ATM2020+ | Enabling selective growth

Capacity development mainport Schiphol

Final report

AIR TRAFFIC CONTROL
THE NETHERLANDS

Reference number	S&P/215/2018	**Status**	Final
Version number	1.0	**Classification**	Internal
Version date	22 February 2018		

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1. Introduction

Air Traffic Control the Netherlands (LVNL) develops a strategy that describes what is needed to support traffic growth beyond the year 2020, in a project designated ATM2020+. The current report is the final report of this project. This report describes the strategic direction for capacity development with the current Air Traffic Management (ATM) System and what is required for further capacity development.

1.1 Context

Various strategic projects on Dutch aviation are recently or will soon be delivered. This includes, but is not limited to, the Schiphol air traffic safety study [1] by the Dutch Safety Board (OVV), the Environmental Impact Assessment (MER – Milieu Effect Rapport) on the new aircraft noise policy by Schiphol and the Lelystad Airport route consultation. At the same time, a new cabinet has been formed after March 2017 elections and negotiations at the Airport Environment Council (ORS) for the period beyond 2020 will resume. These projects and negotiations all influence each other.

1.2 Scope

The focus of ATM2020+ is on capacity development of Schiphol airport for hub- and mainport related traffic. The development of regional airports Eindhoven and Lelystad is crucial in the development of Schiphol, to serve as airport for non-mainport related traffic. Only commercial IFR flights are considered; development of general aviation is not taken into account.

The scope of this study includes the air traffic control (ATC) processes within the Amsterdam Flight Information Region (FIR) that are related to handling traffic for the mainport. This includes:

- Schiphol Ground Control;
- Schiphol Runway Control;
- Schiphol Approach (terminal area (TMA) control);
- Amsterdam Area Control (ACC);
- Military radar ATC (civil traffic handling, including area control and approach for Eindhoven and Lelystad airports).

Identified solutions may be impact or relate to ATC processes that are not related to the mainport Schiphol, such as regional airports Groningen Airport Eelde and Maastricht Aachen Airport or to other military airports. A full analysis will be conducted when the identified solutions are elaborated in follow-up projects.

1.3 Main questions

The starting point of ATM2020+ is to determine how much traffic LVNL and CLSK can handle at Schiphol, at the regional airports and in the ACC sectors with the current ATM system and after implementation of scheduled projects. In an iterative process, the feasibility of handling various market demand scenarios is assessed. This answers the following questions:

- What are the bottlenecks for capacity development with the current ATM system?
- What capacity will be developed by the scheduled projects?

ATM2020+ continues by defining solutions to support future traffic growth beyond the capacity developed by the scheduled projects. This is split into the following questions:

- What are the requirements for Schiphol development up to 540k annual movements?
- What are the requirements for Schiphol development beyond 540k annual movements?
  - What are the requirements for development of regional airports?

These questions and their answers will be addressed in the next chapters.

1.4 Market demand scenarios

Seven market demand scenarios are defined for the project [2]. The scenarios include traffic to and from Schiphol (EHAM), Lelystad (EHLE), Eindhoven (EHEH), Rotterdam (EHRD) and overflying traffic below Flight Level (FL) 245. Table 1 indicates the traffic volumes per scenario.

Table 1: Market Demand Scenarios - Traffic Volume (in 1,000 movements) per Airport

Scenario	A	B	C	D	E	F	G
EHAM	500	500	530	530	560	560	600
EHLE	4	45	10	25	10	45	45
EHEH	43	43	43	58	43	73	73
EHRD	26	26	26	26	26	26	26
TOTAL	573	614	609	639	639	704	744
+ overflight	66	70	70	70	70	74	76

All traffic scenarios are developed for a full year, including a summer and winter schedule. Traffic volumes are based on the following starting points:

- EHAM: traffic volumes are defined in increments of 30k movements, starting from the 500k scenario which is the maximum number of movements for the year 2020 (resulting in scenarios of 500k, 530k, 560k and 600k). Traffic schedules were derived from the Schiphol integrated capacity planning process. Growth initially takes place in existing declared hourly capacity (filling the gaps between the peak hours), from 560k also in peak hours (i.e. this requires an increased declared peak hour capacity).[1]
- EHLE: traffic volumes are related to opening of the airport (4k), the initial development within existing airspace structure (10k), first (25k) and second (45k) phase from the Environmental Impact Assessment of Lelystad Airport [3].
- EHEH: traffic volumes are based on the current maximum within existing noise limits (43k), an intermediate growth scenario (58k) and the additional demand to accommodate traffic growth for the Netherlands (73k).
- EHRD: traffic volume constant (26k) because of the local noise limits.
- Overflights: based on current demand + STATFOR based growth (+1,5% per year). This includes traffic growth of neighbouring airports such as Brussels, Düsseldorf, etc. Arrivals to and departures from these airports fly through Dutch airspace below FL245.

The traffic volumes for the respective airports are combined to develop realistic scenarios, e.g. scenarios that are considered likely for a certain year. Scenarios B-C-D-E are for example possible options for year 2024, depending on a lower (B and C) and higher (D and E) traffic

[1] The traffic scenarios are used for analysis of the ATM system. The described increments of 500k, 530k, 560k and 600k movements for Schiphol were used in the feasibility analysis (reported in Chapter 2). Requirements for further development focus on two increments: traffic levels up to 540k and beyond 540k. The figure of 540k is derived from the MER discussion that takes place in parallel. Therefore, in this document the results of the scenario analysis refer to the traffic samples whereas future requirements will be translated into the “up to 540k” and “beyond 540k” traffic levels.

growth. More on the development of these scenarios can be found in the report that describes market demand used in this program [2].

1.5 Approach of the project

The ATM2020+ project approach distinguishes itself from previous projects by taking a performance-based, integral and solution-oriented approach to define a direction for further development.

A performance-based approach with a focus on capacity development

ATM2020+ approaches the development of a future ATM concept in a performance-based way: it is aimed at reaching a performance target and defines what is needed to achieve this target. The performance target is based on user requirements, both from civil as well as from military airspace users. The focus is on an increase in the yearly traffic volume and more specifically, an increased peak hour capacity at Schiphol for yearly traffic volumes beyond 540k movements. Other performance indicators such as safety, environment, compliance and human performance define the framework within which the capacity development has to take place.

An integral and chain-wide approach

The ATM system is a complex socio-technical system in which interactions between the operational processes determine the overall system performance. For example, bottlenecks in ground control operations may manifest in delays in area control sectors. The ATM2020+ project is therefore not limited to single or separate operational processes, but takes into account the complete ATM system and approaches capacity development in a chain-wide manner. This becomes apparent in that solutions may be defined that resolve bottlenecks in other parts of the operational process.

A solution-oriented strategic direction

ATM2020+ aims at developing concrete solutions for a future ATM concept. It continues beyond a strategic vision by defining the solutions that can be actually applied in the Dutch ATM system and that contribute to capacity development. However, ATM2020+ does not design the solution itself. The design of procedures, system support and training will take place in following implementation projects.

1.6 Approach and phasing of the ATM2020+ project

The first two main questions of the project are related to the current ATM system and what is scheduled for the development of the ATM system in the next years:

- What are the bottlenecks for capacity development with the current ATM system?
- What capacity will be developed by the scheduled projects?

These questions are addressed in Chapter 2 and are based on two phases in ATM2020+:

  - Feasibility analysis of the current ATM system and existing capacity bottlenecks [4][5];
  - Identification of capacity development by scheduled projects (project portfolio of LVNL and CLSK - Commando Luchtstrijdkrachten – and Schiphol Ground Capacity 2017 - 2021) [6];

The other main questions are related to further development of the ATM system and what is needed to support this further growth. These questions were addressed in the third phase of the ATM2020+ project. These questions are addressed in Chapters 3, 4 and 5.

Figure 1 pictures the three phases of the ATM2020+ project approach.

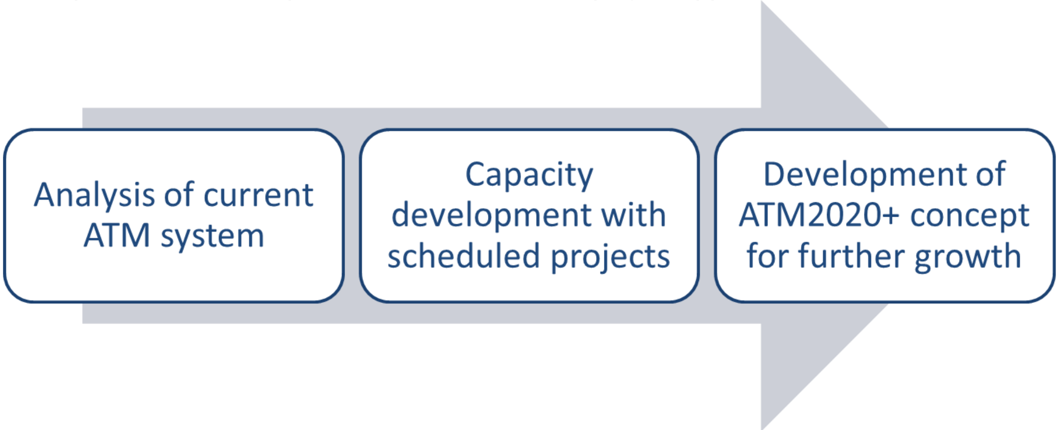

Figure 1: Project approach of ATM2020+

1.7 Methods

The ATM system has been designed with the aim to strike a balance between safety, efficiency and the environment. These three Key Performance Areas (KPAs) are also applied in this project. Within each of the KPAs, key performance indicators (KPIs) have been defined. The KPIs are used within these areas to assess the impact of traffic growth. The methods, models and sources applied in the analysis include (see also [4] and [5] for more details and further references):

- Analysis of safety occurrences in current operation and for foreseen changes, used to identify safety bottlenecks;
- The runway queuing model, to determine the required number of runways and the required runway time for each flight. Used to identify ATC delays at the runway and number of movements on the various runways (including movements on the 4^{th} runway);
- Schedule Analysis Tool, to determine the duration and severity of capacity shortages for a given entity (i.e. the runway system, Schiphol TMA, IAFs, EHFIRAM or Schiphol Ground);
- ATC Cognitive Process & Operational Situation (ACoPOS) model, to derive complexity factors and human performance issues;
- The Network Strategic Tool (NEST) to create 4D trajectories based on flight schedules and a model of the Computer Assisted Slot Allocation (CASA) algorithm to simulate the effects of ATFM regulations;
- AirTOp Model of Schiphol Ground, a fast-time simulation of airport and airspace operations, used to identify bottlenecks in the ground infrastructure.
- Workload Model ACC, is used for assessing effects of changes on the ATM system with respect to ACC controller workload. Changes in controller workload can be assessed for acceptability with validated/calibrated threshold values.

Operational expertise was used to verify the analysis results and to provide input from operational practice. Furthermore, the following documents were used to provide additional input on existing bottlenecks in the ATM system:

- Report “Veiligheid vliegverkeer Schiphol” by the Dutch Safety Board OVV [1];
- The Tower Vision to identify improvements of the tower operation [7];

- The Sufficient Air Traffic Controller internal program (2017), to identify the precise needs to increase the number of air traffic controllers;
- Lelystad project documentation, to identify the ACC capacity limitations when regional traffic is growing;
- A study on the impact analysis on military mission effectiveness and controller workload for new routes to connect Lelystad airport.

In the determination of the requirements for further capacity development, various solutions are considered, including those mentioned in:

- The report Increase Schiphol TMA Capacity [8], with potential solutions in the area of arrival management, airspace management, including optimization of sectorization, different Transition Altitude and a 4th IAF, route system, training and awareness, management of demand and capacity and civil-military co-operation.
- The report Netherlands Airspace review [9] and its appreciation [10], with an assessment of relevant options of airspace redesign, including the Frysian airspace.
- The SESAR solutions catalogue [11], including several operational improvements of different technology readiness levels, ranging from Airborne Separation Assurance System to Time-Based Separation. Some of these solutions do not increase the capacity but reduce the negative effects of an increase of the throughput or just enable other steps. Some of these implementations are obliged by the Pilot Common Projects regulations anyway.
- The projects LVNL has performed over the last decade, including various operational concepts, procedural solutions and technical support tools.

Subsequently, a series of four workshops was organized, with experts[2] with backgrounds in strategy, performance, human factors and research and development. The aim of these workshops was to identify improvements of the ATM system that would solve the bottlenecks inhibiting capacity development (as identified in the feasibility analysis). The final aim was that all traffic scenarios could be handled in all domains. The set of appropriate and necessary solutions was then integrated in some iteration and review cycles.

Although the focus of these ATM system improvements was on capacity development, no analysis or estimate of resulting capacity was conducted. To be able to provide such an estimate, a more detailed design of the various solutions is needed. The goal of the current exercise was to define an chain-wide and solution-oriented strategic direction.

1.8 Status of the report

The sections above present the context, objective, scope and approach of this project. The main result is a set of requirements that have to be fulfilled in order to support the traffic growth after the year 2020.

Several general reservations are to be made, such as: market scenarios are uncertain (e.g. in what way will the traffic scenarios develop), unforeseen technologies might pop up and society might set different requirements.
The original aim was to identify solutions for all scenario's, including scenario G. Striving to find solutions that can be actually applied instead of remaining in a research phase, it appeared that

[2] The experts involved are familiar with the current civil ATC operations in the Netherlands but do not have in-depth operational experience of air traffic control in practice, military operations and ATC hardware.

scenario G was introducing too many uncertainties to develop requirements for. It is therefore that this scenario is not investigated (see Figure 13 in Chapter 4).

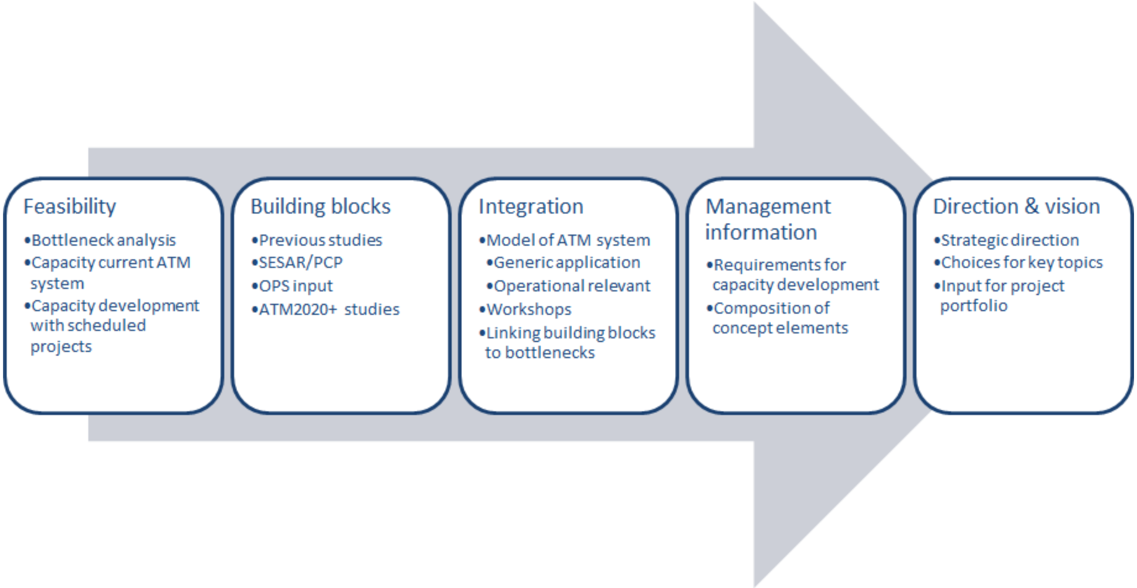

Figure 2: The steps of the methodology applied in the ATM 2020+ project. This report documents the analysis, the identification of the building blocks and their integration. The report can be seen as management information for strategic direction and input for new projects. The actual realization is out of scope.

2. Capacity development after realisation of scheduled projects

This chapter provides an overview of the capacity development after implementation of currently agreed projects. Figure 3 shows for each of the market demand scenarios A to G whether it is deemed feasible to achieve for the respective operational process[3]. The operational process is considered as total: the combination of available infrastructure, staffing, procedures and technical systems, plus applicable regulations. The score is the sum of various key performance indicators.

A detailed report describes the capacity bottlenecks [5] and underlying analyses [4].

The table uses three scores:

- V this traffic scenario can be handled;
- X this traffic scenario cannot be handled;
- ~ it is undecided whether this traffic scenario can be handled.

	Market demand (x 1000 movements)	Ground control	Runway control	Schiphol TMA	AMS ACC	Military radar
A	EHAM 500 EHLE 4 EHEH 43 EHRD 26 Total 573 + 66 overflight	V	V	V	~	V
B	EHAM 500 EHLE 45 EHEH 43 EHRD 26 Total 614 + 70 overflight	V	V	V	X	X
C	EHAM 530 EHLE 10 EHEH 43 EHRD 26 Total 609 + 70 overflight	V	V / X	~	~	V
D	EHAM 530 EHLE 25 EHEH 58 EHRD 26 Total 639 + 70 overflight	V	V / X	~	X	X
E	EHAM 560 EHLE 10 EHEH 43 EHRD 26 Total 639 + 70 overflight	X	X	X	X	V
F	EHAM 560 EHLE 45 EHEH 73 EHRD 26 Total 704 + 74 overflight	X	X	X	X	X
G	EHAM 600 EHLE 45 EHEH 73 EHRD 26 Total 744 + 76 overflight	X	X	X	X	X

Figure 3: Capacity development for each operational process and each traffic scenario, after realisation of scheduled projects.

[3] The traffic scenarios are used for analysis of the ATM system. The described increments of 500k, 530k, 560k and 600k movements for Schiphol were used in the feasibility analysis (reported in Chapter 2). Requirements for further development focus on two increments: traffic levels up to 540k and beyond 540k. The figure of 540k is derived from the MER discussion that takes place in parallel. Therefore, in this document the results of the scenario analysis refer to the traffic samples whereas future requirements will be translated into the “up to 540k” and “beyond 540k” traffic levels.

2.1 Overview of projects

The analysis considers the ATM system as is (reference situation April 2017, documented in [6]) and the situation after realisation of scheduled projects. The ATM system as is includes the infrastructure (air and ground), technical systems, procedures and agreements and staffing of the current ATM concept. This includes the various staffing options available nowadays, such as working with three ground controllers at Schiphol Tower or working in a split TMA-East / TMA-West configuration for the feeder controller (assuming sufficient controllers are available to work in this configuration).

The situation after realisation of scheduled projects includes the implementation of existing LVNL and CLSK project portfolio and Schiphol Ground Capacity 2017 -2021. These projects are foreseen to be implemented in the next 2-5 years, therefore this is the expected ATM system around the year 2022-2023.

These projects included amongst others:

- LVNL project portfolio (as defined on April 5th, 2017), including:
    - Short term solutions for Amsterdam Area control sector 3 bottlenecks;
    - Workload model;
    - Civil / Military co-location;
    - Increase upper level Schiphol TMA to FL135;
    - Arrival MANagement 1.0 (inbound planning system including training for approach planning tasks);
    - Development of Lelystad Airport up to 10k scheduled movements;
    - iCAS (implementation of new Air Traffic Services system);
    - Capacity management (initial steps);
    - Schiphol tower-centre developments (increase floorspace, introduction of electronic flight strips).
- CLSK scheduled projects:
    - Segregation of inbound and outbound routes for Eindhoven;
    - Staffing rearrangements to optimise rostering.
- Schiphol Roadmap Ground Capacity 2017 - 2021:
    - Doubling taxiway Quebec;
    - Expand Uniform platform;
    - Additional entry/exit runway 06-24;
    - Extra taxi-lane in the GH-bay.

A full overview of projects considered is provided in a separate report [6].

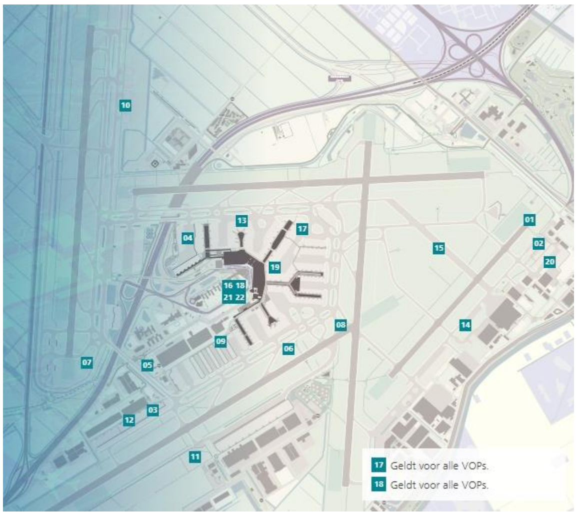

Figure 4: Overview of locations for which changes are considered in the Roadmap Ground Capacity 2017-2021 [12].

2.2 Schiphol Ground Control

Figure 4 gives a summary of the capacity scores Schiphol Ground per traffic scenario.

	Market demand (x 1000 movements)	Ground control
A	EHAM 500 EHLE 4 EHEH 43 EHRD 26 Total 573 + 66 overflight	V
B	EHAM 500 EHLE 45 EHEH 43 EHRD 26 Total 614 + 70 overflight	V
C	EHAM 530 EHLE 10 EHEH 43 EHRD 26 Total 609 + 70 overflight	V
D	EHAM 530 EHLE 25 EHEH 58 EHRD 26 Total 639 + 70 overflight	V
E	EHAM 560 EHLE 10 EHEH 43 EHRD 26 Total 639 + 70 overflight	X
F	EHAM 560 EHLE 45 EHEH 73 EHRD 26 Total 704 + 74 overflight	X
G	EHAM 600 EHLE 45 EHEH 73 EHRD 26 Total 744 + 76 overflight	X

Figure 4: Capacity development for Schiphol Ground Control after implementation of scheduled projects

Ground infrastructure solutions for ground congestions

The current Schiphol Ground operation has various bottlenecks that have been identified in other projects and studies [e.g. 7]. The existing airport infrastructure (including a shortage in the number of aircraft parking positions but also single taxi lanes at busy locations) causes congestion in the traffic flows in the ground operation. These congestions result in delay, potential safety issues and additional workload for the personnel involved.

The “Roadmap Ground capacity Schiphol 2017 -2021” [12], as agreed between relevant stakeholders, offers solutions for most of the infrastructure bottlenecks at existing traffic levels, but not to all. This roadmap includes infrastructural projects such as doubling of taxiway Quebec, an additional entry/exit for runway 24, an extra taxi lane in the GH-bay, additional remote holding positions and additional aircraft parking positions. These last two will need continuous attention as they are only temporary solutions: the number of remote holding positions and aircraft parking positions will have to increase with further increasing traffic numbers.

Complex ground operation due to frequent runway changes and non-standard working

In addition to infrastructural bottlenecks, frequent changes in Runway Mode of Operation and some of the procedural agreements with partners and stakeholders also cause additional movements or conflicts within the ground operation. This is particularly evident for taxi/tow instructions, where non-standard procedures often need to be applied and responsibility within the working area is shared between LVNL (ground control) and the airport (apron control), sometimes resulting in safety occurrences.

Improved maintenance planning and agreements with Schiphol and airlines is required to reduce the impact this has on the operation, for example on tow-movements to and from maintenance locations. By rearranging some agreements with apron control (responsible for tow traffic) as proposed in the tower vision [7] some bottlenecks can be resolved.

Tower 2.0: preparing Tower-Center for future operations

Working conditions at the main tower (Tower-Center) and the staff shortage also form bottlenecks in the current ATM system. Current LVNL projects “Electronic Flight Strips” and “Increasing Tower-Center floor space” will improve the working conditions at Tower-Center and will solve the related bottleneck. The ongoing program aimed to solve the operational staff shortage will have a positive effect, but it is unclear whether it will be sufficient.

Conclusion Schiphol Ground Control

It is expected that the activities mentioned above will provide sufficient improvements to enable traffic growth up to scenario C/D (with Schiphol 530k movements). For traffic volumes beyond 530k, further structural improvements will need to be implemented.

2.3 Runway Control Schiphol

Figure 4 gives a summary of the capacity scores for Runway Control Schiphol per scenario. It also entails the ability to deliver sufficient runway capacity and the ability to meet the targets with respect to the number of movements on the 4th runway.

	Market demand (x 1000 movements)	Runway control
A	EHAM 500 EHLE 4 EHEH 43 EHRD 26 Total 573 + 66 overflight	V
B	EHAM 500 EHLE 45 EHEH 43 EHRD 26 Total 614 + 70 overflight	V
C	EHAM 530 EHLE 10 EHEH 43 EHRD 26 Total 609 + 70 overflight	V / X
D	EHAM 530 EHLE 25 EHEH 58 EHRD 26 Total 639 + 70 overflight	V / X
E	EHAM 560 EHLE 10 EHEH 43 EHRD 26 Total 639 + 70 overflight	X
F	EHAM 560 EHLE 45 EHEH 73 EHRD 26 Total 704 + 74 overflight	X
G	EHAM 600 EHLE 45 EHEH 73 EHRD 26 Total 744 + 76 overflight	X

Figure 5: Capacity development for Schiphol Runway Control after implementation of scheduled projects

Tower 2.0: preparing Tower-Center for future operations

Working conditions at the main tower (Tower-Center) and the permanent staff shortage form bottlenecks in the current runway control process. Current LVNL projects "Electronic Flight Strips" and "Increasing Tower-Center floor space" will improve the working conditions at Tower-Center and will solve the related bottleneck. The ongoing program aimed to solve the operational staff shortage will have a positive effect, but it is unclear whether it will be sufficient.

Environmental performance target for movements on 4th runway is exceeded after 500k

The current environmental performance target for the number of movements on the 4th runway is set at a maximum of 80 movements per day, with 40 movements per day on average. Analyses [4] have shown that with increasing traffic volumes while maintaining the current peak hour capacity, the 4th runway has to be used more frequently than the current performance target specifies. For example, the maximum of 80 movements is exceeded in about a third of the year for the scenario with 530k annual movements and even more often in higher traffic scenarios. This is the result of an increased duration of the inbound and outbound peaks and longer overlap between both. The need for use of the 4th runway with increasing traffic volumes has to be taken into account in the advice of the Airport Environment Council (ORS) in response to the motion Visser [13].

Increased capacity for runway combinations requires safety and capacity solutions

The available runway capacity of 106/110 movements per hour is already exceeded by demand several times during the day with 500k annual movements. This is apparent during each arrival peak (inbound capacity) and for some departure peaks (outbound capacity). The limitation of the maximum runway capacity will remain without projects planned yet to increase this capacity. The 530k scenario is deemed feasible with the existing runway capacity, since this scenario is characterised by filling the gaps between the current peaks.

Conclusion Schiphol Runway Control

It is expected that after the implementation of the Tower 2.0 projects the Runway Control process will be able to handle the 530k traffic level at existing peak hour capacity, if the measures to resolve staff shortage are effective and if a solution for the use of the 4th runway is found.

2.4 Schiphol TMA

Figure 5 gives a summary of the capacity scores for the Schiphol TMA per traffic scenario.

	Market demand (x 1000 movements)	Schiphol TMA
A	EHAM 500 EHLE 4 EHEH 43 EHRD 26 Total 573 + 66 overflight	V
B	EHAM 500 EHLE 45 EHEH 43 EHRD 26 Total 614 + 70 overflight	V
C	EHAM 530 EHLE 10 EHEH 43 EHRD 26 Total 609 + 70 overflight	~
D	EHAM 530 EHLE 25 EHEH 58 EHRD 26 Total 639 + 70 overflight	~
E	EHAM 560 EHLE 10 EHEH 43 EHRD 26 Total 639 + 70 overflight	X
F	EHAM 560 EHLE 45 EHEH 73 EHRD 26 Total 704 + 74 overflight	X
G	EHAM 600 EHLE 45 EHEH 73 EHRD 26 Total 744 + 76 overflight	X

Figure 6: Capacity development for Schiphol TMA after implementation of scheduled projects

Solving conflicts between inbound and outbound traffic in the Schiphol TMA

The Schiphol TMA is complex both in terms of its limited size and in terms of how air traffic is handled. Conflicts between inbound and outbound traffic do occur in the TMA and are solved tactically and under high time pressure. This is expected to be unfeasible for traffic numbers above 530k without additional measures. The existing Schiphol TMA operation includes the option to work with five persons: a TMA-West Controller, a TMA-East Controller, two arrival controllers and an approach planner. De-combining working positions reduces RT-load and workload for the respective working position, since it allows the respective controller to focus at the inbound-outbound conflicts in a specific area of the TMA.

Optimisation of traffic flows by improved planning

The introduction of a new arrival management system (AMAN 1.0) is primarily a one-on-one system replacement, but the additional training for the approach planner provides some benefits for inbound planning. These projects contribute to optimise traffic flows and reduce workload in the Schiphol TMA, however it is not expected to result in major capacity improvements and therefore this will not be sufficient for traffic volumes beyond 530k.

Increased peak hour capacity requires additional measures

The TMA has an hourly capacity of 121 (inbound mode) to 125 (outbound mode) movements. These figures include inbound and outbound traffic to Schiphol but also inbound and outbound traffic to regional airports and crossing TMA traffic. For growth beyond 530k, the TMA capacity is expected to be insufficient. In addition, for scenarios with EHAM traffic 560k and beyond, an increased peak hour capacity is required, which introduces additional demands for the Schiphol TMA.

Various projects are currently being implemented, such as increasing the upper level of the Schiphol TMA to FL135 and the program aimed to solve the staff shortage. With the existing project portfolio, the TMA does have limited growth potential. At 560k traffic volumes further structural improvements will need to be implemented and further projects have to be defined.

Conclusion Schiphol TMA

It is expected that a more frequent split in separate positions for TMA-East and TMA-West and improved planning of traffic results in sufficient capacity for the 500k traffic level, while this is uncertain for the 530k traffic level. Structural improvements are needed for further growth.

2.5 Amsterdam Area Control (ACC)

Figure 6 gives a summary of the capacity scores for the Amsterdam Area Control (ACC) per conflict scenario. Developments in upper airspace (above FL245), controlled by Maastricht Upper Area Control (MUAC), are not in the scope of this analysis.

	Market demand (x 1000 movements)	AMS ACC
A	EHAM 500 EHLE 4 EHEH 43 EHRD 26 Total 573 + 66 overflight	~
B	EHAM 500 EHLE 45 EHEH 43 EHRD 26 Total 614 + 70 overflight	X
C	EHAM 530 EHLE 10 EHEH 43 EHRD 26 Total 609 + 70 overflight	~
D	EHAM 530 EHLE 25 EHEH 58 EHRD 26 Total 639 + 70 overflight	X
E	EHAM 560 EHLE 10 EHEH 43 EHRD 26 Total 639 + 70 overflight	X
F	EHAM 560 EHLE 45 EHEH 73 EHRD 26 Total 704 + 74 overflight	X
G	EHAM 600 EHLE 45 EHEH 73 EHRD 26 Total 744 + 76 overflight	X

Figure 7: Capacity development for Amsterdam ACC after implementation of scheduled projects

Structural capacity shortages in East and South sectors

Capacity analyses show capacity shortages for sectors 2 (East) and 3 (South) for more than 10% of the time, resulting in the conclusion that the traffic levels of scenario A are already causing structural bottlenecks. Both sectors also significantly contribute to Air Traffic Flow Management (ATFM) delays. Averaged over the entire day, sector 5 (North-West) is not considered to be a bottleneck. However, sector 5 traffic is concentrated in a few relatively short peaks in the morning where there is a structural capacity shortage.

Integral air traffic flow and capacity management for the Dutch FIR: improved planning of peak hours and non-Schiphol traffic

The capacity shortages result from the way traffic is scheduled throughout the day and how much ACC sector capacity is available. Traffic to and from Schiphol is characterised by in- and outbound peak hours and for Amsterdam ACC, also large fluctuations in the direction of the traffic occur (e.g. concentrated in the North-West in the morning peak and in the (North-) East in the evening peak). This distribution of traffic over the day results in capacity bottlenecks at specific moments of the day in specific sectors.

More advanced planning methods will contribute to manage ACC bottlenecks, but more improvements may be needed to efficiently handle 500-530k movements. AMAN 1.0 and related training for the approach planner support the operation but more advanced arrival management is needed for further growth.

Furthermore, non-Schiphol traffic, such as Eindhoven traffic, is currently not part of the traffic planning and thereby creates additional complexity and disruptions in the already busy sectors. An integral air traffic flow and capacity management for the entire Dutch FIR, including regional airports, is needed to improve this.

The unpredictable and complex nature of the South sector limits capacity

In addition to the high traffic numbers, sector 3 (South) is complex because of traffic interaction with regional (Eindhoven, Rotterdam) and Belgian (Brussels, Antwerp) airports. This results in crossing traffic flows and requires a lot of coordination. The foreseen development of Lelystad airport and traffic flows to and from Lelystad through the South sector will even increase complexity. The sector is also highly unpredictable, resulting in sudden switches from low to high workload. Compared to sector 2, the capacity shortages occur more frequently in sector 3.

Current LVNL projects address some of the known bottlenecks in sector 3. Since these bottlenecks already exist in the current operation, with traffic levels that are below the levels of scenario A, is it not sure whether the implementation of sector 3 measures will be sufficient to increase capacity, or that it is merely resulting in maintaining current capacity. This results in the uncertainty for scenario A and C.

Scenarios in which the regional airports Lelystad (EHLE) and Eindhoven (EHEH) have increased traffic volumes require additional improvements that are not planned in the project portfolio. The airspace will need to be redesigned for EHLE to grow beyond 10k annual aircraft movements. For growth beyond 43k annual movements at EHEH a new airspace design will be needed as well.

Coordination between units and traffic handling methods can lead to high workload and potential safety risks and as such are also considered (to become) bottlenecks.

Conclusion Amsterdam Area Control
It is expected that ongoing projects will bring benefits for the Amsterdam ACC operation, but that further structural improvements will therefore be needed for a capacity increase for the ACC sectors.

2.6 Military radar air traffic control

Figure 7 gives a summary of the capacity scores for Military radar air traffic control per traffic scenario. This considers the *military service provision* (the ANSP function, at EHEH, EHLE and area control) and not the military mission effectiveness (which is a performance indicator).

	Market demand (x 1000 movements)		Military radar
A	EHAM EHLE EHEH EHRD	500 4 43 26 Total 573 + 66 overflight	V
B	EHAM EHLE EHEH EHRD	500 45 43 26 Total 614 + 70 overflight	X
C	EHAM EHLE EHEH EHRD	530 10 43 26 Total 609 + 70 overflight	V
D	EHAM EHLE EHEH EHRD	530 25 58 26 Total 639 + 70 overflight	X
E	EHAM EHLE EHEH EHRD	560 10 43 26 Total 639 + 70 overflight	V
F	EHAM EHLE EHEH EHRD	560 45 73 26 Total 704 + 74 overflight	X
G	EHAM EHLE EHEH EHRD	600 45 73 26 Total 744 + 76 overflight	X

Figure 8: Capacity development for military radar ATC after implementation of scheduled projects

Increasing traffic volumes at Schiphol do not impact military service provision
Military service provision is mainly related to the traffic growth at the regional airports EHLE and EHEH. Traffic growth at EHAM is unlikely to influence military service provision, therefore scenario E (with 560k annual EHAM movements) has the same bottlenecks from a military ATC perspective as scenario C (with 530k annual EHAM movements).

Staff shortages limit further development of the regional airports
The Dutch Royal Air Force provides tower and approach services at EHEH, approach services at EHLE and area control services. Staff shortages at approach control (EHEH, EHLE) and area control form a bottleneck in the ATM system that already impact current service provision. Staffing limitations continue to be the main bottleneck for further growth beyond 10k for EHLE and 43k for EHEH.

Further development of Eindhoven requires segregation of inbound and outbound routes
The development of EHLE up to 10k annual movements and EHEH up to 43k annual movements is possibly feasible with the current ATM system, including airspace and routing. However, inbound and outbound flows are not segregated at EHEH which complicates growth beyond 43k at EHEH. Segregating inbound and outbound flows at EHEH will enhance capacity.

It should however be noted that growth of EHEH is not only dependent on capacity development from a service provider perspective. Because of the geographical location of EHEH and its vicinity to various military airports, the accessibility of these military airports should be considered as well with increasing (civil) movements at EHEH.

Conclusion Military Radar air traffic control
Staffing limitations and the existing design of airspace and routing for Eindhoven limit further growth of the regional airports. The development of Schiphol is not likely to influence military service provision and is therefore expected to be feasible.

2.7 Conclusion

The baseline scenario (A) is feasible after implementation of agreed projects
Based on the analysis, it can be concluded that traffic scenario A is feasible after implementation of the projects agreed upon in the LVNL project portfolio and Schiphol Ground Capacity 2017 - 2021. This scenario is related to traffic numbers expected for the year 2020, based on currently agreed traffic numbers for the various airports. However, bottlenecks are already presenting themselves in different areas/units and continue to exist after implementation of above mentioned projects. These bottlenecks require attention but are not considered to limit the baseline scenario after scheduled projects have been implemented.

Schiphol development up to 530k annual movements introduces additional requirements
While the Schiphol Ground Capacity 2017 -2021 and implementation of projects at Schiphol Tower-Center are expected to provide capacity improvements that last up to 530k, additional measures beyond the scheduled projects are needed to make the 530k EHAM scenarios possible. This includes a less strict environmental target of the use of the 4th runway, which in its current form, is exceeded structurally for the 530k scenarios. In addition, improved planning support and solving some of the known bottlenecks in ACC sector 3 is expected to improve capacity for Schiphol TMA and Amsterdam ACC, needed to make the 530k scenario feasible.

The scheduled projects are planned to deliver in 2-5 years from now, thereby define the ATM system around the year 2022-2023. The traffic growth for Schiphol around this year is expected to match the 530k scenarios. With above requirements in mind, the traffic growth and the capacity development resulting from planned projects are more or less consistent.

Growth of Schiphol beyond 530k annual movements requires new projects
The known and agreed projects do not provide sufficient capacity improvements to make growth of Schiphol beyond 530k annual movements possible. Traffic numbers of 560k and above require additional measures, not only to handle the larger annual traffic volume but also to increase peak hour capacity. An increased peak hour capacity is required for handling these traffic figures.

Further development of regional airports requires redesign of the airspace structure in the Netherlands
The further development of regional airports EHEH (beyond 43k) and EHLE (beyond 10k) requires a redesign in the airspace structure of the Netherlands. These changes in airspace are both required for Eindhoven approach and for Amsterdam ACC. This redesign includes the definition of a training area for the future fighter aircraft F35, in such a way that airspace is used optimally to satisfy civil and military users' needs. In addition to airspace redesign, further development of regional airports is limited by staffing shortages at military radar (that service the approach functions for these airports). Structural improvements in staffing are required for further development of EHEH and EHLE.

3. Requirements for Schiphol development up to 540k

3.1 Aiming point

The annual number of 500k movements was almost reached in 2017. As is concluded in the previous chapter, the scheduled projects will not be sufficient to develop capacity beyond the level of 500k movements at Schiphol. The current chapter provides potential solutions for that the first step in capacity development at Schiphol: for levels up to 540k annual movements. Implementation of the solutions described in the current chapter result in the capacity scores as indicated in the table below[4].

	Market demand (x 1000 movements)	Ground control	Runway control	Schiphol TMA	AMS ACC	Military radar
A	EHAM 500 EHLE 4 EHEH 43 EHRD 26 Total 573 + 66 overflight	V	V	V	V	V
B	EHAM 500 EHLE 45 EHEH 43 EHRD 26 Total 614 + 70 overflight	V	V	V	X	X
C	EHAM 530 EHLE 10 EHEH 43 EHRD 26 Total 609 + 70 overflight	V	V	V	V	V
D	EHAM 530 EHLE 25 EHEH 58 EHRD 26 Total 639 + 70 overflight	V	V	V	X	X
E	EHAM 560 EHLE 10 EHEH 43 EHRD 26 Total 639 + 70 overflight	X	X	X	X	V
F	EHAM 560 EHLE 45 EHEH 73 EHRD 26 Total 704 + 74 overflight	X	X	X	X	X
G	EHAM 600 EHLE 45 EHEH 73 EHRD 26 Total 744 + 76 overflight	X	X	X	X	X

Figure 9: Capacity development for each operational process and each traffic scenario, after implementation of solutions for development of Schiphol up to 540k movements

[4] The traffic scenarios are used for analysis of the ATM system. The described increments of 500k, 530k, 560k and 600k movements for Schiphol were used in the feasibility analysis (reported in Chapter 2). Requirements for further development focus on two increments: traffic levels up to 540k and beyond 540k. The figure of 540k is derived from the MER discussion that takes place in parallel. Therefore, in this document the results of the scenario analysis refer to the traffic samples whereas future requirements will be translated into the “up to 540k” and “beyond 540k” traffic levels.

3.2 Starting points for development of Schiphol up to 540k movements

The development of Schiphol up to 540k annual movements is based on the following starting points:

- Development of Schiphol up to 540k annual movements is possible with current peak hour capacity: first the available capacity within the declared capacity boundaries (outside the peaks) is used to accommodate growth. [2]
- Development of Schiphol up to 540k annual movements is based on a selective market demand for mainport related traffic, slots issues based on 2+1 runway use and a traffic distribution rule in place.

3.3 Additional requirements beyond the scheduled projects

As concluded in the previous chapter, there are requirements in addition to the scheduled projects for Runway Control, Schiphol TMA and Amsterdam ACC to develop a capacity beyond the baseline scenario of 500k annual movements. This chapter gives an overview of these requirements. The major requirements are:

- A less strict norm for the use of the 4th runway (section 3.3.1). This releases the pressure of the inbound and outbound peaks during transitions and makes traffic streams in the TMA and on the runway more stable and more predictable.
- Integral air traffic flow and capacity management for the Dutch FIR (section 3.3.2). This capacity management will lead to a better balancing of available airspace or airport capacity with expected traffic demand.

3.3.1 Increased usage of 4th runway

The standard Schiphol runway combinations during inbound peaks consist of two landing and one take-off runways (2+1); while the standard Schiphol runway combinations during outbound peaks consist of one landing and two take-off runways (1+2). In order to handle the traffic during the transition phase between the peaks, when traffic is too much for the single take-off or landing runway, a 4th runway is often used.

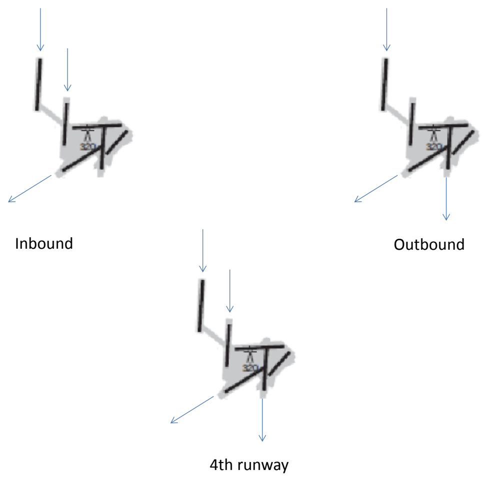

Figure 10: When traffic levels in the transition from 2 landing and 1 take-off runways (2 + 1) to 1 landing and 2 take-off runways (1 + 2) (or vice versa) are too high for the single runway, a 4th runway is used in the transition.

The usage of the 4th runway is limited by the so-called Nieuwe Normen en Handhavings Stelsel (NNHS). This NNHS has formally no regulative power but is adhered to in practice, thus balancing traffic demand and community interests. The target values for the Performance Indicator correspond to an average of 40 and a maximum of 80 movements per day on the 4th runway. These levels are exceeded when Schiphol develops up to 540k annual movements.

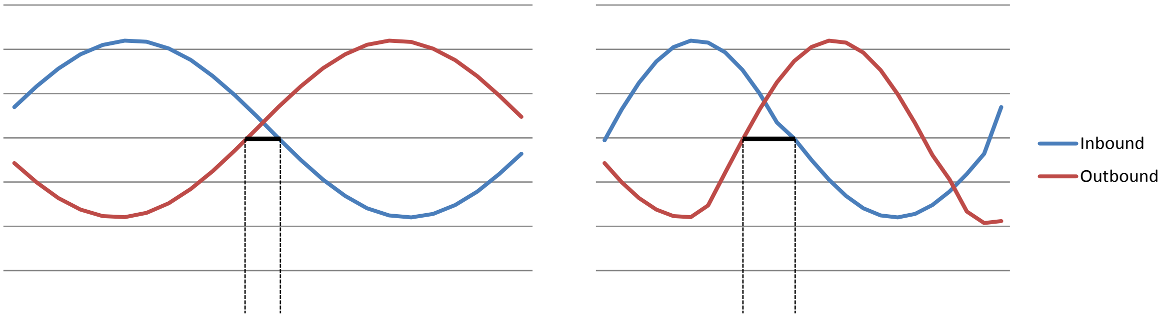

Figure 11: The curves indicate hypothetical amounts of inbound and outbound flight (in blue and red) and the period in which none of the streams can be handled on one runway (in black) as function of the time during the day. The curves in the right show a situation with equally high peaks but a longer period required for usage of the 4th runway.

A solution for the use of the 4th runway is therefore crucial in further Schiphol development. The main requirements are that usage of the 4th runway should be safe, should be able to handle the amount of traffic offered and should avoid noise hindrance. The rules for the usage of the 4th runway should therefore take into account the Key Performance Areas Safety, Efficiency and Environment. Frequent changes in runway configurations may introduce safety issues, e.g. as reported by the OVV [1]. In designing a solution for the use of the 4th runway, rules should be considered of when to open and use a 4th runway and when to close it to support a stable and predictable operation, for example:

- no change of take-off runway after … minutes before start-up of an aircraft;
- no change of landing runway after … NM before TMA entry of an aircraft;
- no 4th runway if 2+1 or 1+2 suffices for … minutes;
- 4th runway is made available … minutes before it is actually required;
- 4th runway can be used to prevent holding;
- 4th runway is not closed if that makes that ACC leaves planning behind;
- …

Such set of rules then results in a number of actual movements per day on the 4th runway, and hence in an average over a year, given a certain airport slot allocation –per season, with the community interests taken into account– and given a certain traffic demand –depending on the disturbances of the day.

The main advantages of such increased usage of the 4th runway include: less delay and less ATC effort in case of traffic disturbances before transitions of peaks, steadier and more predictable ground traffic patterns, steadier and more predictable TMA traffic patterns, wider possibilities to allocate the most appropriate runway to aircraft given its destination or its TMA entry point, less late take-off runway changes with the risk of SID confusion and less late landing runway changes with the risk of wrong cockpit calculations.

3.3.2 Capacity management

The objective of capacity management is to prepare, plan and configure operations such that optimal performance is achieved. In effect this will lead to a better balancing of available airspace or airport capacity with expected traffic demand; latent capacity is identified and put to use. The results will be improved traffic throughput and more efficient use of airspace with less impact of flow measures (less delay) and better use of available resources (staffing).

Capacity management contains a variety of (planning) activities including strategic planning (yearly forecasting, seasonal planning), pre-tactical planning (special event planning,D-1) and tactical planning (daily operations). A variety of possible future developments to improve the capacity management functionality are described below:

- More precise airport slot allocation including better time distributions of slots, allocation taking into account airspace capacities or slot allocation based on workload/complexity of flights;
- Optimization of airline schedules, in communication with the airport operator and the ANSP, taking the effects on the network into account;
- Pre-coordination between Dutch airports with clear priority rules;
- Local capacity coordination at airports;
- Development of advanced decision support tools to be used in daily planning and execution of operations;
- More balanced and predictable regulations, development of short-term ATFCM (STAM);
- Introduction of (advanced) D-1 planning;
- Continuous post-operation evaluations and establishment of best practices for capacity management in daily operations;
- Identification of latent capacity and opportunities for capacity improvements.

The roadmap of the future development of capacity management is still being developed and therefore not completely clear. Small growth of Lelystad traffic in scenario A may already require the first steps in development of capacity management e.g. the use of new ATFCM measures or the implementation of priority rules. The traffic volumes of scenario C, including 530k Schiphol and 10k Lelystad movements, might demand for:

- Adaptations of the sectorization to decrease the workload of Sector 3 controllers;
- Specific capacity management measures to balance the number of Lelystad flights Southbound through Sector 3 with the Schiphol traffic flows during certain peaks;
- An extended AMAN, in an elementary implementation, that creates an accurate schedule of flights entering the ACC for a sufficient period beforehand, on the basis of accurate predictions concerning weather and traffic coming from abroad, among other things;
- More specific time allocation and a closer examination of whether airlines schedules correspond to allocated slots for Schiphol;
- Optimization of airline schedules for Lelystad flights, in communication with LVNL.

3.4 Summary of requirements

provides an overview of the requirements for Schiphol development up to 540k.

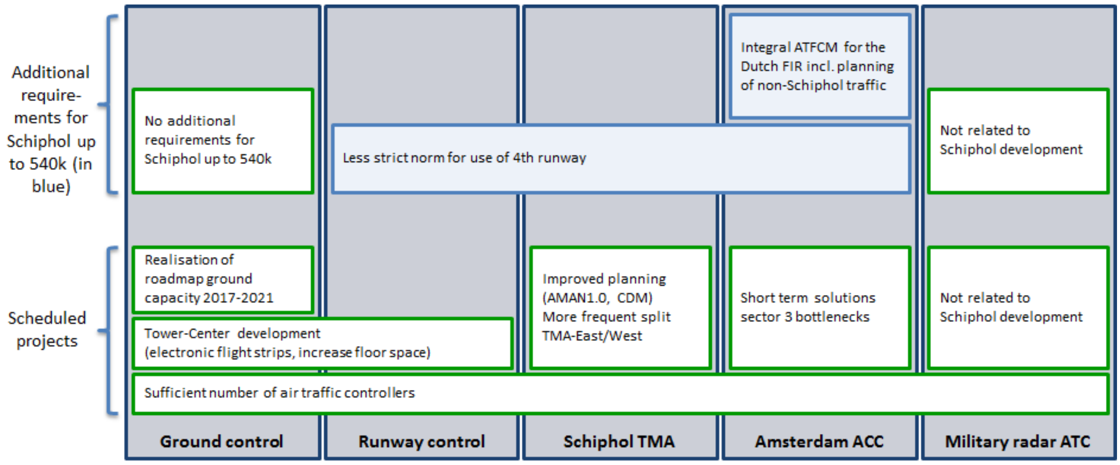

Figure 12: Summary of requirements for Schiphol development up to 540k

In addition to realization of already scheduled projects, increased usage of the 4th runway and further development of capacity management will allow development of Schiphol up to 540k movements, with current peak hour capacity.

4. Schiphol beyond 540k: increased peak hour capacity

4.1 Aiming point

This chapter considers the requirements Schiphol growth beyond 540k movements, yet disregarding growth of regional traffic. The growth of Schiphol beyond 540k requires an increased peak hour capacity [2]. The capacity development for the 600k scenario is considered uncertain and therefore not taken into the capacity scores presented below[5].

	Market demand (x 1000 movements)	Ground control	Runway control	Schiphol TMA	AMS ACC	Military radar
A	EHAM 500 EHLE 4 EHEH 43 EHRD 26 Total 573 + 66 overflight	V	V	V	V	V
B	EHAM 500 EHLE 45 EHEH 43 EHRD 26 Total 614 + 70 overflight	V	V	V	V	V
C	EHAM 530 EHLE 10 EHEH 43 EHRD 26 Total 609 + 70 overflight	V	V	V	V	V
D	EHAM 530 EHLE 25 EHEH 58 EHRD 26 Total 639 + 70 overflight	V	V	V	V	V
E	EHAM 560 EHLE 10 EHEH 43 EHRD 26 Total 639 + 70 overflight	V	~	~	V	V
F	EHAM 560 EHLE 45 EHEH 73 EHRD 26 Total 704 + 74 overflight	V	~	~	V	~ / ?
G	EHAM 600 EHLE 45 EHEH 73 EHRD 26 Total 744 + 76 overflight	~ / ?	~ / ?	~ / ?	~ / ?	~ / ?

Figure 13: Capacity development for each operational process and each traffic scenario, after implementation of solutions for development of Schiphol beyond 540k movements.

[5] The traffic scenarios are used for analysis of the ATM system. The described increments of 500k, 530k, 560k and 600k movements for Schiphol were used in the feasibility analysis (reported in Chapter 2). Requirements for further development focus on two increments: traffic levels up to 540k and beyond 540k. The figure of 540k is derived from the MER discussion that takes place in parallel. Therefore, in this document the results of the scenario analysis refer to the traffic samples whereas future requirements will be translated into the "up to 540k" and "beyond 540k" traffic levels.

4.2 Requirements for ground control

The capacity of ground control with all projects in the portfolio executed, including the activities on the Roadmap Ground Capacity Schiphol 2017 -2021, supports up to 540k movements at Schiphol per year. Furthermore, more frequent use of the 4th runway, as discussed in the previous chapter, supports more predictable and stable ground traffic flows, since the pressure on a single runway with high (too much) traffic is less. It is expected that additional measures are needed to accommodate volumes beyond 540k ground movements at Schiphol, as forecasted in the scenarios E and F.

4.2.1 Ground infrastructure: more aircraft parking positions

The required number of aircraft parking positions (VOPs) to support beyond 540k movements is not yet exactly known, but will be more than what is currently part of the roadmap Ground Capacity 2017-2021. The number and location of the VOPs depends on the nature of the operations of the airlines executing the additional flights. This amount of movements may further require that current hotspots in the ground infrastructure are redesigned.

4.2.2 Advanced technological support systems for ground control

Technological support of ground control is further extended by enhancing electronic flight strips. One enhancement is the possibility to automatically generate clearances over CPDLC[6] after certain strip manipulations. Another enhancement is generating alerts in case of inconsistent clearances, eventually coupling the strips to other safety nets as RIASS and GARDS[7].

The concept of Follow-the-Green lies between airport infrastructure and support for ground control: the main idea of it is that the cockpit crew is guided by light signals over the taxiways, between gates and runways. This is considered a form of what is called A-SMGCS[8]. A full scale option of A-SMGCS as foreseen in research will not need to be implemented to increase capacity beyond 540k movements, but local implementations may solve particular hot spots.

4.2.3 Integrated ground process (ground cluster)

A more significant increase of capacity is brought by the implementation of a more integrated ground process by means of the ground cluster. With the ground cluster, in which the various ground-related functions including ground control and apron control are integrated, better coordination, planning and communication between these functions is foreseen. This reduces complexity of the operation and thereby reduces the possibility for miscommunication and resulting safety occurrences.

4.2.4 Improved planning and working according plan

The frequent non-standard working, deviations from planning and unpredictable ground traffic streams cause a high complexity for the ground control operation. These issues have to be addressed for further Schiphol growth beyond 540k movements.

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[6] CPDLC stands for Controller-Pilot Data Link Communications and constitutes a means to communicate clearances, instructions and instructions over a data link instead of over R/T, with several advantages. The main advantage for the controller is that the R/T load is reduced.

[7] RIASS stands for Runway Incursion Alerting System Schiphol and GARDS stand for Go ARound Detection System. Both are already implemented for the Schiphol Tower operations, alerting the controllers directly in case of runway incursions and go arounds.

8 A-SMGCS stands for Advanced Surface Movements Guidance and Control system. The generic name is used for several systems, modules and functionalities to support routing, guidance and surveillance of aircraft and vehicles on an airport to facilitate safe, orderly and expeditious movements.

This implies among other things a higher and a more accurate slot adherence by the airspace users, within blocks of less than the current 20 minutes. The push-back, towing and gate allocation processes will be further integrated in the ATC ground handling, making ground control leading in the design of the processes and the specification of requirements. Airport Collaborate Decision Making might also be further enhanced, in particular to quickly get back to steady traffic streams after significant disturbances.

4.3 Requirements for runway control

In order to accommodate runway movements for a level of beyond 560k movements at Schiphol, the hourly airport slot capacities during the day need to increase, in the order of 10%. Appendix A presents an analysis of what this implies in terms of capacities of runway combinations in good visibility during day time. An increase of the hourly capacity in other states would not significantly increase the capacity in terms of the yearly traffic volumes, although it might significantly improve sustainability.

4.3.1 Increased capacity of runway combinations

The ATC capacity in the inbound and outbound peaks is currently limited by the TMA capacity[9]. Assuming that this capacity is increased -see the following section-, the next limitation is due to bottlenecks in runway control. It seems that the actual bottleneck is the combination of runways, which is frequently used at Schiphol in a 2+1 or 1+2 configuration:

- Two independent landing runways have a capacity of 70 arrivals per hour, that is approximately 10% less than 76, the capacity of one landing runway times two;
- Two independent take-off runways have a capacity of 74 departures per hour, that is approximately 10% less than 80, the capacity of one take-off runway times two.

Although more predictable and accurate delivery of traffic from the TMA to the runway will support a higher capacity on the runways, runway capacity is impacted by various factors. These circumstances include: dependent runway usage, high frequency of runway crossings, limited visibility and outside UDP operations and external disturbances.

Figure 14: Example of converging runway use

A major issue in increasing capacity of runway combinations is the use of converging runway combinations. Safety issues related to intersecting flight paths in case of a go-around result in a lower capacity, to allow timing of aircraft landing on and departing from these runways. This issue cannot easily be solved, since one of the safety nets applied is this timing of take-offs.

These risks have to be assessed in a safety case for converging runway combinations with increased capacity. After assessing the risks in detail, it may turn out that the throughput can be increased, possibly only after implementing risk mitigations, or cannot be increased.

[9] The background of the maximal 38 departure slots in the inbound peak per hour is therefore not known. The actual regulation may be based on 65 arrivals per hour except for some peaks, corresponding to the limited TMA capacity.

4.3.2 Increased single runway capacity

In addition to dependencies in runway combinations that may limit runway capacity, the single runway capacity also has to be increased to support a higher peak hour capacity. This requires the increase of the maximal throughput of a runway, currently 38 landings or 40 take-offs per hour. The potential solutions for this include[10]:

- Reduced separation on final approach, for example by applying other wake turbulence separation, like RECAT, time-based and weather-based. This may lead to a capacity up to 40 landings per hour, depending on the circumstances;
- More frequent decombining ARR and FDR/DCO positions;
- Downlink of Final Approach Speed, leading to better predictions of aircraft behavior and less margins that have to be applied to cope with uncertainty;
- Decrease of Runway Occupancy Time (ROT), by more high speed exits and more pilot awareness;
- Decrease of number of runway crossings.

4.4 Requirements for Schiphol TMA

For the development of the Schiphol TMA capacity to accommodate levels beyond 540k annual movements, the following solutions are identified:

- More predictable and accurate delivery of traffic from the TMA to the runway, for example supported by:
    - A more advanced arrival management system (enhanced AMAN);
    - A reduction of exceptional and special traffic in the TMA;
    - An increase of the transition altitude, to provide more vectoring space for approach control.
- Redesign of airspace and routing in the TMA:
    - A 4th IAF and a potential relocation of the other IAFs;
    - A segregation of the inbound and outbound flows in the TMA;
- A fully developed iCAS, to allow for the development of advanced technological support systems.

The implementation of a fully developed iCAS includes advanced AMAN, which is further discussed in the section on Arrival management below. It may also include a merging tool, to optimize spacing in merging traffic streams from different IAFs towards one runway, or a separation indicator tool (see also Figure 15), advising on the preferred spacing.

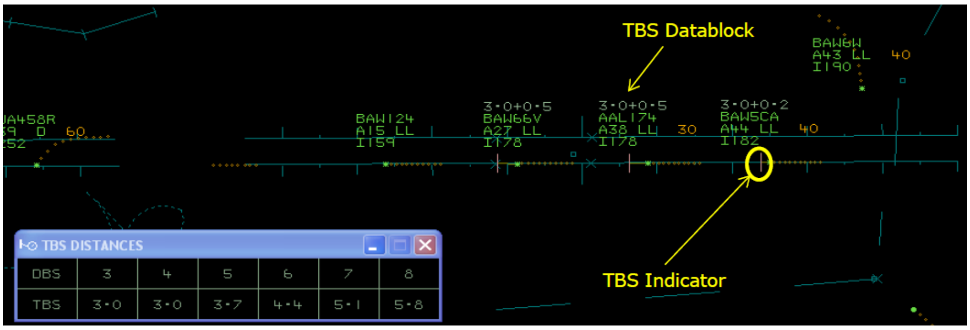

Figure 15: Indicators on the Radar screen point at the optimized aircraft positions when applying Time Based Separation. This concept can also be used for other types of separation and also for example when merging streams in the TMA. Source: [NATS Lockheed, 14].

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[10] The word potential is used to indicate that the risks and other impacts are not assessed yet. An increase of the fraction of visual approaches would increase runway throughput as well but is not considered sufficiently sustainable.

The 4th IAF and a potential relocation of the existing IAFs and the segregation of the TMA inbound and outbound streams are also both further discussed in two dedicated sections below but the analysis of the segregation of the Schiphol and other streams is postponed to a dedicated section on the Holland Regional TMA in the next chapter.

The increase of the transition altitude is studied in the past but the realization has been postponed. It makes that more flight levels can be used to separate traffic vertically in certain circumstances, depending on the QNH, and thus increases the TMA capacity.

4.4.1 Arrival management

Currently, traffic entering the Schiphol TMA at the IAFs sometimes arrives in bunches: the aircraft are separated from each other but are not accurately timed. Holding is in general avoided, and the approach controllers therefore need to give several speed, heading and altitude instructions to build an appropriately spaced sequences of aircraft that can be landed in an efficient way. This costs time and efforts, and hence capacity.

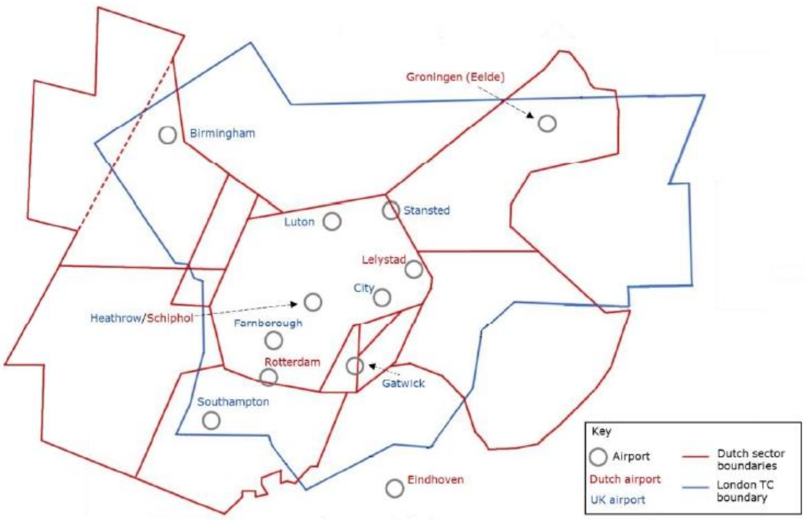

Figure 16: An overlay of the Sectors around Heathrow and Schiphol on the same geographic scale. The total number of movements on the UK airports shown is more than a million per year, much higher than the maximum aggregated throughput in scenario G. One of the enablers is the almost continuous holding of aircraft at the entry points of the London TMA, which can be considered as a way to smooth approach traffic in time at the cost of less flight efficiency compared to a streaming approach. Source: [8].

Arrival management is the building of an optimized sequence of appropriately timed aircraft. It is currently applied but not by means of the most advanced AMAN tools that are in research and development. For this study, it is relevant that there are feasible mechanisms to deliver traffic at predetermined times at the IAF with a high performance, up to an accuracy of seconds, and the possibility to extend the horizon, up to the boundaries of the CTA.

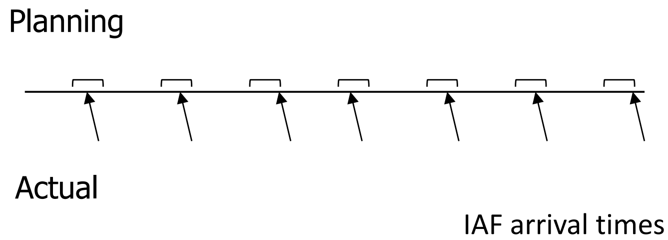

Figure 17: Arrival management implies an appropriate planning and the realization of that planning.

The implementation of more RNAV-transitions during day time is related to this: flights do not need to be vectored when they enter the TMA appropriately timed and if the throughput is not too high. However, RNAV-transitions do require more spacing between the aircraft in sequence compared to radar vectoring: since manual intervention during the transition is not preferred, separation buffers have to be created in advance. So, AMAN can increase capacity when necessary and can also improve sustainability, increase predictability and reduce complexity, but at lower traffic densities if combined with RNAV transitions. Sustainability can further be improved by the introduction of RNP (or RNAV) approaches as they offer landing opportunities in case of ILS failures and low minima. As the RNAV-transitions and – approaches do not increase capacity for high demand situations, they are not adopted as solutions in this study.

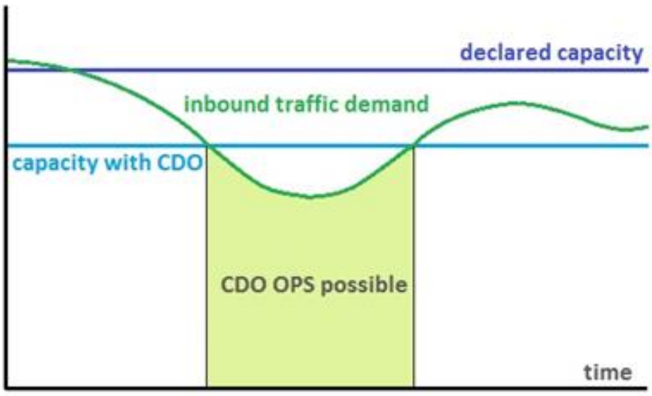

Figure 18: RNAV transition can be flown if traffic enters the TMA appropriately timed and if the traffic load is not too high. The advantages are: higher predictability, less complexity and the possibility to fly Continuous Descend Operations (CDOs), implying in return less fuel burnt and less noise generated. As the RNAV-transitions do not lead to an increase of the capacity, their implementation is not mentioned as a solution for one of the scenarios.

4.4.2 4th IAF and potential relocation of other IAFs

The Schiphol TMA has three IAFs: SUGOL, RIVER and ARTIP, from which the inbound Schiphol traffic is vectored towards the landings runways, if not flying on fixed RNAV-transitions. On the longer term, three IAFs do not suffice, in particular as the required throughput at ARTIP will surpass its threshold:

- ARTIP has a capacity of 30 arrivals per hour and that does currently not constitute a bottleneck;
- RIVER has a capacity of 21 arrivals per hour and that does currently not constitute a bottleneck;
- SUGOL has a capacity of 26 arrivals per hour and that currently constitutes a bottleneck in the early morning.

The introduction of a 4th IAF has been researched in the past, especially in the context of the CBA Land / Central West airspace and is mentioned in the Dutch Airspace Vision [15] to unlatch the air routes in the South East of the Netherlands. Currently, access to the TMA from the South East is limited due to the presence of the military airspace TMA D/TRA12. A 4th IAF can be introduced and is more likely to be introduced after the TRA12 airspace has become available for civil usage. The location of it and the potential relocation of the other IAFs depend on a number of factors, including the precise geometry of the airspace reconfiguration, the traffic volumes forecasted by then, the TMA traffic handling and, above all, the balancing of the performance requirements, like capacity, flight efficiency and air traffic controller workload.

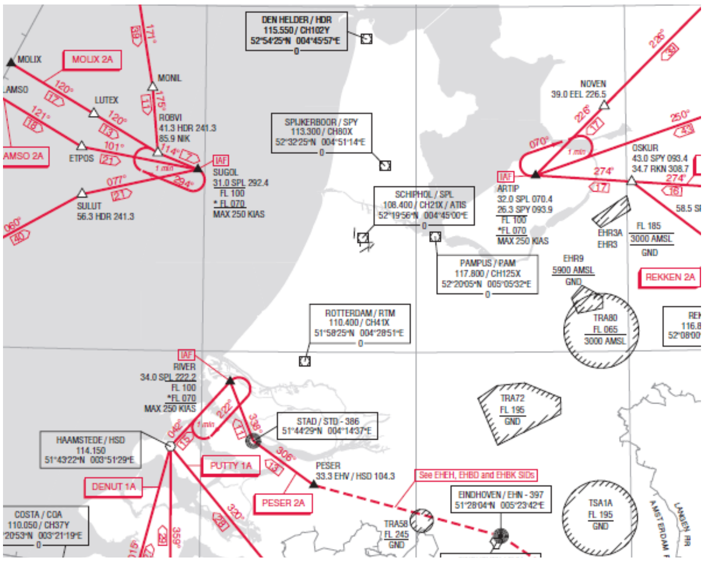

Figure 19: There are three entry-points for the Schiphol TMA: de IAFs ARTIP, RIVER and SUGOL. For each IAF there are standard arrival routes and there is a holding, all indicated in red. Source: [16].

The introduction of a 4th IAF implies a different geometry of the inbound traffic streams, both in the ACC sectors and in the TMA. This may imply different outbound traffic streams as well, depending on the precise geometry. A 4th IAF may therefore also involve flight procedure redesigns of STARs, RNAV-transitions and SIDs, and perhaps even ATS-routes after relocation of waypoints (comparable to EEL, RKN or HELEN). This all has an impact on the way traffic is actually handled and vectored by the APP/FDR controllers and the ACC controllers. This in turn impacts the boundaries of the ACC sectors and the TMA-division.

A redesign of all these traffic flows is also linked to another solution for capacity bottlenecks, the separation of inbound and outbound-streams in the TMA, explained below.

4.4.3 Segregation of TMA inbound and outbound streams

Inbound traffic enters the Schiphol TMA at FL70 or above, typically up to FL100. Schiphol standard instrument departures (SIDs) have their typical climb altitude defined up to FL60. Thus, according to the procedures, approaches fly above the departures within the Schiphol TMA. In the operational practice however, the departures are allowed to climb unrestrictedly. Modern aircraft climb much faster than those at the time the SIDs were designed and FL60 is reached soon after departure. To support flight efficiency, continuous climb departures are common practice, with flights leaving the TMA at flight levels above FL100.

As a result, controllers tactically solve conflicts between approaches and departures in the Schiphol TMA. The frequency and nature of the conflicts depend on the runway combination in use; potential conflicts between approaches to runway 18R coming from RIVER and the departures from runway 24 to Sector 4 are a typical example. The related increase of traffic complexity and work load limits the TMA capacity.

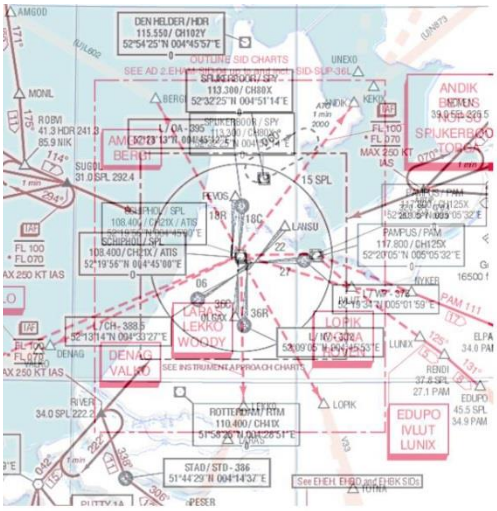

Figure 20: An overlay of the arrival and departures maps. The main departure currents (dotted lines) are segregated from the main approach flow. Due to vectoring from the IAFs to the starting points of the final straight-in approach, due to disturbances and due the lack of procedural altitude restrictions, inbounds and outbound would in practice come into conflicts with each other if controllers would do not spend efforts to prevent this. Source: [AIP, 16].

This issue is solved at some other large airports by geometrical segregation of the inbound and outbound streams: there are no conflicts between inbound and outbound streams in the stable, nominal situation. This leads to vertically split sectors or horizontal splits if sufficient airspace is available. The net effect is typically more capacity and a higher predictability at the cost of lower flight efficiency and more delay. For Schiphol however, with its complex runway lay-out, its frequent runway combination changes and its large freedom for aircrew to select their vertical profile, such complete segregation of streams is not preferred, if not impossible. In addition, the Schiphol operation is characterised by a very small airspace. Terminal area operations for example for London Heathrow cover an airspace that would cover the majority of Dutch FIR (see Figure 15).

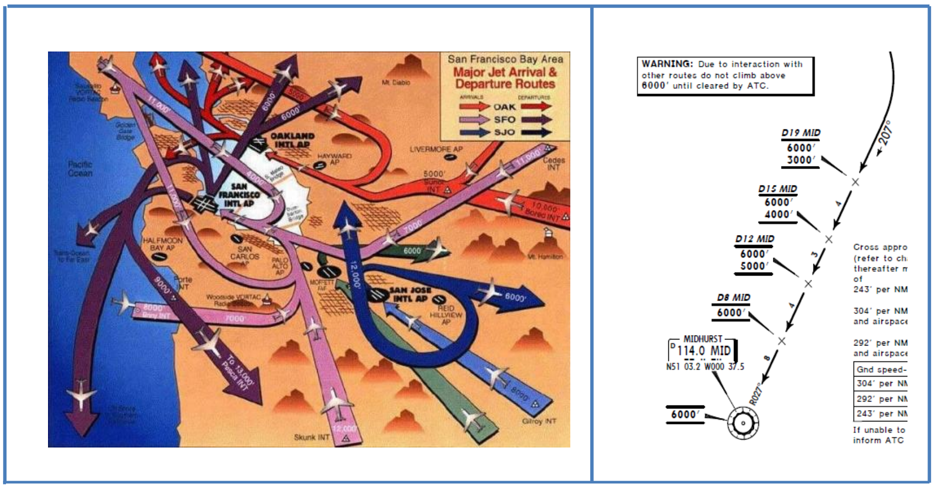

Figure 21: At the left an indication of the traffic streams to and from airports in the neighbourhood of San Francisco. At the right, a SID from Heathrow airport, showing the several altitude restrictions due to "interaction with other routes". Sources: [17] and [AIP UK].

The issue can be solved by simply restricting continuous climbs, with disadvantages in terms of flight efficiency and Amsterdam ACC capacity. The issue might also be solved, at least partially, by a redesign of the vertical and lateral paths of the inbound and outbound flights. Taking this into account when introducing the 4th IAF and relocating the existing IAFs increases the TMA capacity.

4.4.4 Open question: increased capacity in inbound and outbound peaks

As indicated above, the Schiphol TMA operation is characterised by merging traffic streams from various initial approach fixes to one or two landing runways, while tactically solving conflicts with outbound traffic flows – all in a small airspace and with dependencies arising from the various runway combinations. These aspects are the cornerstones of the operational concept and it remains to be seen if the solutions indicated in the previous sections provide sufficient opportunity to increase capacity of the Schiphol TMA to levels beyond 540k.

4.5 Requirements for Amsterdam ACC

The nature of the identified main bottlenecks of the Amsterdam ACC relates to unpredictability of traffic and limitations in vectoring space, this resulting in high workload situations. One important solution in the prevention of ACC overload is capacity management, as already discussed in Section 3.3. Another important solution is an airspace redesign. That is discussed in the next section.

4.5.1 Airspace redesign

The Dutch airspace is divided airspace available for civil use and airspace available for military use. Some flexibility is applied over the day, for example when military airspace users are not active, this airspace can be used for civil means. Airspace layout has developed over the years and reaches its limits. The needs for both civil and military users have changed and cannot be fully met. Traffic has increased significantly and poses other requirements and constraints. FIR-wide airspace redesign, with an overall optimization of flight efficiency, delay, capacity and military mission effectiveness, is one of the key solutions for future traffic growth.

From the perspective of civil ATC, one specific airspace constraint is due to the current TRA 12 as this covers a large parth of the South East of the Netherlands and thereby puts constraints on traffic between the South and Schiphol, Lelystad and Eindhoven. Moreover, the current airspace design limits the options to optimize the current number and locations of the Schiphol IAFs and the options to handle significant amounts of Lelystad traffic (above 10k Lelystad movement per year).

In the Luchtruimvisie from 2012, the introduction of the TMA Holland Regional, the two-phase implementation of the CBA Land / Central West airspace and the cooperation within FABEC was proposed. The current airspace redesign program commenced by the Ministry of Infrastructure and Watermanagement considers and researches other airspace redesigns, see also [9]. The ATM 2020+ project provides input for this program by providing bottlenecks of current airspace and design requirements for a future design.

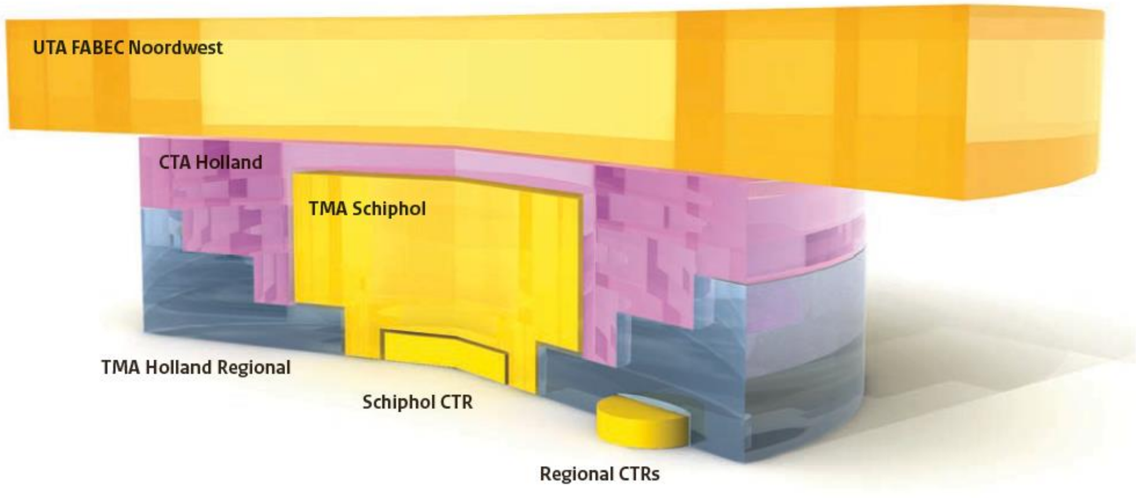

Figure 22: An illustration of the generic geometry of the CTRs, TMAs, CTA Holland and the higher airspace. Source: [15].

The starting points for the reconfiguration on the long term in this study are:

- The current TRA 12 is made available for civil traffic.
- A large airspace above the North Sea, called Frysian Airspace, is made available for military exercises by RNLAF. The airspace is sufficiently large for F35 exercises; there is a direct access from Leeuwarden but not from Volkel.
- The Frysian Airspace is a Flexible Usage Airspace: its dynamic segregations are based on the actual usage, as coordinated and planned by a co-operation of civil and military ATC. This coordination is that effective that this airspace is open for approximately 90% of the civil traffic that would prefer to pass, also thanks to the civil-military colocation at Schiphol-East. The impact of the introduction of the Frysian Airspace on civil flight efficiency is potentially overall positive.
- An airspace, referred to as the TMA Holland Regional[11], is used for military and civil traffic that not flying inbound or outbound Schiphol. This includes jets on their way to military exercises, General Aviation activities, commercial traffic from Rotterdam, Maintenance Repair and Overhaul flights towards Airport Twente, et cetera. This mix requires a flexible ATC service provisioning with civil-military co-operation. The airspace may potentially also include the airspaces with the approaches towards the airports of Liège, Antwerp and Düsseldorf.
- The TMA Schiphol is used for Mainport traffic, with exceptions for special flights by the police and alike. Traffic in the TMAs Schiphol and Holland Regional does not interfere.
- The Amsterdam CTA is a bit extended: Sector 2 to the West and Sector 3 to the East.

A relative low increase of Lelystad traffic might have a relative large impact on the complexity of the traffic within the Amsterdam ACC. Anticipating future growth of Lelystad traffic, initial concepts concerning capacity management are therefore already built.

[11] This name is adopted from the Dutch Airspace Vision [15] which introduced its concept. The actual geometry may however be different from the airspace drawn in that document, as holds true for geometry of the TMA Schiphol as well (i.e., not necessarily the upside down wedding cake).

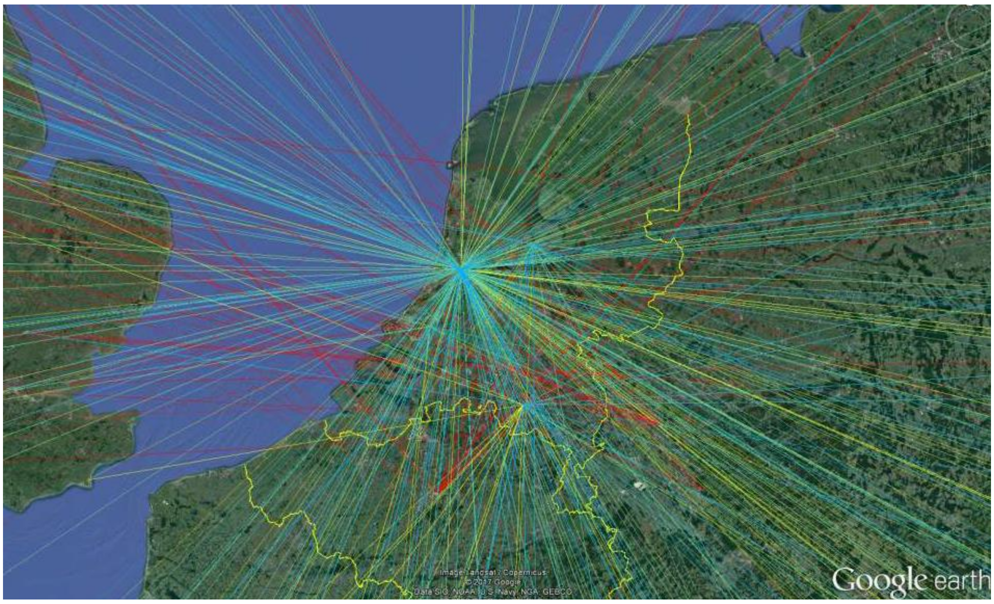

Figure 23: One element in the redesign of the airspace is the traffic demand and the geographical location of the flights. The picture gives a graphical representation of the shortest route of departures (blue) and arrivals (yellow) to the main Dutch airports and the transit flights through lower airspaces (red) during daytime as direct origin-destination flights. Sample taken is scenario G from the scenario analysis.

4.5.2 Improved predictability of traffic flows

The unpredictable nature of traffic flows is the major bottleneck for Amsterdam ACC. Traffic may increase significantly during peaks and/or non-standard traffic increases complexity of handling the major flows to and from Schiphol. In addition to airspace redesign, the key solution lies in improving predictability of the traffic flows. Applicable solutions to accommodate levels beyond 540k annual movements have been mentioned in previous chapters and are therefore only summarised below:

- A fully developed iCAS, to allow for the development of advanced technological support systems, such as:
    - A more advanced arrival management system (enhanced AMAN);
    - Advanced support tools for conflict detection, flight path monitoring, etc.;
- Integral air traffic flow and capacity management for the Dutch FIR, including airports EHLE and EHEH.

4.6 Summary of requirements

Figure 24 provides an overview of the requirements for Schiphol development beyond 540k annual movements and increased peak hour capacity.

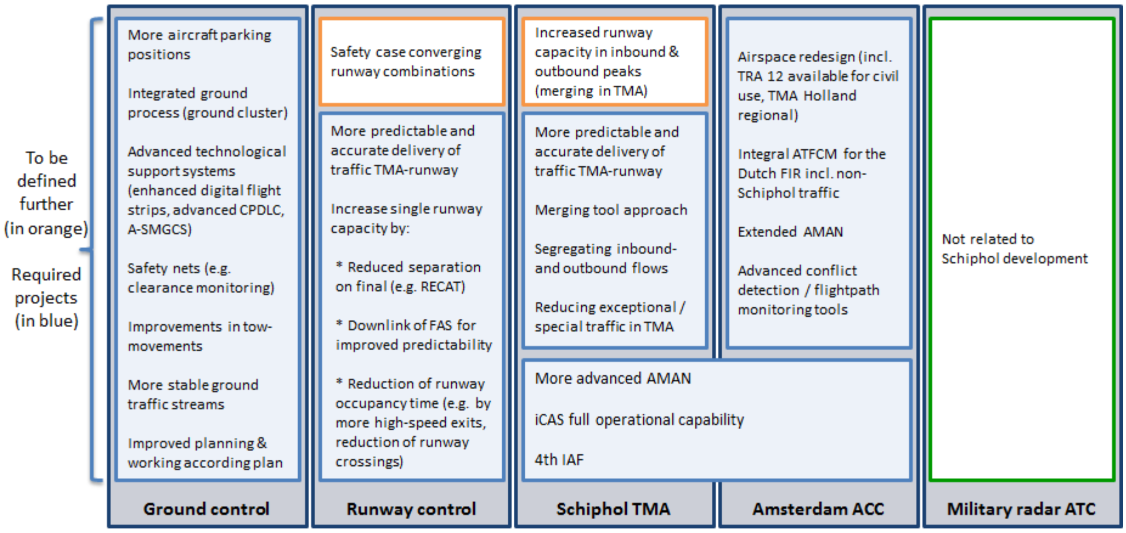

Figure 24: Summary of requirements for Schiphol development beyond 540k and increased peak hour capacity

The implementation of each of these solutions will take significant efforts and investments and are rather large projects on their own with specific difficulties, in-depth analysis, co-operation with stakeholders and uncertain pitfalls. Some of the requirements indicated above are already addressed in follow-up projects. For example, the airspace redesign program initiated by the Ministry of Infrastructure and Watermanagement addresses the Dutch FIR airspace redesign.

It is crucial that the other required projects are started timely to make sure air traffic control is ready for the expected traffic growth when it arrives.

5. Requirements for development of regional airports

5.1 Aiming point

This chapter considers potential solutions for capacity development at regional airports. It is not known how the traffic demand for the regional airports will develop over time in comparison with the traffic demand for Schiphol. In this chapter only the additional solutions to realize the capacity at the regional airports are indicated, assuming that the solutions mentioned in the previous chapters are implemented. It is also assumed that regional traffic will not impact the Schiphol ground control, runway control or TMA operation.

5.2 Requirements

Requirements for development of regional airports can be summarised in three topics:

- Airspace supporting the regional operation;
- Planning of traffic to/from regional airports with respect to traffic to/from Schiphol;
- Military radar control prepared for further growth.

Since these topics have been partially addressed in previous chapters, the current chapter will refer to that and add specific requirements for development of the regional airports.

5.2.1 Airspace supporting the regional operation: TMA Holland Regional

The limitations of area control airspace and the current availability for civil and military use has been addressed in section 4.5.1. However, not only the area control airspace requires redesign. In the Dutch FIR there are various civil and military airports outside the mainport area, each with their own TMA. Part of the Airspace Vision document is the development of the TMA Holland Regional, proposing airspace redesign for the TMAs, to optimize flight efficiency, delay, capacity and military mission effectiveness.

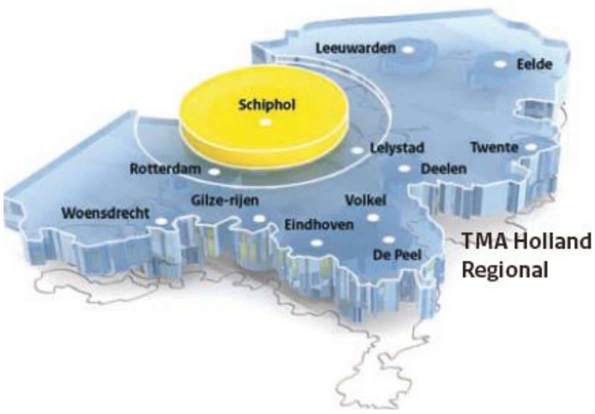

Figure 25: Impression of a TMA Holland Regional. Source: [15].

The main implication of the airspace reconfiguration for the TMA Schiphol is that it will be used for Mainport traffic only, with exceptions for special flights by the police and alike. Military and civil traffic that is not flying inbound or outbound Schiphol is handled in a dedicated airspace referred to as the TMA Holland Regional[12]. Flights in the TMAs Schiphol and Holland Regional do not interfere.

The design of this airspace depends on the traffic streams to and from the regional fields, on the introduction of a 4th IAF and on a potential relocation of the other IAFs. The segregation of the inbound and outbound Schiphol traffic streams as mentioned in the previous chapter might have an impact too. This redesign will be initiated by the airspace redesign program from the Ministry of Infrastructure and Watermanagement.

5.2.2 Planning of traffic to/from regional airports vs. to traffic to/from Schiphol

Integral flow and capacity management was described previously in this report. This is crucial for the development of the regional airports, since interferences between the major traffic flows to and from Schiphol and the regional traffic flows can significantly increase complexity and thereby limit capacity development.

5.2.3 Military radar control prepared for further growth

Military radar control is the main supplier for air traffic services to the regional airports. An increased capacity for the regional airports introduces some requirements for military radar control. These are summarised below. An in depth study on requirements for full growth of the regional airports has not been performed as part of the ATM2020+ project but will be addressed in follow-up activities.

Identified requirements for military radar control include:

- A staff expansion: staff shortages limit the operation and with increasing traffic numbers and required services (e.g. EHLE approach or splitting Lower Area Control into two positions), more staff is required;
- Sector-based responsibility instead of flight-based responsibility. Traffic is currently handles on a flight-based responsibility, resulting in that different air traffic controllers may control aircraft in the same airspace. This type of operation is no longer feasible with increasing traffic numbers;
- Airspace redesign, in particular development of the Frysian airspace, as mentioned in the section on cross domain solutions;

[12] This name is adopted from the Dutch Airspace Vision [15] which introduced its concept. The actual geometry may however be different from the airspace drawn in that document, as holds true for geometry of the TMA Schiphol as well (i.e., not necessarily the upside down wedding cake).

5.3 Summary of requirements

Figure 26 provides an overview of the requirements for development of the regional airports.

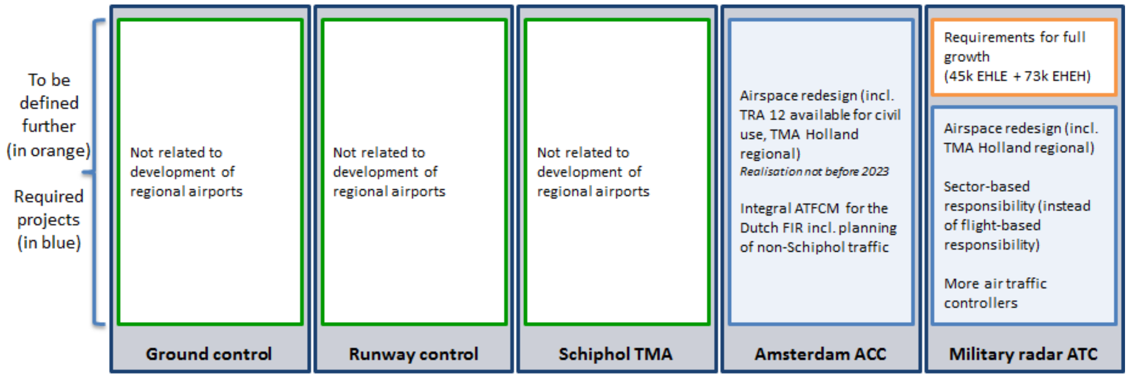

Figure 26: Summary of requirements for development of regional airports

6. Conclusions

The ATM2020+ project presents a strategic direction for further capacity development for the Dutch FIR. With a performance based and solution-oriented approach, the project concludes that:

- The baseline scenario, with 500k annual movements at Schiphol and limited or no growth at the regional airports, is feasible after implementation of scheduled projects.
- Schiphol development up to 540k annual movements with current peak hour capacity introduces additional requirements beyond the realisation of scheduled projects. This includes a less strict environmental target of the use of the 4th runway and integral ATFCM for the Dutch FIR.
- With the additional requirements for development up to 540k annual movements in mind, expected traffic growth and capacity development resulting from planned projects are consistent.
- Growth of Schiphol beyond 540k annual movements requires new projects, both to handle the larger annual traffic volume but also to increase peak hour capacity. These projects aim at more predictable and stable traffic flows on the ground and in the air, improved planning and adherence and advanced technological support systems.
- Further development of regional airports requires redesign of the airspace structure in the Netherlands. This redesign includes the definition of a training area for the future fighter aircraft F35, in such a way that airspace is used optimally to satisfy civil and military users' needs. In addition, structural improvements in staffing and way of traffic handling for military air traffic control are required for further development of Eindhoven and Lelystad.

A plan for realisation of identified activities in relation to expected traffic growth is required as next step. This includes the definition of an update of the project portfolio with these activities, but also by setting specific capacity goals for the new projects. In this way, LVNL and CLSK can deliver the operational performance that is required for traffic growth in the Dutch FIR.

Uncertainty exists about what is required for an increased peak hour capacity at the airport, related to the use of various runway combinations. This requires further elaboration on two topics:

- An in-depth study what is needed for a capacity increase at Schiphol for both inbound & outbound runway combinations.
- Development of a safety case for converging runway use with increased peak hour capacity.

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8. Abbreviations

A

ACC	Area Control Center
ACoPOS	Air traffic controller Cognitive Process and Operational Situation (model)
AMAN	Arrival MANagement
ANSP	Air Navigation Service Provider
ARR	Arrival (controller)
A-SMGCS	Advanced Surface Movements Guidance and Control system
ATC	Air Traffic Control
ATFCM	Air Traffic Flow and Capacity Management
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATS	Air Traffic Services

B

C

CASA	Computer Assisted Slot Allocation
CBA	Cross Border Area
CDM	Collaborative Decision Making
CLSK	Commando Luchtstrijdkrachten
CPDLC	Controller-Pilot Data Link Communications
CTA	Control Area

D

E

EHAM	Amsterdam Airport Schiphol
EHEH	Eindhoven Airport
EHFIRAM	Aerdrome Dutch FIR
EHLE	Lelystad Airport
EHRD	Rotterdam The Hague Airport

F

FABEC	Functional Airspace Block Europe Central
FAS	Final Approach Speed
FDR/DCO	Feeder / Departure controller
FIR	Flight Information Region
FL	Flight Level

G

GARDS	Go-Around Detection System

H

I

IAF	Initial Approach Fix
iCAS	iTEC Center Automation System
ILS	Instrument Landing System

J

K

L

LVNL	Luchtverkeersleiding Nederland (Air Traffic Control the Netherlands)

M

MER	Milieu Effect Rapport

MUAC	Maastricht Upper Area Control

N

NEST	Network Strategic Tool
NNHS	Nieuwe Normen en Handhavings Stelsel

O

ORS	Omgevings Raad Schiphol (Airport Environment Council Schiphol)
OVV	Onderzoeksraad Voor Veiligheid (Dutch Safety Board)

P

Q

QNH	Atmospheric pressure adjusted to sea level

R

RECAT	Re-categorisation (of wake vortex)
RIASS	Runway Incursion Alerting System Schiphol
RNAV	Area Navigation
RNLAF	Royal Netherlands Air Force
RNP	Required Navigation Performance
ROT	Runway Occupancy Time
RT	Radio Telephony

S

SID	Standard Instrument Departure
STAR	Standard Arrival Route
STATFOR	Statistics and Forecast Service

T

TMA	Terminal Area
TRA	Temporary Reserved Airspace

U

UDP	Uniform Daylight Period

V

VOP	Vliegtuig Opstel Plaats (aircraft parking position)

W

X

Y

Z

9. Appendix

In order to accommodate 560k runway movements, the hourly airport slot capacities during the day need to increase. The table below indicates a potential, feasible increase that is considered sufficient for this, in accordance with the request for a high quality of the network of connections to other airports.

	# arrivals per hour	# departures per hour	# movements per hour
Current			
Inbound	68	38	106
Outbound	36	74	110
Potential			
Inbound	76	40	116
Outbound	38	80	118

Table 2: Current airport slot capacity (summer 2017) and potential airport slot capacity to accommodate 560k movements per year.

This potential capacity requires an increase of the ATC capacity in good visibility within UDP. An increase of the hourly ATC capacity in other states would not significantly increase the capacity in terms of the yearly traffic volumes, although it might significantly improve sustainability. The most relevant hourly capacities are given in the table below.

	# arrivals per hour	# departures per hour
Inbound peak		
Declared airport slot capacity	68	38
ATC capacity range (all modes)	60 - 68	30 - 40
ATC capacity range (preferred modes)	65 - 68	37 - 40
Outbound peak		
Declared airport slot capacity	36	74
ATC capacity range	30 - 38	55 - 80
ATC capacity range (preferred modes)	38	70 - 74

Table 3: Current airport slot capacity, range of ATC capacities (disregarding mixed mode runway usage) and ATC capacities of the preferred modes, in good visibility, within UDP.

The ATC capacity in the inbound peak is currently limited by the TMA capacity of 68 arrivals and 40 departures per hour in nominal circumstances[13]. Assuming again that this capacity is increased, see the following section, the next limitation is due to runway bottlenecks as indicated in the table below, derived from figures presented in "Onderbouwing uurcapaciteit" [18][14].

[13] The background of the maximal 38 departure slots in the inbound peak per hour is therefore not known. The actual regulation may be based on 65 arrivals per hour (except for some peaks), corresponding to the limited TMA capacity.

[14] The question why the capacity of two landing runways without dependencies is lower than two times the capacity of one landing runway is still open. It is speculated that this is due to Approach, for example as it is more difficult to arrange an approach sequence with traffic from one side as in case of parallel approaches than to arrange an approach sequence with traffic from two sides as in case of a single runway.

Equivalent of two landing runways	# arrivals per hour	# departures per hour
Two times one single runway	76	80
Two runways without dependencies	70	74
Two runways with dependencies	< 70	< 74
Two runways with one that is crossed more than 4 times an hour	< 70	< 74

Table 4: Generic ATC runway capacities in good visibility within UDP. The "dependencies" refer to geometries of runway configurations in which an approach might come in conflict with an approach on the other runway or with the take-off.

The ATC capacity in the outbound peak is currently limited by the TMA capacity of 38 arrivals and 74 departures per hour in case of nominal staffing, no further constraints, assuming averaged frequencies of regional and crossing traffic[15]. Assuming again that this capacity is increased, the next limitation is due to the runway bottlenecks as indicated in the table below, derived from figures presented in [4][16].

It is therefore cautiously concluded that the 560k runway movements required in scenario's E and F can be accommodated, assuming that other bottleneck are removed, if a) the capacity of two landing runways without dependencies in good visibility within UDP could be increased to 76 arrivals per hour and b) the capacity of two take-off runways without dependencies in good visibility within UDP could be increased to 80 arrivals per hour.

In order to provide sustainability, it might at the same time be necessary to increase capacities in circumstances in which the maximal throughput cannot be delivered. These circumstances include: dependent runway usage, high frequencies of runway crossings, limited visibility, outside UDP and external disturbances. The most relevant dependencies in this context are: parallel departures, parallel approaches, convergent approaches and convergent landings and take-offs.

[15] The background of the maximal 36 landing slots in the outbound peak per hour is therefore not known
[16] The question why the capacity of two landing runways without dependencies is lower than two times the capacity of one landing runway is still open.

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