1	0
1607180610	9	8	1	0	0	0	0	32	26	3	1	2	0	1	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180610	9	8	1	0	0	0	0	33	27	3	1	2	0	1	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180610	10	8	2	0	0	0	0	33	27	3	1	2	0	1	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180610	10	8	2	0	0	0	0	34	28	3	1	2	0	1	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180610	10	8	2	0	0	0	0	33	27	3	1	2	0	1	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180615	10	8	2	0	0	0	0	34	28	3	1	2	0	1	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180615	10	8	2	0	0	0	0	35	29	3	1	2	0	1	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180615	10	8	2	0	0	0	0	36	29	4	1	2	0	1	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180615	10	8	2	0	0	0	0	37	30	4	1	2	0	1	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180615	10	8	2	0	0	0	0	38	31	4	1	2	0	1	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180615	10	8	2	0	0	0	0	39	32	4	1	2	0	1	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180615	10	8	2	0	0	0	0	40	32	4	2	2	0	1	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180615	10	8	2	0	0	0	0	41	33	4	2	2	0	1	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180615	10	8	2	0	0	0	0	40	32	4	2	2	0	0	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180615	10	8	2	0	0	0	0	39	31	4	2	2	0	0	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180615	10	8	2	0	0	0	0	39	31	4	2	2	0	0	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180615	10	8	2	0	0	0	0	39	31	4	2	2	0	0	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180615	10	8	2	0	0	0	0	39	31	4	2	2	0	0	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180615	10	8	2	0	0	0	0	39	31	4	2	2	0	0	11	0	5	4	2	0	0	4	0	1	2	0	1	0
1607180615	10	8	2	0	0	0	0	39	31	4	2	2	0	0	11	0	5	4	2	0	0	5	0	1	2	1	1	0
1607180615	10	8	2	0	0	0	0	38	31	4	2	1	0	0	11	0	5	4	2	0	0	5	0	1	2	1	1	0
1607180620	10	8	2	0	0	0	0	38	31	4	2	1	0	0	11	0	5	4	2	0	0	6	0	1	2	1	2	0
1607180620	10	8	2	0	0	0	0	39	32	4	2	1	0	0	11	0	5	4	2	0	0	6	0	1	2	1	2	0
1607180620	10	8	2	0	0	0	0	38	31	4	2	1	0	0	11	0	5	4	2	0	0	6	0	1	2	1	2	0
1607180620	10	8	2	0	0	0	0	37	30	4	2	1	0	0	11	0	5	4	2	0	0	6	0	1	2	1	2	0
1607180620	10	8	2	0	0	0	0	37	30	4	2	1	0	0	11	0	5	4	2	0	0	6	0	1	2	1	2	0
1607180620	10	8	2	0	0	0	0	37	30	4	2	1	0	0	11	0	5	4	2	0	0	6	0	1	2	1	2	0

Figure 5.2: Excel-excerpt showing the cumulative stand demand at Schiphol from 6:10 to 6:20 on 16 July 2018

However, in this demand analysis, no buffer time has yet been taken into account. In order to show the impact of increasing buffer times, an additional cumulative stand demand is calculated for buffer times of 5, 10, 15, and 20 minutes. These times are implemented subtracting the buffer times from the stand arrival time and adding them to the stand departure time in case of 'short' turnarounds. For 'long' and 'medium' arrivals, the buffer times are only subtracted and added respectively to the initial arrival and final departure of the flight. For intermediate tows, a buffer time of 5 minutes is used, as stated in Section 3.3. This means that 5 minutes are added to the tow stand arrival time and subtracted from the tow stand departure time. In practice, this means that the initial arrival and the final departure stand are occupied 5 five minutes longer, in addition to the specified buffer time of 5, 10, 15, or 20 minutes.

To conclude this section, the example of the 737-800 scheduled passenger aircraft is given again, now with an added buffer time of 20 minutes. As the flight arrives at 8:00 and departs at 11:10, the arrival stand will now be occupied from 7:40, which it will remain for a duration of the specified buffer time of 20 minutes, 55 minutes of arrival occupancy time for NABO aircraft, and a towing buffer time of 5 minutes. At 9:00, the flight will be towed away, after which it will arrive at the tow stand at 9:10. It will remain there until 9:50. As the flight departs at 11:10, the final departure stand is occupied from 10:00 until 11:30, covering the towing buffer time, 65 minutes of departure occupancy time for NABO aircraft, and the specified buffer time. The results would be similar to the ones shown in Figure 5.2, but with a longer stand occupancy. An increase in stand demand would be the result.

5.1.2. Overview of flight schedule analysis results

With the set-up described in Subsection 5.1.1, the corresponding flight schedule analysis results are presented in this section. Before going into detail with regard to the demand versus the capacity, static numbers with regard to the flight schedule are presented first. From the ’B Tactical’ module from the BEONTRA Scenario Planning tool, it is depicted in a breakdown schedule what the most used aircraft type is, as well as the airline performing the most movements, and the most popular destination. These schedules are given in Appendix E. In week 29, the aircraft types that are used most are the Boeing 737-800 with winglets, used in 2,247 flight movements; the Embraer 190, used in 1,362 flight movements; and the Airbus A320, used in 1,095 flight movements. The airlines with the most flight movements are KLM with 4,992; Transavia with 948; and easyJet with 716. The most popular flight destinations are Heathrow with 252 movements; Munich with 182 flight movements; and Manchester with 176 movements.

More important for allocation purposes and to gain a better understanding of the demand, is to present numbers representing the aircraft size categories, the flight types, and the border control statuses. Table 5.1 shows that the total number of flight movements in week 29 is 10,727, with Monday 16 July being the busiest day with 1,573 flight movements, and Saturday 21 July being the quietest with 1,413 flight movements. 96.5% Of the total flight movements in the schedule is performed as a passenger flight, of which 56.5% are Schengen flights, 27.7% are Non-Schengen screened flights, and 15.8% are Non-Schengen unscreened flights (respectively 54.5%, 27.8%, and 15.2% of the total flight number). 3.4% Of the total flight movements in the schedule is performed as a cargo flight, and less than 0.1% of the total flight movements in the schedule is performed as a positioning flight. 8,807 Movements, or 82.1% of the total, are carried out by NABO aircraft; 1,915 movements, or 17.1% of the total; are carried out by WIBO aircraft. As traffic at airports is usually expressed in Wake Turbulence Category (WTC) numbers, additional information is given in Table 5.1 on numbers of light (L), medium (M), heavy (H), and superheavy (S) aircraft that are handled at Schiphol in week 29.

Table 5.1: Informative numbers on time slot allocation schedule week 29, 2018

Date	**Flight movements [-]**	**Flight type**					**Category**													
		J and C [-]			**P [-]**	**F [-]**	**NABO [-]**				**WIBO [-]**					**WTC [-]**			
		SCH	*NS_scr*	*NS_uns*			*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*L*	*M*	*H*	*S*
16-7	1,573	848	443	230	1	51	2	2	424	865	9	23	139	93	16	2	1,291	274	6
17-7	1,536	821	421	247	2	45	4	2	418	850	10	23	139	82	8	2	1,272	256	6
18-7	1,538	839	416	226	0	57	4	0	426	837	10	22	130	97	12	2	1,265	265	6
19-7	1,560	857	426	218	0	59	2	2	420	861	6	28	136	94	11	2	1,283	269	6
20-7	1,569	840	432	243	3	51	0	2	422	874	5	28	132	91	15	0	1,298	265	6
21-7	1,413	786	343	232	1	51	0	0	378	764	11	20	131	91	18	0	1,142	265	6
22-7	1,533	850	395	234	0	54	0	2	396	850	9	27	142	93	14	0	1,248	279	6
TOTAL	**10,722**	**5,841**	**2,876**	**1,630**	**7**	**368**	**12**	**10**	**2,884**	**5,901**	**60**	**171**	**949**	**641**	**94**	**8**	**8,799**	**1,873**	**42**

Regarding the flight movement density for different buffer times, the results are obtained using the set-up as described in Subsection 5.1.1. The total stand demand for passenger flights on both contact and (remote) tow stands for Monday 16 July 2018, is given in Figure 5.3. In this figure, several peaks can be seen in the stand demand over time. This is a characteristic wave structure for hub-and-spoke networks, where WIBO flights are fed by passengers from arrived NABO flights, and WIBO flight passengers are further distributed to their destinations by NABO flights.

When looking at the results for NABO passenger stand requirements for Monday 16 July 2018 in Figure 5.4, and for WIBO passenger stand requirements in Figure 5.5, it can be distinguished that NABO passenger flights have several peaks. These peaks are repeated throughout week 29 around the same times. The peaks are seen around 6:00, 9:00, 12:00, 14:00, 16:00, and 20:00. WIBO flights, on the other hand, have one strongly distinguished peak from 7:00 to 13:00, after which the demand gradually decreases. With regard to the total passenger flight movements throughout the day in Figure 5.3, the largest peak in flight movements is present at 9:00, corresponding to what is stated in Section 4.1.1 and shown by Figure 4.2.

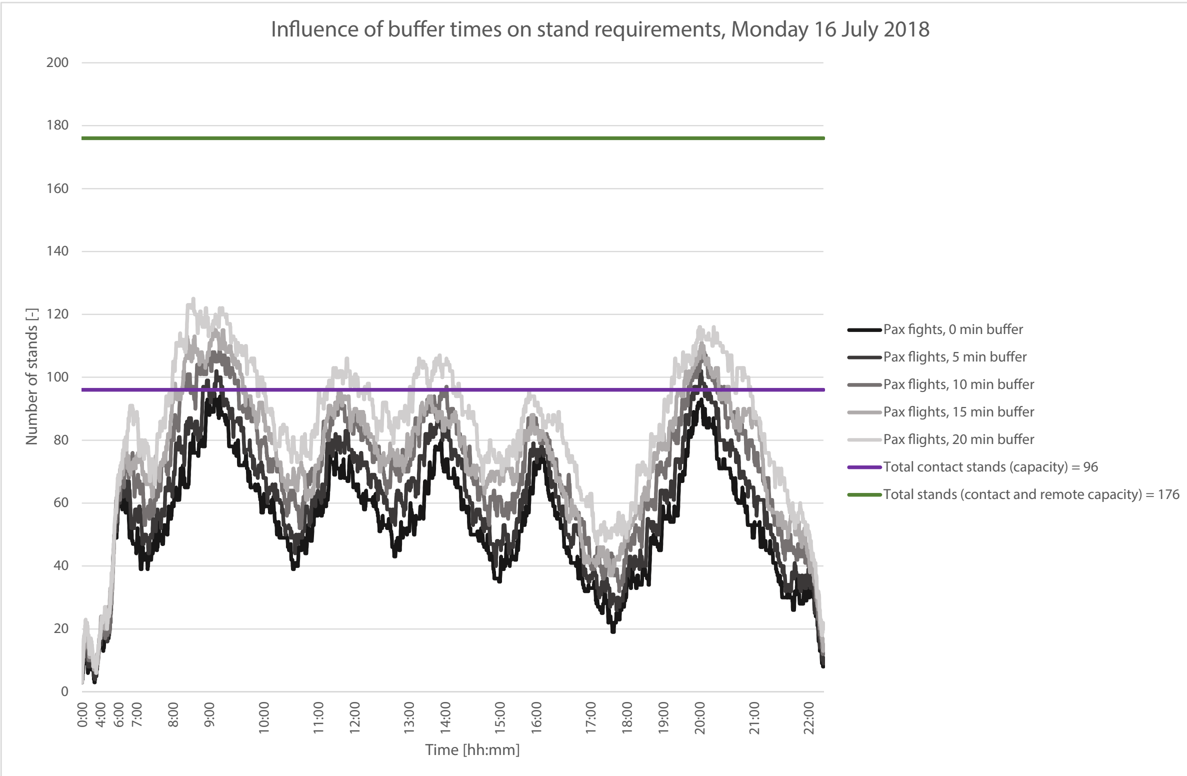

Figure 5.3: Total passenger stand demand on Monday 16 July 2018 with regard to stand capacity

In the three figures, the influence of buffer times can be seen. In Figure 5.4, Figure 5.5, and Figure 5.3, the stand demand is plotted for a buffer time of 0 minutes, illustrated with a dark-coloured graph; 5, 10, and 15 minutes; and 20 minutes, illustrated with a light-coloured graph. With an increasing buffer time, the graph colour becomes lighter and shows an increase in stand demand.

It can be seen in Figure 5.4 that it is impossible to handle all NABO flights at corresponding NABO contact stands alone during peak periods. When including NABO remote stands, however, there would be no capacity issues with regard to the stand demand, except for the evening peak: here, it can be seen that the demand approaches and even overshoots the total NABO stand capacity around 20:00. In case of low WIBO demand, however, WIBO stands can be considered for allocation to NABO flights as well. In that case, the demand would not exceed the capacity in this case.

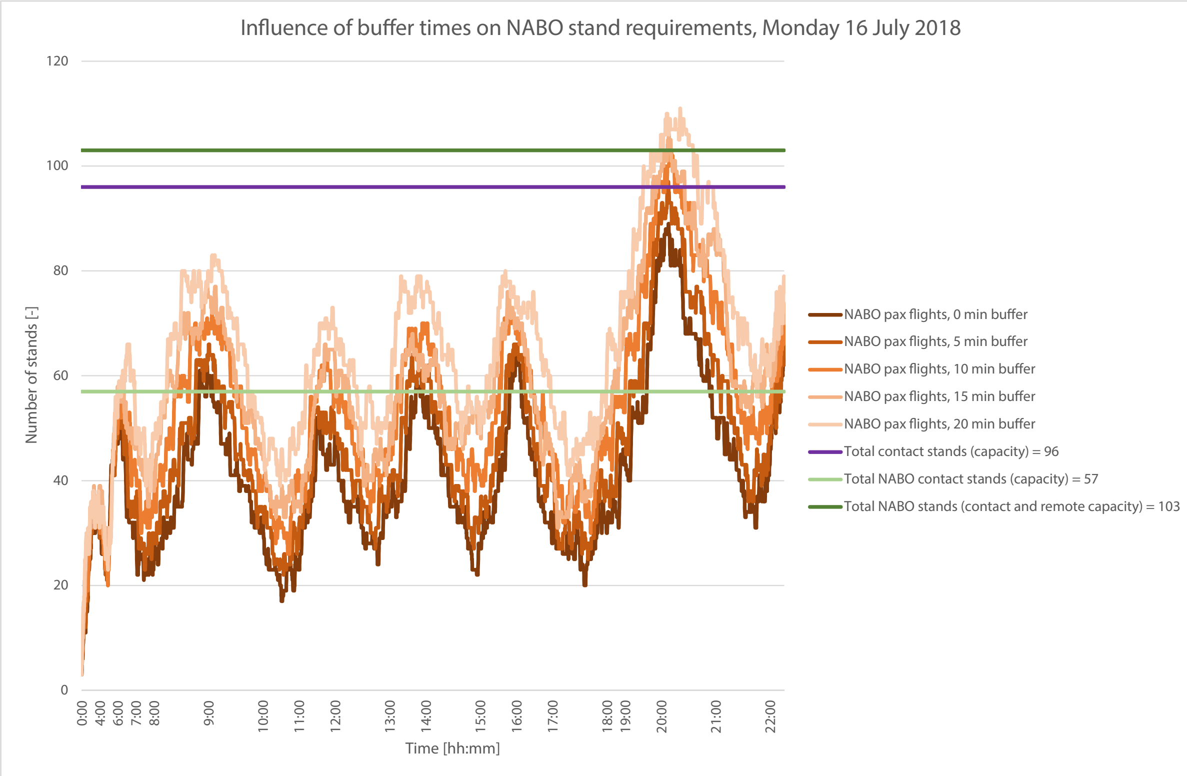

Figure 5.4: NABO Passenger stand demand on Monday 16 July 2018 with regard to stand capacity

It can be seen in Figure 5.5 that from 7:00 to 14:00, there is a capacity shortage in WIBO contact stands. The demand does not exceed the total number of WIBO stands available, both contact and remote, however. Still, as most WIBO flights need to be handled at a contact stand, as specified both in RASAS [3] and in the business rules, this causes a problem when allocation rules and preferences are taken into account.

As described in the previous paragraph, assumptions have been made regarding the stand capacity. First, it is not taken into account with what facilities the aircraft stands are equipped and what the business rules are. Shown is the total number of contact and tow stands required to handle the flight numbers, but no preferences are taken into account regarding contact or remote handling. Ways in which taxiing and push-back are performed are not taken into account, which would otherwise narrow down allocation combinations of flights to certain stands even more. This is not taken into account in the flight schedule analysis, nor in the model configuration, however.

Furthermore, when considering the total number of stands with similar features, the difficulty arises of excluding or combining stands with overlapping specifications. Every stand at Schiphol is able to handle an aircraft of one of the nine size categories as specified in Table 3.1; is assigned to passenger flights and/or other flight types; can handle one or more border control statuses; and is either a contact or a remote stand. If a remote passenger stand of size category 1 is considered, it has little overlapping specifications. One could still argue, however, that this stand could be counted twice if one would want to represent the total number of stands that are able of handling Schengen flights, as well as represent the total number of stands capable of handling Non-Schengen screened flights.

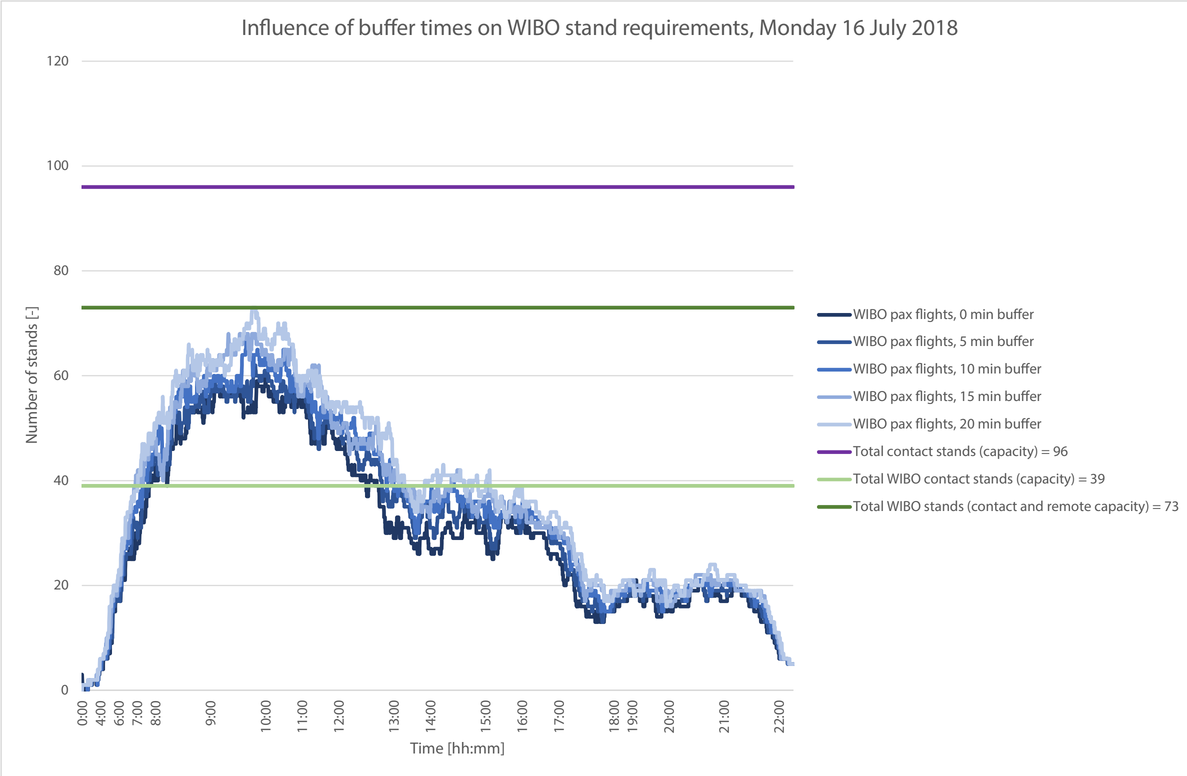

Figure 5.5: WIBO Passenger stand demand on Monday 16 July 2018 with regard to stand capacity

A remote stand is able to handle all border control statuses, as any required security check would only take place at a matching bussed gate; therefore, one could include it in the total number of Schengen as well as in Non-Schengen stands. If a swing stand of category 7 is considered, however, the stand can handle both Schengen and Non-Schengen stands of category 3 up to 7 (category 1 and 2 are handled at apron A and B). If the total number of Schengen stands is counted, as well as the total number of Non-Schengen stands, this stand will also appear twice. The same is the case when the total number of NABO stands is counted, as well as the total number of WIBO stands: 'up to category 7' falls into both NABO and WIBO category.

Another remark can be made on the fact that the aircraft size categories are grouped together as NABO and WIBO aircraft. Where NABO flights primarily consist of category 4 aircraft, the total NABO stand number includes apron A and B, on which the maximum size category is category 3. Furthermore, not all WIBO stands are able to handle a category 8 aircraft, let alone an Airbus A380.

Another problem that arises in using remote stands for passenger flights, is that it requires a bussed gate to be available. If all bussed gates would be occupied, an aircraft would have to wait, possibly increasing its turnaround time and, subsequently, its stand occupation times. The bussed gate capacity is not taken into account here. Furthermore, remote handling of passenger flights is not possible at night between 23:00 and 06:00, as no shuttle bus service is available: contact handling is the only option then.

Another difficulty appears when considering blocked gates: e.g., for MARS stands that can handle up to category 9 aircraft, but block adjacent gates when serving a category 8 or category 9 aircraft. In that case, one could consider these two stands as two NABO stands; as one WIBO stand; or even as one stand capable of hosting both a WIBO aircraft of a smaller category, as well as one NABO stand. One last ambiguity lies in the usage of the R apron: stands of this apron can be used both for passenger flights, as well as for positioning and cargo flights. When considering the total stand number of both passenger and cargo stands, the ten stands of apron R are included in the count of both.

Most important is that business rules and preferences are not taken into account when showing the demand with regard to the capacity. As mentioned with regard to WIBO aircraft, these aircraft are to be handled at a contact stand. Remote stands capable of handling WIBO aircraft should only be used for intermediate parking; not for passenger handling. If the same demands are issued for certain NABO aircraft or by airlines during a peak period, capacity shortage will be the result, as there are too few contact stands. If allocation preferences are taken into account where only a few stands are considered an option for allocation, allocation possibilities are narrowed down even more.

In conclusion, regarding the analysis of the flight schedule, the demand, or the number of aircraft at the ground in a certain category, is plotted against the capacity, or the total number of stands in that category. In doing so, the reproduction of the capacity is not entirely realistic, as plotting the demand of NABO passenger flights against the capacity of NABO passenger stands does not take into account that possibilities might be narrowed down even more, such as by allocation preferences. Possibilities might be widened as well, such as by the consideration of WIBO stands for NABO flight allocation. However, when plotting the demand of WIBO passenger flights against the capacity of WIBO passenger stands, this would mean that fewer stands would be available for WIBO flights. Potentially present capacity issues are presented in more realistic detail in the model results in Section 5.2.

5.2. Output analysis of BEONTRA Stand and Gate Allocation schedules

With the configuration of the SGA model of Amsterdam Airport Schiphol described in Chapter 4, and the time slot allocation schedule that serves as model input analysed in Section 5.1, the allocation optimisation can take place. This section covers an overview on the model results. Information is obtained by performing Excel analyses on the allocation schedules. The allocation calculation runs are performed using different buffer times for regular airlines: 0, 5, 10, 15, and 20 minutes. For low-cost airlines, a fixed buffer time of 10 minutes is used. As can be seen in Figure 5.3 up to 5.5 in Subsection 5.1.2, an increased buffer time can cause a higher stand demand. Therefore, the allocation model results are evaluated in Subsection 5.2.1 up to 5.2.5, respectively covering the results for a buffer time of 0 up to a buffer time of 20 minutes.

Before continuing to the results, a few remarks are made about the allocation calculation in this chapter. The allocation calculations in the SGA feature of the BEONTRA Scenario Planning tool can be done in a quick manner, taking roughly 10 minutes in calculation time; in a default manner, taking roughly up to 45 minutes; or in an exhaustive manner, taking roughly up to 90 minutes. The default calculation time is used to obtain results, as it is the middle ground, and as the amount of time necessary is within acceptable bounds. Furthermore, the results discussed are based on flight movements as scheduled on Monday 16 July 2018.

Last, it needs to be mentioned that the outcome produced by the BEONTRA Scenario Planning tool is a Gantt chart or an Excel file. The Gantt chart shows which flight is allocated to what gate and what stand for what amount of time. It gives a clear visual understanding of the duration that flights are assigned to stands. An example excerpt from the allocation Gantt chart with a buffer time of 0 minutes for Monday 16 July 2018 is given in Figure 5.6. A part of the stands of pier D; buffer D; pier E; buffer E; pier F; and a part of pier G are shown for the time period 1:00 up to 7:00. In this Gantt chart, the defined groups in 'Group Editor' of the BEONTRA Scenario Planning tool can be used as filters to search for flights allocated within a specific group. The defined groups can be found in Section 4.2. For example, filtering using the 'Border control status'-group, it can be seen that pier B and pier C, which should only contain Schengen flights, indeed only get Schengen flights assigned.

The Excel file shows what flight is assigned to what gate and what stand, showing start and end times of the occupation of both gate and stand; and shows per flight if, when, and to where it is towed away. As the Gantt charts cannot be exported, only the allocation Excel sheets are shown in Appendix F. The number of arrivals and departures in these schedules equals 1,726 instead of the flight movement number of 1,573: this difference of 153 movements is caused by the fact that arrivals on 15 July that are linked to departures scheduled on 16 July, as well as departures on 17 July that are linked to arrivals scheduled on 16 July, are taken into account.

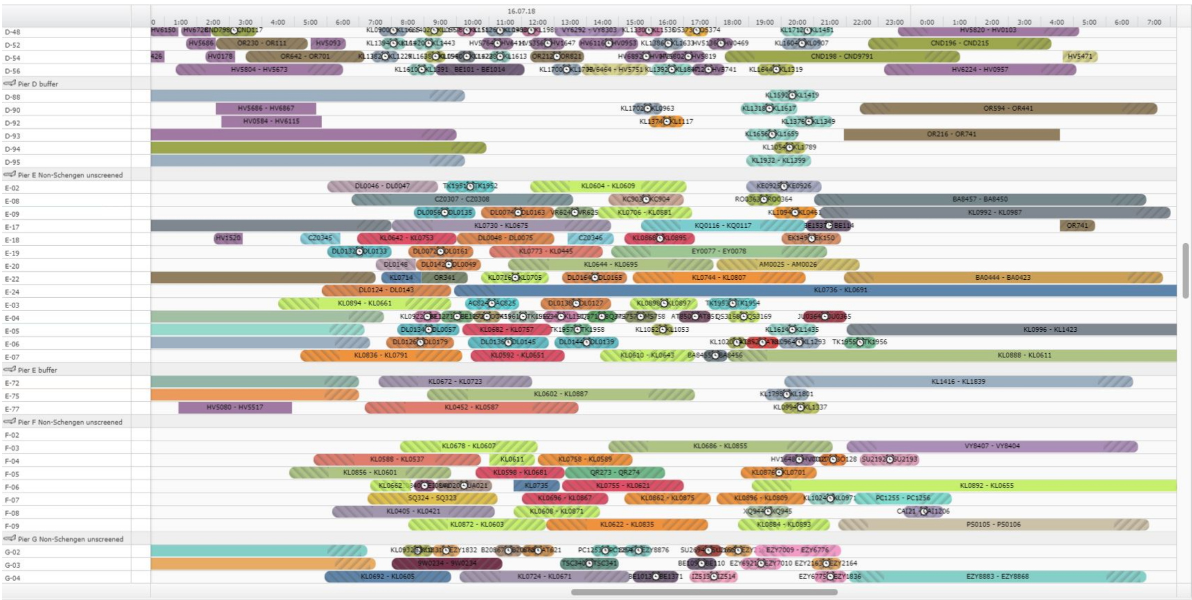

Figure 5.6: Example excerpt from allocation Gantt chart for Monday 16 July 2018, with a buffer time of 0 minutes, produced by SGA feature of BEONTRA Scenario Planning tool

5.2.1. Model results for a buffer time of 0 minutes

With regard to the allocation calculation with a buffer time of 0 minutes, the result is an allocation with 0 unallocated flights. As the SGA feature of the BEONTRA Scenario Planning tool only considers flights consisting of an arrival and a departure movement, all flight movements in the flight schedule without both movements get the missing arrival or departure movement assigned on the preceding or subsequent day. For the results discussion, only flight movements that take place on Monday 16 July 2018 are taken into account. Hence, 1,573 flight movements in total are considered and 153 flight movements are ignored.

In Table 5.3, the utilisation per stand area is given for Monday 16 July 2018. As can be seen, pier H is used most intensively with 75.0%, followed closely by the G buffer with 72.3% and pier C with 66.6%. Per time a stand area is used on average, it can be seen that for the piers, the times are shortest with a minimum of 47.9 minutes for pier C, 54.3 minutes for pier D, and 61.5 minutes for pier B. For the aprons, the times are longest with a maximum of 500.0 minutes at apron U, 357.9 minutes at apron R, and 284.1 minutes at buffer G. This is as expected, as long turnarounds are towed away for long parking periods to remote stands. Furthermore, the stand areas that are used most often are the piers. Pier D leads the way with the 542 times it is used, followed by pier C with 280 and pier B with 188 times. The total stand utilisation time is 129,518 minutes, or 2,158.6 hours. The utilisation times in hours are also visualised per stand area in Figure 5.7.

From the numbers regarding passenger handling as presented in Table 5.2, it can be seen that 50.1% of the allocated flights is an arrival movement, and that 49.9% is a departure movement. 2.0% Of the flights is towed. 3.3% Of the flight movements is of a non-passenger class, and 96.7% is of a passenger one. Regarding these passenger flight movements, 91.3% is handled at a contact stand, and 8.7% is handled at a remote stand.

Table 5.2: Allocation details for an increasing buffer time on Monday 16 July 2018

	Integers					**Percentages**					
Buffer Time:	**0**	**5**	**10**	**15**	**20**	**0**	**5**	**10**	**15**	**20**	
Unallocated:	0	18	45	79	121	0.0	1.1	2.9	5.0	7.7	of on 16 July scheduled movements
Allocated:	1,573	1,555	1,528	1,494	1,452	100.0	98.9	97.1	95.0	92.3	of on 16 July scheduled movements
Arrivals:	788	780	766	749	729	50.1	50.2	50.1	50.1	50.2	of allocated movements
Departures:	785	775	762	745	723	49.9	49.8	49.9	49.9	49.8	of allocated movements
Tows:	31	45	63	53	65	2.0	2.9	4.1	3.5	4.5	of allocated movements
Non-pax movements:	52	52	52	52	51	3.3	3.3	3.4	3.5	3.5	of allocated movements
Pax movements:	1,521	1,503	1,476	1,442	1,401	96.7	96.7	96.6	96.5	96.5	of allocated movements
Pax NABO:	1,290	1,282	1,269	1,247	1,226	84.8	85.3	86.0	86.5	90.4	of allocated pax movements
Pax WIBO:	231	221	197	195	175	15.2	14.7	14.0	13.5	12.5	of allocated pax movements
Pier handled pax a/c:	1,389	1,329	1,279	1,273	1,222	91.3	88.4	86.7	88.3	87.2	of allocated pax movements
Pier handled pax NABO:	1,199	1,145	1,106	1,107	1,072	92.9	89.3	87.2	88.8	87.4	of allocated pax NABO
Pier handled pax WIBO:	190	184	173	166	150	82.5	83.3	87.8	85.1	85.7	of allocated pax WIBO
Remotely handled pax a/c:	132	174	197	169	179	8.7	11.6	13.3	11.7	12.8	of allocated pax movements
NABO:	91	137	163	140	154	7.1	10.7	12.8	11.2	12.6	of allocated pax NABO
WIBO:	41	37	34	29	25	17.7	16.7	17.3	14.9	14.3	of allocated pax WIBO

Table 5.3: Stand utilisation for BT=0 on Monday 16 July 2018

Stand area	**Times Used [-]**	**Number of stands on apron/pier [-]**	**Total Utilisation [min]**	**Utilisation in 24 hours [%]**	**Avg utilisation time per 'Times Used' [min]**
ALFA APRON	18	11	1470	9.3	81.7
BRAVO APRON	7	21	870	2.9	124.3
BRAVO PIER	188	13	11570	61.8	61.5
CHARLIE PIER	280	14	13419	66.6	47.9
DELTA PIER	542	33	29434	61.9	54.3
DELTA RAMP	24	6	5020	58.1	209.2
ECHO PIER	132	14	11480	56.9	87.0
ECHO RAMP	17	3	2220	51.4	130.6
FOXTROT PIER	57	8	6070	52.7	106.5
GOLF PIER	82	8	6785	58.9	82.7
GOLF RAMP	11	3	3125	72.3	284.1
HOTEL PIER	108	7	7555	75.0	70.0
JULIET RAMP	30	8	4995	43.4	166.5
KILO APRON	0	32	0	0.0	0.0
LIMA RAMP	0	3	0	0.0	0.0
MIKE RAMP	0	14	0	0.0	0.0
NOVEMBER RAMP	0	2	0	0.0	0.0
PAPA HOLDING	0	10	0	0.0	0.0
PAPA PLATFORM	15	8	3650	31.7	243.3
ROMEO CARGO APRON	24	10	8590	59.7	357.9
SIERRA CARGO APRON	41	11	9675	61.1	236.0
UNIFORM RAMP	4	5	2000	27.8	500.0
YANKEE RAMP	10	3	1590	36.8	159.0

5.2.2. Model results for a buffer time of 5 minutes

With regard to the allocation calculation with a buffer time of 5 minutes, the result is an allocation with 18 unallocated flights. In Table 5.4, the utilisation per stand area is given for Monday 16 July 2018. As can be seen, pier H is used most intensively with 74.2%, followed closely by pier C with 69.7% and pier D with 66.0%. Per time a stand area is used on average, it can be seen that the times are shortest with a minimum of 53.8 minutes for pier C, 61.3 minutes for pier D, and 62.5 minutes for apron B. The times are longest with a maximum of 484.2 minutes at apron U, 253.6 minutes at apron Y, and 235.7 minutes at apron R. This is as expected, as long turnarounds are towed away to long-parking positions. Furthermore, the stand areas that are used most often are the piers. Pier D leads the way with the 511 times it is used, followed by pier C with 261 and pier B with 174 times. The total stand utilisation time is 133,383 minutes, or 2,223.1 hours. The utilisation times in hours are also visualised per stand area in Figure 5.7.

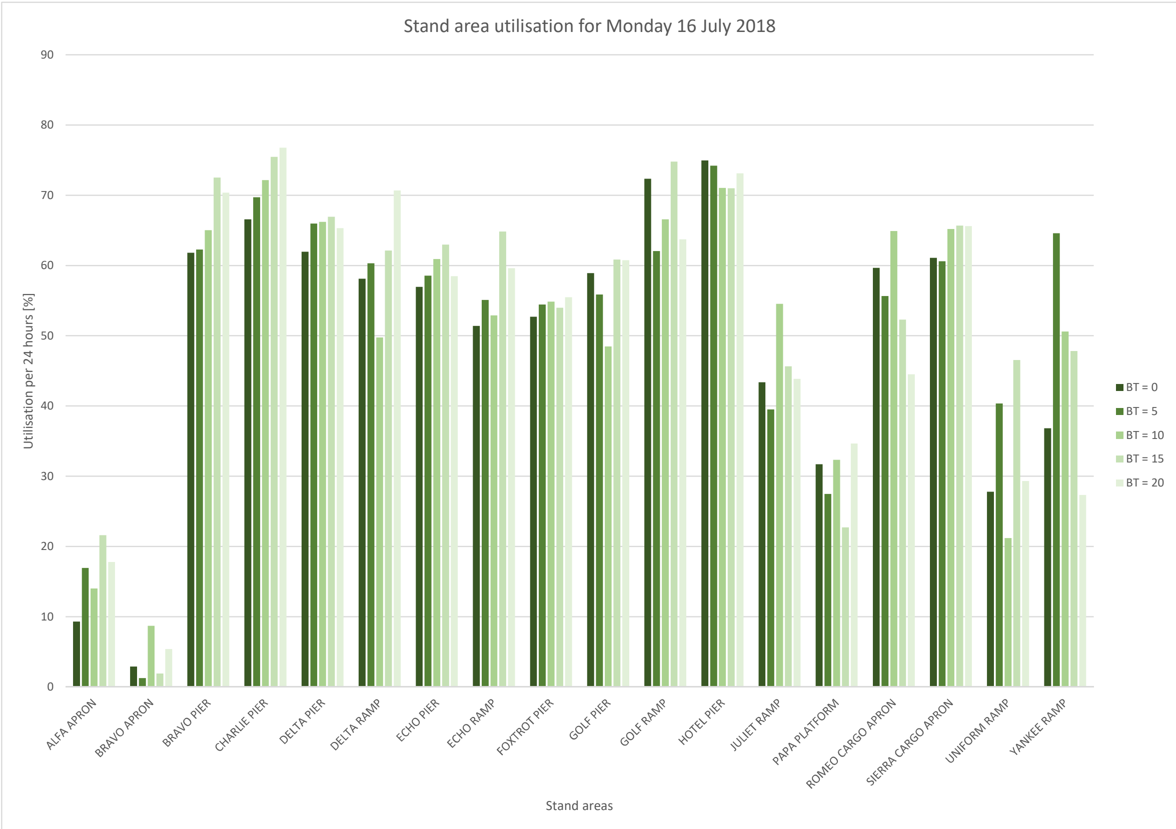

Figure 5.7: Stand area utilisation as a percentage per day of Monday 16 July 2018 for buffer times of 0, 5, 10, 15, and 20 minutes

From the numbers regarding passenger handling as presented in Table 5.2, it can be seen that 50.2% of the allocated flights is an arrival movement, and that 49.8% is a departure movement. 2.9% Of the flights is towed. 3.3% Of the flight movements is of a non-passenger class, and 96.7% is of a passenger one. Regarding these passenger flight movements, 88.4% is handled at a contact stand, and 11.6% is handled at a remote stand. With regard to the schedule with a buffer time of 0 minutes, it can be seen that fewer movements are allocated, and fewer flight movements of the allocated ones are pier handled.

The unallocated flights for a buffer time of 5 minutes, as shown in the corresponding allocation chart, are given in Figure 5.8. The arrivals and departures for these flights are scheduled around 19:00 and 20:00. In Section 5.1.2, it is stated that the largest peak in the wave structure for NABO flights is from approximately 18:00 to 21:00. As the highest stand demand is visible from 19:00 to 20:00, as shown by Figure 5.4, it is not entirely unexpected that the first unallocated NABO flights occur around these times.

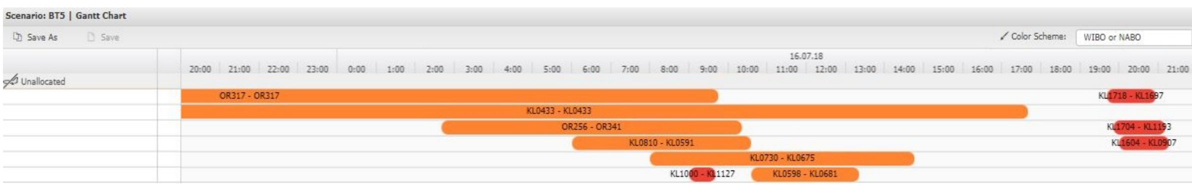

Figure 5.8: Excerpt regarding unallocated flights from allocation Gantt chart for Monday 16 July 2018, with a buffer time of 5 minutes, produced by SGA feature of BEONTRA Scenario Planning tool (WIBO flights being orange; NABO flights being red)

Table 5.4: Stand utilisation for BT=5 on Monday 16 July 2018

Stand area	Times Used [-]	Number of stands on apron/pier [-]	Total Utilisation [min]	Utilisation in 24 hours [%]	Avg utilisation time per 'Times Used' [min]
ALFA APRON	27	11	2680	16.9	99.3
BRAVO APRON	6	21	375	1.2	62.5
BRAVO PIER	174	13	11655	62.3	67.0
CHARLIE PIER	261	14	14050	69.7	53.8
DELTA PIER	511	33	31346	66.0	61.3
DELTA RAMP	38	6	5211	60.3	137.1
ECHO PIER	134	14	11801	58.5	88.1
ECHO RAMP	20	3	2380	55.1	119.0
FOXTROT PIER	71	8	6270	54.4	88.3
GOLF PIER	71	8	6435	55.9	90.6
GOLF RAMP	14	3	2680	62.0	191.4
HOTEL PIER	108	7	7480	74.2	69.3
JULIET RAMP	30	8	4550	39.5	151.7
KILO APRON	0	32	0	0.0	0.0
LIMA RAMP	0	3	0	0.0	0.0
MIKE RAMP	0	14	0	0.0	0.0
NOVEMBER RAMP	0	2	0	0.0	0.0
PAPA HOLDING	0	10	0	0.0	0.0
PAPA PLATFORM	21	8	3165	27.5	150.7
ROMEO CARGO APRON	34	10	8013	55.6	235.7
SIERRA CARGO APRON	44	11	9597	60.6	218.1
UNIFORM RAMP	6	5	2905	40.3	484.2
YANKEE RAMP	11	3	2790	64.6	253.6

5.2.3. Model results for a buffer time of 10 minutes

With regard to the allocation calculation with a buffer time of 10 minutes, the result is an allocation with 45 unallocated flights. In Table 5.5, the utilisation per stand area is given for Monday 16 July 2018. As can be seen, pier C is used most intensively with 72.1%, followed closely by pier H with 71.0% and pier D with 66.5%. With the buffer times now being equal for both low-cost as well as regular airlines, it can be seen that pier H is now one of the most intensively used piers. Per time a stand area is used on average, it can be seen that for the piers, the times are shortest with a minimum of 54.1 minutes for pier C, 59.4 minutes for pier H, and 64.5 minutes for pier D. For the aprons, the times are longest with a maximum of 467.3 minutes at apron R, 305.0 minutes at apron Y, and 299.2 minutes at apron J. This is as expected, as long turnarounds are towed away for long parking periods to remote stands. Furthermore, the stand areas that are used most often are the piers. Pier D leads the way with the 482 times it is used, followed by pier C with 245 and pier B with 178 times. The total stand utilisation time is 137,208 minutes, or 2,286.8 hours. The utilisation times in hours are also visualised per stand area in Figure 5.7.

From the numbers regarding passenger handling as presented in Table 5.2, it can be seen that 50.1% of the allocated flights is an arrival movement, and that 49.9% is a departure movement. 4.1% Of the flights is towed. 3.4% Of the flight movements is of a non-passenger class, and 96.6% is of a passenger one. Regarding these passenger flight movements, 86.7% is handled at a contact stand, and 13.3% is handled at a remote stand. With regard to schedules with a buffer time less than 10 minutes, it can be seen that fewer movements are allocated, and fewer flight movements of the allocated ones are pier handled.

The unallocated flights for a buffer time of 10 minutes, as shown in the corresponding allocation chart, are given in Figure 5.9. WIBO Flights are given in orange, NABO flights are given in red. It can be seen that most unallocated WIBO flights are scheduled from approximately 5:00 to 14:00 and that most unallocated NABO flights are scheduled around 19:00 and 20:00. In Section 5.1.2, it is stated that the peak in WIBO flights occurs from approximately 7:00 to 14:00, and the largest peak in NABO flights is from approximately 18:00 to 21:00. As the corresponding stand demand is highest during peak hours, as shown by Figure 5.4 and 5.5, it is not entirely unexpected that the unallocated WIBO flights occur in the morning and that the unallocated NABO flights occur around 19:00 and 20:00. Due to the high demand in WIBO stands in the morning, it is not entirely unexpected that two NABO flights cannot be assigned between 8:00 and 10:00: free WIBO stands could be used by NABO flights otherwise.

Figure 5.9: Excerpt regarding unallocated flights from allocation Gantt chart for Monday 16 July 2018, with a buffer time of 10 minutes, produced by SGA feature of BEONTRA Scenario Planning tool (WIBO flights being orange; NABO flights being red)

Table 5.5: Stand utilisation for BT=10 on Monday 16 July 2018

Stand area	Times Used [-]	Number of stands on apron/pier [-]	Total Utilisation [min]	Utilisation in 24 hours [%]	Avg utilisation time per 'Times Used' [min]
ALFA APRON	41	11	2220	14.0	54.1
BRAVO APRON	24	21	2630	8.7	109.6
BRAVO PIER	178	13	12171	65.0	68.4
CHARLIE PIER	245	14	14543	72.1	59.4
DELTA PIER	482	33	31463	66.2	65.3
DELTA RAMP	42	6	4297	49.7	102.3
ECHO PIER	128	14	12278	60.9	95.9
ECHO RAMP	20	3	2285	52.9	114.3
FOXTROT PIER	73	8	6318	54.8	86.5
GOLF PIER	69	8	5583	48.5	80.9
GOLF RAMP	22	3	2875	66.6	130.7
HOTEL PIER	111	7	7160	71.0	64.5
JULIET RAMP	21	8	6283	54.5	299.2
KILO APRON	0	32	0	0.0	0.0
LIMA RAMP	0	3	0	0.0	0.0
MIKE RAMP	0	14	0	0.0	0.0
NOVEMBER RAMP	0	2	0	0.0	0.0
PAPA HOLDING	0	10	0	0.0	0.0
PAPA PLATFORM	25	8	3722	32.3	148.9
ROMEO CARGO APRON	20	10	9345	64.9	467.3
SIERRA CARGO APRON	52	11	10325	65.2	198.6
UNIFORM RAMP	5	5	1525	21.2	305.0
YANKEE RAMP	11	3	2185	50.6	198.6

5.2.4. Model results for a buffer time of 15 minutes

With regard to the allocation calculation with a buffer time of 15 minutes, the result is an allocation with 121 unallocated flights. In Table 5.6, the utilisation per stand area is given for Monday 16 July 2018. As can be seen, pier C is used most intensively with 75.5%, followed closely by the G buffer with 74.8% and pier B with 72.5%. Per time a stand area is used on average, it can be seen that the times are shortest with a minimum of 57.0 minutes for apron B, 64.5 minutes for pier H, and 66.1 minutes for pier C. The times are longest with a maximum of 558.3 minutes at apron U, 313.8 minutes at apron R, and 295.0 minutes at apron Y. This is as expected, as long turnarounds are towed away for long parking periods to remote stands. Furthermore, the stand areas that are used most often are the piers. Pier D leads the way with the 480 times it is used, followed by pier C with 230 and pier B with 181 times. The total stand utilisation time is 140,258 minutes, or 2,337.6 hours. The utilisation times in hours are also visualised per stand area in Figure 5.7.

From the numbers regarding passenger handling as presented in Table 5.2, it can be seen that 50.1% of the allocated flights is an arrival movement, and that 49.9% is a departure movement. 3.5% Of the flights is towed. 3.5% Of the flight movements is of a non-passenger class, and 96.5% is of a passenger one. Regarding these passenger flight movements, 88.3% is handled at a contact stand, and 11.7% is handled at a remote stand. With regard to schedules with a buffer time less than 15 minutes, it can be seen that fewer movements are allocated, and fewer flight movements of the allocated ones are pier handled.

The unallocated flights for a buffer time of 15 minutes, as shown in the corresponding allocation chart, are given in Figure 5.10. WIBO Flights are given in orange, NABO flights are given in red. It can be seen that most unallocated WIBO flights are scheduled between 7:00 to 14:00 and that most unallocated NABO flights are scheduled around 19:00 and 20:00. In Section 5.1.2, it is stated that the peak in WIBO flights occurs from approximately 7:00 to 14:00, and the largest peak in NABO flights is from approximately 18:00 to 21:00. As the corresponding stand demand is highest during peak hours, as shown by Figure 5.4 and 5.5, it is not entirely unexpected that the unallocated WIBO flights occur in the morning and that the unallocated NABO flights occur around 19:00 and 20:00. Due to the high demand in WIBO stands in the morning, it is not entirely unexpected that some NABO flights cannot be assigned between 7:00 and 14:00: free WIBO stands could be used by NABO flights otherwise.

Figure 5.10: Excerpt regarding unallocated flights from allocation Gantt chart for Monday 16 July 2018, with a buffer time of 15 minutes, produced by SGA feature of BEONTRA Scenario Planning tool (WIBO flights being orange; NABO flights being red)

Table 5.6: Stand utilisation for BT=15 on Monday 16 July 2018

Stand area	Times Used [-]	Number of stands on apron/pier [-]	Total Utilisation [min]	Utilisation in 24 hours [%]	Avg utilisation time per 'Times Used' [min]
ALFA APRON	40	11	3420	21.6	85.5
BRAVO APRON	10	21	570	1.9	57.0
BRAVO PIER	181	13	13571	72.5	75.0
CHARLIE PIER	230	14	15213	75.5	66.1
DELTA PIER	480	33	31799	66.9	66.2
DELTA RAMP	42	6	5366	62.1	127.8
ECHO PIER	131	14	12694	63.0	96.9
ECHO RAMP	18	3	2800	64.8	155.6
FOXTROT PIER	67	8	6217	54.0	92.8
GOLF PIER	78	8	7007	60.8	89.8
GOLF RAMP	18	3	3230	74.8	179.4
HOTEL PIER	111	7	7155	71.0	64.5
JULIET RAMP	28	8	5256	45.6	187.7
KILO APRON	0	32	0	0.0	0.0
LIMA RAMP	0	3	0	0.0	0.0
MIKE RAMP	0	14	0	0.0	0.0
NOVEMBER RAMP	0	2	0	0.0	0.0
PAPA HOLDING	0	10	0	0.0	0.0
PAPA PLATFORM	11	8	2615	22.7	237.7
ROMEO CARGO APRON	24	10	7530	52.3	313.8
SIERRA CARGO APRON	48	11	10400	65.7	216.7
UNIFORM RAMP	6	5	3350	46.5	558.3
YANKEE RAMP	7	3	2065	47.8	295.0

5.2.5. Model results for a buffer time of 20 minutes

With regard to the allocation calculation with a buffer time of 20 minutes, the result is an allocation with 121 unallocated flights. In Table 5.7, the utilisation per stand area is given for Monday 16 July 2018. As can be seen, pier C is used most intensively with 76.8%, followed closely by pier H with 73.1% and buffer D with 70.7%. Per time a stand area is used on average, it can be seen that the times are shortest with a minimum of 65.8 minutes for pier H, 68.7 minutes for apron A, and 69.1 minutes for pier C. The times are longest with a maximum of 527.5 minutes at apron U, 267.0 minutes at apron R, and 236.1 minutes at apron S. This is as expected, as long turnarounds are towed away for long parking periods to remote stands. Furthermore, the stand areas that are used most often are the piers. Pier D leads the way with the 436 times it is used, followed by pier C with 224 and pier B with 166 times. The total stand utilisation time is 137,222 minutes, or 2,287.0 hours. The utilisation times in hours are also visualised per stand area in Figure 5.7.

From the numbers regarding passenger handling as presented in Table 5.2, it can be seen that 50.2% of the allocated flights is an arrival movement, and that 49.8% is a departure movement. 4.5% Of the flights is towed. 3.5% Of the flight movements is of a non-passenger class, and 96.5% is of a passenger one. Regarding these passenger flight movements, 87.2% is handled at a contact stand, and 12.8% is handled at a remote stand. With regard to schedules with a buffer time less than 20 minutes, it can be seen that fewer movements are allocated, and fewer flight movements of the allocated ones are pier handled.

The unallocated flights for a buffer time of 20 minutes, as shown in the corresponding allocation chart, are given in Figure 5.11. WIBO Flights are given in orange, NABO flights are given in red. It can be seen that most unallocated WIBO flights are scheduled between 7:00 to 14:00 and that most unallocated NABO flights are scheduled around 19:00 and 20:00. In Section 5.1.2, it is stated that the peak in WIBO flights occurs from approximately 7:00 to 14:00, and the largest peak in NABO flights is from approximately 18:00 to 21:00. As the corresponding stand demand is highest during peak hours, as shown by Figure 5.4 and 5.5, it is not entirely unexpected that the unallocated WIBO flights occur in the morning and that the unallocated NABO flights occur around 19:00 and 20:00. Due to the high demand in WIBO stands in the morning, it is not entirely unexpected that some NABO flights cannot be assigned between 7:00 and 14:00: free WIBO stands could be used by NABO flights otherwise.

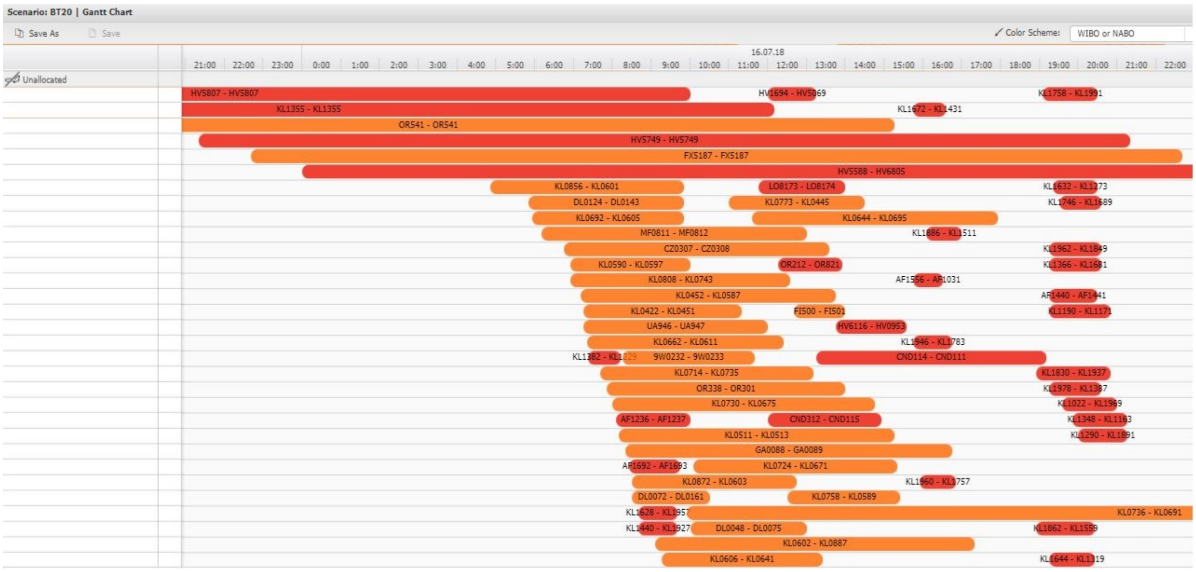

Figure 5.11: Excerpt regarding unallocated flights from allocation Gantt chart for Monday 16 July 2018, with a buffer time of 20 minutes, produced by SGA feature of BEONTRA Scenario Planning tool (WIBO flights being orange; NABO flights being red)

In conclusion, the number of unallocated flights increases with an increasing buffer time. This can also be seen in Figure 5.12. It has to be noted that the y-axis of this figure skips to 60%. Unallocations regarding WIBO flights happen around and mostly during the morning peak from 7:00 to 14:00; unallocations regarding NABO flights happen around and mostly during the evening peak, between 19:00 and 20:00. From the flight schedule analysis in Section 5.1, it has been concluded that there are bottlenecks in capacity during these times. The allocation calculations show how these bottlenecks gain impact with an increasing buffer time. As expected, the total stand utilisation increases as well with an increasing buffer time. Furthermore, the Pier Service Level (PSL) decreases, as more aircraft are handled remotely.

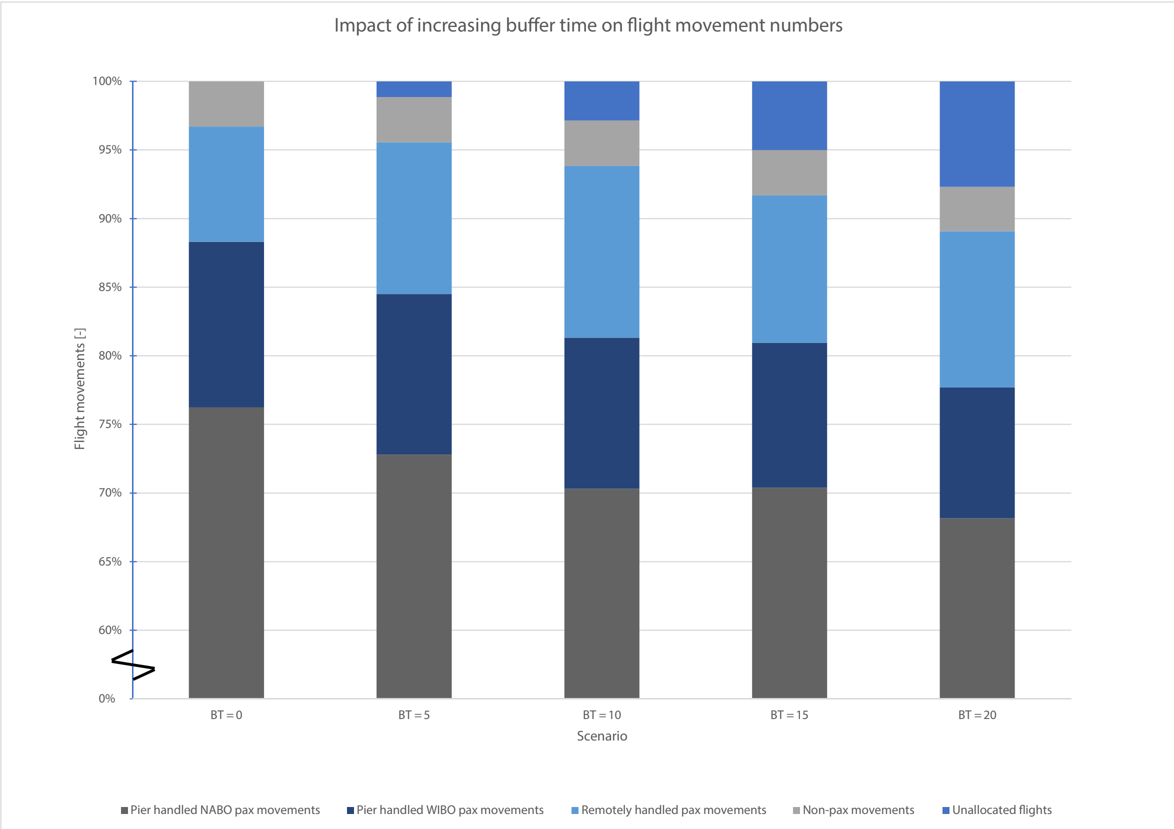

Figure 5.12: The impact of an increasing buffer time on the number of allocations and the number of pier handled movements

Table 5.7: Stand utilisation for BT=20 on Monday 16 July 2018

Stand area	Times Used [-]	Number of stands on apron/pier [-]	Total Utilisation [min]	Utilisation in 24 hours [%]	Avg utilisation time per 'Times Used' [min]
ALFA APRON	41	11	2815	17.8	68.7
BRAVO APRON	12	21	1625	5.4	135.4
BRAVO PIER	166	13	13171	70.4	79.3
CHARLIE PIER	224	14	15477	76.8	69.1
DELTA PIER	436	33	31033	65.3	71.2
DELTA RAMP	46	6	6105	70.7	132.7
ECHO PIER	131	14	11785	58.5	90.0
ECHO RAMP	19	3	2575	59.6	135.5
FOXTROT PIER	77	8	6390	55.5	83.0
GOLF PIER	82	8	6996	60.7	85.3
GOLF RAMP	23	3	2752	63.7	119.7
HOTEL PIER	112	7	7370	73.1	65.8
JULIET RAMP	27	8	5050	43.8	187.0
KILO APRON	0	32	0	0.0	0.0
LIMA RAMP	0	3	0	0.0	0.0
MIKE RAMP	0	14	0	0.0	0.0
NOVEMBER RAMP	0	2	0	0.0	0.0
PAPA HOLDING	0	10	0	0.0	0.0
PAPA PLATFORM	18	8	3990	34.6	221.7
ROMEO CARGO APRON	24	10	6408	44.5	267.0
SIERRA CARGO APRON	44	11	10390	65.6	236.1
UNIFORM RAMP	4	5	2110	29.3	527.5
YANKEE RAMP	8	3	1180	27.3	147.5

6 Configuration of individually optimised buffer times

Flights at an international hub airport arrive and depart in waves. This generates peak hours, at which the stand capacity is reached at times or even exceeded. As discussed in Chapter 5, the stand demand reaches or even exceeds the WIBO stand capacity during the morning peak from 7:00 to 14:00, and reaches or exceeds the NABO stand capacity during the evening peak from 19:00 to 20:00. During these peak hours, it is, therefore, preferable to keep buffer times to a minimum in order to allocate a larger number of flights. During off-peak hours, however, this objective is less pressing. At Schiphol, the theoretical buffer time of 20 minutes is often manually adapted already during peak hours. It can be concluded that a buffer time that varies during the day is preferable to a set time of 20 minutes in order to optimise stand capacity.

Furthermore, delays or early arrivals of specific flights can be predicted using documented delays and earliness. Some flights are known to arrive early due to downwind flight routes; some airlines are known to arrive late due to their tight schedule, in which there is little room for unforeseen alterations. This can be used to optimise buffer times even more and to make an allocation schedule more robust. In this chapter, it is described how individually optimised buffer times are established, based on documented delay data on flights in the summer period of 2017. The number of documented arrival and departure movements is 307,332, of which 307,092 flights are passenger flights: as 0.1% of these flights are non-passenger flights, their data is included in the buffer time determination calculations. The flight delay data is given in Appendix G.

Two buffer time scenarios are generated using these data. The first, scenario 1, is based on time period, aircraft size, and border control status only. The second, scenario 2 is a hybrid one, based on time period, flight route, and airline for frequent flights; but on scenario 1 for less frequent flights. In other words: if there are more than 500 flights documented for which the flight route, the airline, and the time period match, then a buffer time is established for this group of matching flight route, airline and time period, based on the delay data of the corresponding flights. If there are less than 500 flights documented for which the flight route, the airline, and the time period match, then a buffer time from scenario 1 is used, based on time period, aircraft size, and border control status. In this chapter, first, some assumptions regarding the scenario definitions are given in Section 6.1. Next, the definitions of the buffer times for scenario 1 and scenario 2 are respectively given in Section 6.2 and Section 6.3.

6.1. Buffer time optimisation assumptions

For the establishment of the buffer times, some assumptions and simplifications are made to make the corresponding model implementations and adaptations manageable. First, low-cost airlines are excluded from optimal buffer times: these times are set at the prescribed 10 minutes, as these flights do not interfere with other flights and do not experience unallocated flights in the allocation schedules, being the result of the initial model that is discussed in Chapter 5. Second, arrival and departure buffer times are evaluated separately. Third, there are four time periods: from 0:00 up to 5:59, from 6:00 up to 10:59, from 11:00 up to

17:29, and from 17:30 up to 23:59. This division is chosen in order to cover the rather quiet night time period from 0:00 up to 5:59, and the busiest hours in the morning from 6:00 up to 10:59. The rest of the day is divided into two time periods of 6.5 hours.

Furthermore, aircraft sizes are not divided into category size, but in WIBO and NABO. In order to establish a buffer time for scenario 1, it is assumed at least 50 flights should be documented in a specific group. If this is not the case, the buffer time is set to 20 minutes. This is done for the following groups:

- WIBO Schengen departures between 0:00 and 5:59;
- WIBO Non-Schengen screened departures between 0:00 and 5:59;
- WIBO Non-Schengen unscreened departures between 0:00 and 5:59;
- WIBO Schengen arrivals between 6:00 and 10:59;
- WIBO Non-Schengen screened arrivals between 17:30 and 23:59.

All established buffer times are rounded to the nearest multiple of five, and set at the number that covers respectively at least 60%, 70%, 80%, and 90% of the recorded flights in the empirical distribution of delay data in a specific group. An empirical distribution is used, as the delay data is not normally distributed: testing the data with an online Shapiro-Wilk test [55] proves this, as well as a look at the plotted distributions. The empirical delay distribution plots for scenario 1 show that they are skewed to the right, while a normal distribution is symmetrical.

This makes sense, as flights are more likely to arrive much later than the Scheduled Time of Arrival (STA) or depart much later than the Scheduled Time of Departure (STD). This is also illustrated by the distribution in Figure 6.3 and the cumulative distribution in Figure 6.2, in which 33,969 NABO Schengen arrivals are depicted. For this group of flights, it can be seen that most flights are on time. Still, a great deal of these flights is early, which can be absorbed with a fitting buffer time; and a greater deal is late, which can partly be absorbed by the stand occupancy time. Four subscenarios are now created, in which the buffer time is augmented in each subscenario in order to cover a larger percentage of documented flights.

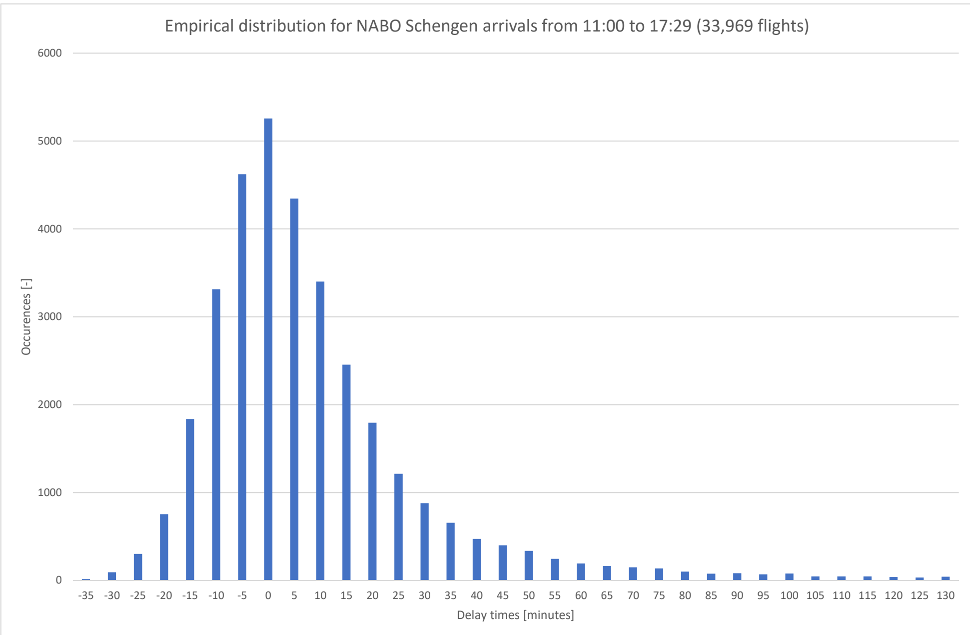

Figure 6.1: Empirical distribution for NABO Schengen arrivals from 11:00 to 17:29

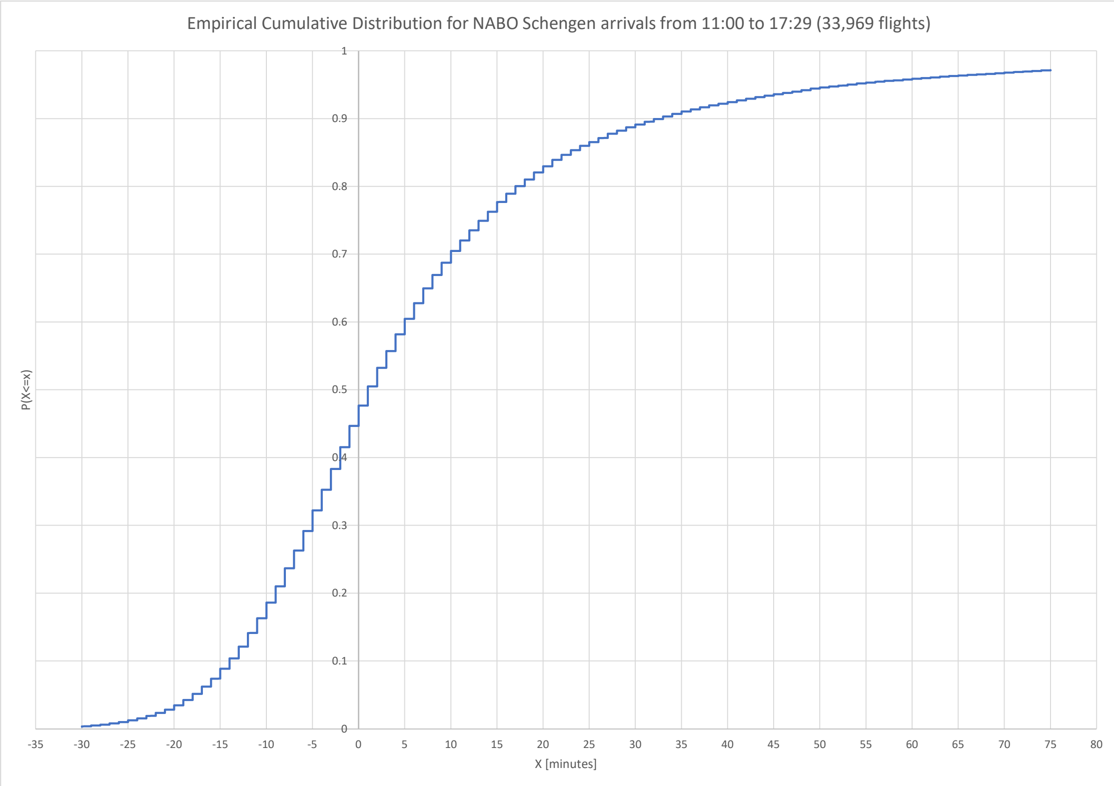

Figure 6.2: Empirical Cumulative Distribution for NABO Schengen arrivals from 11:00 to 17:29

In the preceding paragraph, it is stated that late arrival flights can be partly absorbed by the stand occupancy time. To illustrate this statement, a medium or long turnaround is considered. For example, if a NABO flight is to stay 75 minutes at one specific stand, a delay of 20 minutes would not be disastrous with regard to the stand occupancy time, and is likely to be absorbed. A delay of 60 minutes, however, would not provide enough time to proceed with all ground handling activities at that stand. A delay that jeopardises the turnaround activities or even surpasses the stand occupancy time requires reallocations in the SGA schedule.

It is assumed for this research, however, that when a flight arrives after the STA or departs before the STD, it is covered by the stand occupancy time. Even if a flight departs two hours after STA, it is considered covered. This assumption makes distributions independent. The last assumption is made with regard to negative buffer times: e.g. if for an arrival flight at least 60% of the flights is covered 10 minutes after STA, or if for a departure flight at least 70% of the flights is covered 5 minutes before STD, the buffer time is not set at a negative number, but at zero instead. A buffer time upper limit is not specified. Regarding the buffer times that are set to zero minutes: this is only the case for arrival flights. The corresponding groups are:

- NABO Non-Schengen screened between 0:00 and 5:59, covering 60% of the empirical distributed flights;
- WIBO Schengen between 0:00 and 5:59, covering 60% and 70% of the empirical distributed flights;
- WIBO Schengen between 11:00 and 17:29, covering 60% and 70% of the empirical distributed flights;
- KLM flights from Dublin between 11:00 and 17:29, covering 60% and 0% of the empirical distributed flights;
- Lufthansa flights from Frankfurt between 11:00 and 17:29, covering 60% and 0% of the empirical distributed flights;
- British Airways flights from London Heathrow between 11:00 and 17:29, covering 60% of the empirical distributed flights;
- KLM flights from Birmingham between 11:00 and 17:29, covering 60% of the empirical distributed flights;
- easyJet flights from London Gatwick between 17:30 and 23:59, covering 60% and 70% of the empirical distributed flights.

6.2. Scenario 1 set-up: buffer times depending on aircraft size, border control status and time period

Scenario 1 assigns an individual buffer time to groups based on arrival or departure movement; to one of four time blocks in which the arrival or departure is scheduled, being 0:00-5:59, 6:00-10:59, 11:00-17:29, or 17:30-23:59; to the aircraft size, being WIBO or NABO; and to one of the border control statuses, being Schengen, Non-Schengen screened, or Non-Schengen unscreened. In total, 48 groups are established, for which each a corresponding buffer time is to be determined. Using Excel, the recorded flights from the summer period of 2017 are each assigned to a corresponding group, based on their STA or STD, their aircraft type and their origin or destination airport. An excerpt of the input delay data from Appendix G, filtered for NABO Schengen arrivals between 0:00 and 5:59, is given in Appendix H. Here, all delays are assigned to a corresponding time interval, or 'bin', that is rounded to the nearest multiple of five.

The percentage of flights covered in each bin is used to determine an optimal buffer time. The bin up to which the sum of the total of bin percentages is at least 60%, 70%, 80%, or 90%, is the bin for which the corresponding interval is the buffer time to be used to cover the respective percentage of flight. For this, the sum is taken from the bin with the most delayed flights for arrivals, up to the bin in which the sum is at least the required percentage. This last bin then gives the corresponding buffer time. For departures, the sum is taken from the bin with the earliest departures, up to the bin that determines the buffer time. This is also depicted in Figure 6.3, in which the empirical distributions are used for both arrivals and departures for NABO Schengen from 6:00 to 10:59.

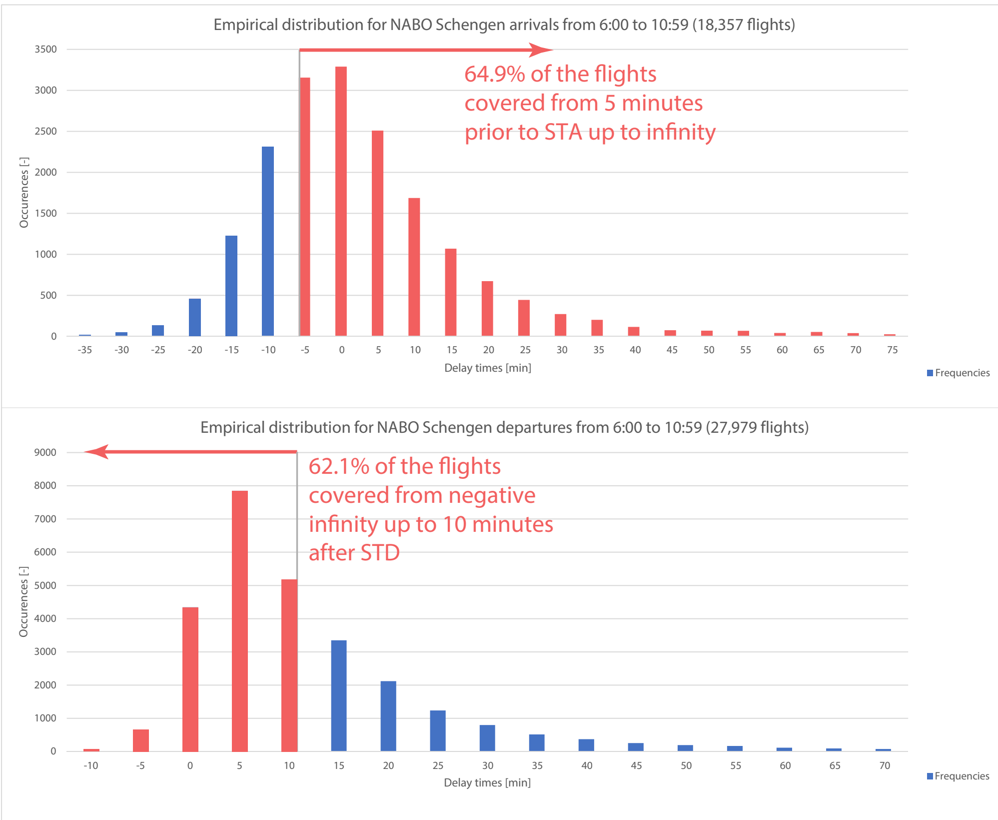

Figure 6.3: Visualisation of determination of a buffer time that covers at least 60% of recorded flights for an arrival group and a departure group

In Appendix I, the buffer times per group for scenario 1 are given, for which respectively at least 60%, 70%, 80%, and 90% of the recorded flights in the empirical distribution of delay data are covered. The frequencies of the buffer times that are used per scenario are also given in Figure 6.4. As expected, the buffer times during the night are relatively large, and for buffer times that cover a larger percentage of recorded flights are equal to or, more often, larger than the buffer times that cover a lower percentage. Five groups have a buffer time that is set at the prescribed 20 minutes, as for these groups less than 50 flights have been recorded. When there are less than 50 flights recorded, this means that for a specific group approximately less than two flights a week are recorded. For each subscenario, the mean, the median, and the mode of used buffer times are given in Table 6.1.

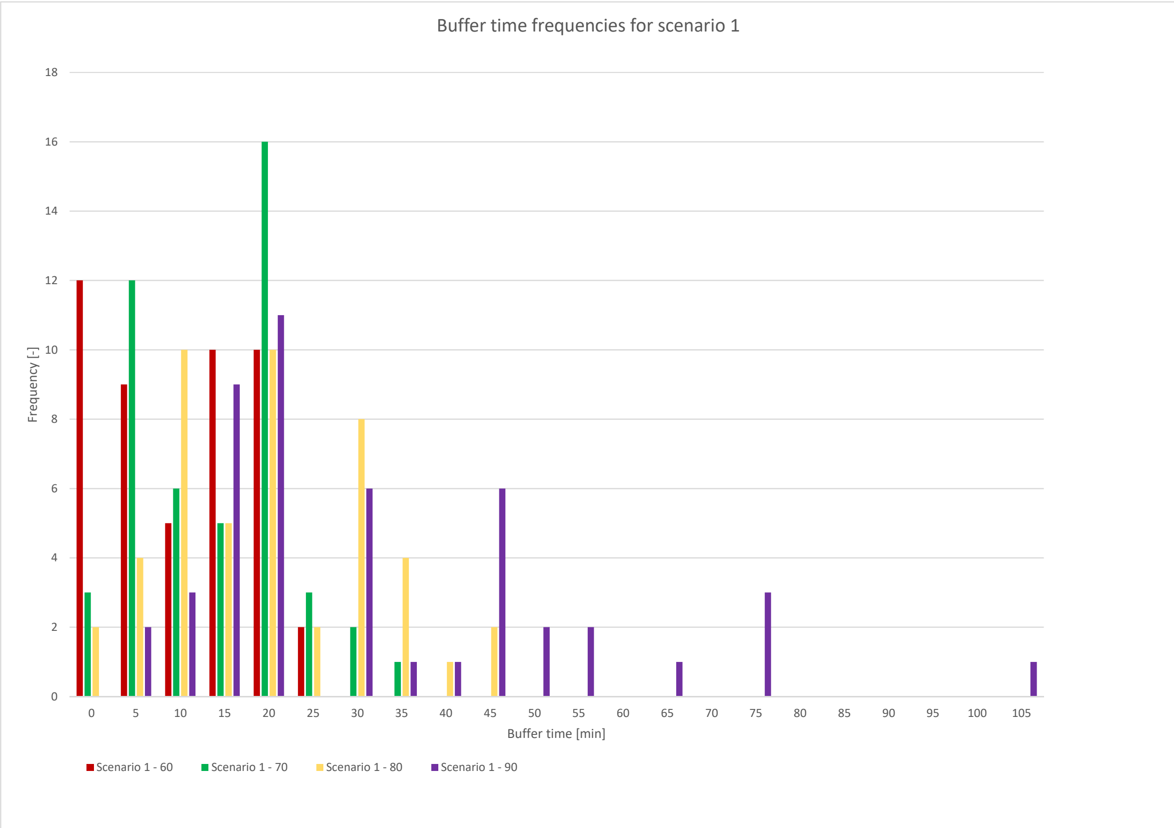

Figure 6.4: Frequencies of buffer times in scenario 1

Table 6.1: Mean, median and mode of buffer times as used in scenario 1

	Scenario 1			
	60	**70**	**80**	**90**
Mean	10.3	14.3	19.9	31.8
Median	10	15	20	20
Mode	0	20	10	20

As shown in Chapter 4, buffer times can be adapted in the 'Occupancy Times' configuration part. In order to implement the established buffer times in the SGA model, additional groups need to be defined first. With the Group Editor in the 'B Capacity' module of the BEONTRA Scenario Planning Tool, 26 groups are created. Two groups define low-cost flights for both WIBO and NABO. As per group in 'Occupancy Times' a buffer time can be defined for both arrival and departure, 24 groups are created to cover the buffer times of the 48 established groups regarding aircraft size, border control status, and time block.

As described in Chapter 4, for the occupancy times of both pier served and bussed stands, as well as for pier served gates, 55 minutes is used for NABO and 75 minutes is used for WIBO arrivals. For the occupancy times of both pier served and bussed stands, as well as for pier served gates, 65 minutes for NABO and 85 minutes for WIBO departures is used. The arrival and departure occupancy times for bussed gates are 20 minutes for NABO and 40 minutes for WIBO. For the low-cost flights, a buffer time of 10 minutes is used. Together with the established buffer times for this scenario, the Occupancy Times configuration exports for the subscenarios that cover at least 60%, 70%, 80%, and 90% of the recorded flights are given in Appendix I.

The allocation schedules for scenario 1 for buffer times that cover at least 60%, 70%, 80%, and 90% of the recorded flights are given in Appendix I. The number of unallocated flights for these allocation schedules is respectively 39, 56, 110, and 218. The increasing number of unallocated flights for a larger percentage of flight coverage is expected, as the buffer times increase respectively as well. The impact of the increasing buffer time in the subscenarios is also given in Figure 6.6. It has to be noted that the y-axis of this figure starts at 60%. As can be seen in Table 6.2, the total stand utilisation for the four scenarios is 2,206.5, 2,251.6, 2,336.5, and 2,317.3 hours, resulting in an average of 2,278.0 hours with a standard error of the mean of 30.0. The visualisation of the average stand utilisation per stand area is given in Figure 6.9: it can be seen that, in general, the contact stand areas have the highest utilisation ratios. If the stand utilisation per allocated movement is regarded, as shown in Figure 6.5, it can be seen that for an increasing buffer time, the stand utilisation increases. Here, with the stand utilisation, the time that a stand is occupied for a specific flight is meant: i.e. the buffer times are included.

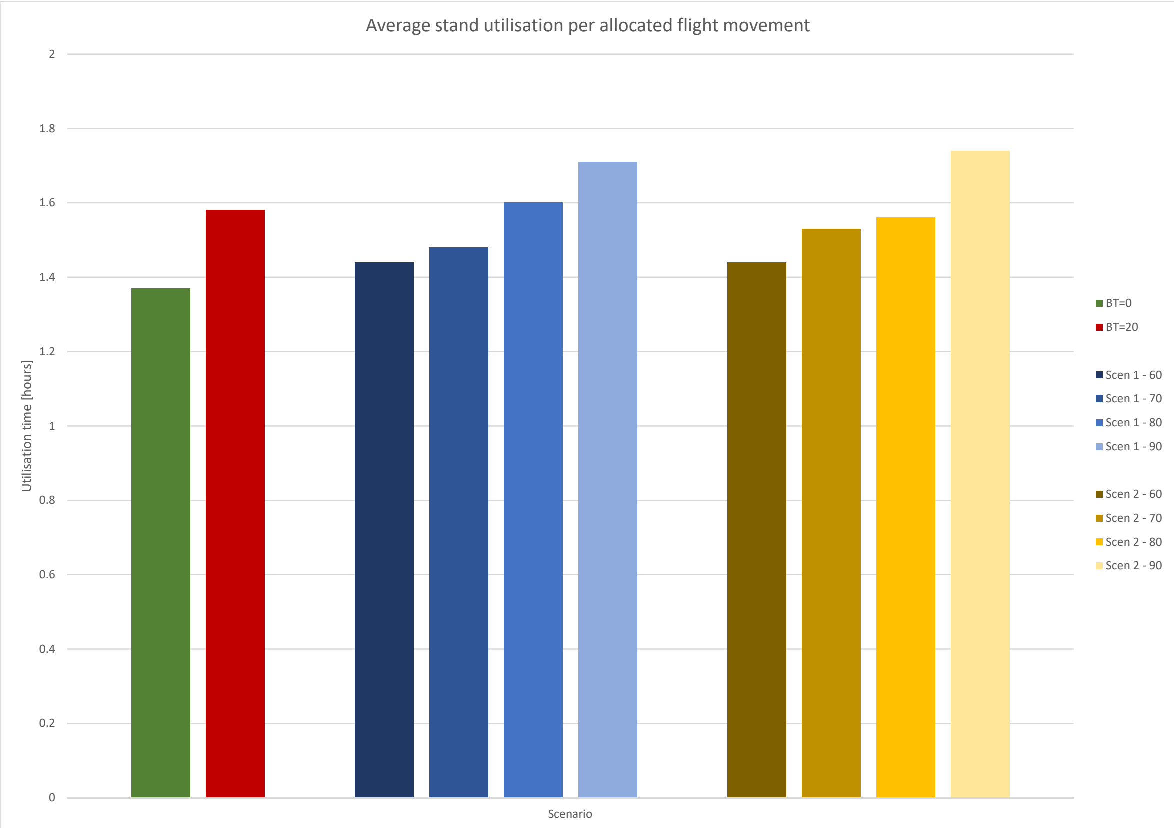

Figure 6.5: Average stand utilisation per allocated flight movement for all scenarios

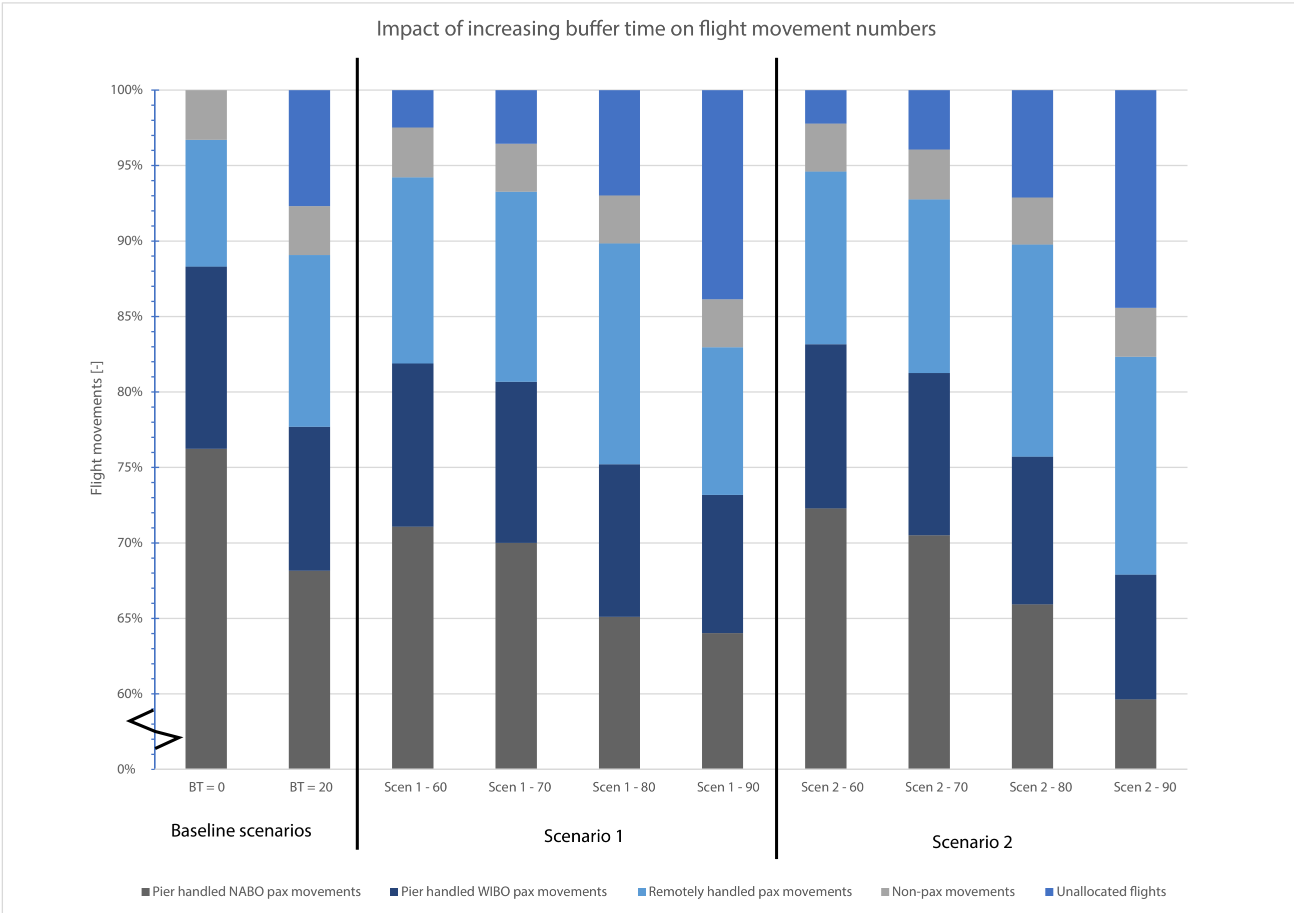

Figure 6.6: The impact of an increasing buffer time on the number of allocations and the number of pier handled movements

From the numbers regarding passenger handling as presented in Table 6.3, it can be seen that the ratio of allocated arrivals and departures approximately stays the same throughout scenario 1. It can be seen, as also visualised in Figure 6.7, that the towing percentage has an increasing trend for an increasing buffer time for both scenario 1 and 2. More towing means that contact stands can be used more intensively, but it also means that the probability of delays and corresponding congestions increases. This is due to the additional handlings, in which towing movements may block other flight movements in their operation. Also, tow truck numbers might be limited and waiting for one can also add up to the delay. Therefore, a higher towing percentage is not necessarily beneficial. Furthermore, it can be seen, as also visualised in Figure 6.8, that the PSL fluctuates with an increasing buffer time for both scenario 1 and 2: respectively 86.9%, 86.5%, 83.7%, and 88.2% of the flight movements are handled at a contact stand for scenario 1 - 60 up to scenario 1 - 90. Only the PSL of WIBO movements increases with an increasing buffer time.

6.3. Scenario 2 set-up: hybrid buffer times depending on frequent flight routes and on aircraft size, border control status and time period

As described in the introduction of this chapter, some flights are known to arrive early due to downwind flight routes. Furthermore, some airlines are known to arrive late due to their tight schedule, in which there is little room for unforeseen alterations. Therefore, another logical choice for buffer time optimisation is to link buffer times to a specific flight number. In this scenario, buffer times are assigned to groups based on arrival or departure movement; to one of four time blocks in which the arrival or departure is scheduled, being 0:00-5:59, 6:00-10:59, 11:00-17:29, or 17:30-23:59; to an origin or destination; and to an airline.

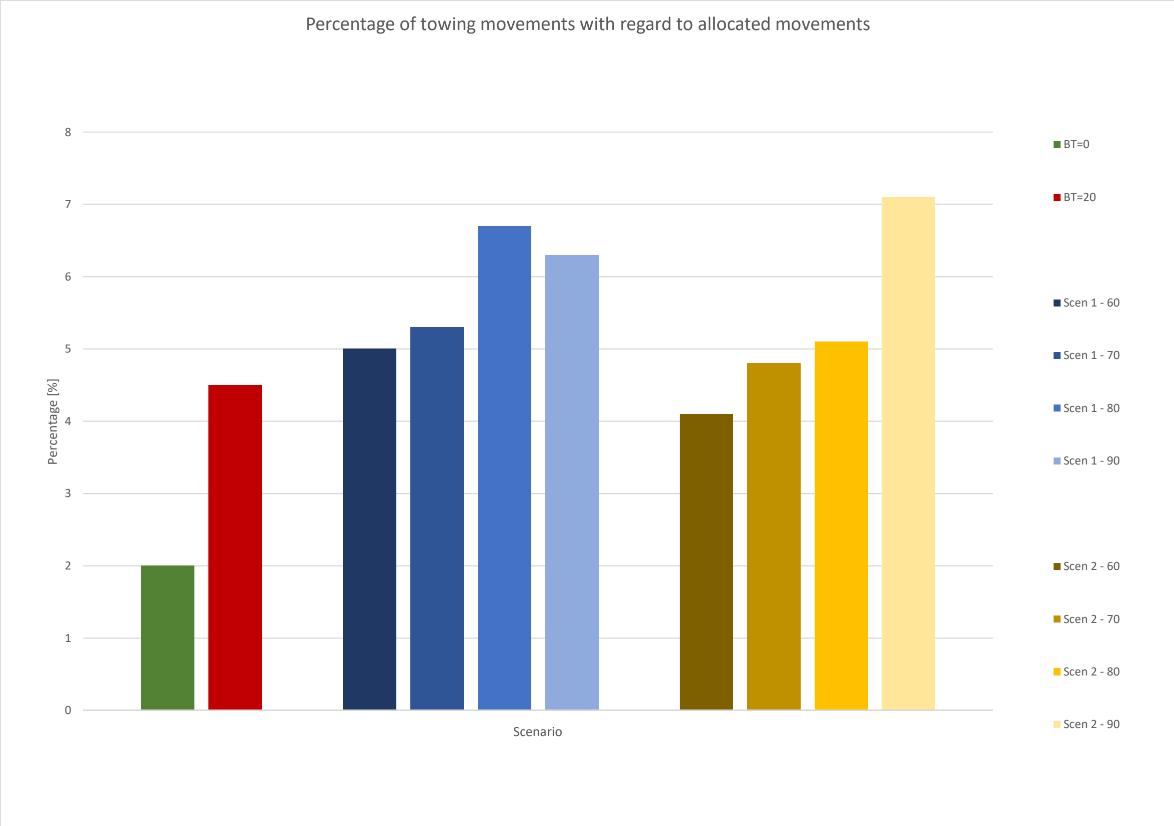

Figure 6.7: Percentage of tows with regard to allocated flight movements

Table 6.2: Stand utilisation hours for Scenario 1 on Monday 16 July 2018

Stand area	**Number of stands [-]**	**Scen 1 - 60 [min]**	**Scen 1 - 70 [min]**	**Scen 1 - 80 [min]**	**Scen 1 - 90 [min]**
ALFA APRON	11	3,160	4,070	4,125	2,450
BRAVO APRON	21	1,500	820	810	1,865
BRAVO PIER	13	11,807	12,921	12,475	11,807
CHARLIE PIER	14	14,398	13,853	13,302	14,324
DELTA PIER	33	27,131	31,623	32,533	30,343
DELTA RAMP	6	5,071	3,765	5,596	4,830
ECHO PIER	14	11,721	11,391	12,162	11,633
ECHO RAMP	3	2,569	2,837	1,975	2,515
FOXTROT PIER	8	5,548	5,665	6,234	5,106
GOLF PIER	8	5,337	7,765	7,370	6,560
GOLF RAMP	3	2,793	2,328	2,995	2,485
HOTEL PIER	7	6,540	7,590	6,830	6,880
JULIET RAMP	8	6,845	5,525	5,073	6,225
KILO APRON	32	0	0	0	0
LIMA RAMP	3	0	0	0	0
MIKE RAMP	14	0	0	0	0
NOVEMBER RAMP	2	0	0	0	0
PAPA HOLDING	10	0	0	0	0
PAPA PLATFORM	8	2,820	4,475	3,828	4,465
ROMEO CARGO APRON	10	8,023	6,905	7,907	6,615
SIERRA CARGO APRON	11	10,895	9,885	10,848	9,435
UNIFORM RAMP	5	2960	1,195	3,460	2,960
YANKEE RAMP	3	2,535	2,485	2,665	2,405
Total utilisation [hours]		**2,206.5**	**2,251.6**	**2,336.5**	**2,317.3**

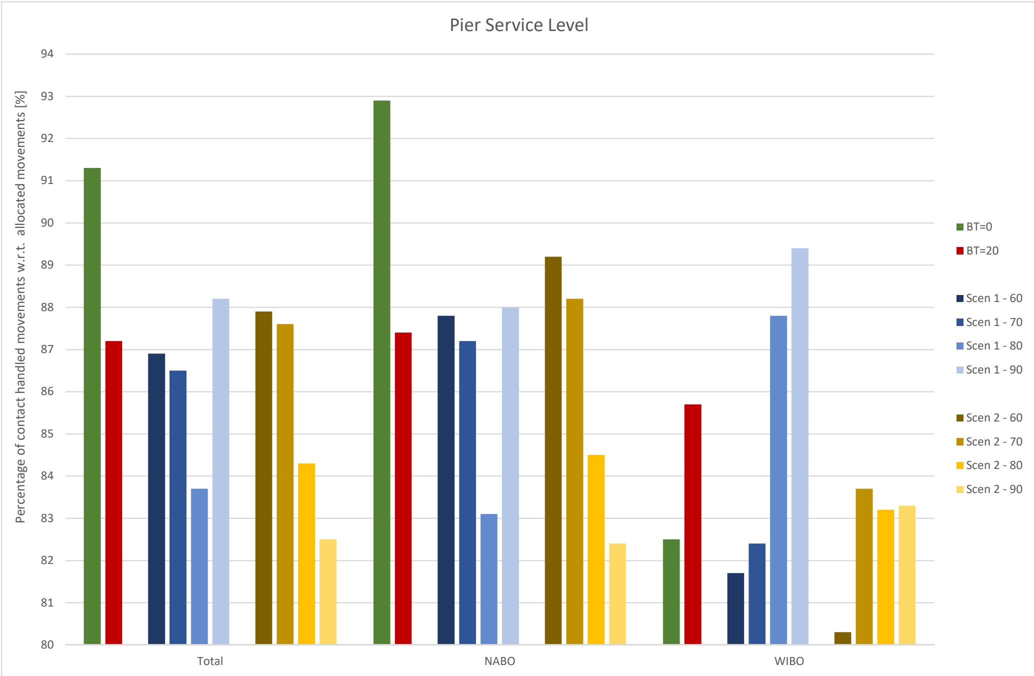

Figure 6.8: Percentage of contact handled flight movements with regard to allocated flight movements

Table 6.3: Allocations details for Scenario 1 on Monday 16 July 2018

	Scenario 1								
	Integers				**Percentages**				
	60%	**70%**	**80%**	**90%**	**60%**	**70%**	**80%**	**90%**	
Unallocated:	39	56	110	218	2.5	3.6	7.0	13.9	of on 16 July scheduled movements
Allocated:	1,534	1,517	1,463	1,355	97.5	96.4	93.0	86.1	of on 16 July scheduled movements
Arrivals:	769	763	734	684	50.1	50.3	50.2	50.5	of allocated movements
Departures:	765	754	729	671	49.9	49.7	49.8	49.5	of allocated movements
Tows:	76	81	98	85	5.0	5.3	6.7	6.3	of allocated movements
Non-pax movements:	52	50	50	50	3.4	3.3	3.4	3.7	of allocated movements
Pax movements:	1,482	1,467	1,413	1,305	96.6	96.7	96.6	96.3	of allocated movements
Pax NABO:	1,274	1,263	1,232	1,144	86.0	86.1	87.2	87.7	of allocated pax movements
Pax WIBO:	208	204	181	161	14.0	13.9	12.8	12.3	of allocated pax movements
Pier handled pax a/c:	1,288	1,269	1,183	1,151	86.9	86.5	83.7	88.2	of allocated pax movements
Pier handled pax NABO:	1,118	1,101	1,024	1,007	87.8	87.2	83.1	88.0	of allocated pax NABO
Pier handled pax WIBO:	170	168	159	144	81.7	82.4	87.8	89.4	of allocated pax WIBO
Remotely handled pax a/c:	194	198	230	154	13.1	13.5	16.3	11.8	of allocated pax movements
NABO:	156	162	208	137	12.2	12.8	16.9	12.0	of allocated pax NABO
WIBO:	38	36	22	17	18.3	17.6	12.2	10.6	of allocated pax WIBO

However, the delay data from the summer period of 2017 does not provide enough data for each flight. 'Enough' is roughly defined to be at least 50, as this would imply that a flight is carried out approximately twice a week. Next, there is the issue of convenient model adaptation: it is preferred to keep the number of groups to a minimum in order to keep the implementation of buffer times in the SGA feature of BEONTRA Scenario Planning Tool manageable. If an allocation schedule based on the buffer time optimisation for this scenario proves to be a potential solution to the research question, it is recommended to increase the number of groups for this scenario.

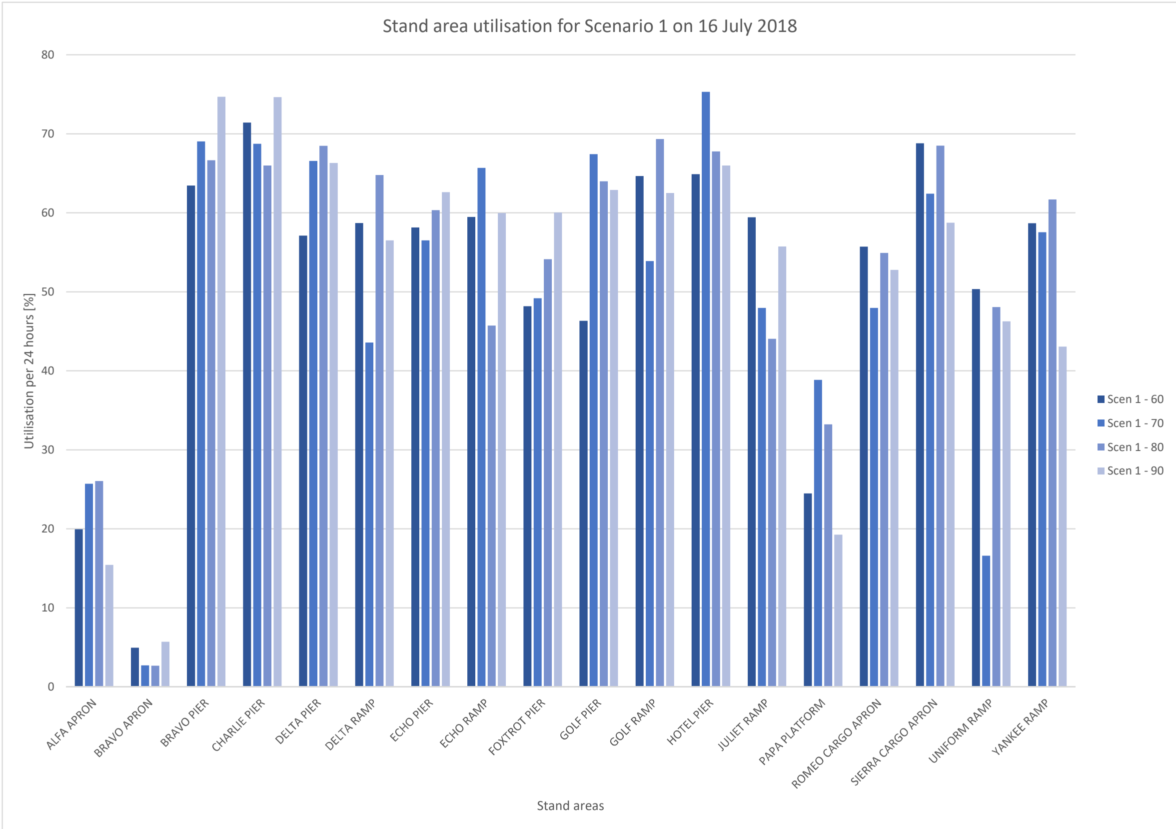

Figure 6.9: Stand area utilisation as a percentage per day for Monday 16 July 2018 for scenario 1

Here, it is decided after iteration to filter the delay data by groups with matching arrival or departure movement, time block, origin and destination, and airline: if one of the groups covers more than 500 flights, the group is used to define a buffer time in a similar fashion as described in Section 6.2. This is done using the programming language Python v3.7, for which the corresponding script is given in Appendix H. Again, flights within groups are distributed over 5 minute intervals. The percentage of flights covered in each bin is then used to determine an optimal buffer time.

The bin up to which the sum of the total of bin percentages is at least 60%, 70%, 80%, or 90%, is the bin for which the corresponding interval is the buffer time to be used to cover the respective percentage of flight. For this, the sum is taken from the bin with the most delayed flights for arrivals, up to the bin in which the sum is at least the required percentage. This last bin then gives the corresponding buffer time. For departures, the sum is taken from the bin with the earliest departures, up to the bin that determines the buffer time. In Appendix J, the buffer times per group for scenario 2 are given, for which respectively at least 60%, 70%, 80%, and 90% of the recorded flights in the empirical distribution of delay data are covered.

Similar to what has been described in Section 6.2, buffer times can be adapted in the 'Occupancy Times' configuration part in the BEONTRA SGA feature. Besides the 26 already existing groups, 48 additional groups are created for the buffer times of scenario 2. These groups have been created by combining the flight numbers with the corresponding time block and the arrival or departure movement. Together with the established buffer times for this scenario, the Occupancy Times configuration exports for the subscenarios that cover at least 60%, 70%, 80%, or 90% of the recorded flights are given in Appendix J.

In Appendix J, also the buffer times per group for the hybrid scenario 2 are given, for which respectively at least 60%, 70%, 80%, and 90% of the recorded flights in the empirical distribution of delay data are covered. The frequencies of the buffer times that are used per subscenario are also given in Figure 6.10. As expected, the buffer times during the night are relatively large, and for buffer times that cover a larger percentage of recorded flights are equal to or, more often, larger than the buffer times that cover a lower percentage. For each subscenario, the mean, the median, and the mode of used buffer times are given in Table 6.4.

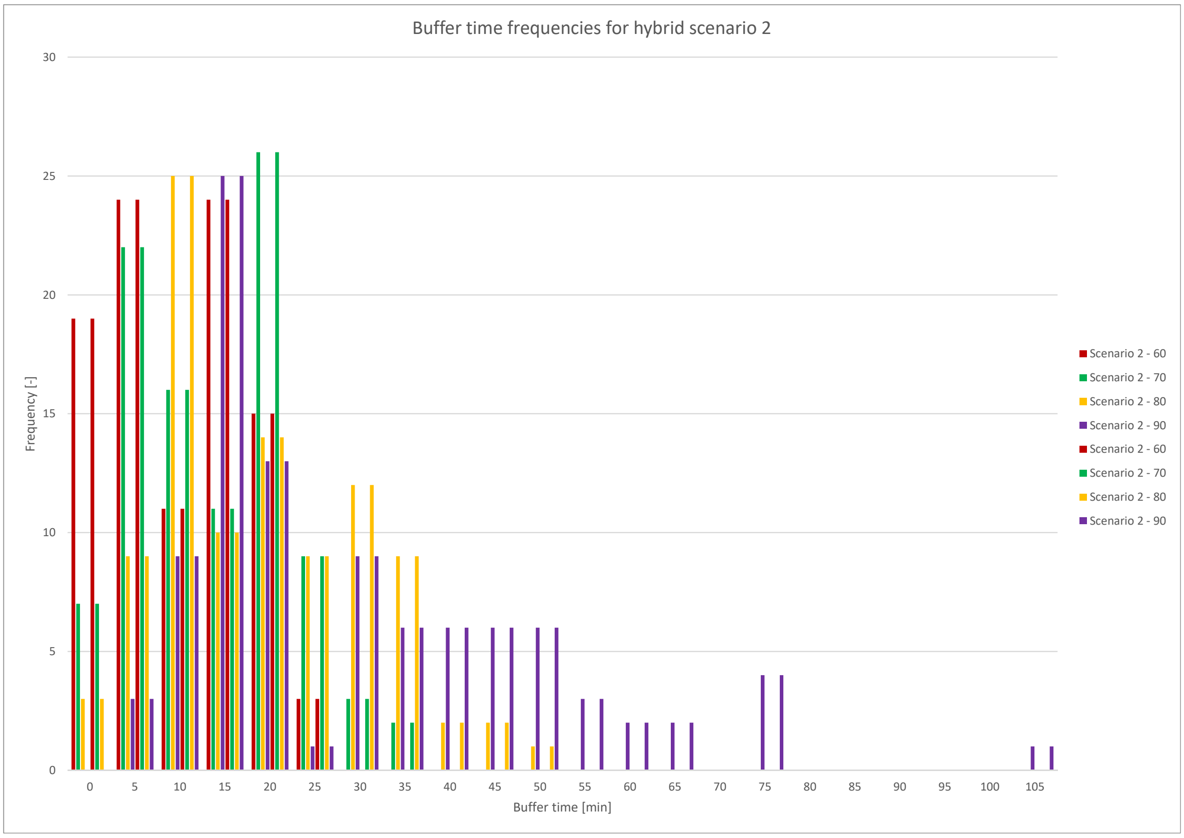

Figure 6.10: Frequencies of buffer times in hybrid scenario 2

Table 6.4: Mean, median and mode of buffer times as used in hybrid scenario 2

	Hybrid scenario 2			
	60	**70**	**80**	**90**
Mean	10.1	14.0	19.2	29.9
Median	10	15	20	20
Mode	5	20	10	15

The allocation schedules for scenario 2 for buffer times that cover at least 60%, 70%, 80%, and 90% of the recorded flights are also given in Appendix J. The number of unallocated flights for these allocation schedules is respectively 35, 62, 112, and 227. The increasing number of unallocated flights for a larger percentage of flight coverage is expected, as the buffer times increase respectively as well. The impact of the increasing buffer time in the subscenarios is also given in Figure 6.6. As can be seen in Table 6.5, the total stand utilisation for the four scenarios is 2,215.1, 2,308.1, 2,286.0, and 2,337.8 hours, resulting in an average of 2,286.7 hours with a standard error of the mean of 26.1. The visualisation of the stand utilisation per stand area is given in Figure 6.11: it can be seen that, in general, the contact stand areas have the highest utilisation ratios.

From the numbers regarding passenger handling as presented in Table 6.6, it can be seen that the ratio of allocated arrivals and departures approximately stays the same throughout scenario 2. It can be seen, as also visualised in Figure 6.7, that the towing percentage has an increasing trend for an increasing buffer time for both scenario 1 and 2. More towing means that contact stands can be used more intensively, but it also means that the probability of delays and corresponding congestions increases. This is due to the additional handlings, in which towing movements may block other flight movements in their operation. Also, tow truck numbers might be limited and waiting for one can also add up to the delay. Therefore, a higher towing percentage is not necessarily beneficial. Furthermore, it can be seen, as also visualised in Figure 6.8, that the PSL fluctuates with an increasing buffer time for both scenario 1 and 2: respectively 87.9%, 87.6%, 84.3%, and 82.5% of the flight movements are handled at a contact stand for scenario 2 - 60 up to scenario 2 - 90. The PSL of NABO movements fluctuates; the PSL of WIBO movements decreases with an increasing buffer time. It has to be noted that the y-axis of this figure starts at 80%.

Table 6.5: Stand utilisation hours for Scenario 2 on Monday 16 July 2018

Stand area	**Number of stands [-]**	**Scen 2 - 60 [min]**	**Scen 2 - 70 [min]**	**Scen 2 - 80 [min]**	**Scen 1 - 90 [min]**
ALFA APRON	11	2,450	3,610	3,220	3,780
BRAVO APRON	21	1,865	1,370	1,775	1,360
BRAVO PIER	13	11,807	12,981	11,832	12,646
CHARLIE PIER	14	14,324	13,964	14,049	14,712
DELTA PIER	33	30,343	31,136	31,368	29,568
DELTA RAMP	6	4,830	4,706	4,197	5,026
ECHO PIER	14	11,633	11,705	11,960	12,861
ECHO RAMP	3	2,515	2,273	2,672	1,885
FOXTROT PIER	8	5,106	5,707	5,926	6,122
GOLF PIER	8	6,560	7,169	7,635	6,873
GOLF RAMP	3	2,485	2,835	2,890	2,847
HOTEL PIER	7	6,880	7,375	7,020	7,310
JULIET RAMP	8	6,225	5,397	5,503	6,067
KILO APRON	32	0	0	0	0
LIMA RAMP	3	0	0	0	0
MIKE RAMP	14	0	0	0	0
NOVEMBER RAMP	2	0	0	0	0
PAPA HOLDING	10	0	0	0	0
PAPA PLATFORM	8	4,465	3,940	4,217	5,113
ROMEO CARGO APRON	10	6,615	8,695	7,450	8,331
SIERRA CARGO APRON	11	9,435	10,450	10,795	10,077
UNIFORM RAMP	5	2,960	2,795	2,705	3,795
YANKEE RAMP	3	2,405	2,375	1,948	1,895
Total utilisation [hours]		**2,215.1**	**2,308.1**	**2,286.0**	**2,337.8**

Table 6.6: Allocations details for Scenario 2 on Monday 16 July 2018

	Scenario 2								
	Integers				Percentages				
	60%	70%	80%	90%	60%	70%	80%	90%	
Unallocated:	35	62	112	227	2.2	3.9	7.1	14.4	of on 16 July scheduled movements
Allocated:	1,538	1,511	1,461	1,346	97.8	96.1	92.9	85.8	of on 16 July scheduled movements
Arrivals:	772	758	735	678	50.2	50.2	50.3	50.4	of allocated movements
Departures:	766	753	726	668	49.8	49.8	49.7	49.6	of allocated movements
Tows:	63	73	74	96	4.1	4.8	5.1	7.1	of allocated movements
Non-pax movements:	50	52	49	51	3.3	3.4	3.4	3.8	of allocated movements
Pax movements:	1,488	1,459	1,412	1,295	96.7	96.6	96.6	96.2	of allocated movements
Pax NABO:	1,275	1,257	1,227	1,139	85.7	86.2	86.9	88.0	of allocated pax movements
Pax WIBO:	213	202	185	156	14.3	13.8	13.1	12.0	of allocated pax movements
Pier handled pax a/c:	1,308	1,278	1,191	1,068	87.9	87.6	84.3	82.5	of allocated pax movements
Pier handled pax NABO:	1,137	1,109	1,037	938	89.2	88.2	84.5	82.4	of allocated pax NABO
Pier handled pax WIBO:	171	169	154	130	80.3	83.7	83.2	83.3	of allocated pax WIBO
Remotely handled pax a/c:	180	181	221	227	12.1	12.4	15.6	17.5	of allocated pax movements
NABO:	138	148	190	201	10.8	11.8	15.5	17.6	of allocated pax NABO
WIBO:	42	33	31	26	19.7	16.3	16.8	16.7	of allocated pax WIBO

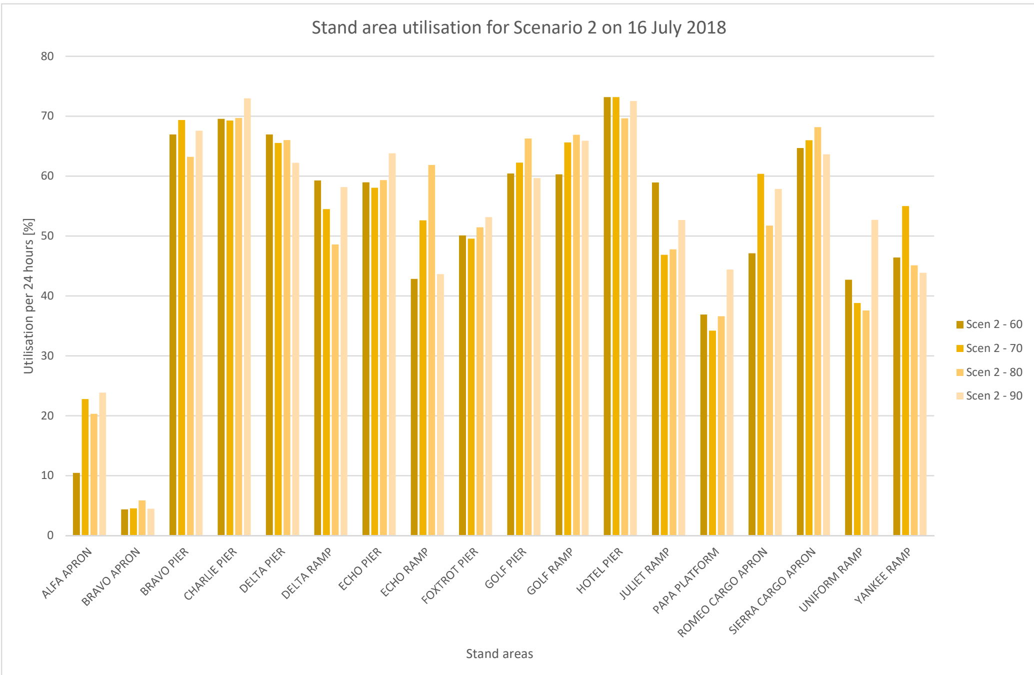

Figure 6.11: Stand area utilisation as a percentage per day for Monday 16 July 2018 for scenario 2

7 Optimised buffer time model results

With the configuration of the optimised buffer time scenarios discussed in Chapter 4, an evaluation of the allocation schedules with regard to robustness measuring KPIs is necessary in order to provide a substantiated answer on the research question. In the previous chapter, four KPIs have been identified that indicate the effectiveness and usefulness of a schedule in terms of capacity and handling according to preference. The first KPI is the number of unallocated flights for each schedule. Next, the stand utilisation and the tow movement percentage could provide information on the effectiveness of an allocation. Furthermore, the PSL can provide insight into the ability of a schedule to comply with RASAS [3] and the business rules at Schiphol. Four important KPIs that can provide insight into the ability of a schedule to withstand changes and delays are discussed in this chapter. In Section 7.1, the average clash probability per allocated movement is determined. In Section 7.2, the stand change percentage, the average delay per executed movement, and the average stand delay per executed movement are discussed.

7.1. Results of clash probability analysis

The average probability per allocated movement that a subsequent allocation will overlap with the preceding allocation on a specific stand, or the average clash probability, provides a useful KPI to compare allocation schedules. The clash probability is based on the recorded flight delay data as given in Appendix G. For all scheduled flight movements, an empirical distribution of delay corresponding to scenario 1-groups or scenario 2-groups can be assigned. This section evaluates the size of the overlapping empirical distributions for the allocation schedules of scenario 1 and scenario 2. For this purpose, an empirical delay distribution is used for departures, and an empirical cumulative distribution is used for the arrivals.

For this purpose, the assumptions are stated first. With regard to flight movements as presented in the allocation schedules, seven different, subsequent movement pairs at the same stand can be detected:

- An arrival without a departure, in case movements on 16 July 2018 only are considered;
- A departure without an arrival, in case movements on 16 July 2018 only are considered;
- An arrival, followed by a departure of the same flight;
- An arrival, followed by an arrival, in case the first arrival is towed out;
- A departure, followed by a departure, in case the second departure is towed in;
- An arrival, followed by a departure of a different flight, in case the first is towed out and the second movement is towed in;
- A departure, followed by an arrival of a different flight.

It is assumed that towing can happen in such a flexible manner that potential delays can be absorbed by advancing or postponing the time a tow takes place. Therefore, no empirical distribution on delays is linked to tow movements. This means that only the last movement pair is considered in the clash probability calculation and only if the stand is the same, the flight registration number is not, and the concerning STD and the STA are scheduled right after each other, without any other movements scheduled in between. Furthermore, overlapping distributions are only considered from the STD up until the STA of the subsequent flight.

Now, the delay distribution calculation for scenario 1 and scenario 2, as well as the clash probability calculation, are performed in Python v3.7. The corresponding scripts are given in Appendix K. The method in which the clash probability is computed is described next, supported by Figure 7.1. In this figure, the STD and empirical delay distribution for a flight is given, followed by the STA and empirical delay distribution of another flight. The time in between the STD and the STA is the idle time, which is equal to or larger than the largest buffer time corresponding to one of the two flights. Now, with regard to a reference time, c_D is the time up to the STD, and c_A is the time up to the STA. The idle time is then equal to $c_A - c_D$. The most right, or delayed position in time of the empirical distribution of the departure is c_f, which is equal to $c_D + b_D$. b_D Is the time between c_f and the STD. The most left, or early position of the empirical cumulative distribution of the arrival is c_i, which is equal to $c_A + b_A$, in which b_A is negative. b_A Is the time between c_i and the STA. The overlapping time is then equal to $c_f - c_i$.

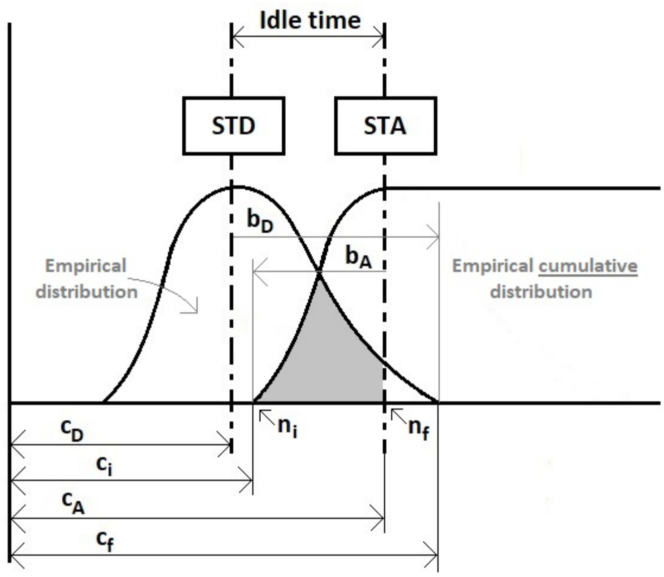

Figure 7.1: Overlapping empirical delay distributions of two subsequent flight movements on the same stand

However, as overlapping distributions are only considered from the STD up until the STA, the overlapping time of interest is equal to $n_f - n_i$, in which n_f equals c_f if it is smaller than c_A; otherwise n_f equals c_A. Similarly, n_i equals c_i if it is smaller than c_D; otherwise n_i equals c_D. The overlapping time of interest is then divided in bins of 5 minutes. For each bin, the bin probability is calculated by multiplying the probability of the departure flight for that position by the cumulative probability of the arrival flight at that position. The clash probability consists of the sum of all the bin probabilities within the time $n_f - n_i$. If this clash probability is smaller than 0.01%, it shows a probability of zero instead.

Now, the results as generated by Python are given in Appendix K. The results on the total clash probability and the corresponding, average clash probability per allocated movement, are given in Table 7.1. The average clash probability per allocated movement is also given in Figure 7.2. As can be seen, the total clash probability and the average clash probability per allocated movement decrease with an increasing buffer time. In general, scenario 1 results perform better in terms of lower average clash probabilities per movement than scenario 2 results.

With regard to the buffer time of 0 minutes, however, both scenario 1 and scenario 2 start with larger values. It has to be regarded in this case, that a buffer time of 0 minutes leaves no room for clash probability in case flights are positioned right after each other. With regard to the buffer time of 20 minutes, only scenario 1 - 90 performs better. This makes sense, as the mean, the median, and the mode for scenario 1 - 80 are respectively 19.9, 20, and 10 minutes; for scenario 1 - 90, these are respectively 31.8, 20, and 20. The case where the buffer time is 20 minutes is right in between of these average values.

Table 7.1: Clash probability results per scenario

Scenario	Total clash probability [%]	Avg. clash probability per movement [%]
Scenario 1 - BT=0	2,469.81	1.43
Scenario 2 - BT=0	2,689.43	1.56
Scenario 1 - BT=20	1,538.34	0.96
Scenario 2 - BT=20	1,911.76	1.20
Scenario 1 - 60	3,280.18	1.95
Scenario 1 - 70	2,667.82	1.60
Scenario 1 - 80	1,725.93	1.07
Scenario 1 - 90	831.12	0.56
Scenario 2 - 60	3,540.13	2.10
Scenario 2 - 70	3,099.49	1.87
Scenario 2 - 80	2,091.70	1.30
Scenario 2 - 90	1,318.85	0.89

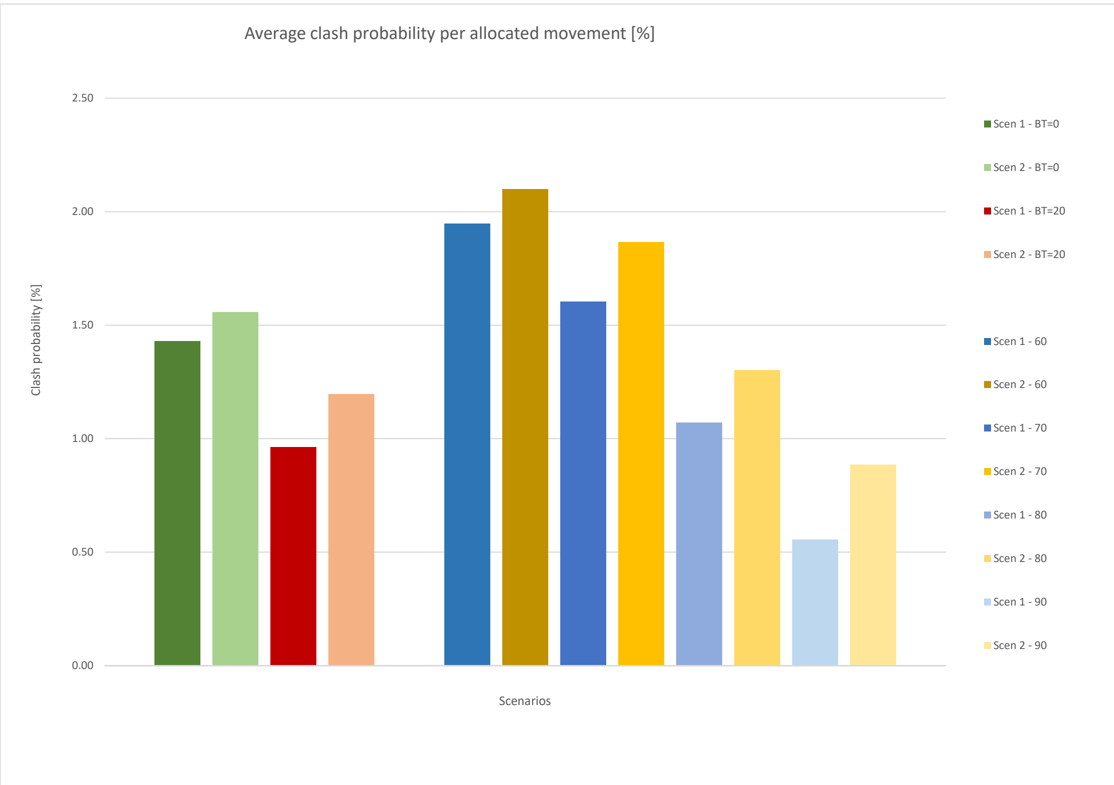

Figure 7.2: Average clash probability per allocated movement

In order to provide insight into the average clash probabilities per stand as distributed over the stand areas, the total clash probability per stand area is divided over the number of corresponding stands, averaged across the four subscenarios that correspond to respectively scenario 1 and 2. As can be seen in Figure 7.3, the largest average cumulative clash probabilities occur at the piers with the largest stand utilisation times, as shown in Figure 6.9 and Figure 6.11. Pier H has the largest average clash probability per stand, which can be explained by the fact that the assigned probabilities are not applicable to low-cost flights, as low-cost stands have their own buffer time of 10 minutes, and as low-cost flights have the lowest turnaround times.

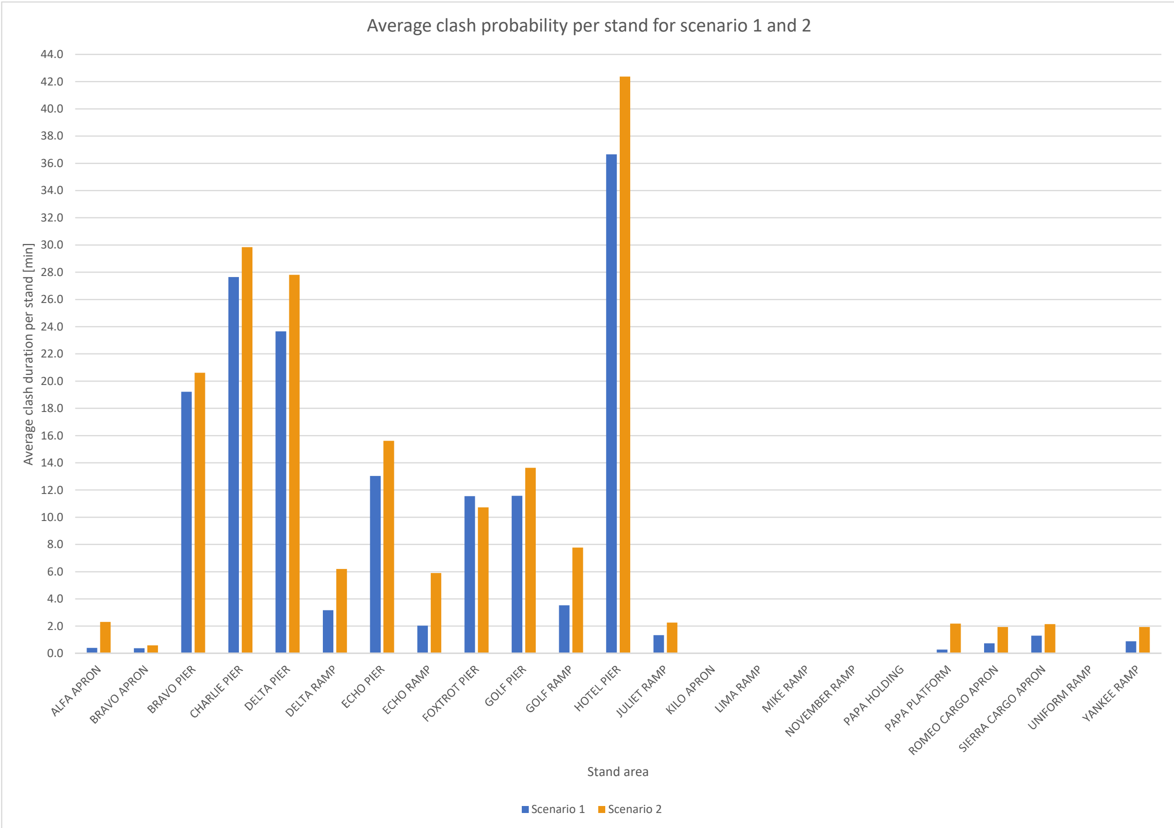

Figure 7.3: Average clash probability per stand of a stand area for scenario 1 and 2, averaged across subscenarios corresponding to scenario 1 and 2

7.2. Results of fast-time simulation programme AirTOp on cumulative delay and stand change numbers

An important KPI to determine the robustness of an allocation schedule is the cumulative delay on the day of operation a schedule is tested. If the buffer times in an allocation schedule are able to absorb common delays, such as delays occurring during runway sequencing or while awaiting push-back clearance, the total delay is expected to be smaller than for an allocation schedule with smaller or no buffer times. In Chapter 6, eight different sets of buffer times have been established, each generating an allocation schedule. In order to test the ability to withstand common delays of these schedules, the schedules are tested using the fast-time airport simulation programme AirTOp. Using an existing model of Schiphol, which has been validated by Schiphol and by the Dutch air traffic control, the LVNL, and using historical flight delays as input to generate the common delays, the feasibility of the allocation schedules is tested in terms of the cumulative delay duration and the number of stand changes after simulation of Monday 16 July 2018.

Before continuing to the results of scenario 1 and scenario 2, the assumptions are discussed first. In the AirTOp model, it is assumed that no stand is unavailable due to maintenance. Next, no detailed stand specifications that might narrow down allocation are regarded, such as fuel pit positioning. Furthermore, the minimum and maximum of the simulated delays is respectively set to -30 and 30 minutes. Regarding the inclusion of flights: the 77 flight arrivals that have been generated by the BEONTRA SGA feature, and that are to be positioned at Schiphol for more than 24 hours, are excluded from simulation, as these arrivals are not present in the initial time slot allocation schedule. All allocations that are present in the time slot allocation schedule are further included, regardless of their arrival or departure being scheduled on 15 or 17 July 2018. Next, flights that remain unallocated in the allocation schedules are excluded from the simulation. Last, the number of simulation runs to test an allocation schedule is set to 10, which is based on the expert knowledge of aviation consultants from To70, where the tendency is to use seven simulation runs.

The resulting flight plans, based on the allocation schedules, are given in Appendix L. As a baseline, the simulation results for the eight scenarios are compared to the simulation results for a buffer time of 0 minutes, for which all flight movements are allocated, and to those for a buffer time of 20 minutes, which is the theoretical buffer time to be used at Schiphol. The corresponding results are given in Table 7.2.

Table 7.2: Baseline AirTOp simulation results for buffer time of 0 and 20 minutes

Scenario	Stand changes [%]			Cumulative total delay [hrs]			Avg total delay per movement [s]			Cumulative stand delay [hrs]			Avg stand delay per movement [s]		
	AVG	STDEV	SE	AVG	STDEV	SE	AVG	STDEV	SE	AVG	STDEV	SE	AVG	STDEV	SE
BT = 0	16.0	0.7	0.2	42.0	8.4	2.7	86.1	17.3	5.5	17.4	5.3	1.7	35.7	10.8	3.4
BT=20	8.7	0.5	0.2	18.9	3.0	0.9	42.0	6.6	2.1	4.9	1.5	0.5	11.0	3.3	1.0

The subsequent simulation results for scenario 1 are now given in Table 7.3, the results for scenario 2 are given in Table 7.4. More details on the simulation results can be found in Appendix L. First, the number of stand changes is portrayed in Figure 7.4. One of the first things that can be noticed is that stand change percentages decrease for an increasing buffer time. Stand changes occur when in AirTOp different stands are used for a flight movement with regard to the original allocation schedule. When at touchdown, a flight checks whether its predisposed stand is available. If this is not the case, it goes to the P holding area, where it waits up to 20 minutes until its stand becomes available. When the stand is not released within those 20 minutes, the flight is assigned to another stand.

The largest contribution to stand change numbers are the tow movements: AirTOp generates more tow movements than initially scheduled to provide more room in case of delayed flights. The resulting percentage of stand changes with regard to the number of movements for scenario 1 is 12.2% on average, with a standard error of 0.5. The resulting percentage of stand changes with regard to the number of movements for scenario 2 is 12.9% on average, with a standard error of 0.3. In comparison, scenario 1 performs better than scenario 2 in terms of lower stand changes for equivalent subscenarios. The baseline stand change percentage for a buffer time of 0 minutes is the largest value with 16.0%; the baseline stand change percentage for a buffer time of 20 minutes is the lowest value with 8.7%.

Next, important remarks can be made about the delay values. Where delays are simulated in AirTOp, based on historical flight delay distributions, these delays are not regarded in the values as considered in this chapter. Rather, these flight delays based on historical data are reflected in the number of stand changes, as a flight needs to be redirected to another stand if its predisposed stand is taken by another, delayed flight. Delays as considered in this results analysis may occur at the stands, consisting of delays regarding the time it takes to get towing or push-back clearance: these are the stand delays. Delays may also occur during all ground procedures, consisting of queuing for runway crossing, of being stopped at a runway or taxi crossing, as well as of the delays at the stand: these are the total delays. When a group of flights is delayed and all flights then depart around the same time, this could lead to congestions, which are reflected in the delays as discussed in this chapter. Therefore, the cumulative delay averages, averaged across ten simulations for each subscenario, are a measure of the ability of an allocation schedule to keep flight movements distributed in such fashion that congestions are kept to a minimum, rather than an accurate display of total flight delays.

Table 7.3: AirTOp delay and stand change results for Scenario 1

Scenario 1												
Subscenario:	**60**			**70**			**80**			**90**		
Average BEONTRA movements considered in simulation [-]:	**1,611**			**1,595**			**1,540**			**1,432**		
	AVG	STDEV	SE	AVG	STDEV	SE	AVG	STDEV	SE	AVG	STDEV	SE
Unique movements in AirTOp results [-]	1718.0	2.4	0.7	1704.8	2.9	0.9	1667.9	4.4	1.4	1545.8	1.8	0.6
Total stand changes [-]	226.3	12.8	4.1	214.6	14.8	4.7	204.1	18.7	5.9	166.8	8.6	2.7
Total stand changes [%]	13.2	0.7	0.2	12.6	0.9	0.3	12.2	1.1	0.4	10.8	0.5	0.2
Arrival stand changes [%]	9.0	0.8	0.3	7.9	0.8	0.3	6.9	1.2	0.4	6.0	0.5	0.2
Departure stand changes [%]	9.7	0.7	0.2	9.1	1.0	0.3	8.1	1.1	0.4	6.4	0.6	0.2
Tow stand changes [%]	70.2	1.3	0.4	71.8	1.1	0.3	68.6	1.7	0.5	68.5	1.6	0.5
Total delay [hrs]	36.4	26.2	8.3	35.5	10.5	3.3	21.5	3.2	1.0	15.6	3.2	1.0
Total delay frequency [-]	1115.1	184.1	58.2	1090.6	107.9	34.1	862.4	49.5	15.6	715.8	65.5	20.7
Avg delay per movement [s]	76.2	55.0	17.4	74.9	22.1	7.0	46.5	6.9	2.2	36.3	7.5	2.4
Total stand delay [hrs]	13.2	18.3	5.8	13.6	5.5	1.7	4.7	1.5	0.5	3.4	0.6	0.2
Total stand delay frequency [-]	239.5	97.7	30.9	292.9	60.1	19.0	163.5	23.3	7.4	129.9	18.6	5.9
Avg stand delay per movement [s]	27.7	38.3	12.1	28.7	11.5	3.6	10.1	3.2	1.00	7.8	1.5	0.5

The scenario with all flights allocated and a buffer time of 0 generates the largest delay, both in terms of the average cumulative total delay duration, as given in Figure 7.5, as well as in terms of average cumulative stand delay duration, as given in Figure 7.6. It also generates the largest average delay per aircraft movement in AirTOp, as averaged across the ten simulations, both in terms of the total delay average per executed movement, as can be seen in Figure 7.7, and in terms of the stand delay average per executed movement, as can be seen in Figure 7.8. Furthermore, it can be seen in these four figures, that the schedules for a buffer time of 20 minutes and for subscenario 1 - 80, 1 - 90, 2 - 80, and 2 - 90, have the smallest standard deviations. From this, it can be concluded with more accuracy that these schedules, the ones with the largest buffer times, are able to withstand the in AirTOp simulated delays best. Comparing subscenario 1 - 80 and 1 - 90 to 2 - 80 and 2 - 90, scenario 1 achieves lower delay values.

Table 7.4: AirTOp delay and stand change results for Scenario 2

Scenario 2												
Subscenario:	**60**			**70**			**80**			**90**		
Average BEONTRA movements considered in simulation [-]:	**1,606**			**1,588**			**1,538**			**1,423**		
	AVG	STDEV	SE	AVG	STDEV	SE	AVG	STDEV	SE	AVG	STDEV	SE
Unique movements in AirTOp results [-]	1,715.5	3.47	1.10	1,697.3	3.27	1.03	1,646.5	1.84	0.58	1,552.8	22.65	7.16
Total stand changes [-]	236.1	15.4	4.9	221.3	5.6	1.8	209.7	9.9	3.1	188.1	25.2	8.0
Total stand changes [%]	13.8	0.9	0.3	13.0	0.3	0.1	12.7	0.6	0.2	12.1	1.4	0.4
Arrival stand changes [%]	8.9	1.0	0.3	8.1	0.5	0.1	8.3	0.7	0.2	6.6	0.5	0.2
Departure stand changes [%]	9.6	0.9	0.3	9.3	0.4	0.1	8.9	0.7	0.2	8.3	2.4	0.8
Tow stand changes [%]	79.0	1.0	0.3	75.5	1.1	0.3	71.2	0.7	0.2	66.6	2.1	0.7
Total delay [hrs]	31.4	9.4	3.0	32.4	16.2	5.1	22.9	4.4	1.4	16.7	1.6	0.5
Total delay frequency [-]	1077.7	84.3	26.7	1061.7	142.6	45.1	927.7	58.9	18.6	733.1	38.4	12.1
Avg delay per movement [s]	65.9	19.7	6.2	68.7	34.4	10.9	50.1	9.5	3.0	38.7	3.7	1.2
Total stand delay [hrs]	10.8	7.2	2.3	11.3	10.4	3.3	6.6	3.4	1.1	3.5	0.7	0.2
Total stand delay frequency [-]	257.0	58.1	18.4	248.4	76.3	24.1	197.3	41.8	13.2	130.4	21.6	6.8
Avg stand delay per movement [s]	22.6	15.0	4.7	24.0	22.0	6.9	14.3	7.5	2.4	8.1	1.7	0.6

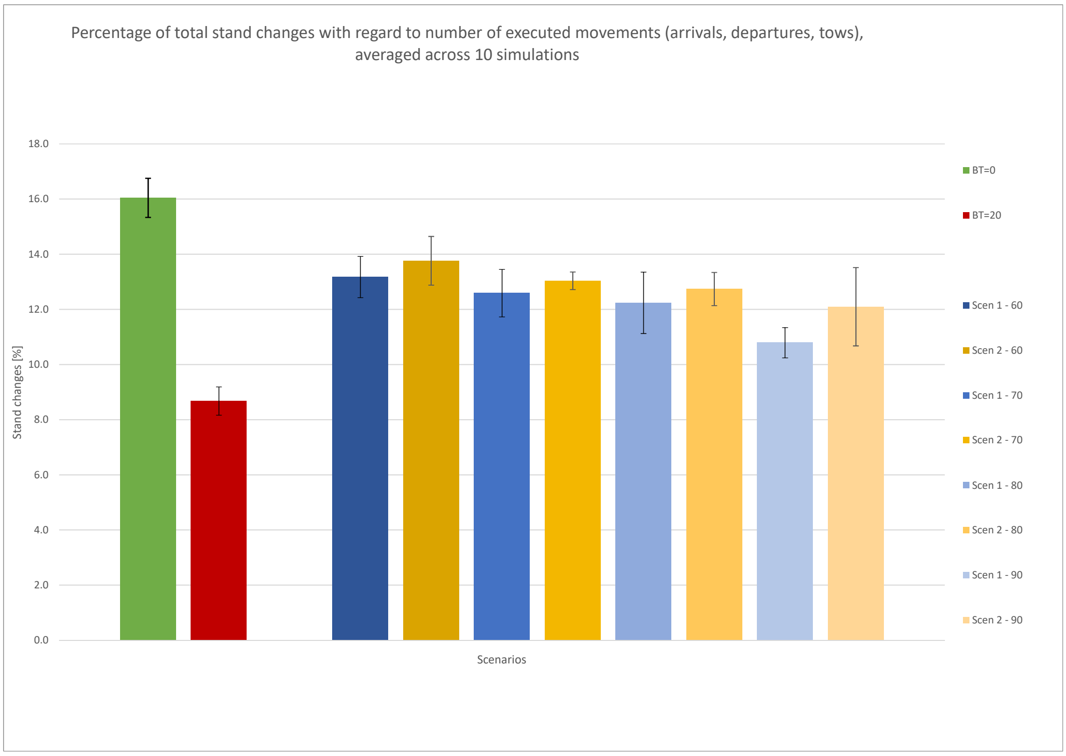

Figure 7.4: Percentage of stand changes in AirTOp with regard to initial BEONTRA allocation

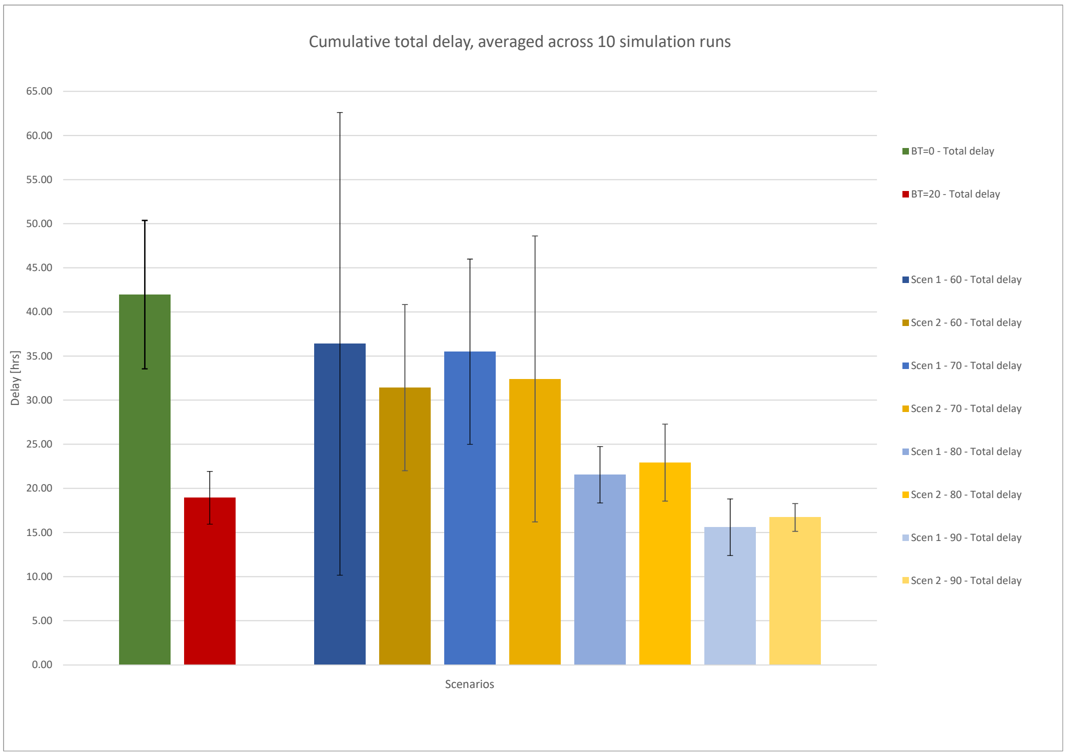

Figure 7.5: Cumulative total delay from AirTOp results, averaged across 10 simulations

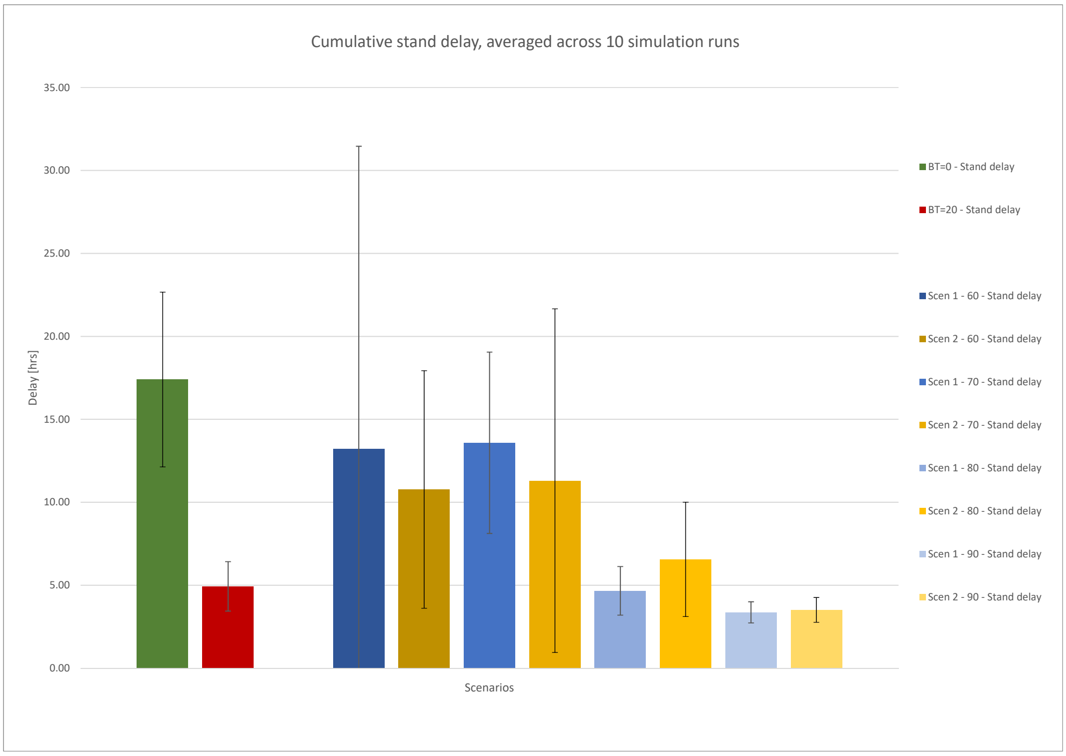

Figure 7.6: Cumulative stand delay from AirTOp results, averaged across 10 simulations

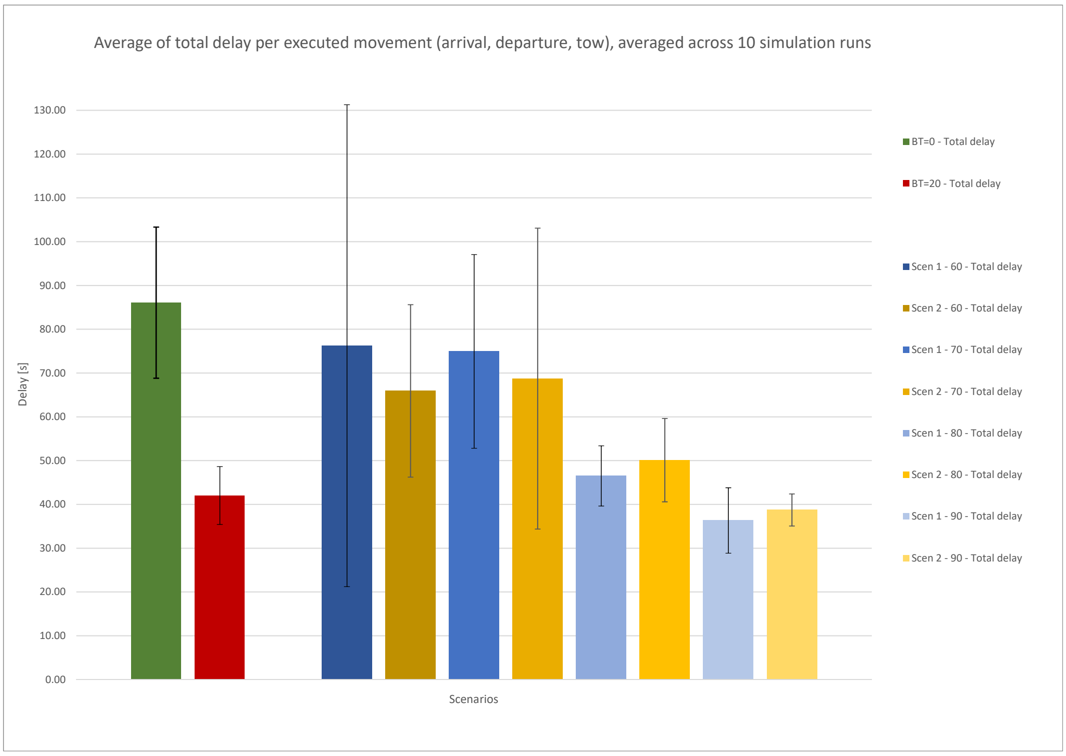

Figure 7.7: Average total delay per executed movement from AirTOp results, averaged across 10 simulations

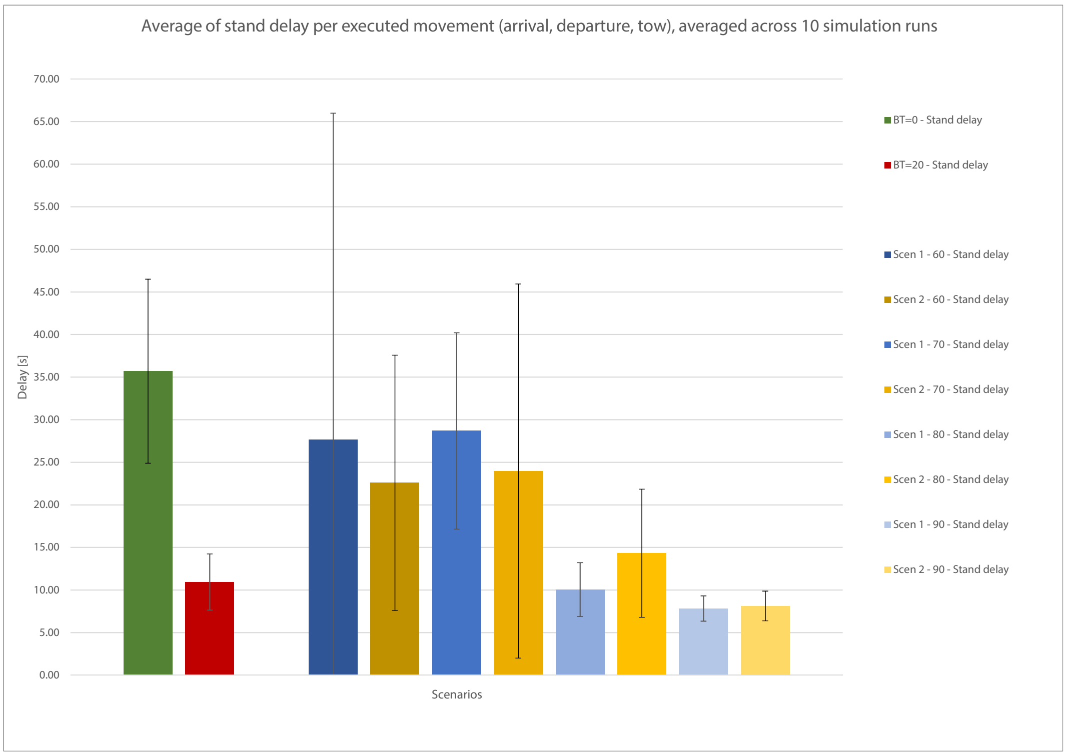

Figure 7.8: Average stand delay per executed flight movement from AirTOp results, averaged across 10 simulations

8 Discussion, conclusions and recommendations

With the background, the methods, and the results of buffer time optimisation for Amsterdam Airport Schiphol given in the preceding chapters, the research question needs to be answered in a substantiated fashion. In order to provide insight into the interpretations and the limitations of the main findings on buffer time optimisation according to scenario 1 and scenario 2, the results are discussed in Section 8.1 first. Scenario 1 consists of buffer times that have been optimised by grouping flight delay data by arrival or departure, time period, aircraft size, and border control status. Scenario 2 is hybrid and consists of buffer times that have been optimised by grouping flight delay data for frequent flights by arrival or departure, time period, flight route, and airline, and grouping flights by scenario 1 methods flights that do not fit in the first groups. Next, the conclusions are presented in Section 8.2. Last, based on the discussion and the conclusions, recommendations for further research are given in Section 8.3.

8.1. Discussion

After the configuration of eight scenarios with different buffer times in Chapter 6, several KPIs are established throughout Chapter 6 and Chapter 7 in order to compare the allocation schedules with one another and in order to express a measure of robustness. In this section, the interpretations and limitations of the results are discussed.

First, the KPIs as used in this research are:

- Percentage of unallocated movements with regard to scheduled movements
- Average stand utilisation per allocated movement
- Percentage of tow movements with regard to allocated movements
- Pier Service Level, or the percentage of contact handled passenger flight movements with regard to total allocated passenger movements
- Average clash probability per allocated movement
- Percentage of stand changes after simulation in AirTOp with regard to allocation schedule
- Average total delay per executed movement
- Average stand delay per executed movement

The first four KPIs can be extracted from the allocation schedules as generated by the SGA feature of the BEONTRA Scenario Planning tool. Some generalising assumptions have been made in these models with regard to stand size, however. In practice, stands of a specific category might exclude aircraft types of that category due to physical limitations, such as fuel pit positioning: such details have not been included in the model configuration. Furthermore, some business rules are generalised when covering too much detail, such as time of the day, not concerning day- or nighttime, or remote stand preferences. More information on these assumptions is given in Chapter 4. It is not expected that these generalisations have a significant impact on the results, as the model approximates Amsterdam Airport Schiphol in all other areas, and as the impact of buffer times on allocation results can be analysed nevertheless.

The resulting KPIs are presented in Table 8.1. The percentage of unallocated flights increases with an increasing buffer time, making it preferable to keep the buffer time as low as possible. Furthermore, it can be seen that the ratio of average stand utilisation over the number of allocated flights increases with an increasing buffer time. Towing numbers depend on the turnaround times of the allocated flights, but show an upward trend for an increasing buffer time. Therefore, it is preferable to keep buffer times low when the towing percentage needs to be kept to a minimum. It has to be noted that limitations with regard to available tow truck numbers are not taken into account. Pier Service Levels fluctuate, but PSLs for WIBO aircraft show to be highest for scenario 1 - 90 and scenario 1 - 80, respectively.

Table 8.1: KPIs from BEONTRA allocation schedules: percentage of unallocated flights, average stand utilisation per allocated movement, tow movement percentage, and Pier Service Level

	KPIs from BEONTRA allocation schedules					
Scenario	**Percentage of unallocated movements [%]**	**Avg. stand utilisation per allocated movement (incl. buffer time) [hours]**	**Tow movements [%]**	**Pier Service Level [%]**		
				Total [%]	**NABO [%]**	**WIBO [%]**
BT = 0	0.0	1.37	2.0	91.3	92.9	82.5
BT = 20	7.7	1.58	4.5	87.2	87.4	85.7
Scenario 1 - 60	2.5	1.44	5.0	86.9	87.8	81.7
Scenario 1 - 70	3.6	1.48	5.3	86.5	87.2	82.4
Scenario 1 - 80	7.0	1.60	6.7	83.7	83.1	87.8
Scenario 1 - 90	13.9	1.71	6.3	88.2	88.0	89.4
Scenario 2 - 60	2.2	1.44	4.1	87.9	89.2	80.3
Scenario 2 - 70	3.9	1.53	4.8	87.6	88.2	83.7
Scenario 2 - 80	7.1	1.56	5.1	84.3	84.5	83.2
Scenario 2 - 90	14.4	1.74	7.1	82.5	82.4	83.3

The next KPI can be extracted from the clash probability computations. Probabilities are based on the empirical delay distributions for the specific group, based on historical flight delay data for the summer period of 2017. Therefore, the dataset is limited and might have an inaccurate impact on both buffer time establishment as well as on clash probability. As the clash probability dataset is used for all allocation schedules, potential inaccuracy would have the same impact on all allocation schedule results. This would cause no reason to discard the clash probability values, as the results are merely used for comparison. Furthermore, the clash probability is considered for departures and arrivals of different flights only, which might have an impact on the results for an allocation schedule with relatively more tows.

From Table 8.2, it can be seen that all scenarios have a decreasing clash value for an increasing buffer time. However, for the allocation schedules with buffer time of 0 minutes, it can be noticed that it has a lower clash probability per allocated movement than scenario 1 - 60 and 70, and scenario 2 - 60 and 70. As the idle times between allocations are often negligible for the schedule with a buffer time of 0 minutes, the overlapping delay distribution surfaces that are taken into account in the computation are often small, and the total probability is divided by a larger number of allocated movements: the clash probability value for the baseline schedule with a buffer time of 0 minutes is therefore not unexpected. In terms of average clash probability per movement, scenario 1 has lower, and, therefore, preferable results with regard to scenario 2. With regard to preferable results, scenario 1 - 90, the baseline with a buffer time of 20 minutes, scenario 2 - 90, and scenario 1 - 80 are leading. Both clash values decrease for an increasing buffer time.

The last three KPIs are extracted from the simulation results from fast-time simulation programme AirTOp. Assumptions are made with regard to the fact that no stands are discarded due to maintenance reasons; no additional physical limitations are regarded, such as fuel pit positioning; and the minimum and maximum of induced delays is set to -30 and 30 minutes respectively. As this is done for all simulations, and as the results are used for comparison, this should cause no further limitations.

Table 8.2: KPIs from clash probability computation: total clash probability and average clash probability per allocated movement

	KPIs from clash probability computation	
Scenario	**Total clash probability [%]**	**Avg. clash probability per movement [%]**
Scenario 1 - BT=0	2,469.81	1.43
Scenario 2 - BT=0	2,689.43	1.56
Scenario 1 - BT=20	1,538.34	0.96
Scenario 2 - BT=20	1,911.76	1.20
Scenario 1 - 60	3,280.18	1.95
Scenario 1 - 70	2,667.82	1.60
Scenario 1 - 80	1,725.93	1.07
Scenario 1 - 90	831.12	0.56
Scenario 2 - 60	3,540.13	2.10
Scenario 2 - 70	3,099.49	1.87
Scenario 2 - 80	2,091.70	1.30
Scenario 2 - 90	1,318.85	0.89

As can be seen in Table 8.3, the stand change percentage values are decreasing with an increasing buffer time, and tend to be lower for scenario 1. The lowest percentage of stand changes, however, is generated for the baseline scenario with a buffer time of 20 minutes. The mentioned limitations in the AirTOp results are reflected in the delay data of scenarios with relatively low buffer times: both standard deviations and standard errors of the mean are large for scenarios with a low buffer time. Therefore, accurate conclusions cannot be drawn and the results for scenario 1 - 60, scenario 1 -70, scenario 2 - 60, and scenario 2 - 70 should be used with caution. However, this also implies that scenario data with relatively low standard deviations is more accurate and, therefore, the corresponding scenarios are better able to withstand delays.

Table 8.3: KPIs from AirTOp simulations: stand change percentage, average total delay per executed movement, and average stand delay per executed movement

	KPIs from AirTOp simulation results (averaged across 10 simulation runs)														
Scenario	**Stand changes [%]**			**Cumulative total delay [hrs]**			**Average total delay per movement [s]**			**Cumulative stand delay [hrs]**			**Average stand delay per movement [s]**		
	AVG	STDEV	SE	AVG	STDEV	SE	AVG	STDEV	SE	AVG	STDEV	SE	AVG	STDEV	SE
BT = 0	16.0	0.7	0.2	42.0	8.4	2.7	86.1	17.3	5.5	17.4	5.3	1.7	35.7	10.8	3.4
BT = 20	8.7	0.5	0.2	18.9	3.0	0.9	42.0	6.6	2.1	4.9	1.5	0.5	10.9	3.3	1.0
Scenario 1 - 60	13.2	0.7	0.2	36.4	26.2	8.3	76.2	55.0	17.4	13.2	18.3	5.8	27.7	38.3	12.1
Scenario 1 - 70	12.6	0.9	0.3	35.5	10.5	3.3	74.9	22.1	7.0	13.6	5.5	1.7	28.7	11.5	3.6
Scenario 1 - 80	12.2	1.1	0.4	21.5	3.2	1.0	46.5	6.9	2.2	4.7	1.5	0.5	10.1	3.2	1.0
Scenario 1 - 90	10.8	0.5	0.2	15.6	3.2	1.0	36.3	7.5	2.4	3.4	0.6	0.2	7.8	1.5	0.5
Scenario 2 - 60	13.8	0.9	0.3	31.4	9.4	3.0	65.9	19.7	6.2	10.8	7.2	2.3	22.6	15.0	4.7
Scenario 2 - 70	13.0	0.3	0.1	32.4	16.2	5.1	68.7	34.4	10.9	11.3	10.4	3.3	24.0	22.0	6.9
Scenario 2 - 80	12.7	0.6	0.2	22.9	4.4	1.4	50.1	9.5	3.0	6.6	3.4	1.1	14.3	7.5	2.4
Scenario 2 - 90	12.1	1.4	0.4	16.7	1.6	0.5	38.7	3.7	1.2	3.5	0.7	0.2	8.1	1.7	0.6

Based on the available data, however, it shows that delay data decreases with an increasing buffer time. An interesting exception can be seen for scenario 2 - 70 regarding the cumulative total and the cumulative stand delay, and regarding the corresponding average total and stand delay per executed movement. This might be an effect of the slightly larger tow movement percentage, providing more room for delay, and, in comparison, similar or slightly larger buffers with regard to scenario 1 - 60 and scenario 2 - 60. However, it should be noted that the standard deviation and standard error of the mean values show that averages on delay might be off. Overall, it can be stated with more confidence that scenarios with relatively large buffer times tend to absorb delays better.

8.2. Conclusions

In answer to the research question: it has not yet been proven that the robustness of a model for operational stand and gate allocation at Amsterdam Airport Schiphol is increased by optimising buffer times and covering all allocation rules and procedures. In the process of providing an answer and with regard to the subresearch questions: the relevant criteria and objectives to create a model for operational stand and gate allocation in general are given in Chapter 2, and, regarding the criteria and objectives for Amsterdam Airport Schiphol specifically, in Chapter 3. Next, methods to adapt buffer times and their implementations into a model are given in Chapter 4 and Chapter 5. Suitable KPIs to assess an allocation schedule on robustness and aircraft handling capacity are presented in Chapter 6 and Chapter 7. The KPI results are summarised in Section 8.1 as well.

Before the answer to the research question is explained in more detail, it has to be taken into account that the operational SGA schedule at Schiphol is merely a baseline that is manually adapted until all flights are allocated. In this process, the requirement to use the theoretical buffer time of 20 minutes is discarded in case the stand demand requires so. Furthermore, the schedule is adapted throughout the day, based on up-to-date delay data. Therefore, it is difficult to compare the for this thesis modelled allocation schedules to real schedules.

As has been described in Chapter 3, the allocation schedules as used at Schiphol are incomplete with regard to allocation rules and procedures. Therefore, the for this thesis modelled allocation schedules do surpass the baseline allocation schedules in completeness of incorporation of these rules. With the implementation of all allocation rules and procedures in the SGA model, the operational schedule is already more robust in the sense that less manual adjustments are necessary. A KPI that proves an improvement with regard to the current allocation procedures at Schiphol, is the stand change percentage as a result of testing the for this thesis created allocation schedules in AirTOp: all stand change percentages as a result of simulation in AirTOp are far under the estimation of 40% [12].

With regard to the buffer time optimisation, the results corresponding to the optimised allocation schedule scenarios are compared to two baseline schedules that are modelled for this thesis: one is a schedule that uses a buffer time of 0 minutes, which has the benefit that all flights are allocated; the other is a schedule that uses a buffer time of 20 minutes, which has the benefit that the theoretical buffer time as stated in RASAS [3] is used. With regard to the first schedule: it performs worst in terms of the set KPIs, except for the percentage of unallocated flights and the clash probability. With regard to the second schedule: it performs similar to the optimised subscenario 1 - 80 and 90, which are schedules for which the mean, the median and the mode are approximately 20 minutes.

In short, the increase of buffer times proves to have an influence on the increase in the average stand utilisation per allocated movement; on the increase in Pier Service Level (PSL) of WIBO aircraft; on the decrease in average clash probability per allocated movement, based on recorded flight delay data; and on the decrease in stand change percentage. For these KPIs, scenario 1 buffer times provide better results than scenario 2 buffer times, and similar results as the allocation schedule with a buffer time of 20 minutes. Scenario 1 - 80 and 90 perform better in terms of WIBO PSL, however.

An interesting result is obtained for the delay data using the fast-time simulation programme AirTOp, averaged across ten simulations. The standard deviations and the standard errors of the mean for the delay data indicate that the results on the averages for scenarios with low buffer times are less accurate than the results on the averages for scenarios with large buffer times. With low buffer time scenarios, the scenarios 1 - 60, 1 - 70, 2 - 60, 2 - 70, and the scenario using a buffer time of 0 minutes are meant. In any case, the delay data shows a tendency of decreasing for an increasing buffer time, however. For the scenarios 1 - 80, 1 - 90, 2 - 80, 2 - 90, and the scenario using a buffer time of 20 minutes, it can be stated with more confidence that delay values are relatively low, and that the corresponding allocation schedules are more robust with regard to absorbing delays.

In spite of the lack of a watertight answer, the results of this research are of valuable contribution to the body of knowledge. It appears that grouping and optimising buffer times in time blocks for certain flights has a positive impact on KPIs that indicate robustness, or at least is similar to a schedule for which the theoretical buffer time of 20 minutes is used. The KPIs that indicate robustness here are the average clash probability per allocated movement, the stand change percentage, and the average delay and stand delay per executed movement. It shows that it is of value to vary buffer times during the day for the optimisation of resources and operations at an airport, as well as to implement business rules into the model in order to provide a practical and operational plan that needs little to none manual adjustments. With regard to the resource optimisation, the scenarios with the largest optimised buffer times generate the best results in terms of WIBO PSLs.

The research is of contribution in a practical sense as well, as the ability of allocation schedules from the BEONTRA Scenario Planning tool to withstand common delays is tested in a fast-time simulation programme. Furthermore, more insight is gained into factors that might optimise the operations at Schiphol, such as the inclusion of all allocation procedures and the use of delay data for buffer time optimisation. The research also proves the capacity issues at Schiphol, from which it can be concluded that more stands are necessary to improve operations. The building of pier A has already started, which could provide better results in terms of the in this thesis determined KPIs.

In summary, optimising buffer times has proven to increase robustness. It has shown that improving operations alone is not realistic for a peak day for which the maximum stand capacity is reached, however, and that more stands would be preferable on a peak day such as Monday 16 July 2018. Together with a model that includes all allocation rules and procedures, optimised buffer times show great potential to improve airport operations. With the predicted growth in air traffic travel numbers, the need for optimal use of airport resources has already been mentioned in Chapter 1. Hence, stand and gate allocation indeed is an interesting and challenging subject for corresponding research: therefore, follow-up research is highly recommended and specified further in Section 8.3.

8.3. Recommendations

As stated in the previous section, a substantiated answer to the research question can be provided if the modelled allocation schedule results are compared to actual allocations at Amsterdam Airport Schiphol on 16 July 2018. This data is hard to achieve, however, as Schiphol hardly uses operational allocation schedules: rather tactical schedules are used. If possible, it would be of great value to compare the research results of this thesis to actual allocation data, perhaps by focussing on tactical scheduling more.

Furthermore, it shows that the delay data as generated by AirTOp may vary considerably per simulation run, as shown by the standard deviations and the standard errors of the mean. In order to draw more accurate conclusions, additional simulation runs could be performed.

Regarding more accurate conclusions, it could be of positive contribution to use more historical delay data in order to compute the clash probabilities and individually optimised buffer times. The additional data can then be used to further optimise buffer times as well: the influences of more specification details can then be investigated, such as narrowing the time periods down to an hour during peak hours, or by grouping flights differently.

Regarding the grouping of flights, it might be an interesting area of research to carry out buffer time optimisation on other airports as well, and research whether the grouping is subject to the configuration of an airport. Different flight grouping might have a different influence on the robustness of one airport with regard to another.

Buffer times can also be optimised for the winter period. A challenging, additional requirement is one of de-icing and the corresponding implementation of de-icing activities in the SGA model, as well as the potential influences of harsh weather conditions and corresponding delay outliers.

Last, an interesting topic would be to research the influence of buffer time optimisation as part of the SGA problem, integrated with other airport ground management operations, being the runway allocation and scheduling, and the aircraft ground movement.

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A

Stand specifications Schiphol

APRON/PIER	Name	Stand	Connected	BCS	Screened?	EU-flight?	Bus@gate?	Max. length	Max. wingspan	Cat.
ALFA APRON	A30-STROOK	A31	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
ALFA APRON	A30-STROOK	A32	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
ALFA APRON	A30-STROOK	A33	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
ALFA APRON	A30-STROOK	A34	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
ALFA APRON	A30-STROOK	A35	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
ALFA APRON	A40-STROOK	A41	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
ALFA APRON	A40-STROOK	A42	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
ALFA APRON	A40-STROOK	A43	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
ALFA APRON	A40-STROOK	A44	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
ALFA APRON	A40-STROOK	A45	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
ALFA APRON	A40-STROOK	A46	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A50-STROOK	A51	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A50-STROOK	A52	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A50-STROOK	A53	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A50-STROOK	A54	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A50-STROOK	A55	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A50-STROOK	A56	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A60-STROOK	A61	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A60-STROOK	A62	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A60-STROOK	A63	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A60-STROOK	A64	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A60-STROOK	A65	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A70-STROOK	A71	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A70-STROOK	A72	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A70-STROOK	A73	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A70-STROOK	A74	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	A70-STROOK	A75	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
BRAVO APRON	B80-STROOK	B81	R	W	Unscreened ARR	Yes	No	37.00	29.00	3-
BRAVO APRON	B80-STROOK	B82	R	W	Unscreened ARR	Yes	No	37.00	29.00	3-
BRAVO APRON	B80-STROOK	B83	R	W	Unscreened ARR	Yes	No	37.00	29.00	3-
BRAVO APRON	B80-STROOK	B84	R	W	Unscreened ARR	Yes	No	37.00	29.00	3-
BRAVO APRON	B80-STROOK	B85	R	W	Unscreened ARR	Yes	No	37.00	29.00	3-
BRAVO APRON	B90-STROOK	B91	R	W	Unscreened ARR	Yes	No	37.00	29.00	3-
BRAVO APRON	B90-STROOK	B92	R	W	Unscreened ARR	Yes	No	37.00	29.00	3-
BRAVO APRON	B90-STROOK	B93	R	W	Unscreened ARR	Yes	No	37.00	29.00	3-
BRAVO APRON	B90-STROOK	B94	R	W	Unscreened ARR	Yes	No	37.00	29.00	3-
BRAVO APRON	B90-STROOK	B95	R	W	Unscreened ARR	Yes	No	37.00	29.00	3-
BRAVO PIER	B-PIER	B13	C	S	Screened ARR	No	No	46.50	36.00	4+
BRAVO PIER	B-PIER	B15	C	S	Unscreened ARR	No	Yes	46.50	36.00	4+
BRAVO PIER	B-PIER	B16	C	S	Unscreened ARR	No	Yes	37.00	29.00	3
BRAVO PIER	B-PIER	B17	C	S	Unscreened ARR	No	Yes	46.50	36.00	4+
BRAVO PIER	B-PIER	B20	C	S	Screened ARR	No	No	37.00	29.00	3
BRAVO PIER	B-PIER	B23	C	S	Screened ARR	No	No	46.50	36.00	4+
BRAVO PIER	B-PIER	B24	C	S	Screened ARR	No	No	37.00	29.00	3
BRAVO PIER	B-PIER	B27	C	S	Unscreened ARR	No	Yes	46.50	36.00	4+
BRAVO PIER	B-PIER	B28	C	S	Screened ARR	No	No	37.00	29.00	3
BRAVO PIER	B-PIER	B31	C	S	Screened ARR	No	No	46.50	36.00	4+
BRAVO PIER	B-PIER	B32	C	S	Screened ARR	No	No	37.00	29.00	3
BRAVO PIER	B-PIER	B35	C	S	Screened ARR	No	No	46.50	36.00	4+
BRAVO PIER	B-PIER	B36	C	S	Screened ARR	No	No	37.00	29.00	3

CHARLIE PIER	C-PIER	C04	C	S	Unscreened ARR	No	Yes	45.00	36.00	4
CHARLIE PIER	C-PIER	C05	C	S	Screened ARR	No	No	54.43	41.10	4+
CHARLIE PIER	C-PIER	C06	C	S	Unscreened ARR	No	Yes	45.00	36.00	4
CHARLIE PIER	C-PIER	C07	C	S	Screened ARR	No	No	54.43	41.10	4+
CHARLIE PIER	C-PIER	C08	C	S	Unscreened ARR	No	Yes	45.00	36.00	4
CHARLIE PIER	C-PIER	C09	C	S	Screened ARR	No	No	54.43	41.10	4+
CHARLIE PIER	C-PIER	C10	C	S	Screened ARR	No	No	45.00	36.00	4
CHARLIE PIER	C-PIER	C11	C	S	Screened ARR	No	No	45.00	36.00	4
CHARLIE PIER	C-PIER	C12	C	S	Screened ARR	No	No	45.00	36.00	4
CHARLIE PIER	C-PIER	C13	C	S	Screened ARR	No	No	45.00	36.00	4
CHARLIE PIER	C-PIER	C14	C	S	Screened ARR	No	No	45.00	36.00	4
CHARLIE PIER	C-PIER	C15	C	S	Screened ARR	No	No	45.00	36.00	4-
CHARLIE PIER	C-PIER	C16	C	S	Screened ARR	No	No	45.00	36.00	4
CHARLIE PIER	C-PIER	C18	C	S	Screened ARR	No	No	45.00	36.00	4
DELTA PIER	D-PIER	D02	C	W	Screened ARR	Yes	No	61.60	52.00	6+
DELTA PIER	D-PIER	D03	C	W	Screened ARR	Yes	No	72.00	61.00	7
DELTA PIER	D-PIER	D04	C	W	Screened ARR	Yes	No	55.50	52.00	6-
DELTA PIER	D-PIER	D05	C	W	Screened ARR	Yes	No	45.00	36.00	4
DELTA PIER	D-PIER	D07	C	W	Unscreened ARR	Yes	Yes	72.00	61.00	7-
DELTA PIER	D-PIER	D08	C	W	Screened ARR	Yes	No	55.50	52.00	6
DELTA PIER	D-PIER	D10	C	W	Screened ARR	Yes	No	49.00	44.00	5-
DELTA PIER	D-PIER	D12	C	W	Screened ARR	Yes	No	49.00	44.00	5
DELTA PIER	D-PIER	D14	C	NS	Screened ARR	Yes	No	45.00	36.00	4-
DELTA PIER	D-PIER	D16	C	NS	Screened ARR	Yes	No	46.50	36.00	4+
DELTA PIER	D-PIER	D18	C	NS	Screened ARR	Yes	No	46.50	36.00	4+
DELTA PIER	D-PIER	D22	C	NS	Unscreened ARR	Yes	Yes	46.50	36.00	4+
DELTA PIER	D-PIER	D23	C	NS	Unscreened ARR	Yes	Yes	45.00	36.00	4-
DELTA PIER	D-PIER	D24	C	NS	Unscreened ARR	Yes	Yes	46.50	36.00	4+
DELTA PIER	D-PIER	D25	C	NS	Unscreened ARR	Yes	Yes	45.00	36.00	4
DELTA PIER	D-PIER	D26	C	NS	Screened ARR	Yes	No	46.50	36.00	4+
DELTA PIER	D-PIER	D27	C	NS	Unscreened ARR	Yes	Yes	45.00	36.00	4
DELTA PIER	D-PIER	D28	C	NS	Unscreened ARR	Yes	Yes	46.50	36.00	4+
DELTA PIER	D-PIER	D29	C	NS	Unscreened ARR	Yes	Yes	45.00	36.00	4
DELTA PIER	D-PIER	D31	C	NS	Screened ARR	Yes	No	45.00	36.00	4
DELTA PIER	D-PIER	D41	C	W	Screened ARR	Yes	No	45.00	36.00	4
DELTA PIER	D-PIER	D43	C	W	Screened ARR	Yes	No	76.00	65.00	8-
DELTA PIER	D-PIER	D44	C	W	Screened ARR	Yes	No	45.00	36.00	4-
DELTA PIER	D-PIER	D47	C	W	Screened ARR	Yes	No	72.00	61.00	7-
DELTA PIER	D-PIER	D48	C	W	Unscreened ARR	Yes	Yes	45.00	36.00	4
DELTA PIER	D-PIER	D49	C	W	Screened ARR	Yes	No	72.00	61.00	7-
DELTA PIER	D-PIER	D51	C	W	Screened ARR	Yes	No	45.00	36.00	4
DELTA PIER	D-PIER	D52	C	W	Unscreened ARR	Yes	Yes	45.00	36.00	4
DELTA PIER	D-PIER	D53	C	W	Screened ARR	Yes	No	72.00	61.00	7-
DELTA PIER	D-PIER	D54	C	W	Unscreened ARR	Yes	Yes	45.00	36.00	4
DELTA PIER	D-PIER	D55	C	W	Screened ARR	Yes	No	45.00	36.00	4
DELTA PIER	D-PIER	D56	C	W	Unscreened ARR	Yes	Yes	45.00	36.00	4
DELTA PIER	D-PIER	D57	C	W	Screened ARR	Yes	No	72.00	61.00	7-
DELTA RAMP	D-BUFFER	D88	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
DELTA RAMP	D-BUFFER	D90	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
DELTA RAMP	D-BUFFER	D92	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
DELTA RAMP	D-BUFFER	D93	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
DELTA RAMP	D-BUFFER	D94	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
DELTA RAMP	D-BUFFER	D95	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
ECHO PIER	E-PIER	E02	C	NS	Unscreened ARR	No	No	72.00	61.00	7
ECHO PIER	E-PIER	E03	C	NS	Unscreened ARR	No	No	72.00	61.00	7
ECHO PIER	E-PIER	E04	C	NS	Unscreened ARR	Yes	No	45.00	36.00	4
ECHO PIER	E-PIER	E05	C	NS	Unscreened ARR	Yes	No	72.00	61.00	7

ECHO PIER	E-PIER	E06	C	NS	Unscreened ARR	Yes	No	72.00	61.00	7
ECHO PIER	E-PIER	E07	C	NS	Unscreened ARR	Yes	No	76.00	65.00	8
ECHO PIER	E-PIER	E08	C	NS	Unscreened ARR	No	No	76.00	65.00	8
ECHO PIER	E-PIER	E09	C	NS	Unscreened ARR	No	No	76.00	65.00	8
ECHO PIER	E-PIER	E17	C	NS	Unscreened ARR	No	No	76.00	65.00	8
ECHO PIER	E-PIER	E18	C	NS	Unscreened ARR	No	No	77.00	80.00	9-
ECHO PIER	E-PIER	E19	C	NS	Unscreened ARR	No	No	76.00	65.00	8
ECHO PIER	E-PIER	E20	C	NS	Unscreened ARR	No	No	76.00	65.00	8
HOTEL PIER	H-PIER	H01	C	W	Unscreened ARR	Yes	Yes	45.00	36.00	4
HOTEL PIER	H-PIER	H02	C	W	Unscreened ARR	Yes	Yes	45.00	36.00	4
HOTEL PIER	H-PIER	H03	C	W	Screened ARR	Yes	No	45.00	36.00	4
HOTEL PIER	H-PIER	H04	C	W	Screened ARR	Yes	No	45.00	36.00	4
HOTEL PIER	H-PIER	H05	C	W	Screened ARR	Yes	No	45.00	36.00	4
HOTEL PIER	H-PIER	H06	C	W	Screened ARR	Yes	No	45.00	36.00	4
HOTEL PIER	H-PIER	H07	C	W	Screened ARR	Yes	No	45.00	36.00	4
JULIET RAMP	J-BUFFER	J80	R	W	Unscreened ARR	Yes	No	46.50	36.00	4
JULIET RAMP	J-BUFFER	J81	R	W	Unscreened ARR	Yes	No	77.00	80.00	9
JULIET RAMP	J-BUFFER	J82	R	W	Unscreened ARR	Yes	No	46.50	36.00	4
JULIET RAMP	J-BUFFER	J83	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
JULIET RAMP	J-BUFFER	J84	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
JULIET RAMP	J-BUFFER	J85	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
JULIET RAMP	J-BUFFER	J86	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
JULIET RAMP	J-BUFFER	J87	R	W	Unscreened ARR	Yes	No	70.67	65.00	8-
KILO APRON	OOST-PLATFORM	K11	R	W	Unscreened ARR	Yes	No	28.00	24.00	2-
KILO APRON	OOST-PLATFORM	K12	R	W	Unscreened ARR	Yes	No	28.00	24.00	2-
KILO APRON	OOST-PLATFORM	K13	R	W	Unscreened ARR	Yes	No	28.00	24.00	2-
KILO APRON	OOST-PLATFORM	K14	R	W	Unscreened ARR	Yes	No	28.00	24.00	2-
KILO APRON	OOST-PLATFORM	K15	R	W	Unscreened ARR	Yes	No	28.00	24.00	2-
KILO APRON	OOST-PLATFORM	K16	R	W	Unscreened ARR	Yes	No	28.00	24.00	2-
KILO APRON	OOST-PLATFORM	K20	R	W	Unscreened ARR	Yes	No	22.00	18.90	1-
KILO APRON	OOST-PLATFORM	K21	R	W	Unscreened ARR	Yes	No	22.00	18.90	1-
KILO APRON	OOST-PLATFORM	K22	R	W	Unscreened ARR	Yes	No	22.00	18.90	1-
KILO APRON	OOST-PLATFORM	K23	R	W	Unscreened ARR	Yes	No	22.00	18.90	1-
KILO APRON	OOST-PLATFORM	K24	R	W	Unscreened ARR	Yes	No	22.00	18.90	1-
KILO APRON	OOST-PLATFORM	K25	R	W	Unscreened ARR	Yes	No	22.00	18.90	1-
KILO APRON	OOST-PLATFORM	K26	R	W	Unscreened ARR	Yes	No	22.00	18.90	1-
KILO APRON	OOST-PLATFORM	K27	R	W	Unscreened ARR	Yes	No	22.00	18.90	1-
KILO APRON	OOST-PLATFORM	K35	R	W	Unscreened ARR	Yes	No	49.00	44.00	5
KILO APRON	OOST-PLATFORM	K36	R	W	Unscreened ARR	Yes	No	49.00	44.00	5
KILO APRON	OOST-PLATFORM	K37	R	W	Unscreened ARR	Yes	No	49.00	44.00	5
KILO APRON	OOST-PLATFORM	K38	R	W	Unscreened ARR	Yes	No	49.00	44.00	5
KILO APRON	OOST-PLATFORM	K39	R	W	Unscreened ARR	Yes	No	49.00	44.00	5
KILO APRON	OOST-PLATFORM	K40	R	W	Unscreened ARR	Yes	No	22.00	24.00	1
KILO APRON	OOST-PLATFORM	K41	R	W	Unscreened ARR	Yes	No	22.00	16.00	1-
KILO APRON	OOST-PLATFORM	K42	R	W	Unscreened ARR	Yes	No	22.00	19.40	1-
KILO APRON	OOST-PLATFORM	K43	R	W	Unscreened ARR	Yes	No	22.00	17.00	1-
KILO APRON	OOST-PLATFORM	K44	R	W	Unscreened ARR	Yes	No	22.00	30.00	1+
KILO APRON	OOST-PLATFORM	K71	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
KILO APRON	OOST-PLATFORM	K72	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
KILO APRON	OOST-PLATFORM	K73	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
KILO APRON	OOST-PLATFORM	K74	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
KILO APRON	OOST-PLATFORM	K75	R	W	Unscreened ARR	Yes	No	15.00	11.00	1-
KILO APRON	OOST-PLATFORM	K76	R	W	Unscreened ARR	Yes	No	15.00	11.00	1-
KILO APRON	OOST-PLATFORM	K77	R	W	Unscreened ARR	Yes	No	15.00	11.00	1-
KILO APRON	OOST-PLATFORM	K78	R	W	Unscreened ARR	Yes	No	15.00	11.00	1-
LIMA RAMP	L-BUFFER (RIJBAAN G03)	L01	R	W	No	Yes	No	45.00	36.00	4
LIMA RAMP	L-BUFFER (RIJBAAN G03)	L02	R	W	No	Yes	No	45.00	36.00	4
LIMA RAMP	L-BUFFER (RIJBAAN G03)	L03	R	W	No	Yes	No	45.00	36.00	4
MIKE RAMP	M-BUFFER	M61	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
MIKE RAMP	M-BUFFER	M62	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
MIKE RAMP	M-BUFFER	M63	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
MIKE RAMP	M-BUFFER	M65	R	W	Unscreened ARR	Yes	No	45.00	36.00	4

MIKE RAMP	M-BUFFER	M66	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
MIKE RAMP	M-BUFFER	M67	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
MIKE RAMP	M-BUFFER	M69	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
MIKE RAMP	M-BUFFER	M70	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
MIKE RAMP	M-BUFFER	M71	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
MIKE RAMP	M-BUFFER	M73	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
MIKE RAMP	M-BUFFER	M74	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
MIKE RAMP	M-BUFFER	M75	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
MIKE RAMP	M-BUFFER	M77	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
MIKE RAMP	M-BUFFER	M79	R	W	Unscreened ARR	Yes	No	45.00	36.00	4
NOVEMBER RAMP	N-BUFFER	Yes41	R	W	Unscreened ARR	Yes	No	76.00	65.00	8-
NOVEMBER RAMP	N-BUFFER	Yes42	R	W	Unscreened ARR	Yes	No	76.00	65.00	8-
PAPA HOLDING	P-HOLDING	PA	No	No	No	No	No	45.00	36.00	4
PAPA HOLDING	P-HOLDING	P1	No	No	No	No	No	77.00	80.00	9-
PAPA HOLDING	P-HOLDING	PB	No	No	No	No	No	45.00	36.00	4
PAPA HOLDING	P-HOLDING	PB	No	No	No	No	No	77.00	80.00	9
PAPA HOLDING	P-HOLDING	P2	No	No	No	No	No	45.00	36.00	4
PAPA HOLDING	P-HOLDING	PC	No	No	No	No	No	45.00	36.00	4
PAPA HOLDING	P-HOLDING	P3	No	No	No	No	No	77.00	80.00	9
PAPA HOLDING	P-HOLDING	PD	No	No	No	No	No	45.00	36.00	4
PAPA HOLDING	P-HOLDING	P20	No	No	No	No	No	45.00	36.00	4
PAPA HOLDING	P-HOLDING	P21	No	No	No	No	No	45.00	36.00	4
PAPA PLATFORM	DE-ICING BUFFER	P10	R	W	Unscreened ARR	Yes	No	77.00	80.00	9
PAPA PLATFORM	DE-ICING BUFFER	P11	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
PAPA PLATFORM	DE-ICING BUFFER	P12	R	W	Unscreened ARR	Yes	No	77.00	80.00	9
PAPA PLATFORM	DE-ICING BUFFER	P13	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
PAPA PLATFORM	DE-ICING BUFFER	P14	R	W	Unscreened ARR	Yes	No	77.00	80.00	9
PAPA PLATFORM	DE-ICING BUFFER	P15	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
PAPA PLATFORM	DE-ICING BUFFER	P16	R	W	Unscreened ARR	Yes	No	77.00	80.00	9
PAPA PLATFORM	DE-ICING BUFFER	P10	R	W	Unscreened ARR	Yes	No	77.00	80.00	9-
PAPA PLATFORM	DE-ICING BUFFER	P12	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
PAPA PLATFORM	DE-ICING BUFFER	P14	R	W	Unscreened ARR	Yes	No	77.00	80.00	9
PAPA PLATFORM	DE-ICING BUFFER	P16	R	W	Unscreened ARR	Yes	No	77.00	80.00	9
ROMEO CARGO APRON	R-PLATFORM	R71	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
ROMEO CARGO APRON	R-PLATFORM	R72	R	W	Unscreened ARR	Yes	No	77.00	80.00	9-
ROMEO CARGO APRON	R-PLATFORM	R73	R	W	Unscreened ARR	Yes	No	37.00	29.00	3
ROMEO CARGO APRON	R-PLATFORM	R74	R	W	Unscreened ARR	Yes	No	77.00	80.00	9-
ROMEO CARGO APRON	R-PLATFORM	R77	R	W	Unscreened ARR	Yes	No	77.00	80.00	9-
ROMEO CARGO APRON	R-PLATFORM	R80	R	W	Unscreened ARR	Yes	No	77.00	80.00	9-
ROMEO CARGO APRON	R-PLATFORM	R81	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
ROMEO CARGO APRON	R-PLATFORM	R82	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
ROMEO CARGO APRON	R-PLATFORM	R83	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
ROMEO CARGO APRON	R-PLATFORM	R87	R	W	Unscreened ARR	Yes	No	55.50	52.00	6
SIERRA CARGO APRON	S-PLATFORM	S72	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
SIERRA CARGO APRON	S-PLATFORM	S74	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
SIERRA CARGO APRON	S-PLATFORM	S77	R	W	Unscreened ARR	Yes	No	77.00	80.00	9-
SIERRA CARGO APRON	S-PLATFORM	S79	R	W	Unscreened ARR	Yes	No	77.00	80.00	9-
SIERRA CARGO APRON	S-PLATFORM	S82	R	W	Unscreened ARR	Yes	No	77.00	80.00	9-
SIERRA CARGO APRON	S-PLATFORM	S84	R	W	Unscreened ARR	Yes	No	77.00	80.00	9-
SIERRA CARGO APRON	S-PLATFORM	S87	R	W	Unscreened ARR	Yes	No	77.00	80.00	9-
SIERRA CARGO APRON	S-PLATFORM	S90	R	W	Unscreened ARR	Yes	No	77.00	80.00	9-
SIERRA CARGO APRON	S-PLATFORM	S92	R	W	Unscreened ARR	Yes	No	77.00	80.00	9-
SIERRA CARGO APRON	S-PLATFORM	S94	R	W	Unscreened ARR	Yes	No	77.00	80.00	9-
SIERRA CARGO APRON	S-PLATFORM	S96	R	W	Unscreened ARR	Yes	No	77.00	80.00	9-
UNIFORM RAMP	U-BUFFER	U01	R	W	Unscreened ARR	Yes	No	77.00	80.00	9
UNIFORM RAMP	U-BUFFER	U02	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
UNIFORM RAMP	U-BUFFER	U03	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
UNIFORM RAMP	U-BUFFER	U04	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
UNIFORM RAMP	U-BUFFER	U05	R	W	Unscreened ARR	Yes	No	76.00	65.00	8
Yankee RAMP	Y-BUFFER	Y71	R	W	Unscreened ARR	Yes	No	72.00	61.00	7
Yankee RAMP	Y-BUFFER	Y72	R	W	Unscreened ARR	Yes	No	72.00	61.00	7
Yankee RAMP	Y-BUFFER	Y73	R	W	Unscreened ARR	Yes	No	72.00	61.00	7

B
Allocation business rules

Due to confidentiality, the business rules are not included to this report.

C

Timeslot allocation schedule for Schiphol, Monday 16 July 2018 (excerpt)

A/D	Airline_2L	Airline_3L	Aircraft	Category	Callsign	Date and time	Origin/Dest.	Flight type	Status
D	KL	KLM	73H	4	KL1823	16-07-18 10:15	TXL	J	DEPARTURE_SCHENGEN
D	KL	KLM	73H	4	KL1839	16-07-18 6:50	VIE	J	DEPARTURE_SCHENGEN
D	FX	FDX	75F	5	FX5187	16-07-18 22:40	CDG	F	DEPARTURE_SCHENGEN
D	KL	KLM	E75	3	KL1853	16-07-18 6:50	DUS	J	DEPARTURE_SCHENGEN
D	KL	KLM	73H	4	KL1103	16-07-18 6:50	ARN	J	DEPARTURE_SCHENGEN
D	KL	KLM	E90	3	KL1141	16-07-18 7:00	OSL	J	DEPARTURE_SCHENGEN
D	KL	KLM	E90	3	KL1165	16-07-18 6:55	HEL	J	DEPARTURE_SCHENGEN
D	KL	KLM	73W	4	KL1223	16-07-18 6:45	CDG	J	DEPARTURE_SCHENGEN
D	KL	KLM	73W	4	KL1277	16-07-18 7:10	EDI	J	DEPARTURE_EU
D	KL	KLM	E90	3	KL1925	16-07-18 7:00	GVA	J	DEPARTURE_SCHENGEN
D	KL	KLM	E90	3	KL1953	16-07-18 7:05	ZRH	J	DEPARTURE_SCHENGEN
D	KL	KLM	E90	3	KL1351	16-07-18 6:50	PRG	J	DEPARTURE_SCHENGEN
D	KL	KLM	73W	4	KL1355	16-07-18 12:10	PRG	J	DEPARTURE_SCHENGEN
D	LH	DLH	32S	4	LH1003	16-07-18 8:05	FRA	J	DEPARTURE_SCHENGEN
D	LH	DLH	CR9	3	LH2311	16-07-18 7:00	MUC	J	DEPARTURE_SCHENGEN
D	HV	TRA	73H	4	HV5749	16-07-18 21:20	CMN	J	DEPARTURE_NEU_UNSCREENED
D	S5	LLC	320	4	LLX5011	16-07-18 7:20	KGS	C	DEPARTURE_SCHENGEN
D	LO	LOT	E95	4	LO270	16-07-18 7:05	WAW	J	DEPARTURE_SCHENGEN
D	HV	TRA	73H	4	HV5807	16-07-18 10:00	SKG	J	DEPARTURE_SCHENGEN
D	AZ	AZA	320	4	AZ0111	16-07-18 7:20	FCO	J	DEPARTURE_SCHENGEN
D	AZ	AZA	319	4	AZ0119	16-07-18 7:15	LIN	J	DEPARTURE_SCHENGEN
D	BA	BAW	319	4	BA0423	16-07-18 7:45	LHR	J	DEPARTURE_EU
D	BA	BAW	E70	3	BA8450	16-07-18 7:15	LCY	J	DEPARTURE_EU
D	QY	BCS	ABY	6	BCS1239	16-07-18 23:10	LEJ	F	DEPARTURE_SCHENGEN
D	HV	TRA	73H	4	HV6917	16-07-18 7:40	OLB	J	DEPARTURE_SCHENGEN
D	I2	IBS	320	4	I23721	16-07-18 8:00	MAD	J	DEPARTURE_SCHENGEN
D	CD	CND	738	4	CND113	16-07-18 5:20	MJT	C	DEPARTURE_SCHENGEN
D	KL	KLM	772	7	KL0433	16-07-18 17:40	IKA	J	DEPARTURE_NEU_UNSCREENED
D	LX	CRX	319	4	LX737	16-07-18 7:00	ZRH	J	DEPARTURE_SCHENGEN
D	OR	TFL	73H	4	OR161	16-07-18 7:30	OHD	J	DEPARTURE_NEU_UNSCREENED
D	OR	TFL	76W	6	OR231	16-07-18 13:00	HER	C	DEPARTURE_SCHENGEN
D	OR	TFL	343	7	OR541	16-07-18 15:15	LPA	C	DEPARTURE_SCHENGEN
D	OR	TFL	73H	4	OR603	16-07-18 7:30	CTA	J	DEPARTURE_SCHENGEN
D	OR	TFL	73H	4	OR617	16-07-18 7:50	PMI	J	DEPARTURE_SCHENGEN
D	OR	TFL	73H	4	OR649	16-07-18 7:30	TFS	J	DEPARTURE_SCHENGEN

D	KL	KLM	73J	4	KL1597	16-07-18 7:15	FCO	J	DEPARTURE_SCHENGEN
D	OS	AUA	E95	4	OS378	16-07-18 7:00	VIE	J	DEPARTURE_SCHENGEN
D	KL	KLM	73H	4	KL1629	16-07-18 10:25	MXP	J	DEPARTURE_SCHENGEN
D	PC	PGT	738	4	PC1256	16-07-18 0:05	SAW	J	DEPARTURE_NEU_UNSCREENED
D	RU	ABW	74Y	8	RU154	16-07-18 22:00	SVO	F	DEPARTURE_NEU_UNSCREENED
D	RU	ABW	74N	9	RU742A	16-07-18 11:00	SVO	F	DEPARTURE_NEU_UNSCREENED
D	SK	SAS	320	4	SK550	16-07-18 6:20	CPH	J	DEPARTURE_SCHENGEN
D	KL	KLM	73H	4	KL1671	16-07-18 10:15	BCN	J	DEPARTURE_SCHENGEN
D	CD	CND	738	4	CND197	16-07-18 10:55	FAO	C	DEPARTURE_SCHENGEN
D	SU	AFL	73H	4	SU2193	16-07-18 0:15	SVO	J	DEPARTURE_NEU_UNSCREENED
D	CD	CND	320	4	CND311	16-07-18 3:20	HER	C	DEPARTURE_SCHENGEN
D	KL	KLM	73H	4	KL1699	16-07-18 7:00	MAD	J	DEPARTURE_SCHENGEN
D	TP	TAP	320	4	TP669	16-07-18 7:00	LIS	J	DEPARTURE_SCHENGEN
D	KL	KLM	E90	3	KL1721	16-07-18 6:50	BRU	J	DEPARTURE_SCHENGEN
D	VY	VLG	320	4	VY6291	16-07-18 7:00	FCO	J	DEPARTURE_SCHENGEN
D	CZ	CSN	77F	8	CZ0479	16-07-18 9:00	PVG	F	DEPARTURE_NEU_UNSCREENED
D	VY	VLG	320	4	VY8318	16-07-18 7:20	BCN	J	DEPARTURE_SCHENGEN
D	VY	VLG	320	4	VY8404	16-07-18 7:00	LTN	J	DEPARTURE_EU
D	KL	KLM	E75	3	KL1765	16-07-18 10:00	FRA	J	DEPARTURE_SCHENGEN
D	Y8	YZR	74Y	8	Y87456	16-07-18 17:00	PVG	F	DEPARTURE_NEU_UNSCREENED
D	EI	EIN	320	4	EI0609	16-07-18 17:00	DUB	J	DEPARTURE_EU
D	U2	EZY	319	4	EZY1354	16-07-18 7:25	GVA	J	DEPARTURE_SCHENGEN
D	KL	KLM	73W	4	KL1791	16-07-18 7:20	MUC	J	DEPARTURE_SCHENGEN
D	U2	EZY	320	4	EZY7903	16-07-18 7:50	ZRH	J	DEPARTURE_SCHENGEN
D	U2	EZY	319	4	EZY7905	16-07-18 10:55	PRG	J	DEPARTURE_SCHENGEN
D	U2	EZY	319	4	EZY7911	16-07-18 7:30	LYS	J	DEPARTURE_SCHENGEN
D	U2	EZY	320	4	EZY7925	16-07-18 7:00	NCE	J	DEPARTURE_SCHENGEN
D	U2	EZY	320	4	EZY7933	16-07-18 7:20	TLV	J	DEPARTURE_NEU_UNSCREENED
D	U2	EZY	320	4	EZY7957	16-07-18 5:00	AGP	J	DEPARTURE_SCHENGEN
D	KL	KLM	73W	4	KL1821	16-07-18 7:00	TXL	J	DEPARTURE_SCHENGEN
D	U2	EZY	319	4	EZY7975	16-07-18 7:20	FCO	J	DEPARTURE_SCHENGEN
D	KL	KLM	AR8	3	KL0945	16-07-18 9:45	DUB	J	DEPARTURE_EU
D	U2	EZY	321	4	EZY8868	16-07-18 7:05	LGW	J	DEPARTURE_EU
D	KL	KLM	AR8	3	KL0979	16-07-18 7:00	LCY	J	DEPARTURE_EU
D	KL	KLM	AR8	3	KL0987	16-07-18 8:00	LCY	J	DEPARTURE_EU
D	KL	KLM	73H	4	KL1001	16-07-18 7:20	LHR	J	DEPARTURE_EU
A	KL	KLM	E75	3	KL1960	16-07-18 15:47	ZRH	J	ARRIVAL_SCHENGEN
A	KL	KLM	73H	4	KL1962	16-07-18 19:07	ZRH	J	ARRIVAL_SCHENGEN
A	AF	AFR	320	4	AF1806	16-07-18 8:42	MRS	J	ARRIVAL_SCHENGEN
A	SK	SAS	320	4	SK2551	16-07-18 9:37	CPH	J	ARRIVAL_SCHENGEN
A	AF	AFR	319	4	AF1820	16-07-18 11:32	MRS	J	ARRIVAL_SCHENGEN
A	AF	AFR	321	4	AF1874	16-07-18 19:37	MRS	J	ARRIVAL_SCHENGEN
A	SQ	SIA	359	8	SQ324	16-07-18 7:07	SIN	J	ARRIVAL_NEU_UNSCREENED
A	AF	AFR	CRK	4	AF1892	16-07-18 18:52	NTE	J	ARRIVAL_SCHENGEN
A	AM	AMX	788	7	AM0025	16-07-18 17:52	MEX	J	ARRIVAL_NEU_UNSCREENED
A	SQ	SIA	74Y	8	SQ7343	16-07-18 9:42	NBO	F	ARRIVAL_NEU_UNSCREENED
A	AT	RAM	734	3	AT620	16-07-18 20:07	AHU	J	ARRIVAL_NEU_UNSCREENED
A	AT	RAM	320	4	AT670	16-07-18 11:52	NDR	J	ARRIVAL_NEU_UNSCREENED
A	SQ	SIA	74Y	8	SQ7370	16-07-18 16:17	SIN	F	ARRIVAL_NEU_UNSCREENED
A	AT	RAM	738	4	AT686	16-07-18 14:37	TNG	J	ARRIVAL_NEU_UNSCREENED
A	AT	RAM	738	4	AT850	16-07-18 16:42	CMN	J	ARRIVAL_NEU_UNSCREENED
A	AT	RAM	73G	4	AT852	16-07-18 18:47	CMN	J	ARRIVAL_NEU_UNSCREENED
A	SU	AFL	73H	4	SU2192	16-07-18 22:17	SVO	J	ARRIVAL_NEU_UNSCREENED
A	AY	FIN	321	4	AY841	16-07-18 9:37	HEL	J	ARRIVAL_SCHENGEN
A	AY	FIN	321	4	AY845	16-07-18 17:37	HEL	J	ARRIVAL_SCHENGEN
A	SU	AFL	320	4	SU2550	16-07-18 11:52	SVO	J	ARRIVAL_NEU_UNSCREENED
A	AZ	AZA	321	4	AZ0108	16-07-18 10:37	FCO	J	ARRIVAL_SCHENGEN
A	AZ	AZA	321	4	AZ0110	16-07-18 16:52	FCO	J	ARRIVAL_SCHENGEN
A	SU	AFL	320	4	SU2694	16-07-18 17:12	SVO	J	ARRIVAL_NEU_UNSCREENED

A	KL	KLM	77W	8	KL0622	16-07-18 12:37	ATL	J	ARRIVAL_NEU_SCREENED
A	KL	KLM	772	7	KL0642	16-07-18 6:47	JFK	J	ARRIVAL_NEU_SCREENED
A	AZ	AZA	320	4	AZ0112	16-07-18 19:12	LIN	J	ARRIVAL_SCHENGEN
A	KL	KLM	74E	8	KL0644	16-07-18 11:27	JFK	J	ARRIVAL_NEU_SCREENED
A	SV	SVA	74Y	8	SV0933	16-07-18 10:52	JED	F	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	772	7	KL0652	16-07-18 7:07	IAD	J	ARRIVAL_NEU_SCREENED
A	KL	KLM	333	7	KL0656	16-07-18 5:52	MSP	J	ARRIVAL_NEU_SCREENED
A	AZ	AZA	319	4	AZ0118	16-07-18 22:47	LIN	J	ARRIVAL_SCHENGEN
A	AZ	AZA	319	4	AZ0120	16-07-18 10:52	LIN	J	ARRIVAL_SCHENGEN
A	KL	KLM	789	7	KL0662	16-07-18 7:12	IAH	J	ARRIVAL_NEU_SCREENED
A	SX	SRK	S20	2	SX300	16-07-18 13:32	BRN	J	ARRIVAL_SCHENGEN
A	KL	KLM	332	7	KL0672	16-07-18 7:27	YUL	J	ARRIVAL_NEU_SCREENED
A	AZ	AZA	320	4	AZ0132	16-07-18 22:47	FCO	J	ARRIVAL_SCHENGEN
A	B2	BRU	735	3	B20867	16-07-18 11:02	MSQ	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	789	7	KL0678	16-07-18 8:07	YYC	J	ARRIVAL_NEU_SCREENED
A	TK	THY	333	7	TK1951	16-07-18 9:32	IST	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	772	7	KL0682	16-07-18 10:02	YVR	J	ARRIVAL_NEU_SCREENED
A	BA	BAW	767	6	BA0428	16-07-18 8:57	LHR	J	ARRIVAL_EU
A	KL	KLM	74E	8	KL0686	16-07-18 14:32	MEX	J	ARRIVAL_NEU_UNSCREENED
A	TK	THY	333	7	TK1953	16-07-18 17:37	IST	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	744	8	KL0692	16-07-18 5:47	YYZ	J	ARRIVAL_NEU_SCREENED
A	BA	BAW	321	4	BA0430	16-07-18 10:32	LHR	J	ARRIVAL_EU
A	KL	KLM	772	7	KL0696	16-07-18 11:52	YYZ	J	ARRIVAL_NEU_SCREENED
A	KL	KLM	789	7	KL0706	16-07-18 14:12	GIG	J	ARRIVAL_NEU_UNSCREENED
A	BA	BAW	320	4	BA0432	16-07-18 16:52	LHR	J	ARRIVAL_EU
A	KL	KLM	744	8	KL0714	16-07-18 7:32	PBM	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	789	7	KL0716	16-07-18 10:37	PBM	J	ARRIVAL_NEU_UNSCREENED
A	BA	BAW	320	4	BA0434	16-07-18 13:57	LHR	J	ARRIVAL_EU
A	KL	KLM	332	7	KL0724	16-07-18 9:57	HAV	J	ARRIVAL_NEU_UNSCREENED
A	BA	BAW	321	4	BA0438	16-07-18 15:07	LHR	J	ARRIVAL_EU
A	KL	KLM	332	7	KL0730	16-07-18 7:52	SXM	J	ARRIVAL_NEU_UNSCREENED
A	BA	BAW	320	4	BA0440	16-07-18 18:22	LHR	J	ARRIVAL_EU
A	KL	KLM	744	8	KL0736	16-07-18 9:47	CUR	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	77W	8	KL0744	16-07-18 15:17	LIM	J	ARRIVAL_NEU_UNSCREENED
A	TK	THY	321	4	TK1955	16-07-18 21:47	IST	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	E90	3	KL1964	16-07-18 20:47	ZRH	J	ARRIVAL_SCHENGEN
A	KL	KLM	772	7	KL0755	16-07-18 13:07	GYE	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	73H	4	KL1972	16-07-18 8:27	BUD	J	ARRIVAL_SCHENGEN
A	KL	KLM	77W	8	KL0758	16-07-18 12:22	PTY	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	73H	4	KL1974	16-07-18 13:27	BUD	J	ARRIVAL_SCHENGEN
A	KL	KLM	333	7	KL0773	16-07-18 10:52	AUA	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	73W	4	KL1976	16-07-18 16:02	BUD	J	ARRIVAL_SCHENGEN
A	KL	KLM	772	7	KL0792	16-07-18 11:37	GRU	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	73H	4	KL1978	16-07-18 19:07	BUD	J	ARRIVAL_SCHENGEN
A	KL	KLM	77W	8	KL0808	16-07-18 6:47	TPE	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	E75	3	KL1984	16-07-18 7:42	BSL	J	ARRIVAL_SCHENGEN
A	KL	KLM	77W	8	KL0810	16-07-18 5:52	KUL	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	E75	3	KL1986	16-07-18 11:37	BSL	J	ARRIVAL_SCHENGEN
A	KL	KLM	E75	3	KL1988	16-07-18 19:47	BSL	J	ARRIVAL_SCHENGEN
A	KL	KLM	77W	8	KL0836	16-07-18 5:02	SIN	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	74E	8	KL0856	16-07-18 4:42	ICN	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	E75	3	KL1990	16-07-18 15:47	BSL	J	ARRIVAL_SCHENGEN
A	KL	KLM	77W	8	KL0862	16-07-18 15:02	NRT	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	E90	3	KL1992	16-07-18 8:32	KRK	J	ARRIVAL_SCHENGEN
A	KL	KLM	772	7	KL0868	16-07-18 15:02	KIX	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	E90	3	KL1996	16-07-18 18:37	KRK	J	ARRIVAL_SCHENGEN
A	KL	KLM	789	7	KL0872	16-07-18 8:22	DEL	J	ARRIVAL_NEU_UNSCREENED
A	KM	AMC	320	4	KM386	16-07-18 15:42	MLA	J	ARRIVAL_SCHENGEN
A	KM	AMC	320	4	KM394	16-07-18 10:42	MLA	J	ARRIVAL_SCHENGEN

A	KL	KLM	77W	8	KL0876	16-07-18 18:37	BKK	J	ARRIVAL_NEU_UNSCREENED
A	KQ	KQA	788	7	KQ0116	16-07-18 15:32	NBO	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	789	7	KL0884	16-07-18 18:32	XMN	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	74E	8	KL0888	16-07-18 18:12	HKG	J	ARRIVAL_NEU_UNSCREENED
A	LH	DLH	32S	4	LH986	16-07-18 9:22	FRA	J	ARRIVAL_SCHENGEN
A	KL	KLM	789	7	KL0892	16-07-18 18:57	CTU	J	ARRIVAL_NEU_UNSCREENED
A	KL	KLM	789	7	KL0894	16-07-18 4:22	PVG	J	ARRIVAL_NEU_UNSCREENED
A	LH	DLH	32S	4	LH988	16-07-18 10:17	FRA	J	ARRIVAL_SCHENGEN
A	KL	KLM	77W	8	KL0896	16-07-18 17:52	PVG	J	ARRIVAL_NEU_UNSCREENED
A	LH	DLH	32S	4	LH992	16-07-18 13:47	FRA	J	ARRIVAL_SCHENGEN
A	KL	KLM	789	7	KL0898	16-07-18 15:12	PEK	J	ARRIVAL_NEU_UNSCREENED
A	LH	DLH	32S	4	LH996	16-07-18 17:22	FRA	J	ARRIVAL_SCHENGEN
A	KL	KLM	73H	4	KL0900	16-07-18 7:29	SVO	J	ARRIVAL_NEU_UNSCREENED
A	LH	DLH	32S	4	LH998	16-07-18 18:32	FRA	J	ARRIVAL_SCHENGEN
A	LH	DLH	32S	4	LH1002	16-07-18 22:07	FRA	J	ARRIVAL_SCHENGEN
A	LH	DLH	EMJ	3	LH2300	16-07-18 8:07	MUC	J	ARRIVAL_SCHENGEN
A	LH	DLH	EMJ	3	LH2302	16-07-18 10:12	MUC	J	ARRIVAL_SCHENGEN
A	LH	DLH	CR9	3	LH2304	16-07-18 14:47	MUC	J	ARRIVAL_SCHENGEN
A	LH	DLH	EMJ	3	LH2306	16-07-18 16:07	MUC	J	ARRIVAL_SCHENGEN
A	LH	DLH	EMJ	3	LH2308	16-07-18 20:17	MUC	J	ARRIVAL_SCHENGEN
A	LH	DLH	CR9	3	LH2310	16-07-18 21:47	MUC	J	ARRIVAL_SCHENGEN
A	S5	LLC	320	4	LLX5012	16-07-18 14:47	KGS	C	ARRIVAL_SCHENGEN
A	S5	LLC	320	4	LLX5014	16-07-18 22:37	FAO	C	ARRIVAL_SCHENGEN
A	LO	LOT	734	3	LO265	16-07-18 9:27	WAW	J	ARRIVAL_SCHENGEN
A	LO	LOT	734	3	LO267	16-07-18 18:47	WAW	J	ARRIVAL_SCHENGEN
A	LO	LOT	E95	4	LO269	16-07-18 21:52	WAW	J	ARRIVAL_SCHENGEN
A	LO	LOT	CR9	3	LO8173	16-07-18 11:37	TLL	J	ARRIVAL_SCHENGEN
A	LS	EXS	73C	4	LS201	16-07-18 8:52	LBA	J	ARRIVAL_EU
A	LX	CRX	320	4	LX724	16-07-18 8:52	ZRH	J	ARRIVAL_SCHENGEN
A	LX	CRX	320	4	LX728	16-07-18 14:02	ZRH	J	ARRIVAL_SCHENGEN
A	LX	CRX	321	4	LX734	16-07-18 19:07	ZRH	J	ARRIVAL_SCHENGEN
A	BA	BAW	321	4	BA0442	16-07-18 20:17	LHR	J	ARRIVAL_EU
A	BA	BAW	320	4	BA0444	16-07-18 21:47	LHR	J	ARRIVAL_EU
A	BA	BAW	320	4	BA2758	16-07-18 10:02	LGW	J	ARRIVAL_EU
A	BA	BAW	320	4	BA2760	16-07-18 13:42	LGW	J	ARRIVAL_EU
A	BA	BAW	319	4	BA2762	16-07-18 18:37	LGW	J	ARRIVAL_EU
A	BA	BAW	E90	3	BA8451	16-07-18 10:37	LCY	J	ARRIVAL_EU
A	BA	BAW	E70	3	BA8455	16-07-18 17:27	LCY	J	ARRIVAL_EU
A	TK	THY	321	4	TK1957	16-07-18 13:07	IST	J	ARRIVAL_NEU_UNSCREENED
A	BA	BAW	E70	3	BA8457	16-07-18 20:52	LCY	J	ARRIVAL_EU
A	BA	BAW	E70	3	BA8497	16-07-18 9:47	LCY	J	ARRIVAL_EU
A	BE	BEE	DH4	3	BE101	16-07-18 9:22	BHX	J	ARRIVAL_EU
A	TK	THY	73H	4	TK1961	16-07-18 11:27	SAW	J	ARRIVAL_NEU_UNSCREENED
A	BE	BEE	DH4	3	BE105	16-07-18 13:22	BHX	J	ARRIVAL_EU
A	BE	BEE	E75	3	BE107	16-07-18 15:12	BHX	J	ARRIVAL_EU
A	BE	BEE	DH4	3	BE109	16-07-18 17:07	BHX	J	ARRIVAL_EU
A	BE	BEE	E75	3	BE111	16-07-18 18:47	BHX	J	ARRIVAL_EU
A	BE	BEE	DH4	3	BE113	16-07-18 21:12	BHX	J	ARRIVAL_EU
A	BE	BEE	DH4	3	BE1011	16-07-18 9:12	SOU	J	ARRIVAL_EU
A	TO	TVF	73H	4	TO3050	16-07-18 8:52	ORY	J	ARRIVAL_SCHENGEN
A	KL	KLM	73H	4	KL0904	16-07-18 19:17	SVO	J	ARRIVAL_NEU_UNSCREENED
A	BE	BEE	DH4	3	BE1013	16-07-18 15:27	SOU	J	ARRIVAL_EU
A	KL	KLM	73H	4	KL0912	16-07-18 19:22	CTA	J	ARRIVAL_SCHENGEN
A	TP	TAP	E90	3	TP658	16-07-18 14:37	OPO	J	ARRIVAL_SCHENGEN
A	KL	KLM	E75	3	KL0920	16-07-18 19:27	SOU	J	ARRIVAL_EU
A	BE	BEE	DH4	3	BE1015	16-07-18 16:22	SOU	J	ARRIVAL_EU

D

BEONTRA Stand and Gate Allocation model configuration

'Gate Areas' export

Name	Terminal	Schengen	Non-Schengen screened	Non-Schengen unscreened	Number of Gates
Pier B Schengen	Terminal 1	true	false	false	13
Pier C Schengen	Terminal 1	true	false	false	14
Pier D Non-Schengen screened	Terminal 1	false	true	false	5
Pier D Non-Schengen unscreened	Terminal 1	false	true	true	7
Pier D Swing screened	Terminal 1	true	true	false	19
Pier D Swing unscreened	Terminal 1	true	true	true	5
Pier E Non-Schengen unscreened	Terminal 1	false	true	true	14
Pier F Non-Schengen unscreened	Terminal 1	false	true	true	8
Pier G Non-Schengen unscreened	Terminal 1	false	true	true	10
Pier H Swing screened	Terminal 1	true	true	false	5
Pier H Swing unscreened	Terminal 1	true	true	true	2

'Gates' export

Name	Gate Area	Blocked Gates	Bus In	Bus Out	Contact In	Contact Out
B13	Pier B Schengen		false	false	true	true
B15	Pier B Schengen		true	true	true	true
B16	Pier B Schengen		true	true	true	true
B17	Pier B Schengen		true	true	true	true
B20	Pier B Schengen		false	false	true	true
B23	Pier B Schengen		false	false	true	true
B24	Pier B Schengen		false	false	true	true
B27	Pier B Schengen		true	true	true	true
B28	Pier B Schengen		false	false	true	true
B31	Pier B Schengen		false	false	true	true
B32	Pier B Schengen		false	false	true	true
B35	Pier B Schengen		false	false	true	true
B36	Pier B Schengen		false	false	true	true

C04	Pier C Schengen		true	true	true	true
C05	Pier C Schengen		false	false	true	true
C06	Pier C Schengen		true	true	true	true
C07	Pier C Schengen		false	false	true	true
C08	Pier C Schengen		true	true	true	true
C09	Pier C Schengen		false	false	true	true
C10	Pier C Schengen		false	false	true	true
C11	Pier C Schengen		false	false	true	true
C12	Pier C Schengen		false	false	true	true
C13	Pier C Schengen		false	false	true	true
C14	Pier C Schengen		false	false	true	true
C15	Pier C Schengen		false	false	true	true
C16	Pier C Schengen		false	false	true	true
C18	Pier C Schengen		false	false	true	true
D02	Pier D Swing screened		false	false	true	true
D03	Pier D Swing screened		false	false	true	true
D04	Pier D Swing screened		false	false	true	true
D05	Pier D Swing screened		false	false	true	true
D07	Pier D Swing unscreened		true	true	true	true
D08	Pier D Swing screened		false	false	true	true
D10	Pier D Swing screened		false	false	true	true
D12	Pier D Swing screened		false	false	true	true
D14	Pier D Non-Schengen screened		false	false	true	true
D16	Pier D Non-Schengen screened		false	false	true	true
D18	Pier D Non-Schengen screened		false	false	true	true
D22	Pier D Non-Schengen unscreened		true	true	true	true
D23	Pier D Non-Schengen unscreened		true	true	true	true
D24	Pier D Non-Schengen unscreened		true	true	true	true
D25	Pier D Non-Schengen unscreened		true	true	true	true
D26	Pier D Non-Schengen screened		false	false	true	true
D27	Pier D Non-Schengen unscreened		true	true	true	true
D28	Pier D Non-Schengen unscreened		true	true	true	true
D29	Pier D Non-Schengen unscreened		true	true	true	true
D31	Pier D Non-Schengen screened		false	false	true	true
D41	Pier D Swing screened		false	false	true	true
D43	Pier D Swing screened		false	false	true	true
D44	Pier D Swing screened		false	false	true	true
D47	Pier D Swing screened		false	false	true	true
D48	Pier D Swing unscreened		true	true	true	true
D49	Pier D Swing screened	D49 blocking D-51	false	false	true	true
D49 blocking D-51	Pier D Swing screened	D49, D51	false	false	true	true
D51	Pier D Swing screened	D49 blocking D-51, D53 blocking D-51 and D-55	false	false	true	true
D52	Pier D Swing unscreened		true	true	true	true
D53	Pier D Swing screened	D53 blocking D-51 and D-55	false	false	true	true
D53 blocking D-51 and D-55	Pier D Swing screened	D51, D53, D55	false	false	true	true
D54	Pier D Swing unscreened		true	true	true	true
D55	Pier D Swing screened	D53 blocking D-51 and D-55, D57 blocking D-55	false	false	true	true
D56	Pier D Swing unscreened		true	true	true	true
D57	Pier D Swing screened	D57 blocking D-55	false	false	true	true
D57 blocking D-55	Pier D Swing screened	D55, D57	false	false	true	true
E02	Pier E Non-Schengen unscreened		false	false	true	true
E03	Pier E Non-Schengen unscreened		false	false	true	true
E04	Pier E Non-Schengen unscreened		false	false	true	true
E05	Pier E Non-Schengen unscreened		false	false	true	true
E06	Pier E Non-Schengen unscreened		false	false	true	true
E07	Pier E Non-Schengen unscreened		false	false	true	true
E08	Pier E Non-Schengen unscreened		false	false	true	true
E09	Pier E Non-Schengen unscreened		false	false	true	true
E17	Pier E Non-Schengen unscreened		false	false	true	true
E18	Pier E Non-Schengen unscreened		false	false	true	true
E19	Pier E Non-Schengen unscreened		false	false	true	true
E20	Pier E Non-Schengen unscreened		false	false	true	true
E22	Pier E Non-Schengen unscreened		false	false	true	true
E24	Pier E Non-Schengen unscreened		false	false	true	true
F02	Pier F Non-Schengen unscreened		false	false	true	true
F03	Pier F Non-Schengen unscreened		false	false	true	true
F04	Pier F Non-Schengen unscreened		false	false	true	true
F05	Pier F Non-Schengen unscreened		false	false	true	true
F06	Pier F Non-Schengen unscreened		false	false	true	true

F07	Pier F Non-Schengen unscreened		false	false	true	true
F08	Pier F Non-Schengen unscreened		false	false	true	true
F09	Pier F Non-Schengen unscreened		false	false	true	true
G02	Pier G Non-Schengen unscreened		false	false	true	true
G03	Pier G Non-Schengen unscreened		false	false	true	true
G04	Pier G Non-Schengen unscreened		false	false	true	true
G05	Pier G Non-Schengen unscreened		false	false	true	true
G06	Pier G Non-Schengen unscreened		false	false	true	true
G07	Pier G Non-Schengen unscreened	G07 if CAT 9 ac on G-09, G09 with CAT 9 ac	false	false	true	true
G07 if CAT 9 ac on G-09	Pier G Non-Schengen unscreened	G07	false	false	true	true
G08	Pier G Non-Schengen unscreened		false	false	true	true
G09	Pier G Non-Schengen unscreened	G09 with CAT 9 ac	false	false	true	true
G09 with CAT 9 ac	Pier G Non-Schengen unscreened	G07, G09	false	false	true	true
H01	Pier H Swing unscreened		true	true	true	true
H02	Pier H Swing unscreened		true	true	true	true
H03	Pier H Swing screened		false	false	true	true
H04	Pier H Swing screened		false	false	true	true
H05	Pier H Swing screened		false	false	true	true
H06	Pier H Swing screened		false	false	true	true
H07	Pier H Swing screened		false	false	true	true

’Stand Areas’ export

Name	Type	Number of Stands
Alfa Apron	Remote	11
Bravo Apron	Remote	26
Juliet Ramp	Remote	8
Kilo Apron	Remote	32
Lima Ramp	Remote	3
Mike Ramp	Remote	14
November Ramp	Remote	2
Papa Platform	Remote	8
Pier B Schengen	Contact	13
Pier C Schengen	Contact	14
Pier D Non-Schengen screened	Contact	5
Pier D Non-Schengen unscreened	Contact	7
Pier D Swing screened	Contact	19
Pier D Swing unscreened	Contact	5
Pier D buffer	Remote	6
Pier E Non-Schengen unscreened	Contact	14
Pier E buffer	Remote	3
Pier F Non-Schengen unscreened	Contact	8
Pier G Non-Schengen unscreened	Contact	10
Pier G buffer	Remote	4
Pier H Swing screened	Contact	5
Pier H Swing unscreened	Contact	2
Romeo Cargo Apron	Remote	10
Sierra Cargo Apron	Remote	11
Uniform Ramp	Remote	5
Yankee Ramp	Remote	3

’Gate Priorities’, ’Stand Arrival/Departure Priorities’, and ’Stand Idle Priorities’ export (excerpt)

Due to confidentiality of the business rules, this export is not included to this report.

’Stand Configuration’ export (excerpt)

Due to its size, this part of the Appendix is only an excerpt: the extended version is available in digital form only.

Name	Stand Area Name	CAT 3 - Cargo	CAT 3 - Pax & positioning	CAT 9 - Cargo	CAT 9 - Pax & positioning	Linked Gates	Blocked Stands
B13	Pier B Schengen	false	true	false	false	B13	
B15	Pier B Schengen	false	true	false	false	B15	
B16	Pier B Schengen	false	true	false	false	B16	
B17	Pier B Schengen	false	true	false	false	B17	
B20	Pier B Schengen	false	true	false	false	B20	
B23	Pier B Schengen	false	true	false	false	B23	
B24	Pier B Schengen	false	true	false	false	B24	
B27	Pier B Schengen	false	true	false	false	B27	
B28	Pier B Schengen	false	true	false	false	B28	
B31	Pier B Schengen	false	true	false	false	B31	
B32	Pier B Schengen	false	true	false	false	B32	
B35	Pier B Schengen	false	true	false	false	B35	
B36	Pier B Schengen	false	true	false	false	B36	
B81	Bravo Apron	false	false	false	false		
B82	Bravo Apron	false	false	false	false		
B83	Bravo Apron	false	false	false	false		
B84	Bravo Apron	false	false	false	false		
B85	Bravo Apron	false	false	false	false		
B91	Bravo Apron	false	true	false	false		
B92	Bravo Apron	false	true	false	false		
B93	Bravo Apron	false	true	false	false		
B94	Bravo Apron	false	true	false	false		
B95	Bravo Apron	false	true	false	false		
C04	Pier C Schengen	false	true	false	false	C04	
C05	Pier C Schengen	false	true	false	false	C05	
C06	Pier C Schengen	false	true	false	false	C06	
C07	Pier C Schengen	false	true	false	false	C07	
C08	Pier C Schengen	false	true	false	false	C08	
C09	Pier C Schengen	false	true	false	false	C09	
C10	Pier C Schengen	false	true	false	false	C10	
C11	Pier C Schengen	false	true	false	false	C11	
C12	Pier C Schengen	false	true	false	false	C12	
C13	Pier C Schengen	false	true	false	false	C13	
C14	Pier C Schengen	false	true	false	false	C14	
C15	Pier C Schengen	false	true	false	false	C15	
C16	Pier C Schengen	false	true	false	false	C16	
C18	Pier C Schengen	false	true	false	false	C18	
D02	Pier D Swing screened	false	true	false	false	D02	
D03	Pier D Swing screened	false	true	false	false	D03	
D04	Pier D Swing screened	false	true	false	false	D04	
D05	Pier D Swing screened	false	true	false	false	D05	
D07	Pier D Swing unscreened	false	true	false	false	D05	
D08	Pier D Swing screened	false	true	false	false	D08	
D10	Pier D Swing screened	false	true	false	false	D10	
D12	Pier D Swing screened	false	true	false	false	D12	
D14	Pier D Non-Schengen screened	false	true	false	false	D14	
D16	Pier D Non-Schengen screened	false	true	false	false	D16	
D18	Pier D Non-Schengen screened	false	true	false	false	D18	
D22	Pier D Non-Schengen unscreened	false	true	false	false	D22	
D23	Pier D Non-Schengen unscreened	false	true	false	false	D23	
D24	Pier D Non-Schengen unscreened	false	true	false	false	D24	
D25	Pier D Non-Schengen unscreened	false	true	false	false	D25	
D26	Pier D Non-Schengen screened	false	true	false	false	D26	
D27	Pier D Non-Schengen unscreened	false	true	false	false	D27	
D28	Pier D Non-Schengen unscreened	false	true	false	false	D28	
D29	Pier D Non-Schengen unscreened	false	true	false	false	D29	
D31	Pier D Non-Schengen screened	false	true	false	false	D31	
D41	Pier D Swing screened	false	true	false	false	D41	
D43	Pier D Swing screened	false	true	false	false	D43	
D44	Pier D Swing screened	false	true	false	false	D44	
D47	Pier D Swing screened	false	true	false	false	D47	
D48	Pier D Swing unscreened	false	true	false	false	D48	
D49	Pier D Swing screened	false	true	false	false	D49	D49 blocking D-51
D49 blocking D-51	Pier D Swing screened	false	true	false	false	D49	D49, D51
D51	Pier D Swing screened	false	true	false	false	D51	D49 blocking D-51, D53 blocking D-51 and D-55
D52	Pier D Swing unscreened	false	true	false	false	D52	
D53	Pier D Swing screened	false	true	false	false	D53	D53 blocking D-51 and D-55
D53 blocking D-51 and D-55	Pier D Swing screened	false	true	false	false	D53	D51, D53, D55
D54	Pier D Swing unscreened	false	true	false	false	D54	
D55	Pier D Swing screened	false	true	false	false	D55	D53 blocking D-51 and D-55, D57 blocking D-55
D56	Pier D Swing unscreened	false	true	false	false	D56	
D57	Pier D Swing screened	false	true	false	false	D57	D57 blocking D-55
D57 blocking D-55	Pier D Swing screened	false	true	false	false	D57	D55, D57
D88	Pier D buffer	false	true	false	false		
D90	Pier D buffer	false	true	false	false		
D92	Pier D buffer	false	true	false	false		
D93	Pier D buffer	false	true	false	false		
D94	Pier D buffer	false	true	false	false		
D95	Pier D buffer	false	true	false	false		
J80	Juliet Ramp	false	true	false	false		J81
J81	Juliet Ramp	false	true	false	true		J82, J80
J82	Juliet Ramp	false	true	false	false		J81
J83	Juliet Ramp	false	true	false	false		
J84	Juliet Ramp	false	true	false	false		
J85	Juliet Ramp	false	true	false	false		
J86	Juliet Ramp	false	true	false	false		
J87	Juliet Ramp	false	true	false	false		
R71	Romeo Cargo Apron	true	true	false	false		R72
R72	Romeo Cargo Apron	true	true	true	true		R71, R73
R73	Romeo Cargo Apron	true	true	false	false		R72
R74	Romeo Cargo Apron	true	true	true	true		
R77	Romeo Cargo Apron	true	true	true	true		
R80	Romeo Cargo Apron	true	true	true	true		
R81	Romeo Cargo Apron	true	true	false	false		
R82	Romeo Cargo Apron	true	true	false	false		
R83	Romeo Cargo Apron	true	true	false	false		
R87	Romeo Cargo Apron	true	true	false	false		

'Occupancy Times' export

Group	Resource Type	PAX Handling	Pre-Arrival Buffer	Post-Departure Buffer	Arrival Occupancy	Departure Occupancy
WIBO, lowcost	Stands	Pier Served	00:00:10	00:00:10	00:01:15	00:01:25
WIBO, lowcost	Stands	Bussed	00:00:10	00:00:10	00:01:15	00:01:25
WIBO, lowcost	Gates	Pier Served	00:00:10	00:00:10	00:01:15	00:01:25
WIBO, lowcost	Gates	Bussed	00:00:10	00:00:10	00:00:40	00:00:40
NABO, lowcost	Stands	Pier Served	00:00:10	00:00:10	00:00:55	00:01:05
NABO, lowcost	Stands	Bussed	00:00:10	00:00:10	00:00:55	00:01:05
NABO, lowcost	Gates	Pier Served	00:00:10	00:00:10	00:00:55	00:01:05
NABO, lowcost	Gates	Bussed	00:00:10	00:00:10	00:00:20	00:00:20
WIBO - SCH [0:00-5:59]	Stands	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - SCH [0:00-5:59]	Stands	Bussed	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - SCH [0:00-5:59]	Gates	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - SCH [0:00-5:59]	Gates	Bussed	00:00:20	00:00:20	00:00:40	00:00:40
WIBO - NS_scr [0:00-5:59]	Stands	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_scr [0:00-5:59]	Stands	Bussed	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_scr [0:00-5:59]	Gates	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_scr [0:00-5:59]	Gates	Bussed	00:00:20	00:00:20	00:00:40	00:00:40
WIBO - NS_uns [0:00-5:59]	Stands	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [0:00-5:59]	Stands	Bussed	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [0:00-5:59]	Gates	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [0:00-5:59]	Gates	Bussed	00:00:20	00:00:20	00:00:40	00:00:40
WIBO - SCH [6:00-10:59]	Stands	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - SCH [6:00-10:59]	Stands	Bussed	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - SCH [6:00-10:59]	Gates	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - SCH [6:00-10:59]	Gates	Bussed	00:00:20	00:00:20	00:00:40	00:00:40
WIBO - NS_scr [6:00-10:59]	Stands	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_scr [6:00-10:59]	Stands	Bussed	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_scr [6:00-10:59]	Gates	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_scr [6:00-10:59]	Gates	Bussed	00:00:20	00:00:20	00:00:40	00:00:40
WIBO - NS_uns [6:00-10:59]	Stands	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [6:00-10:59]	Stands	Bussed	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [6:00-10:59]	Gates	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [6:00-10:59]	Gates	Bussed	00:00:20	00:00:20	00:00:40	00:00:40
WIBO - SCH [11:00-17:29]	Stands	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - SCH [11:00-17:29]	Stands	Bussed	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - SCH [11:00-17:29]	Gates	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - SCH [11:00-17:29]	Gates	Bussed	00:00:20	00:00:20	00:00:40	00:00:40
WIBO - NS_scr [11:00-17:29]	Stands	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_scr [11:00-17:29]	Stands	Bussed	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_scr [11:00-17:29]	Gates	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_scr [11:00-17:29]	Gates	Bussed	00:00:20	00:00:20	00:00:40	00:00:40
WIBO - NS_uns [11:00-17:29]	Stands	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [11:00-17:29]	Stands	Bussed	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [11:00-17:29]	Gates	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [11:00-17:29]	Gates	Bussed	00:00:20	00:00:20	00:00:40	00:00:40
WIBO - SCH [17:30-23:59]	Stands	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - SCH [17:30-23:59]	Stands	Bussed	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - SCH [17:30-23:59]	Gates	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - SCH [17:30-23:59]	Gates	Bussed	00:00:20	00:00:20	00:00:40	00:00:40
WIBO - NS_scr [17:30-23:59]	Stands	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_scr [17:30-23:59]	Stands	Bussed	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_scr [17:30-23:59]	Gates	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_scr [17:30-23:59]	Gates	Bussed	00:00:20	00:00:20	00:00:40	00:00:40
WIBO - NS_uns [17:30-23:59]	Stands	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [17:30-23:59]	Stands	Bussed	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [17:30-23:59]	Gates	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [17:30-23:59]	Gates	Bussed	00:00:20	00:00:20	00:00:40	00:00:40
NABO - SCH [0:00-5:59]	Stands	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - SCH [0:00-5:59]	Stands	Bussed	00:00:20	00:00:20	00:00:55	00:01:05
NABO - SCH [0:00-5:59]	Gates	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - SCH [0:00-5:59]	Gates	Bussed	00:00:20	00:00:20	00:00:20	00:00:20
NABO - NS_scr [0:00-5:59]	Stands	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_scr [0:00-5:59]	Stands	Bussed	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_scr [0:00-5:59]	Gates	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05

NABO - SCH [6:00-10:59]	Stands	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - SCH [6:00-10:59]	Stands	Bussed	00:00:20	00:00:20	00:00:55	00:01:05
NABO - SCH [6:00-10:59]	Gates	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - SCH [6:00-10:59]	Gates	Bussed	00:00:20	00:00:20	00:00:20	00:00:20
NABO - NS_scr [6:00-10:59]	Stands	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_scr [6:00-10:59]	Stands	Bussed	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_scr [6:00-10:59]	Gates	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_scr [6:00-10:59]	Gates	Bussed	00:00:20	00:00:20	00:00:20	00:00:20
NABO - NS_uns [6:00-10:59]	Stands	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_uns [6:00-10:59]	Stands	Bussed	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_uns [6:00-10:59]	Gates	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_uns [6:00-10:59]	Gates	Bussed	00:00:20	00:00:20	00:00:20	00:00:20
NABO - SCH [11:00-17:29]	Stands	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - SCH [11:00-17:29]	Stands	Bussed	00:00:20	00:00:20	00:00:55	00:01:05
NABO - SCH [11:00-17:29]	Gates	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - SCH [11:00-17:29]	Gates	Bussed	00:00:20	00:00:20	00:00:20	00:00:20
NABO - NS_scr [11:00-17:29]	Stands	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_scr [11:00-17:29]	Stands	Bussed	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_scr [11:00-17:29]	Gates	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_scr [11:00-17:29]	Gates	Bussed	00:00:20	00:00:20	00:00:20	00:00:20
NABO - NS_uns [11:00-17:29]	Stands	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_uns [11:00-17:29]	Stands	Bussed	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_uns [11:00-17:29]	Gates	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_uns [11:00-17:29]	Gates	Bussed	00:00:20	00:00:20	00:00:20	00:00:20
NABO - SCH [17:30-23:59]	Stands	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - SCH [17:30-23:59]	Stands	Bussed	00:00:20	00:00:20	00:00:55	00:01:05
NABO - SCH [17:30-23:59]	Gates	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - SCH [17:30-23:59]	Gates	Bussed	00:00:20	00:00:20	00:00:20	00:00:20
NABO - NS_scr [17:30-23:59]	Stands	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_scr [17:30-23:59]	Stands	Bussed	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_scr [17:30-23:59]	Gates	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_scr [17:30-23:59]	Gates	Bussed	00:00:20	00:00:20	00:00:20	00:00:20
NABO - NS_uns [17:30-23:59]	Stands	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_uns [17:30-23:59]	Stands	Bussed	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_uns [17:30-23:59]	Gates	Pier Served	00:00:20	00:00:20	00:00:55	00:01:05
NABO - NS_uns [17:30-23:59]	Gates	Bussed	00:00:20	00:00:20	00:00:20	00:00:20

’Handling Schemes’ export (’*’ denotes all flights)

Arrival Filter					Departure Filter				
Size	Blocktime	Passenger, positioning or cargo	Flights day- and nighttime	Preferences on specific routes	Size	Blocktime	Passenger, positioning or cargo	Flights day- and nighttime	Preferences on specific routes
*	*	Cargo	*	*	*	*	Cargo	*	*
*	*	Cargo	*	*	*	*	Cargo	*	*
*	*	Positioning	*	*	*	*	Positioning	*	*
*	*	Positioning	*	*	*	*	Positioning	*	*
*	*	Passenger	*	*	*	*	Passenger	*	*
*	*	Passenger	*	*	*	*	Passenger	*	*
*	t>=210	Passenger	*	Arrivals from AUA, BON, CUR, PMB, SXM, CCS, PMV	*	t>=210	Passenger	*	*
*	t>=170	Passenger	*	Arrivals from AUA, BON, CUR, PMB, SXM, CCS, PMV	*	t>=170	Passenger	*	*
*	t>=170	Passenger	*	Arrivals from AUA, BON, CUR, PMB, SXM, CCS, PMV	*	t>=170	Passenger	*	*
*	t>=210	Passenger	*	*	*	t>=210	Passenger	*	Departures to US PAX
*	t>=170	Passenger	*	*	*	t>=170	Passenger	*	Departures to US PAX
*	t>=170	Passenger	*	*	*	t>=170	Passenger	*	Departures to US PAX
*	t>=170	Passenger	*	*	*	t>=170	Passenger	*	Departures to CDG - DAY
*	t>=130	Passenger	*	*	*	t>=130	Passenger	*	Departures to CDG - DAY
*	t>=130	Passenger	*	*	*	t>=130	Passenger	*	Departures to CDG - DAY
*	*	Passenger	*	Arrivals from AUA, BON, CUR, PMB, SXM, CCS, PMV	*	*	Passenger	*	*
*	*	Passenger	*	*	*	*	Passenger	*	Departures to US PAX
*	*	Passenger	Day - 06:00-23:59	*	*	*	Passenger	Day - 06:00-23:59	*
*	*	Passenger	*	*	*	*	Passenger	*	Departures to CDG - DAY
WIBO	t>=210	Passenger	*	*	WIBO	t>=210	Passenger	*	*
WIBO	t>=170	Passenger	*	*	WIBO	t>=170	Passenger	*	*
WIBO	t>=170	Passenger	*	*	WIBO	t>=170	Passenger	Day - 06:00-23:59	*
WIBO	t>=170	Passenger	Day - 06:00-23:59	*	WIBO	t>=170	Passenger	*	*
NABO	t>=170	Passenger	*	*	NABO	t>=170	Passenger	*	*
NABO	t>=130	Passenger	*	*	NABO	t>=130	Passenger	*	*
NABO	t>=130	Passenger	*	*	NABO	t>=130	Passenger	Day - 06:00-23:59	*
NABO	t>=130	Passenger	Day - 06:00-23:59	*	NABO	t>=130	Passenger	*	*
*	t>=130	Passenger	*	*	*	t>=130	Passenger	*	*
*	t>=130	Passenger	*	*	*	t>=130	Passenger	Day - 06:00-23:59	*
*	t>=130	Passenger	Day - 06:00-23:59	*	*	t>=130	Passenger	*	*
*	t>=130	Passenger	Day - 06:00-23:59	*	*	t>=130	Passenger	Day - 06:00-23:59	*
*	*	Passenger	*	*	*	*	Positioning	*	*
*	*	Passenger	Day - 06:00-23:59	*	*	*	Positioning	*	*
*	*	Positioning	*	*	*	*	Passenger	*	*
*	*	Positioning	*	*	*	*	Passenger	Day - 06:00-23:59	*

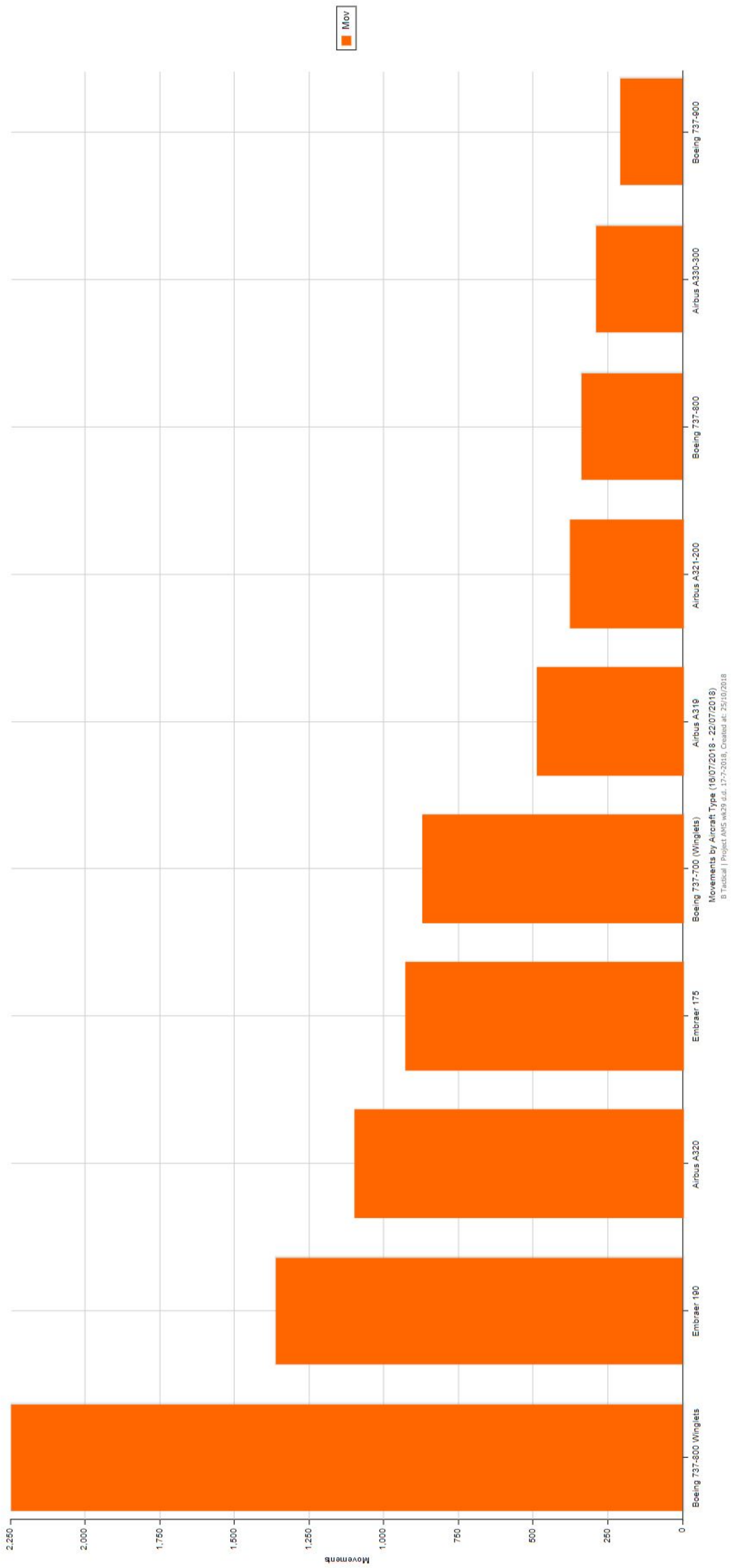
Passenger Handling		Aircraft Handling			
Arrival	**Departure**	**Arrival**	**Departure**	**Towing**	**Priority**
None	None	Remote	Remote	0	1
None	None	Remote	Remote	1	2
None	None	Remote	Remote	0	3
None	None	Remote	Remote	1	4
Pier Served	Pier Served	Contact	Contact	0	5
Pier Served	Pier Served	Contact	Contact	0	6
Pier Served	Pier Served	Contact	Contact	2	7
Pier Served	Pier Served	Contact	Contact	1	8
Pier Served	Bussed	Contact	Remote	1	9
Pier Served	Pier Served	Contact	Contact	2	10
Pier Served	Pier Served	Contact	Contact	1	11
Bussed	Pier Served	Remote	Contact	1	12
Pier Served	Pier Served	Contact	Contact	2	13
Pier Served	Pier Served	Contact	Contact	1	14
Bussed	Pier Served	Contact	Contact	1	15
Pier Served	Pier Served	Contact	Contact	0	16
Pier Served	Pier Served	Contact	Contact	0	17
Bussed	Bussed	Remote	Remote	0	18
Pier Served	Pier Served	Contact	Contact	0	19
Pier Served	Pier Served	Contact	Contact	2	20
Pier Served	Pier Served	Contact	Contact	1	21
Pier Served	Bussed	Contact	Remote	1	22
Bussed	Pier Served	Remote	Contact	1	23
Pier Served	Pier Served	Contact	Contact	2	24
Pier Served	Pier Served	Contact	Contact	1	25
Pier Served	Bussed	Contact	Remote	1	26
Bussed	Pier Served	Remote	Contact	1	27
Pier Served	Pier Served	Contact	Contact	1	28
Pier Served	Bussed	Contact	Remote	1	29
Bussed	Pier Served	Remote	Contact	1	30
Bussed	Bussed	Remote	Remote	1	31
Pier Served	None	Contact	Remote	1	32
Bussed	None	Remote	Remote	0	33
None	Pier Served	Remote	Contact	1	34
None	Bussed	Remote	Remote	0	35

E

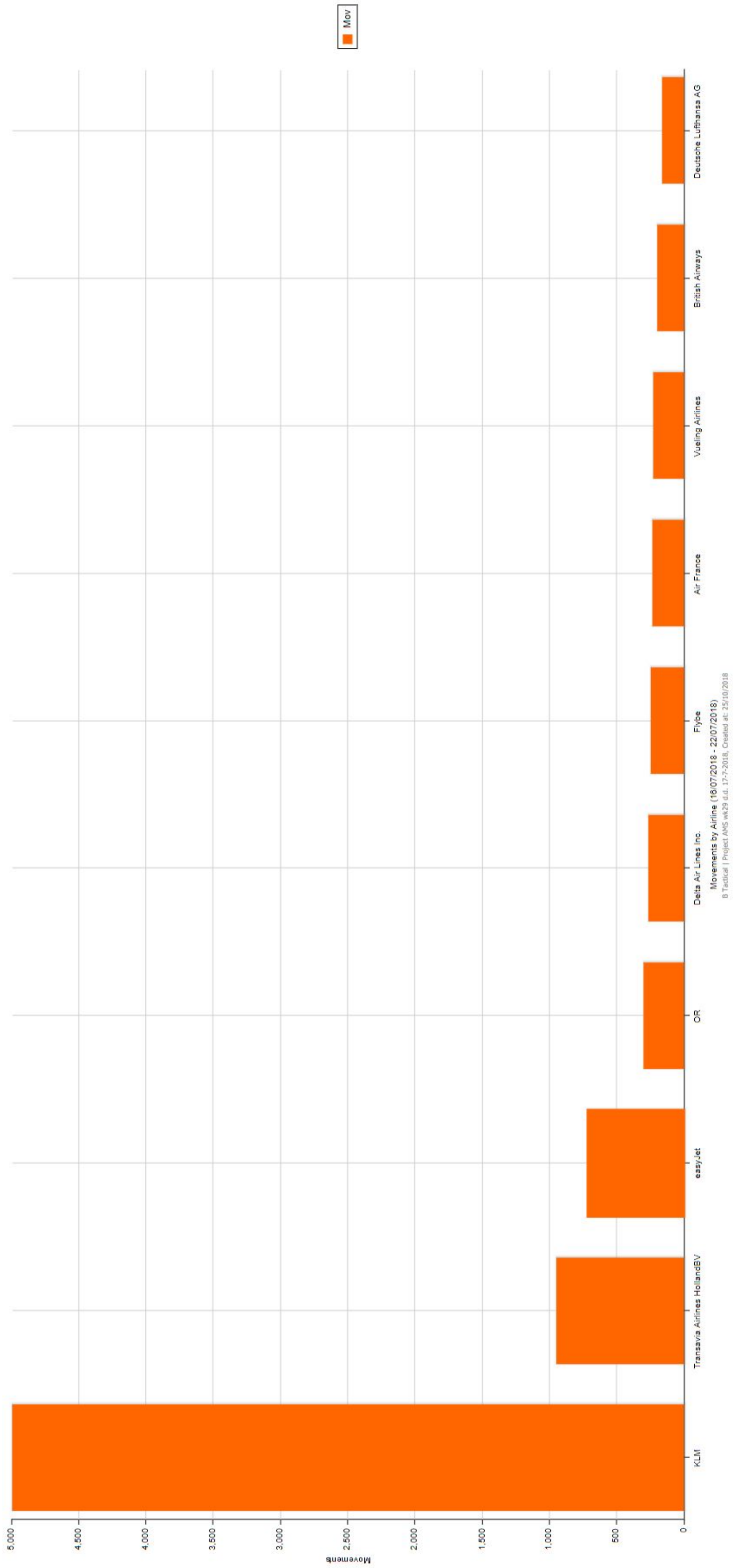
Time slot allocation schedule analysis for Monday 16 July 2018

Due to its size, this part of the Appendix is available in digital form only. The initial linking of an arrival, departure, or tow movement for each buffer time is done in Appendix E.1. The concluding cumulative stand movements per timestamp for Schengen, Non-Schengen screened, and Non-Schengen unscreened; both for NABO as well as for WIBO flights; are counted in Appendix E.2. The digital breakdown schedules as presented in this hardcopy version are given in Appendix E.3.

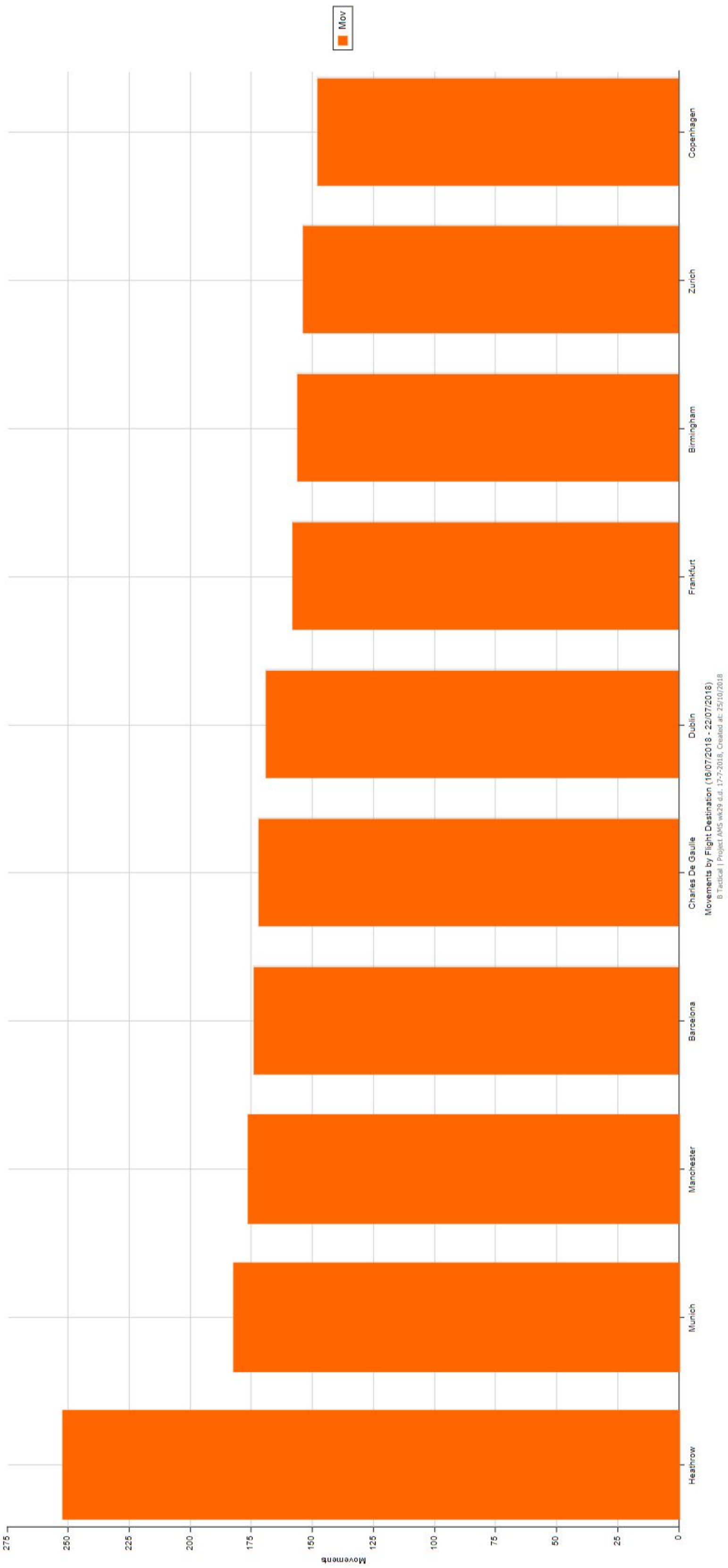
Breakdown of most used aircraft types in week 29:



Breakdown of airlines operating most flights in week 29:



Breakdown of most popular flight destinations in week 29:



F

BEONTRA Allocation schedule for 20 minute buffer time (excerpt)

Due to its size, this part of the Appendix is only showing an excerpt of the allocation schedule for a buffer time of 20 minutes: the allocation schedules for the buffer time of 0, 5, 10, and 15 minutes are available in digital form only.

A/T/D	Flight	Linked Flight	Scheduled	Aircraft	O/D	Flight Type	Stand	Stand Start	Stand End
A	PC1256	PC1256	15/7 0:05	738	SAW	J	F09	14/7 23:45	15/7 12:05
A	SU2193	SU2193	15/7 0:15	73H	SVO	J	D23	14/7 23:55	15/7 12:15
A	CND311	CND311	15/7 3:20	320	HER	C	C07	15/7 3:00	15/7 15:20
A	HV1693	HV1693	15/7 5:00	73H	ZTH	C	D51	15/7 4:40	15/7 17:00
A	HV5625	HV5625	15/7 5:00	73H	PMI	J	C14	15/7 4:40	15/7 17:00
A	EZY7957	EZY7957	15/7 5:00	320	AGP	J	H04	15/7 4:50	15/7 17:00
A	CND113	CND113	15/7 5:20	738	MJT	C	B13	15/7 5:00	15/7 17:20
A	HV6737	HV6737	15/7 6:05	73W	KIT	J	D41	15/7 5:45	15/7 18:05
A	SK550	SK550	15/7 6:20	320	CPH	J	J87	15/7 6:00	15/7 18:20
A	KL1223	KL1223	15/7 6:45	73W	CDG	J	D53	15/7 6:25	15/7 18:45
A	KL1103	KL1103	15/7 6:50	73H	ARN	J	D47	15/7 6:30	15/7 18:50
A	KL1721	KL1721	15/7 6:50	E90	BRU	J	D08	15/7 6:30	15/7 18:50
A	KL1839	KL1839	15/7 6:50	73H	VIE	J	B35	15/7 6:30	15/7 18:50
A	KL1853	KL1853	15/7 6:50	E75	DUS	J	B36	15/7 6:30	15/7 18:50
A	KL1351	KL1351	15/7 6:50	E90	PRG	J	B20	15/7 6:30	15/7 18:50
A	KL1165	KL1165	15/7 6:55	E90	HEL	J	D52	15/7 6:35	15/7 18:55
A	VY6291	VY6291	15/7 7:00	320	FCO	J	C05	15/7 6:40	15/7 19:00
A	TP669	TP669	15/7 7:00	320	LIS	J	C12	15/7 6:40	15/7 19:00
A	EZY7925	EZY7925	15/7 7:00	320	NCE	J	H07	15/7 6:50	15/7 19:00
A	KL1925	KL1925	15/7 7:00	E90	GVA	J	B24	15/7 6:40	15/7 19:00
A	KL1821	KL1821	15/7 7:00	73W	TXL	J	P16	15/7 6:40	15/7 19:00
A	LH2311	LH2311	15/7 7:00	CR9	MUC	J	B28	15/7 6:40	15/7 19:00
A	KL0979	KL0979	15/7 7:00	AR8	LCY	J	D14	15/7 6:40	15/7 19:00
A	OS378	OS378	15/7 7:00	E95	VIE	J	D03	15/7 6:40	15/7 19:00
A	KL1699	KL1699	15/7 7:00	73H	MAD	J	D57	15/7 6:40	15/7 19:00
A	KL1141	KL1141	15/7 7:00	E90	OSL	J	C18	15/7 6:40	15/7 19:00
A	VY8404	VY8404	15/7 7:00	320	LTN	J	D18	15/7 6:40	15/7 19:00
A	LX737	LX737	15/7 7:00	319	ZRH	J	D49	15/7 6:40	15/7 19:00
A	LO270	LO270	15/7 7:05	E95	WAW	J	D94	15/7 6:45	15/7 19:05
A	KL1953	KL1953	15/7 7:05	E90	ZRH	J	B16	15/7 6:45	15/7 19:05
A	EZY8868	EZY8868	15/7 7:05	321	LGW	J	F07	15/7 6:55	15/7 19:05

A	KL1277	KL1277	15/7 7:10	73W	EDI	J	E04	15/7 6:50	15/7 19:10
A	KL1597	KL1597	15/7 7:15	73J	FCO	J	Y72	15/7 6:55	15/7 19:15
A	AZ0119	AZ0119	15/7 7:15	319	LIN	J	C13	15/7 6:55	15/7 19:15
A	BA8450	BA8450	15/7 7:15	E70	LCY	J	D16	15/7 6:55	15/7 19:15
A	EZY7975	EZY7975	15/7 7:20	319	FCO	J	H03	15/7 7:10	15/7 19:20
A	LLX5011	LLX5011	15/7 7:20	320	KGS	C	D93	15/7 7:00	15/7 19:20
A	AZ0111	AZ0111	15/7 7:20	320	FCO	J	D02	15/7 7:00	15/7 19:20
A	KL1791	KL1791	15/7 7:20	73W	MUC	J	D55	15/7 7:00	15/7 19:20
A	KL1001	KL1001	15/7 7:20	73H	LHR	J	D31	15/7 7:00	15/7 19:20
A	EZY7933	EZY7933	15/7 7:20	320	TLV	J	G04	15/7 7:10	15/7 19:20
A	VY8318	VY8318	15/7 7:20	320	BCN	J	B31	15/7 7:00	15/7 19:20
A	EZY1354	EZY1354	15/7 7:25	319	GVA	J	H02	15/7 7:15	15/7 19:25
A	OR649	OR649	15/7 7:30	73H	TFS	J	B23	15/7 7:10	15/7 19:30
A	OR603	OR603	15/7 7:30	73H	CTA	J	G79	15/7 7:10	15/7 19:30
A	EZY7911	EZY7911	15/7 7:30	319	LYS	J	H01	15/7 7:20	15/7 19:30
A	OR161	OR161	15/7 7:30	73H	OHD	J	G02	15/7 7:10	15/7 19:30
A	HV6917	HV6917	15/7 7:40	73H	OLB	J	D95	15/7 7:20	15/7 19:40
A	BA0423	BA0423	15/7 7:45	319	LHR	J	F04	15/7 7:25	15/7 19:45
A	OR617	OR617	15/7 7:50	73H	PMI	J	J84	15/7 7:30	15/7 19:50
A	EZY7903	EZY7903	15/7 7:50	320	ZRH	J	H06	15/7 7:40	15/7 19:50
A	KL0987	KL0987	15/7 8:00	AR8	LCY	J	D26	15/7 7:40	15/7 20:00
A	I23721	I23721	15/7 8:00	320	MAD	J	E77	15/7 7:40	15/7 20:00
A	LH1003	LH1003	15/7 8:05	32S	FRA	J	D88	15/7 7:45	15/7 20:05
A	CZ0479	CZ0479	15/7 9:00	77F	PVG	F	S79	15/7 8:40	15/7 21:00
A	KL0945	KL0945	15/7 9:45	AR8	DUB	J	A34	15/7 9:25	15/7 21:45
A	OR317	OR317	15/7 9:45	788	SFB	J	G03	15/7 9:25	15/7 21:45
A	HV5807	HV5807	15/7 10:00	73H	SKG	J			
A	KL1765	KL1765	15/7 10:00	E75	FRA	J	A61	15/7 9:40	15/7 22:00
A	KL1671	KL1671	15/7 10:15	73H	BCN	J	J82	15/7 9:55	15/7 22:15
A	KL1823	KL1823	15/7 10:15	73H	TXL	J	P10	15/7 9:55	15/7 22:15
A	KL1629	KL1629	15/7 10:25	73H	MXP	J	D90	15/7 10:05	15/7 22:25
A	CND197	CND197	15/7 10:55	738	FAO	C	D92	15/7 10:35	15/7 22:55
A	EZY7905	EZY7905	15/7 10:55	319	PRG	J	H05	15/7 10:45	15/7 22:55
A	RU742A	RU742A	15/7 11:00	74N	SVO	F	S82	15/7 10:40	15/7 23:00
A	KL1355	KL1355	15/7 12:10	73W	PRG	J			
A	OR231	OR231	15/7 13:00	76W	HER	C	J83	15/7 12:40	16/7 1:00
A	OR541	OR541	15/7 15:15	343	LPA	C			
A	Y87456	Y87456	15/7 17:00	74Y	PVG	F	R80	15/7 16:40	16/7 5:00
A	EI0609	EI0609	15/7 17:00	320	DUB	J	D27	15/7 16:40	16/7 5:00
A	KL0433	KL0433	15/7 17:40	772	IKA	J	P11	15/7 17:20	16/7 5:40
A	HV5749	HV5749	15/7 21:20	73H	CMN	J			
A	RU154	RU154	15/7 22:00	74Y	SVO	F	S90	15/7 21:40	16/7 10:00
A	FX5187	FX5187	15/7 22:40	75F	CDG	F			
A	BCS1239	BCS1239	15/7 23:10	ABY	LEJ	F	R83	15/7 22:50	16/7 11:10
A	HV5588	HV6805	16/7 0:00	73H	NCE	J			
A	HV5426	HV6867	16/7 0:05	73H	PSA	J	D12	15/7 23:45	16/7 1:00
D	PC1256	PC1256	16/7 0:05	738	SAW	J	F09	15/7 12:05	16/7 0:25
A	HV5134	HV1679	16/7 0:10	73H	BCN	J	D48	15/7 23:50	16/7 2:37
A	HV1288	HV0755	16/7 0:10	73H	RHO	C	B17	15/7 23:50	16/7 1:05
A	HV6876	HV1919	16/7 0:10	73H	HER	J	D43	15/7 23:50	16/7 1:05
A	HV1544	HV5355	16/7 0:15	73H	KGS	C	B27	15/7 23:55	16/7 2:52

A	HV5314	HV5887	16/7 0:15	73H	LCA	J	D54	15/7 23:55	16/7 2:52
A	HV5006	HV6463	16/7 0:15	73W	DBV	J	E24	15/7 23:55	16/7 1:10
D	SU2193	SU2193	16/7 0:15	73H	SVO	J	D23	15/7 12:15	16/7 0:35
A	HV1118	HV5131	16/7 0:30	73H	HER	C	C08	16/7 0:10	16/7 3:15
A	HV5080	HV5517	16/7 0:30	73H	RHO	J	C15	16/7 0:10	16/7 1:25
A	HV5766	HV5763	16/7 0:30	73H	GRO	J	D10	16/7 0:10	16/7 3:15
A	HV5952	HV5801	16/7 0:30	73H	LIS	J	D56	16/7 0:10	16/7 3:17
A	HV6150	HV0071	16/7 0:30	73H	ALC	J	C16	16/7 0:10	16/7 1:25
A	OR298	OR279	16/7 0:40	73H	CHQ	C	D07	16/7 0:20	16/7 1:35
A	HV6342	HV1161	16/7 0:55	73H	IBZ	J	D04	16/7 0:35	16/7 3:35
T	HV5426		16/7 1:00	73H			U02	16/7 1:10	17/7 4:05
A	HV6004	HV5637	16/7 1:05	73H	OPO	J	C11	16/7 0:45	16/7 3:42
A	HV6916	HV5541	16/7 1:05	73H	OLB	J	C10	16/7 0:45	16/7 2:00
T	HV1288		16/7 1:05	73H			F09	16/7 1:15	16/7 3:50
T	HV6876		16/7 1:05	73H			G09	16/7 1:15	16/7 4:00
T	HV5006		16/7 1:10	73W			Y71	16/7 1:20	16/7 1:00
A	HV5804	HV5673	16/7 1:20	73H	TLV	J	D24	16/7 1:00	16/7 2:15
A	OR624	OR211	16/7 1:25	73H	PMI	J	B17	16/7 1:05	16/7 3:20
T	HV5080		16/7 1:25	73H			E75	16/7 1:35	16/7 4:45
T	HV6150		16/7 1:25	73H			P15	16/7 1:35	16/7 1:15
A	HV6728	HV5581	16/7 1:30	73H	SVQ	J	C06	16/7 1:10	16/7 4:02
A	HV5754	HV5093	16/7 1:30	73H	RAK	J	F08	16/7 1:10	16/7 2:25
A	HV1262	HV6331	16/7 1:35	73H	IBZ	C	D44	16/7 1:15	16/7 4:10
T	OR298		16/7 1:35	73H			S72	16/7 1:45	16/7 3:50
A	HV5686	HV6867	16/7 1:40	73H	ACE	J	D12	16/7 1:20	16/7 2:35
A	HV0584	HV6115	16/7 1:50	73H	HRG	C	E24	16/7 1:30	16/7 2:45
A	HV5028	HV6143	16/7 1:50	73H	LPA	J	C15	16/7 1:30	16/7 4:22
T	HV6916		16/7 2:00	73H			G73	16/7 2:10	16/7 5:15
A	HV0178	HV6873	16/7 2:15	73H	GZP	C	D23	16/7 1:55	16/7 3:10
T	HV5804		16/7 2:15	73H			J85	16/7 2:25	16/7 5:15
A	HV6602	HV6891	16/7 2:20	73H	PMI	J	C16	16/7 2:00	16/7 4:50
A	CND798	CND117	16/7 2:25	738	RHO	C	B15	16/7 2:05	16/7 3:07
T	HV5754		16/7 2:25	73H			S74	16/7 2:35	16/7 5:20
A	HV1520	HV1843	16/7 2:30	73H	AYT	C	D28	16/7 2:10	16/7 3:25
A	OR230	OR111	16/7 2:35	73H	HER	C	D07	16/7 2:15	16/7 4:00
A	OR194	OR647	16/7 2:35	73H	KGS	C	C10	16/7 2:15	16/7 4:37
T	HV5686		16/7 2:35	73H			R87	16/7 2:45	16/7 2:25
A	OR256	OR341	16/7 2:40	76W	RHO	C	D43	16/7 2:20	16/7 3:55
T	HV0584		16/7 2:45	73H			R82	16/7 2:55	16/7 5:40
T	HV0178		16/7 3:10	73H			S87	16/7 3:20	16/7 5:55
D	CND311	CND311	16/7 3:20	320	HER	C	C07	15/7 15:20	16/7 3:40
T	HV1520		16/7 3:25	73H			J80	16/7 3:35	16/7 6:15
A	OR642	OR701	16/7 3:30	73H	LPA	J	C09	16/7 3:10	16/7 4:25
A	CND718	CND195	16/7 3:35	738	BOJ	C	D12	16/7 3:15	16/7 4:15
A	CAI407	CAI202	16/7 3:40	738	AYT	C	E24	16/7 3:20	16/7 4:12
A	CAI105	CAI802	16/7 3:50	738	DLM	C	E17	16/7 3:30	16/7 4:45
D	CND117	CND798	16/7 3:50	738	AGP	C	B15	16/7 3:07	16/7 4:10
T	OR256		16/7 3:55	76W			S84	16/7 4:05	16/7 8:45
T	OR642		16/7 4:25	73H			J86	16/7 4:35	16/7 5:55
A	KL0894	KL0661	16/7 4:30	789	PVG	J	F03	16/7 4:10	16/7 5:45
T	CAI105		16/7 4:45	738			S92	16/7 4:55	16/7 13:00
D	CAI202	CAI407	16/7 4:45	738	BJV	C	E24	16/7 4:12	16/7 5:05
A	KL0856	KL0601	16/7 4:50	74E	ICN	J			
D	CND195	CND718	16/7 4:55	738	HER	C	D12	16/7 4:15	16/7 5:15
D	HV1693	HV1693	16/7 5:00	73H	ZTH	C	D51	15/7 17:00	16/7 5:20
D	HV5625	HV5625	16/7 5:00	73H	PMI	J	C14	15/7 17:00	16/7 5:20
D	EZY7957	EZY7957	16/7 5:00	320	AGP	J	H04	15/7 17:00	16/7 5:10

D	HV1679	HV5134	16/7 5:05	73H	CFU	C	D48	16/7 2:37	16/7 5:25
D	HV0755	HV1288	16/7 5:05	73H	FAO	C	D43	16/7 4:00	16/7 5:25
D	OR279	OR298	16/7 5:05	73H	KGS	C	C07	16/7 4:00	16/7 5:25
A	KL0836	KL0791	16/7 5:10	77W	SIN	J	E19	16/7 4:50	16/7 6:25
A	CZ0345	CZ0346	16/7 5:10	388	PEK	J	E18	16/7 4:50	16/7 6:25
D	HV1919	HV6876	16/7 5:15	73H	HER	C	B15	16/7 4:10	16/7 5:35
D	OR211	OR624	16/7 5:15	73H	ZTH	C	B17	16/7 3:20	16/7 5:35
D	CND113	CND113	16/7 5:20	738	MJT	C	B13	15/7 17:20	16/7 5:40
D	OR111	OR230	16/7 5:25	73H	VAR	C	D07	16/7 4:00	16/7 5:45
D	HV5355	HV1544	16/7 5:30	73H	FAO	J	B27	16/7 2:52	16/7 5:50
D	HV5887	HV5314	16/7 5:30	73H	CHQ	J	D54	16/7 2:52	16/7 5:50
A	KL0588	KL0537	16/7 5:35	333	LOS	J	E06	16/7 5:15	16/7 6:50
A	MP8562	MP8911	16/7 5:40	74Y	NBO	F	S72	16/7 5:20	16/7 7:17
T	KL0894		16/7 5:45	789			G73	16/7 5:55	16/7 8:15
A	DL0070	DL0071	16/7 5:50	333	ATL	J	G09	16/7 5:30	16/7 7:10
A	DL0124	DL0143	16/7 5:50	333	BOS	J			
A	KL0692	KL0605	16/7 5:55	744	YYZ	J			
A	DL0132	DL0133	16/7 6:00	332	DTW	J	E03	16/7 5:40	16/7 7:00
A	DL0046	DL0047	16/7 6:00	763	JFK	J	E22	16/7 5:40	16/7 7:42
A	KL0428	KL0691	16/7 6:00	772	DXB	J	E72	16/7 5:40	16/7 7:52
A	KL0810	KL0591	16/7 6:00	77W	KUL	J	E09	16/7 5:40	16/7 8:17
A	KL0656	KL0765	16/7 6:00	333	MSP	J	E02	16/7 5:40	16/7 7:15
D	HV5131	HV1118	16/7 6:00	73H	BCN	J	C08	16/7 3:15	16/7 6:20
D	HV5517	HV5080	16/7 6:00	73H	PFO	J	D22	16/7 4:55	16/7 6:20
D	HV5763	HV5766	16/7 6:00	73H	GRO	J	D10	16/7 3:15	16/7 6:20
D	HV6737	HV6737	16/7 6:05	73W	KIT	J	D41	15/7 18:05	16/7 6:25
D	HV5801	HV5952	16/7 6:05	73H	TLV	J	D56	16/7 3:17	16/7 6:25
A	KL0405	KL0421	16/7 6:10	332	TSE	J	G76	16/7 5:50	16/7 8:40
A	MF0811	MF0812	16/7 6:10	788	XMN	J			
D	HV6463	HV5006	16/7 6:10	73W	JMK	J	Y71	16/7 1:10	16/7 6:30
D	HV0071	HV6150	16/7 6:15	73H	EIN	P	P15	16/7 1:25	16/7 6:35
D	HV1161	HV6342	16/7 6:15	73H	MJT	C	D04	16/7 3:35	16/7 6:35
A	EK9743	EK9916	16/7 6:20	77X	DWC	F	S74	16/7 6:00	16/7 11:05
D	SK550	SK550	16/7 6:20	320	CPH	J	J87	15/7 18:20	16/7 6:40
D	HV5637	HV6004	16/7 6:20	73H	PMO	J	C11	16/7 3:42	16/7 6:40
T	KL0836		16/7 6:25	77W			R74	16/7 6:35	16/7 6:15
T	CZ0345		16/7 6:25	388			R77	16/7 6:35	16/7 13:15
D	HV5541	HV6916	16/7 6:30	73H	HEL	J	D12	16/7 5:25	16/7 6:50
D	HV5673	HV5804	16/7 6:30	73H	IBZ	J	C04	16/7 5:25	16/7 6:50
A	MU0771	MU0772	16/7 6:35	332	PVG	J	G07	16/7 6:15	16/7 7:50
D	HV5581	HV6728	16/7 6:35	73H	NCE	J	C06	16/7 4:02	16/7 6:55
D	HV5093	HV5754	16/7 6:35	73H	ZTH	J	C07	16/7 5:30	16/7 6:55
A	CX271	CX270	16/7 6:40	77W	HKG	J	J85	16/7 6:20	16/7 9:55
D	OR647	OR194	16/7 6:40	73H	FNC	C	C10	16/7 4:37	16/7 7:00
A	CZ0307	CZ0308	16/7 6:45	332	CAN	J			
D	KL1223	KL1223	16/7 6:45	73W	CDG	J	D53	15/7 18:45	16/7 7:05
D	HV6331	HV1262	16/7 6:45	73H	VLC	J	D44	16/7 4:10	16/7 7:05
D	HV6867	HV5686	16/7 6:45	73H	ATH	J	R87	16/7 2:35	16/7 7:05
A	KL1340	KL1227	16/7 6:47	73W	BLL	J	D41	16/7 6:27	16/7 7:12
A	KL1900	KL1777	16/7 6:50	E75	HAJ	J	D10	16/7 6:30	16/7 7:07
T	KL0588		16/7 6:50	333			E75	16/7 7:00	16/7 6:40
D	KL1103	KL1103	16/7 6:50	73H	ARN	J	D47	15/7 18:50	16/7 7:10
D	KL1721	KL1721	16/7 6:50	E90	BRU	J	D08	15/7 18:50	16/7 7:10

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Historical delay data of summer period 2017

Due to its size, this part of the Appendix is only an excerpt: the extended version is available in digital form only. In the column 'Pax/Cargo', 'P' denotes passenger flights and 'F' denotes cargo flights.

A/D	Flight	Sch. date	Sc. Time	Time block	Delay [min]	O/D	Border Control Status	AC cat.	WIBO NABO	Airline	Pax/Cargo
D	TWG200	4-8-2017	11:00:00	3	-17	TIA	NS_uns	1	NABO	TWG	F
D	FR003	6-7-2017	12:45:00	3	35	DUB	NS_scr	1	NABO	RYR	P
D	TWG121	12-6-2017	18:15:00	4	32	HAJ	SCH	1	NABO	TWG	F
D	DX008	28-6-2017	20:30:00	4	-92	BLL	SCH	1	NABO	DTR	P
D	FR003A	14-8-2017	20:50:00	4	257	STN	NS_scr	1	NABO	RYR	P
A	TWG100	3-8-2017	19:00:00	4	31	RBM	SCH	1	NABO	TWG	F
A	DX007	28-6-2017	18:15:00	4	-5	BLL	SCH	1	NABO	DTR	P
A	FR003	6-7-2017	10:00:00	2	1	DUB	NS_scr	1	NABO	RYR	P
A	FR003	14-8-2017	19:40:00	4	241	STN	NS_scr	1	NABO	RYR	P
A	TWG221	12-6-2017	17:30:00	4	11	BSL	SCH	1	NABO	TWG	F
D	AF1257	30-4-2017	11:55:00	3	7	CFE	SCH	2	NABO	AFR	P
D	AF1257	7-5-2017	11:55:00	3	-1	CFE	SCH	2	NABO	AFR	P
D	AF1257	14-5-2017	11:55:00	3	5	CFE	SCH	2	NABO	AFR	P
D	AF1257	21-5-2017	11:55:00	3	6	CFE	SCH	2	NABO	AFR	P
D	AF1257	28-5-2017	11:55:00	3	24	CFE	SCH	2	NABO	AFR	P
D	AF1257	4-6-2017	11:55:00	3	4	CFE	SCH	2	NABO	AFR	P
D	SK1556	18-4-2017	18:55:00	4	5	ARN	SCH	2	NABO	SAS	P
D	SK1556	2-7-2017	19:55:00	4	20	ARN	SCH	2	NABO	SAS	P
D	SK552	1-4-2017	10:25:00	2	9	CPH	SCH	2	NABO	SAS	P
D	SK552	8-4-2017	10:25:00	2	25	CPH	SCH	2	NABO	SAS	P
D	SK552	15-4-2017	10:25:00	2	0	CPH	SCH	2	NABO	SAS	P
D	SK552	22-4-2017	10:25:00	2	33	CPH	SCH	2	NABO	SAS	P
D	SK552	29-4-2017	10:25:00	2	18	CPH	SCH	2	NABO	SAS	P
D	SK552	6-5-2017	10:25:00	2	18	CPH	SCH	2	NABO	SAS	P
D	SK552	13-5-2017	10:25:00	2	23	CPH	SCH	2	NABO	SAS	P
D	SK552	27-5-2017	10:25:00	2	2	CPH	SCH	2	NABO	SAS	P
D	SK552	3-6-2017	10:25:00	2	146	CPH	SCH	2	NABO	SAS	P
D	SK552	17-6-2017	10:25:00	2	13	CPH	SCH	2	NABO	SAS	P
D	SK552	25-6-2017	10:05:00	2	12	CPH	SCH	2	NABO	SAS	P
D	SK552	26-6-2017	10:25:00	2	4	CPH	SCH	2	NABO	SAS	P
D	SK552	2-7-2017	10:05:00	2	8	CPH	SCH	2	NABO	SAS	P
D	SK552	8-7-2017	10:25:00	2	14	CPH	SCH	2	NABO	SAS	P
D	SK552	9-7-2017	10:05:00	2	5	CPH	SCH	2	NABO	SAS	P
D	SK552	15-7-2017	10:25:00	2	25	CPH	SCH	2	NABO	SAS	P
D	SK552	16-7-2017	10:05:00	2	20	CPH	SCH	2	NABO	SAS	P
D	SK552	17-7-2017	10:25:00	2	3	CPH	SCH	2	NABO	SAS	P
D	SK552	19-7-2017	10:25:00	2	6	CPH	SCH	2	NABO	SAS	P
D	SK552	22-7-2017	10:25:00	2	18	CPH	SCH	2	NABO	SAS	P

D	SK552	23-7-2017	10:05:00	2	3	CPH	SCH	2	NABO	SAS	P
D	SK552	29-7-2017	10:25:00	2	17	CPH	SCH	2	NABO	SAS	P
D	SK552	30-7-2017	10:05:00	2	14	CPH	SCH	2	NABO	SAS	P
D	SK552	5-8-2017	10:25:00	2	11	CPH	SCH	2	NABO	SAS	P
D	SK552	6-8-2017	10:05:00	2	14	CPH	SCH	2	NABO	SAS	P
D	SK552	12-8-2017	10:25:00	2	27	CPH	SCH	2	NABO	SAS	P
D	SK552	13-8-2017	10:05:00	2	14	CPH	SCH	2	NABO	SAS	P
D	SK552	19-8-2017	10:25:00	2	21	CPH	SCH	2	NABO	SAS	P
D	SK552	26-8-2017	10:25:00	2	2	CPH	SCH	2	NABO	SAS	P
D	SK552	2-9-2017	10:25:00	2	16	CPH	SCH	2	NABO	SAS	P
D	SK552	9-9-2017	10:25:00	2	4	CPH	SCH	2	NABO	SAS	P
D	SK552	16-9-2017	10:25:00	2	23	CPH	SCH	2	NABO	SAS	P
D	SK552	23-9-2017	10:25:00	2	9	CPH	SCH	2	NABO	SAS	P
D	SK552	30-9-2017	10:25:00	2	-5	CPH	SCH	2	NABO	SAS	P
D	SK552	7-10-2017	10:25:00	2	4	CPH	SCH	2	NABO	SAS	P
D	SK552	14-10-2017	10:25:00	2	30	CPH	SCH	2	NABO	SAS	P
D	SK552	21-10-2017	10:25:00	2	1	CPH	SCH	2	NABO	SAS	P
D	SK552	28-10-2017	10:25:00	2	6	CPH	SCH	2	NABO	SAS	P
D	SK556	26-6-2017	11:00:00	3	11	ARN	SCH	2	NABO	SAS	P
D	SK556	27-6-2017	11:25:00	3	5	ARN	SCH	2	NABO	SAS	P
D	SK556	28-6-2017	11:00:00	3	28	ARN	SCH	2	NABO	SAS	P
D	SK556	30-6-2017	11:00:00	3	-2	ARN	SCH	2	NABO	SAS	P
D	SK556	3-7-2017	11:00:00	3	21	ARN	SCH	2	NABO	SAS	P
D	SK556	4-7-2017	11:25:00	3	7	ARN	SCH	2	NABO	SAS	P
D	SK556	5-7-2017	11:00:00	3	27	ARN	SCH	2	NABO	SAS	P
D	SK556	7-7-2017	11:00:00	3	1	ARN	SCH	2	NABO	SAS	P
D	SK556	10-7-2017	11:00:00	3	22	ARN	SCH	2	NABO	SAS	P
D	SK556	11-7-2017	11:25:00	3	11	ARN	SCH	2	NABO	SAS	P
D	SK556	14-7-2017	11:00:00	3	-1	ARN	SCH	2	NABO	SAS	P
D	SK556	17-7-2017	11:00:00	3	15	ARN	SCH	2	NABO	SAS	P
D	SK556	18-7-2017	11:25:00	3	1	ARN	SCH	2	NABO	SAS	P
D	SK556	19-7-2017	11:00:00	3	20	ARN	SCH	2	NABO	SAS	P
D	SK556	25-7-2017	11:25:00	3	3	ARN	SCH	2	NABO	SAS	P
D	SK556	26-7-2017	11:00:00	3	3	ARN	SCH	2	NABO	SAS	P
D	SK556	31-7-2017	11:00:00	3	18	ARN	SCH	2	NABO	SAS	P
D	SK556	1-8-2017	11:25:00	3	15	ARN	SCH	2	NABO	SAS	P
D	SK556	2-8-2017	11:00:00	3	13	ARN	SCH	2	NABO	SAS	P
D	SK556	4-8-2017	11:00:00	3	5	ARN	SCH	2	NABO	SAS	P
D	SK556	7-8-2017	11:00:00	3	22	ARN	SCH	2	NABO	SAS	P
D	SK556	8-8-2017	11:25:00	3	6	ARN	SCH	2	NABO	SAS	P
D	SK556	9-8-2017	11:00:00	3	20	ARN	SCH	2	NABO	SAS	P
D	SK556	11-8-2017	11:00:00	3	-7	ARN	SCH	2	NABO	SAS	P
D	SK558	26-3-2017	14:15:00	3	3	ARN	SCH	2	NABO	SAS	P
D	SK558	1-4-2017	15:05:00	3	36	ARN	SCH	2	NABO	SAS	P
D	SK558	2-4-2017	14:15:00	3	11	ARN	SCH	2	NABO	SAS	P
D	SK558	8-4-2017	15:05:00	3	13	ARN	SCH	2	NABO	SAS	P
D	SK558	9-4-2017	14:15:00	3	12	ARN	SCH	2	NABO	SAS	P
D	SK558	15-4-2017	15:05:00	3	7	ARN	SCH	2	NABO	SAS	P

D	SK558	22-4-2017	15:05:00	3	42	ARN	SCH	2	NABO	SAS	P
D	SK558	23-4-2017	14:15:00	3	4	ARN	SCH	2	NABO	SAS	P
D	SK558	29-4-2017	15:05:00	3	13	ARN	SCH	2	NABO	SAS	P
D	SK558	30-4-2017	14:15:00	3	43	ARN	SCH	2	NABO	SAS	P
D	SK558	6-5-2017	15:05:00	3	0	ARN	SCH	2	NABO	SAS	P
D	SK558	7-5-2017	14:15:00	3	13	ARN	SCH	2	NABO	SAS	P
D	SK558	13-5-2017	15:05:00	3	18	ARN	SCH	2	NABO	SAS	P
D	SK558	14-5-2017	14:15:00	3	40	ARN	SCH	2	NABO	SAS	P
D	SK558	20-5-2017	15:05:00	3	14	ARN	SCH	2	NABO	SAS	P
D	SK558	21-5-2017	14:15:00	3	31	ARN	SCH	2	NABO	SAS	P
D	SK558	27-5-2017	15:05:00	3	6	ARN	SCH	2	NABO	SAS	P
D	SK558	28-5-2017	14:15:00	3	71	ARN	SCH	2	NABO	SAS	P
D	SK558	3-6-2017	15:05:00	3	48	ARN	SCH	2	NABO	SAS	P
D	SK558	4-6-2017	14:15:00	3	12	ARN	SCH	2	NABO	SAS	P
D	SK558	10-6-2017	15:05:00	3	55	ARN	SCH	2	NABO	SAS	P
D	SK558	11-6-2017	14:15:00	3	32	ARN	SCH	2	NABO	SAS	P
D	SK558	17-6-2017	15:05:00	3	2	ARN	SCH	2	NABO	SAS	P
D	SK558	18-6-2017	14:15:00	3	47	ARN	SCH	2	NABO	SAS	P
D	SK558	15-8-2017	14:15:00	3	24	ARN	SCH	2	NABO	SAS	P
D	SK558	16-8-2017	14:15:00	3	17	ARN	SCH	2	NABO	SAS	P
D	SK558	17-8-2017	14:15:00	3	9	ARN	SCH	2	NABO	SAS	P
D	SK558	18-8-2017	14:15:00	3	18	ARN	SCH	2	NABO	SAS	P
D	SK558	19-8-2017	15:05:00	3	8	ARN	SCH	2	NABO	SAS	P
D	SK558	20-8-2017	14:15:00	3	3	ARN	SCH	2	NABO	SAS	P
D	SK558	23-8-2017	14:15:00	3	78	ARN	SCH	2	NABO	SAS	P
D	SK558	26-8-2017	15:05:00	3	17	ARN	SCH	2	NABO	SAS	P
D	SK558	27-8-2017	14:15:00	3	0	ARN	SCH	2	NABO	SAS	P
D	SK558	30-8-2017	14:15:00	3	93	ARN	SCH	2	NABO	SAS	P
D	SK558	2-9-2017	15:05:00	3	1	ARN	SCH	2	NABO	SAS	P
D	SK558	9-9-2017	15:05:00	3	28	ARN	SCH	2	NABO	SAS	P
D	SK558	10-9-2017	14:15:00	3	27	ARN	SCH	2	NABO	SAS	P
D	SK558	16-9-2017	15:05:00	3	4	ARN	SCH	2	NABO	SAS	P
D	SK558	23-9-2017	15:05:00	3	0	ARN	SCH	2	NABO	SAS	P
D	SK558	24-9-2017	14:15:00	3	24	ARN	SCH	2	NABO	SAS	P
D	SK558	30-9-2017	15:05:00	3	5	ARN	SCH	2	NABO	SAS	P
D	SK558	1-10-2017	14:15:00	3	1	ARN	SCH	2	NABO	SAS	P
D	SK558	7-10-2017	15:05:00	3	10	ARN	SCH	2	NABO	SAS	P
D	SK558	8-10-2017	14:15:00	3	25	ARN	SCH	2	NABO	SAS	P
D	SK558	14-10-2017	15:05:00	3	15	ARN	SCH	2	NABO	SAS	P
D	SK558	15-10-2017	14:15:00	3	-2	ARN	SCH	2	NABO	SAS	P
D	SK558	21-10-2017	15:05:00	3	2	ARN	SCH	2	NABO	SAS	P
D	SK558	22-10-2017	14:15:00	3	4	ARN	SCH	2	NABO	SAS	P
D	SK558	28-10-2017	15:05:00	3	32	ARN	SCH	2	NABO	SAS	P
D	SK554	26-3-2017	20:20:00	4	1	CPH	SCH	2	NABO	SAS	P
D	SK554	2-4-2017	20:20:00	4	24	CPH	SCH	2	NABO	SAS	P
D	SK554	9-4-2017	20:20:00	4	-6	CPH	SCH	2	NABO	SAS	P
D	SK554	16-4-2017	20:20:00	4	6	CPH	SCH	2	NABO	SAS	P
D	SK554	23-4-2017	20:20:00	4	4	CPH	SCH	2	NABO	SAS	P
D	SK554	30-4-2017	20:20:00	4	2	CPH	SCH	2	NABO	SAS	P
D	SK554	7-5-2017	20:20:00	4	5	CPH	SCH	2	NABO	SAS	P
D	SK554	14-5-2017	20:20:00	4	12	CPH	SCH	2	NABO	SAS	P

D	SK554	21-5-2017	20:20:00	4	7	CPH	SCH	2	NABO	SAS	P
D	SK554	28-5-2017	20:20:00	4	14	CPH	SCH	2	NABO	SAS	P
D	SK554	11-6-2017	20:20:00	4	2	CPH	SCH	2	NABO	SAS	P
D	SK554	18-6-2017	20:20:00	4	-3	CPH	SCH	2	NABO	SAS	P
D	SK554	30-6-2017	21:45:00	4	8	CPH	SCH	2	NABO	SAS	P
D	SK554	7-7-2017	21:45:00	4	19	CPH	SCH	2	NABO	SAS	P
D	SK554	14-7-2017	21:45:00	4	16	CPH	SCH	2	NABO	SAS	P
D	SK554	21-7-2017	21:45:00	4	0	CPH	SCH	2	NABO	SAS	P
D	SK554	28-7-2017	21:45:00	4	8	CPH	SCH	2	NABO	SAS	P
D	SK554	4-8-2017	21:45:00	4	18	CPH	SCH	2	NABO	SAS	P
D	SK554	11-8-2017	21:45:00	4	7	CPH	SCH	2	NABO	SAS	P
D	SK554	20-8-2017	20:20:00	4	0	CPH	SCH	2	NABO	SAS	P
D	SK554	27-8-2017	20:20:00	4	24	CPH	SCH	2	NABO	SAS	P
D	SK554	3-9-2017	20:20:00	4	35	CPH	SCH	2	NABO	SAS	P
D	SK554	10-9-2017	20:20:00	4	0	CPH	SCH	2	NABO	SAS	P
D	SK554	17-9-2017	20:20:00	4	36	CPH	SCH	2	NABO	SAS	P
D	SK554	24-9-2017	20:20:00	4	9	CPH	SCH	2	NABO	SAS	P
D	SK554	1-10-2017	20:20:00	4	25	CPH	SCH	2	NABO	SAS	P
D	SK554	8-10-2017	20:20:00	4	29	CPH	SCH	2	NABO	SAS	P
D	SK554	15-10-2017	20:20:00	4	20	CPH	SCH	2	NABO	SAS	P
D	SK554	22-10-2017	20:20:00	4	23	CPH	SCH	2	NABO	SAS	P
D	SK548	1-4-2017	14:45:00	3	2	CPH	SCH	2	NABO	SAS	P
D	SK548	8-4-2017	14:45:00	3	0	CPH	SCH	2	NABO	SAS	P
D	SK548	22-4-2017	14:45:00	3	27	CPH	SCH	2	NABO	SAS	P
D	SK548	29-4-2017	14:45:00	3	7	CPH	SCH	2	NABO	SAS	P
D	SK548	6-5-2017	14:45:00	3	1	CPH	SCH	2	NABO	SAS	P
D	SK548	20-5-2017	14:45:00	3	26	CPH	SCH	2	NABO	SAS	P
D	SK548	3-6-2017	14:45:00	3	117	CPH	SCH	2	NABO	SAS	P
D	SK548	10-6-2017	14:45:00	3	11	CPH	SCH	2	NABO	SAS	P
D	SK548	1-7-2017	15:25:00	3	-5	CPH	SCH	2	NABO	SAS	P
D	SK548	8-7-2017	15:25:00	3	9	CPH	SCH	2	NABO	SAS	P
D	SK548	15-7-2017	15:25:00	3	23	CPH	SCH	2	NABO	SAS	P
D	SK548	22-7-2017	15:25:00	3	164	CPH	SCH	2	NABO	SAS	P
D	SK548	29-7-2017	15:25:00	3	11	CPH	SCH	2	NABO	SAS	P
D	SK548	5-8-2017	15:25:00	3	47	CPH	SCH	2	NABO	SAS	P
D	SK548	12-8-2017	15:25:00	3	6	CPH	SCH	2	NABO	SAS	P
D	SK548	19-8-2017	14:45:00	3	14	CPH	SCH	2	NABO	SAS	P
D	SK548	26-8-2017	14:45:00	3	1	CPH	SCH	2	NABO	SAS	P
D	SK548	2-9-2017	14:45:00	3	5	CPH	SCH	2	NABO	SAS	P
D	SK548	9-9-2017	14:45:00	3	-4	CPH	SCH	2	NABO	SAS	P
D	SK548	16-9-2017	14:45:00	3	2	CPH	SCH	2	NABO	SAS	P
D	SK548	23-9-2017	14:45:00	3	10	CPH	SCH	2	NABO	SAS	P
D	SK548	30-9-2017	14:45:00	3	6	CPH	SCH	2	NABO	SAS	P
D	SK548	7-10-2017	14:45:00	3	5	CPH	SCH	2	NABO	SAS	P
D	SK548	14-10-2017	14:45:00	3	17	CPH	SCH	2	NABO	SAS	P
D	SK548	21-10-2017	14:45:00	3	13	CPH	SCH	2	NABO	SAS	P
D	SK548	28-10-2017	14:45:00	3	45	CPH	SCH	2	NABO	SAS	P
D	SK1550	1-4-2017	18:45:00	4	27	CPH	SCH	2	NABO	SAS	P

H

Empirical distribution configuration of historical delay data

H.1 - Scenario 1 empirical data excerpt on NABO Schengen arrivals between 0:00 and 5:59, determined using Excel

Due to its size, this part of the Appendix shows only an excerpt of one group: the extended version with all scenario 1 groups is available in digital form only.

Mean Delay		**Count**	**Variance**	
14.06		3,328	4909	
Bins [min]	**Frequencies [-]**	**Cumulative frequencies [-]**	**Percentual bin frequencies [%]**	**Percentual cumulative bin frequencies [%]**
-75	0	0	0.00	0.0
-70	2	2	0.06	0.1
-65	0	2	0.00	0.1
-60	1	3	0.03	0.1
-55	0	3	0.00	0.1
-50	3	6	0.09	0.2
-45	4	10	0.12	0.3
-40	7	17	0.21	0.5
-35	17	34	0.51	1.0
-30	47	81	1.41	2.4
-25	80	161	2.40	4.8
-20	139	300	4.18	9.0
-15	219	519	6.58	15.6
-10	315	834	9.47	25.1
-5	334	1168	10.04	35.1
0	351	1519	10.55	45.6
5	347	1866	10.43	56.1
10	279	2145	8.38	64.5
15	202	2347	6.07	70.5
20	170	2517	5.11	75.6
25	139	2656	4.18	79.8
30	111	2767	3.34	83.1
35	84	2851	2.52	85.7
40	61	2912	1.83	87.5
45	56	2968	1.68	89.2

H.2 - (hybrid) Scenario 2 empirical data determination using Python v3.7

Due to its size, this part of the Appendix is available in digital form only.

Scenario 1 - Configuration and allocation schedules

I.1 - Buffer times as determined for scenario 1

Groups					Buffer times [min]			
Time block	**A/D**	**NABO/WIBO**	**BCS**	**Available flight delays in group**	**60%**	**70%**	**80%**	**90%**
0:00-5:59	A	NABO	SCH	3,328	0	5	10	15
0:00-5:59	D	NABO	SCH	1,936	5	5	10	20
0:00-5:59	A	NABO	NS_scr	262	0	0	5	15
0:00-5:59	D	NABO	NS_scr	50	5	10	10	15
0:00-5:59	A	NABO	NS_uns	1,252	0	5	15	20
0:00-5:59	D	NABO	NS_uns	1,042	5	10	15	30
6:00-10:59	A	NABO	SCH	18,357	5	5	10	15
6:00-10:59	D	NABO	SCH	27,979	10	15	20	30
6:00-10:59	A	NABO	NS_scr	8,280	0	5	10	15
6:00-10:59	D	NABO	NS_scr	27,979	10	15	20	30
6:00-10:59	A	NABO	NS_uns	1971	5	5	10	15
6:00-10:59	D	NABO	NS_uns	1743	15	20	25	45
11:00-17:29	A	NABO	SCH	33,969	0	5	5	10
11:00-17:29	D	NABO	SCH	33,445	15	20	30	50
11:00-17:29	A	NABO	NS_scr	13,005	0	5	5	10
11:00-17:29	D	NABO	NS_scr	12,488	15	20	30	45
11:00-17:29	A	NABO	NS_uns	3,959	0	5	10	15
11:00-17:29	D	NABO	NS_uns	4,748	25	30	40	55
17:30-23:59	A	NABO	SCH	30,253	0	5	5	15
17:30-23:59	D	NABO	SCH	22,439	15	20	30	45
17:30-23:59	A	NABO	NS_scr	13,003	0	5	10	10
17:30-23:59	D	NABO	NS_scr	11,883	15	20	30	50
17:30-23:59	A	NABO	NS_uns	3,225	0	5	10	15
17:30-23:59	D	NABO	NS_uns	2,869	20	25	35	55
0:00-5:59	A	WIBO	SCH	141	0	0	0	5
0:00-5:59	D	WIBO	SCH	10	20	20	20	20
0:00-5:59	A	WIBO	NS_scr	432	15	20	30	35
0:00-5:59	D	WIBO	NS_scr	4	20	20	20	20
0:00-5:59	A	WIBO	NS_uns	791	5	10	10	20
0:00-5:59	D	WIBO	NS_uns	13	20	20	20	20

6:00-10:59	A	WIBO	SCH	33	20	20	20	20
6:00-10:59	D	WIBO	SCH	140	20	30	45	105
6:00-10:59	A	WIBO	NS_scr	7,213	10	15	20	30
6:00-10:59	D	WIBO	NS_scr	4,154	15	20	30	45
6:00-10:59	A	WIBO	NS_uns	6,403	5	10	15	20
6:00-10:59	D	WIBO	NS_uns	2,065	20	25	30	45
11:00-17:29	A	WIBO	SCH	393	0	0	0	5
11:00-17:29	D	WIBO	SCH	535	25	35	45	75
11:00-17:29	A	WIBO	NS_scr	1,713	10	15	20	30
11:00-17:29	D	WIBO	NS_scr	5,077	15	20	30	45
11:00-17:29	A	WIBO	NS_uns	3,401	10	15	20	30
11:00-17:29	D	WIBO	NS_uns	7,299	20	20	35	75
17:30-23:59	A	WIBO	SCH	312	5	10	15	20
17:30-23:59	D	WIBO	SCH	185	15	25	35	65
17:30-23:59	A	WIBO	NS_scr	15	20	20	20	20
17:30-23:59	D	WIBO	NS_scr	148	20	20	35	75
17:30-23:59	A	WIBO	NS_uns	1,944	5	10	15	20
17:30-23:59	D	WIBO	NS_uns	3,161	15	20	25	40

I.2 - BEONTRA 'Occupancy Times' export for scenario 1 - 60 (excerpt)

Due to the size, this part of the Appendix only shows an excerpt of the 'Occupancy Times' export for scenario 1 - 60: the exports for all four subscenarios are available in digital form only.

Group	Resource Type	PAX Handling	Pre-Arrival Buffer	Post-Departure Buffer	Arrival Occupancy	Departure Occupancy
WIBO, lowcost	Stands	Pier Served	00:00:10	00:00:10	00:01:15	00:01:25
WIBO, lowcost	Stands	Bussed	00:00:10	00:00:10	00:01:15	00:01:25
WIBO, lowcost	Gates	Pier Served	00:00:10	00:00:10	00:01:15	00:01:25
WIBO, lowcost	Gates	Bussed	00:00:10	00:00:10	00:00:40	00:00:40
NABO, lowcost	Stands	Pier Served	00:00:10	00:00:10	00:00:55	00:01:05
NABO, lowcost	Stands	Bussed	00:00:10	00:00:10	00:00:55	00:01:05
NABO, lowcost	Gates	Pier Served	00:00:10	00:00:10	00:00:55	00:01:05
NABO, lowcost	Gates	Bussed	00:00:10	00:00:10	00:00:20	00:00:20
WIBO - SCH [0:00-5:59]	Stands	Pier Served	00:00:00	00:00:20	00:01:15	00:01:25
WIBO - SCH [0:00-5:59]	Stands	Bussed	00:00:00	00:00:20	00:01:15	00:01:25
WIBO - SCH [0:00-5:59]	Gates	Pier Served	00:00:00	00:00:20	00:01:15	00:01:25
WIBO - SCH [0:00-5:59]	Gates	Bussed	00:00:00	00:00:20	00:00:40	00:00:40
WIBO - NS_scr [0:00-5:59]	Stands	Pier Served	00:00:15	00:00:20	00:01:15	00:01:25
WIBO - NS_scr [0:00-5:59]	Stands	Bussed	00:00:15	00:00:20	00:01:15	00:01:25
WIBO - NS_scr [0:00-5:59]	Gates	Pier Served	00:00:15	00:00:20	00:01:15	00:01:25
WIBO - NS_scr [0:00-5:59]	Gates	Bussed	00:00:15	00:00:20	00:00:40	00:00:40
WIBO - NS_uns [0:00-5:59]	Stands	Pier Served	00:00:05	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [0:00-5:59]	Stands	Bussed	00:00:05	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [0:00-5:59]	Gates	Pier Served	00:00:05	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [0:00-5:59]	Gates	Bussed	00:00:05	00:00:20	00:00:40	00:00:40
WIBO - SCH [6:00-10:59]	Stands	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - SCH [6:00-10:59]	Stands	Bussed	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - SCH [6:00-10:59]	Gates	Pier Served	00:00:20	00:00:20	00:01:15	00:01:25
WIBO - SCH [6:00-10:59]	Gates	Bussed	00:00:20	00:00:20	00:00:40	00:00:40
WIBO - NS_scr [6:00-10:59]	Stands	Pier Served	00:00:10	00:00:15	00:01:15	00:01:25
WIBO - NS_scr [6:00-10:59]	Stands	Bussed	00:00:10	00:00:15	00:01:15	00:01:25
WIBO - NS_scr [6:00-10:59]	Gates	Pier Served	00:00:10	00:00:15	00:01:15	00:01:25
WIBO - NS_scr [6:00-10:59]	Gates	Bussed	00:00:10	00:00:15	00:00:40	00:00:40
WIBO - NS_uns [6:00-10:59]	Stands	Pier Served	00:00:05	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [6:00-10:59]	Stands	Bussed	00:00:05	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [6:00-10:59]	Gates	Pier Served	00:00:05	00:00:20	00:01:15	00:01:25
WIBO - NS_uns [6:00-10:59]	Gates	Bussed	00:00:05	00:00:20	00:00:40	00:00:40

I.3 - BEONTRA Allocation schedules for scenario 1

Due to the size, the allocation schedules for all subscenarios of scenario 1 are available in digital form only.

J

Scenario 2 - Configuration and allocation schedules

J.1 - Buffer times as determined for scenario 2

Groups					Buffer times [min]			
Time block	**A/D**	**Origin/Destination**	**Airline**	**Available flight delays in group**	**60%**	**70%**	**80%**	**90%**
11:00-17:29	A	DUB	KLM	527	0	0	0	5
11:00-17:29	A	BLL	KLM	584	5	5	10	15
11:00-17:29	A	ARN	KLM	597	5	10	10	15
6:00-10:59	D	ARN	KLM	597	10	15	20	30
17:30-23:59	A	CPH	KLM	519	10	10	15	15
11:00-17:29	D	CPH	KLM	644	15	15	20	35
11:00-17:29	D	OSL	KLM	626	15	20	25	35
11:00-17:29	A	OSL	KLM	644	5	10	10	15
17:30-23:59	A	FRA	DLH	634	0	0	5	10
11:00-17:29	A	FRA	KLM	639	5	10	10	15
11:00-17:29	D	MUC	DLH	593	15	20	30	40
11:00-17:29	A	MUC	KLM	634	5	5	10	10
11:00-17:29	A	CDG	KLM	580	5	10	10	15
6:00-10:59	D	CDG	KLM	588	10	10	15	20
11:00-17:29	D	GOT	KLM	537	10	15	20	30
11:00-17:29	A	GOT	KLM	645	5	10	10	15
17:30-23:59	A	TXL	KLM	583	5	5	10	15
11:00-17:29	D	TXL	KLM	641	15	20	25	40
11:00-17:29	A	SVG	KLM	591	5	10	10	15
11:00-17:29	A	STR	KLM	639	5	5	10	15
11:00-17:29	D	GVA	KLM	637	15	20	25	40
11:00-17:29	D	ZRH	KLM	609	15	20	25	40
11:00-17:29	A	ZRH	KLM	638	10	15	15	25
11:00-17:29	D	DUS	KLM	635	15	20	25	40
17:30-23:59	D	LHR	KLM	642	15	25	35	55
17:30-23:59	A	LHR	KLM	1,117	10	15	15	20
17:30-23:59	D	LHR	BAW	582	15	20	30	50
17:30-23:59	A	LHR	BAW	642	5	5	10	15
11:00-17:29	D	LHR	KLM	903	15	20	30	50
11:00-17:29	A	LHR	KLM	784	5	5	10	15
11:00-17:29	D	LHR	BAW	646	20	25	35	50
11:00-17:29	A	LHR	BAW	582	0	5	5	10

6:00-10:59	D	LHR	KLM	571	15	20	25	35
11:00-17:29	D	PRG	KLM	524	20	25	35	50
11:00-17:29	A	BHX	KLM	636	0	0	5	10
11:00-17:29	A	BHX	BEE	521	0	5	5	10
17:30-23:59	D	BHX	BEE	610	15	25	35	60
11:00-17:29	A	MAN	KLM	642	5	10	10	15
11:00-17:29	D	EDI	KLM	646	15	20	25	35
11:00-17:29	A	NCL	KLM	632	5	10	15	15
17:30-23:59	A	LCY	KLM	719	5	5	10	15
6:00-10:59	D	LCY	KLM	608	15	15	20	30
17:30-23:59	D	LGW	EZY	639	25	35	50	75
17:30-23:59	A	LGW	EZY	823	0	0	5	10
11:00-17:29	D	LGW	EZY	552	20	25	35	65
17:30-23:59	D	LTN	EZY	578	20	30	40	60
17:30-23:59	A	LTN	EZY	578	0	5	10	15
6:00-10:59	A	DTW	DAL	606	20	25	30	35

J.2 - BEONTRA 'Occupancy Times' export for scenario 2 - 60 (excerpt)

Due to the size, this part of the Appendix only shows the 'Occupancy Times' export for scenario 2 - 60: the exports for all four subscenarios are available in digital form only.

Group	Resource Type	PAX Handling	Pre-Arrival Buffer	Post-Departure Buffer	Arrival Occupancy	Departure Occupancy
576 - 'DUB', 'KLM', 'A' [11:00-17:29]	Stands	Pier Served	00:00:00	00:00:00	00:00:55	00:01:05
576 - 'DUB', 'KLM', 'A' [11:00-17:29]	Stands	Bussed	00:00:00	00:00:00	00:00:55	00:01:05
576 - 'DUB', 'KLM', 'A' [11:00-17:29]	Gates	Pier Served	00:00:00	00:00:00	00:00:55	00:01:05
576 - 'DUB', 'KLM', 'A' [11:00-17:29]	Gates	Bussed	00:00:00	00:00:00	00:00:20	00:00:20
475 - 'BLL', 'KLM', 'A' [11:00-17:29]	Stands	Pier Served	00:00:05	00:00:00	00:00:55	00:01:05
475 - 'BLL', 'KLM', 'A' [11:00-17:29]	Stands	Bussed	00:00:05	00:00:00	00:00:55	00:01:05
475 - 'BLL', 'KLM', 'A' [11:00-17:29]	Gates	Pier Served	00:00:05	00:00:00	00:00:55	00:01:05
475 - 'BLL', 'KLM', 'A' [11:00-17:29]	Gates	Bussed	00:00:05	00:00:00	00:00:20	00:00:20
381 - 'ARN', 'KLM', 'A' [11:00-17:29]	Stands	Pier Served	00:00:05	00:00:00	00:00:55	00:01:05
381 - 'ARN', 'KLM', 'A' [11:00-17:29]	Stands	Bussed	00:00:05	00:00:00	00:00:55	00:01:05
381 - 'ARN', 'KLM', 'A' [11:00-17:29]	Gates	Pier Served	00:00:05	00:00:00	00:00:55	00:01:05
381 - 'ARN', 'KLM', 'A' [11:00-17:29]	Gates	Bussed	00:00:05	00:00:00	00:00:20	00:00:20
100 - 'ARN', 'KLM', 'D' [6:00-10:59]	Stands	Pier Served	00:00:00	00:00:10	00:00:55	00:01:05
100 - 'ARN', 'KLM', 'D' [6:00-10:59]	Stands	Bussed	00:00:00	00:00:10	00:00:55	00:01:05
100 - 'ARN', 'KLM', 'D' [6:00-10:59]	Gates	Pier Served	00:00:00	00:00:10	00:00:55	00:01:05
100 - 'ARN', 'KLM', 'D' [6:00-10:59]	Gates	Bussed	00:00:00	00:00:10	00:00:20	00:00:20
407 - 'CPH', 'KLM', 'A' [17:30-23:59]	Stands	Pier Served	00:00:10	00:00:00	00:00:55	00:01:05
407 - 'CPH', 'KLM', 'A' [17:30-23:59]	Stands	Bussed	00:00:10	00:00:00	00:00:55	00:01:05
407 - 'CPH', 'KLM', 'A' [17:30-23:59]	Gates	Pier Served	00:00:10	00:00:00	00:00:55	00:01:05
407 - 'CPH', 'KLM', 'A' [17:30-23:59]	Gates	Bussed	00:00:10	00:00:00	00:00:20	00:00:20
127 - 'CPH', 'KLM', 'D' [11:00-17:29]	Stands	Pier Served	00:00:00	00:00:15	00:00:55	00:01:05
127 - 'CPH', 'KLM', 'D' [11:00-17:29]	Stands	Bussed	00:00:00	00:00:15	00:00:55	00:01:05
127 - 'CPH', 'KLM', 'D' [11:00-17:29]	Gates	Pier Served	00:00:00	00:00:15	00:00:55	00:01:05
127 - 'CPH', 'KLM', 'D' [11:00-17:29]	Gates	Bussed	00:00:00	00:00:15	00:00:20	00:00:20
146 - 'OSL', 'KLM', 'D' [11:00-17:29]	Stands	Pier Served	00:00:00	00:00:15	00:00:55	00:01:05
146 - 'OSL', 'KLM', 'D' [11:00-17:29]	Stands	Bussed	00:00:00	00:00:15	00:00:55	00:01:05
146 - 'OSL', 'KLM', 'D' [11:00-17:29]	Gates	Pier Served	00:00:00	00:00:15	00:00:55	00:01:05
146 - 'OSL', 'KLM', 'D' [11:00-17:29]	Gates	Bussed	00:00:00	00:00:15	00:00:20	00:00:20
341 - OSL', 'KLM', 'A' [11:00-17:29]	Stands	Pier Served	00:00:05	00:00:00	00:00:55	00:01:05
341 - OSL', 'KLM', 'A' [11:00-17:29]	Stands	Bussed	00:00:05	00:00:00	00:00:55	00:01:05
341 - OSL', 'KLM', 'A' [11:00-17:29]	Gates	Pier Served	00:00:05	00:00:00	00:00:55	00:01:05
341 - OSL', 'KLM', 'A' [11:00-17:29]	Gates	Bussed	00:00:05	00:00:00	00:00:20	00:00:20
54 - 'FRA', 'DLH', 'A' [17:30-23:59]	Stands	Pier Served	00:00:00	00:00:00	00:00:55	00:01:05
54 - 'FRA', 'DLH', 'A' [17:30-23:59]	Stands	Bussed	00:00:00	00:00:00	00:00:55	00:01:05
54 - 'FRA', 'DLH', 'A' [17:30-23:59]	Gates	Pier Served	00:00:00	00:00:00	00:00:55	00:01:05
54 - 'FRA', 'DLH', 'A' [17:30-23:59]	Gates	Bussed	00:00:00	00:00:00	00:00:20	00:00:20
363 - 'FRA', 'KLM', 'A' [11:00-17:29]	Stands	Pier Served	00:00:05	00:00:00	00:00:55	00:01:05

J.3 - BEONTRA Allocation schedules for scenario 2

Due to the size, the allocation schedules for all subscenarios of scenario 2 are available in digital form only.

K
Clash probability computation

K.1 - Clash computation set-up

Due to its size, the clash probability computation script in Python v3.7 is available in digital form only.

K.2 - Clash computation results

The corresponding output is also available in digital form, of which this is a summarising table.

	Baseline scenarios				Scenario 1				Scenario 2			
	BT=0	**BT=0**	**BT=20**	**BT=20**	**60**	**70**	**80**	**90**	**60**	**70**	**80**	**90**
Allocated movements	1,726	1,726	1,598	1,598	1,684	1,664	1,612	1,496	1,686	1,660	1,606	1,490
Tows	35	35	72	72	84	91	110	98	67	82	83	111
Registered clashes	694	694	615	615	649	637	601	556	655	639	611	542
	Summed clash probability per stand area [%]											
ALFA APRON	0.25	0.25	3.74	28.41	4.65	4.92	4.41	3.36	10.57	24.43	31.23	35.08
BRAVO APRON	0.00	0.00	0.00	0.00	30.78	0.17	0.00	0.30	0.08	29.12	18.13	1.27
BRAVO PIER	272.71	314.96	147.63	188.23	371.31	375.71	188.47	63.68	397.53	452.91	153.93	67.20
CHARLIE PIER	359.50	384.19	195.52	229.79	693.39	539.15	227.21	88.32	807.84	422.28	289.56	150.91
DELTA PIER	911.82	1027.02	430.18	619.65	1313.74	939.55	598.03	270.91	1236.25	1255.14	782.32	395.67
DELTA RAMP	1.37	1.37	20.60	24.70	23.56	16.11	31.27	5.15	21.63	48.39	20.93	57.67
ECHO PIER	314.29	323.87	162.01	166.67	286.40	241.06	141.96	59.83	375.67	203.42	185.73	109.25
ECHO RAMP	19.14	25.64	3.66	11.88	3.04	13.61	7.21	0.58	14.84	17.88	22.45	15.63
FOXTROT PIER	84.07	87.22	119.93	136.88	161.41	107.30	65.92	34.73	127.61	97.42	68.77	49.48
GOLF PIER	132.18	134.56	124.05	133.73	67.60	110.54	141.69	50.46	124.91	117.60	122.06	71.36
GOLF RAMP	0.24	6.84	5.07	26.54	12.99	5.60	18.56	5.17	12.97	53.06	11.13	15.98
HOTEL PIER	299.23	304.95	291.35	303.64	241.98	269.66	271.88	242.99	288.58	284.54	315.22	298.01
JULIET RAMP	25.13	25.13	3.06	3.06	31.65	2.28	4.99	3.80	42.74	8.10	14.02	7.20
KILO APRON	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LIMA RAMP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIKE RAMP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NOVEMBER RAMP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PAPA HOLDING	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PAPA PLATFORM	4.70	4.70	9.01	9.01	0.66	4.15	4.02	0.08	4.43	33.80	18.08	13.41
ROMEO CARGO APRON	26.41	26.41	10.97	7.13	13.59	7.28	8.22	0.26	39.65	19.88	14.75	2.81
SIERRA CARGO APRON	18.73	22.29	10.90	21.80	23.19	20.69	11.75	1.51	27.20	31.52	21.13	14.57
UNIFORM RAMP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
YANKEE RAMP	0.03	0.03	0.66	0.66	0.26	10.04	0.34	0.00	7.62	0.00	2.25	13.35
Total	2,469.81	2,689.43	1,538.34	1,911.76	3,280.18	2,667.82	1,725.93	831.12	3,540.13	3,099.49	2,091.70	1,318.85

L

AirTOp input and output

L.1 - AirTOp input, based on BEONTRA allocation schedules

Due to their size, the 10 corresponding flight plans are available in digital form only.

L.2 - Summarised AirTOp output, averaged across 10 simulation runs (details in digital form only)

Scenario:	Scen0_BT0			Scen0_BT20			Scen1_60			Scen1_70			Scen1_80			Scen1_90		
Movements considered in simulation [-]:	**1,651**			**1,753**			**1,611**			**1,595**			**1,540**			**1.432**		
	AVG	SD	SE	AVG	SD	SE	AVG	SD	SE	AVG	SD	SE	AVG	SD	SE	AVG	SD	SE
Movements in AirTOp [-]:	1755.00	5.14	1.63	1620.70	2.00	0.63	1718.00	2.36	0.75	1704.80	2.94	0.93	1667.90	4.36	1.38	1545.80	1.81	0.57
Total Stand Changes [-]	281.6	12.8	4.1	140.6	8.4	2.7	226.3	12.8	4.1	214.6	14.8	4.7	204.1	18.7	5.9	166.8	8.6	2.7
Total Stand Changes [%]	16.0	0.7	0.2	8.7	0.5	0.2	13.2	0.7	0.2	12.6	0.9	0.3	12.2	1.1	0.4	10.8	0.5	0.2
A stand changes [%]	11.59	0.74	0.24	4.86	0.44	0.14	8.99	0.80	0.25	7.86	0.85	0.27	6.94	1.21	0.38	5.97	0.54	0.17
D stand changes [%]	11.52	0.68	0.22	5.22	0.55	0.17	9.73	0.72	0.23	9.07	0.95	0.30	8.10	1.13	0.36	6.39	0.65	0.20
Tow stand changes [%]	87.09	1.51	0.48	68.41	1.18	0.37	70.16	1.26	0.40	71.79	1.08	0.34	68.59	1.71	0.54	68.53	1.63	0.52
Total delay [hrs]	41.96	8.41	2.66	18.93	2.98	0.94	36.37	26.22	8.29	35.49	10.50	3.32	21.54	3.19	1.01	15.60	3.20	1.01
Total delay frequency [-]	1224.70	56.09	17.74	812.90	37.55	11.88	1115.10	184.07	58.21	1090.60	107.87	34.11	862.40	49.48	15.65	715.80	65.50	20.71
Avg delay per movement [s]	86.07	17.26	5.46	42.04	6.61	2.09	76.24	55.03	17.40	74.94	22.12	7.00	46.50	6.87	2.17	36.32	7.48	2.37
Total stand delay [hrs]	17.40	5.27	1.67	4.93	1.49	0.47	13.21	18.25	5.77	13.58	5.46	1.73	4.66	1.47	0.46	3.36	0.64	0.20
Total stand delay freq. [-]	321.60	42.03	13.29	166.90	23.20	7.34	239.50	97.73	30.91	292.90	60.06	18.99	163.50	23.33	7.38	129.90	18.56	5.87
Avg stand delay per mov. [s]	35.69	10.81	3.42	10.95	3.30	1.04	27.68	38.30	12.11	28.68	11.53	3.65	10.06	3.17	1.00	7.83	1.49	0.47

Scenario:	Scen0_BT0			Scen0_BT20			Scen2_60			Scen2_70			Scen2_80			Scen2_90		
Movements considered in simulation [-]:	**1,651**			**1,753**			**1,606**			**1,588**			**1,538**			**1,423**		
	AVG	SD	SE	AVG	SD	SE	AVG	SD	SE	AVG	SD	SE	AVG	SD	SE	AVG	SD	SE
Movements in AirTOp [-]:	1755.00	5.14	1.63	1620.70	2.00	0.63	1715.50	3.47	1.10	1697.30	3.27	1.03	1646.50	1.84	0.58	1552.80	22.65	7.16
Total Stand Changes [-]	281.6	12.8	4.1	140.6	8.4	2.7	236.1	15.4	4.9	221.3	5.6	1.8	209.7	9.9	3.1	188.1	25.2	8.0
Total Stand Changes [%]	16.0	0.7	0.2	8.7	0.5	0.2	13.8	0.9	0.3	13.0	0.3	0.1	12.7	0.6	0.2	12.1	1.4	0.4
A stand changes [%]	11.59	0.74	0.24	4.86	0.44	0.14	8.95	0.95	0.30	8.10	0.45	0.14	8.30	0.65	0.21	6.62	0.54	0.17
D stand changes [%]	11.52	0.68	0.22	5.22	0.55	0.17	9.63	0.89	0.28	9.31	0.37	0.12	8.89	0.67	0.21	8.27	2.38	0.75
Tow stand changes [%]	87.09	1.51	0.48	68.41	1.18	0.37	78.95	0.98	0.31	75.48	1.09	0.35	71.24	0.70	0.22	66.62	2.06	0.65
Total delay [hrs]	41.96	8.41	2.66	18.93	2.98	0.94	31.42	9.42	2.98	32.40	16.21	5.13	22.92	4.36	1.38	16.70	1.58	0.50
Total delay frequency [-]	1224.70	56.09	17.74	812.90	37.55	11.88	1077.70	84.28	26.65	1061.70	142.60	45.10	927.70	58.93	18.64	733.10	38.38	12.14
Avg delay per movement [s]	86.07	17.26	5.46	42.04	6.61	2.09	65.93	19.69	6.23	68.72	34.36	10.87	50.11	9.52	3.01	38.73	3.67	1.16
Total stand delay [hrs]	17.40	5.27	1.67	4.93	1.49	0.47	10.77	7.16	2.26	11.30	10.36	3.28	6.56	3.44	1.09	3.51	0.75	0.24
Total stand delay freq. [-]	321.60	42.03	13.29	166.90	23.20	7.34	257.00	58.11	18.38	248.40	76.28	24.12	197.30	41.83	13.23	130.40	21.58	6.83
Avg stand delay per mov. [s]	35.69	10.81	3.42	10.95	3.30	1.04	22.59	14.99	4.74	23.97	21.96	6.95	14.33	7.52	2.38	8.14	1.74	0.55