Sensitivity analysis on aspects of a future Schiphol TMA route design

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ACRONYM	DEFINITION
ACC	Area Control Centre
AEDT	Aviation Environmental Design Tool
AFM	Aircraft Flight Manual
AGL	Above Ground Level
A-IGS	Adaptive Increased Glide Slope
AIP	Aeronautical Information Publication
AIRAC	Aeronautical Information Regulation and Control
AMAN	Arrival Manager
ANP	Aircraft Noise and Performance
AP7P	Approach Centre / Control
APCH	Approach
AROT	Arrival aircraft Runway Occupancy Time
ARP	Aerospace Recommended Practice
ATAEGINA	Airline Trials of Environmental Green Flight Management Functions
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATFCM	Air Traffic Flow and Capacity Management
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
BADA	Base of Aircraft Data
CAA	Civil Aviation Authority
CAP	Civil Aviation Publication
CAPE	Convective Available Potential Energy
CAT	Category
CCO	Continuous Climb Operations
CDA	Continuous Descent Approach
CDO	Continuous Descent Operations
CEAC	Conférence Européenne de l'Aviation Civile
CFIT	Controlled Flight into Terrain
CLSK	Air Force Command
CO_2	Carbon dioxide
CRM	Collision Risk Modelling
CRS	Coordinate Reference System

ACRONYM	DEFINITION
DARP	Dutch Airspace Redesign Programme
dB	Decibel
DCT	Direct
DEM	Digital Elevation Model
DT	Displaced Threshold
EASA	European Union Aviation Safety Agency
EAT	Estimated/Expected Approach Time
ECAC	European Civil Aviation Conference
EHAA	FIR Amsterdam
EHAM	Schiphol airport
EPSG	European Petroleum Survey Group
ERCD	Environmental Research Consultancy Department
EU	European Union
EUROCAE	European Organisation for Civil Aviation Equipment
EUROCONTROL	Pan-European, civil-military organisation dedicated to supporting European aviation.
FAA	Federal Aviation Administration USA
FAF	Final Approach Fix
FAP	Final Approach Point
FAS	Future Airspace Strategy
FASI	Future Airspace Strategy Implementation
FIR	Flight Information Region
FL	Flight level
FSL	Forecast Systems Laboratory
FTS	Fast-Time Simulation
GBAS	Ground Based Augmentation System
GHG	Greenhouse Gases
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
HMI	Human-Machine Interface
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organization
ID	Identifier
IGS	Increased Glide Slope
ISHD	Integrated Surface Hourly Data

ACRONYM	DEFINITION
KPI	Key Performance Indicator
LA_{max}	Maximum Sound Level
LAT	Latitude
LGW	London Gatwick Airport
LHR	London Heathrow (UK)
LNAM	Low Noise Arrivals Metric
LPLD	Low Power Low Drag
LS	Level Segment
LSRM	Loss of Separation Risk Model
LVNL	Luchtverkeersleiding Nederland
MAC	Multi-Airport Concept
MASPS	Minimum Aviation System Performance Standards
MINIENW	Ministry of Infrastructure and Water Management
MITRE	American not-for-profit organization supporting various U.S. government agencies in the aviation (and other) domains
MRS	Minimum Radar Separation
MTOW	Maximum Take Off Weight
NADP	Noise Abatement Departure Procedures
NATS	National Air Traffic Services (UK)
NLR	Netherlands Aerospace Centre
NM	Nautical Mile
NOx	Nitrogen oxides
ORD	Optimised Runway Delivery
PANS	Procedures for Air Navigation Services
PBN	Performance-Based Navigation
PLRH	Airspace Review Programme
PM	Point Merge
PWS	Pair Wise Separation(s)
RDAR	Route Design Analysis Report
RECAT	Re-categorisation of Wake Turbulence Separation Minima
RNAV	Area Navigation
RNP	Required Navigation Performance
ROCAT	Local Runway Occupancy Time characterization
ROT	Runway Occupancy Time

ACRONYM	DEFINITION
RSP	Required Surveillance Performance
RTCA	Radio Technical Commission for Aeronautics
RTS	Real-Time Simulation
RWY	Runway
SAE	Society of Automotive Engineers
SBAS	Satellite-Based Augmentation System
SESAR	Single European Sky ATM Research (Programme)
SID	Standard Instrument Departure
SOx	Sulphur oxides
SRAP	Secondary Runway Aiming Point
SRTM	Shuttle Radar Topography mission
STAR	Standard Instrument Arrival
TBO	Trajectory-Based Operations
TBS	Time-Based Separation
THC	Total hydrocarbons
TMA	Terminal Manoeuvring/Control Area
ToC	Top of Climb
TOD	Top of Descent
UAM	Urban Air Mobility
UK	United Kingdom
USA	United States of America
VNAV	Vertical Navigation
VOC	Volatile organic compound
WDS	Weather Dependent Separation(s)
WG	Working Group
WG-85	EUROCAE Working Group WG-85 "Navigation"
WGS84	The World Geodetic System 1984
WMOID	World Meteorological Organisation Station Identifier

Introduction

I Introduction

I.1 Context

The Netherlands has established a multi-stakeholder Dutch Airspace Redesign Project (DARP) to develop a long-term solution (2035) for the Netherlands airspace. The Ministry of Infrastructure and Water Management (MINIENW) and Ministry of Defence are working closely together with Air Traffic Control the Netherlands (LVNL), the Air Force Command (CLSK) and the Network Manager (NM) to achieve the overall objective.

The key airspace measures, operational concepts and technologies envisaged to help DARP achieve its objectives have been formalised in the Draft Preferential Decision. As of end 2021, the whole programme is transitioning from the high-level conceptual phase towards more detailed description of potential working mechanisms to be expected during initial implementation phase (expected around 2025) and the full implementation (expected circa 2035).

In order to better understand key interdependencies between various airspace measures that may end up being implemented as part of the DARP implantation, the Ministry of Infrastructure and Water Management has contracted Egis to conduct a sensitivity analysis into possible relationships and mechanisms related to the redesign of the Schiphol TMA – not only for the measures envisaged in the Draft Preferential Decision, but also for any other potentially relevant measures that are currently being developed as part of other research initiatives (i.e. SESAR, NextGen, FASI UK etc.).

> This research provides a sensitivity analysis from which it is possible to draw general conclusions but no specific conclusions about the concept.
>
> Only six runway combinations are considered within the scope of the research. Other runway combinations are not applicable for this research and its conclusions.

I.2 Aims of the research

The brief from MINIENW included two high level research questions, which were defined as follows:

- Research question 1: *"What effects … can the proposed measures … have at the time of the first implementation step planned for 2025?"*
- Research question 2: *"Which … measures … are important to guarantee the progression towards the best possible result in 2035? It is important to gain insight into the effects of the measures and the mechanism behind them. This insight can be obtained by performing a sensitivity analysis on these measures."*

The brief from MINIENW indicated this research should be primarily focussed on following airspace measures (with the focus on operations within the Schiphol TMA), with each measure being assessed from both qualitative and quantitative perspective, taking into account as many known assumptions as possible on the likely future operational concept(s) envisaged for both 2025 and 2035:

- Horizontal/vertical spacing of routes,
- Descent/climb gradients,
- Accuracy of traffic delivery and
- Tracking of tubes.

Following a series of discussion with DARP, the scope of this research has been clarified to include also following topics, all aimed at the above 4 measures:

- Qualitative aspects of selected airspace measures:
  - Are the airspace measures proposed in the Draft Preferential Decision enough to warrant achievement of the high-level objectives of DARP?
  - Are there any other measures being currently researched and/or implemented anywhere else in the world that could have a major impact on the proposed DARP concept? If so, what is the maturity of these measures and how significant could their impact be if implemented in Netherlands?
  - How does change in one measure influence performance of the remaining measures? What are the key interdependencies between the measures? What mechanisms and drives are to be expected if a selected combination of measures is implemented?
  - Can implementation of a measure and/or technology in the initial phase influence achievement of the overall objectives in the final implementation phase? For which measures is the order of implementation important?
- Quantitative aspects of selected airspace measures:
  - What is the sensitivity of the selected set of KPIs on each measure if implemented in 2025 and in 2035?
  - What is the sensible range of parameters (e.g. feasible climb or descent gradient, minimum required accuracy of delivery)
  - for consideration for potential implementation of the measure?
  - How sensitive is the measure to changes in these parameters?
  - How sensitive is the measure to changes in other measures?

Following a discussion with DARP stakeholders, the list above has been expanded to include additional potential measures, concepts and technologies identified as potentially relevant for DARP through a literature review, while keeping the focus on the four topics introduced above.

I.3 Structure of the document

This document is structured into three high level logical blocks.

The first block consists of the introductory/background section and description of the approach taken.

The second block constitutes the key analytical part of the document, providing results from the quantitative and qualitative analyses of the selected airspace measures. Each sub-section includes key findings relevant to each measure – these are then combined into a high-level assessment of the proposed combination of measures in the form of report conclusions and recommendations.

The last block of this report includes a number of technical annexes which provide more detail on selected technical aspects of the research. It has the following content:

- Annex 1: Overview of similar concepts researched elsewhere in the world
- Annex 2: Overview of other potentially relevant measures identified throughout desktop research
- Annex 3: Interdependencies between the investigated measures
- Annex 4: Data, assumptions, and models used for assessment of quantitative performance of selected measures
- Annex 5: Expected changes in fleet mix by 2035
- Annex 6: Vectoring areas assumed in the model
- Annex 7: Definition of metrics used in the research
- Annex 8: Detailed quantitative results
- Annex 9: List of sources reviewed during the desktop research

I.4 Disclaimer

The ATM system is a complex environment with a large numbers of actors influencing each other. Change in any part of the system, be it modification of airspace design, change in operating concept, or variation in any other parameter has a potential to trigger different reaction(s) of other interlinked elements of the system. As a result, the findings presented in this study should be interpreted solely within the bounds of assumptions and input data used. The conclusions presented in this study might have been different if different input parameters had been used.

In order to keep the report as succint as possible, some detailed technical elements of the intended future airspace design/operation are not explained in full detail. It is highly recommended that the reader familiarises with other work done in this domain (published by the Ministry of Infrastructure and Water Management), and especially with the Preferential Decision for Airspace Review adopted by the Dutch government.

Description of the approach taken

II Description of the approach taken

II.1.1 High level overview of the approach

As explained in the previous section, the focus of this research is on both qualitative and quantitative effects of selected airspace measures.

The original brief from MINIENW identified the four key measures attached to the Schiphol TMA design that should form the core of this research. These are:

- Horizontal/vertical spacing between the tubes,
- Descent/climb gradient,
- Accuracy of traffic delivery and
- Tracking of tubes up to 6,000ft AGL.

However, by the time they are implemented (2025-2035), all of these measures are likely to be influenced by other developments in the field of air traffic management, route/airspace design and/or aircraft operating procedures. In order to identify these potentially influential developments, research of available literature, studies and review of other Egis projects has been done. As a result of this review, several additional measures have been identified. From these, a selection of eight potentially most relevant measures has been included in Annex 2 for further consideration. These eight measures are assumed to be either highly probable measures to be implemented in the future, or the measures with potentially high impact on the proposed DARP operating concept (or both). This list includes:

- Enhanced arrival procedures,
- Low power – low drag operations,
- Slightly steeper glide path,
- Two-segment approach,
- Minimum pair separations based on RSP,
- Traffic optimisation on single and multiple runway airports,
- Synchronisation of departing traffic flows from multiple airports and
- RNP less than or equal to 0.3NM.

For the four measures originally identified by MINIENW, a detailed qualitative assessment is provided and, where possible, any statements are evidenced through quantitative analysis. For the other measures, a high-level qualitative analysis only is provided in Annex 2, with list of possible interdependencies and mechanisms elaborated further in Annex 3.

The conceptual design of Schiphol TMA provided by LVNL has been used in the analyses performed as part of this research.

Different airspace measures required different analysis techniques and modelling methods to reach qualitative and quantitative answers to the questions asked by MINIENW. Four distinct methods have been utilised in this research to derive the findings that are presented later in this document.

1. **Desktop research:** Using information from the public domain as well as from sources not yet publicly available, it was possible to identify the general operating mechanisms of each considered measure, its maturity levels (likelihood to be ready for implementation by 2025/2035) and its potential implications on other measures. One of the benefits of this method is the relatively easy access to general information. The documents we reviewed rarely included any reference to Netherlands, however, which increased the challenge of applying any (quantitative) findings to DARP.
2. **Expert judgement:** Having worked on some of the airspace measures ourselves, Egis provided our own insight into selected research questions as required. Moreover, wherever possible we used the results of our previous projects to demonstrate some of the expected mechanisms and potential quantitative impacts.
3. **Fast time simulations:** The airspace is a complex environment where all elements are interlinked, so it was necessary to adopt a unified approach to all activities to represent interdependencies in the service chain. Spreadsheet-based modelling (as mentioned above) has significant limitations for understanding interactions between objects and their dependencies. Using fast time simulations, on the other hand, allowed us to take into account many more relationships between a greater number of actors in the complex ATM operating environment, any thereby to provide better-informed answers to quantitative questions (although dependent on model assumptions).
4. **Environmental modelling:** Assuming that capacity levels at Schiphol will increase by only some 7-8% between 2025 and 2035, as envisaged in PlanMER, no capacity issues are expected but based on the current political context there is likely to be more focus on the environmental sustainability of aviation operations in that period. To ensure that the DARP concept will actively contribute towards relevant sustainability initiatives (e.g. the European Green Deal, Destination 2050), the emissions and noise impact of some of the airspace measures considered in this research have been modelled using aviation environmental impact assessment software. This does however not include the NL legal rules and guidelines for noise calculation.

For more detail about the assumptions and software used for airspace and environmental modelling please refer to **Annex 4**.

It should be noted that the key driver for using various modelling techniques is to provide *location-specific* answers to the research questions, which will take into account local operational, geographical, meteorological, demographical and legal constraints as much as possible.

- **Operational constraints** modelled include current assumptions on how the concept will be run in 2025 and 2035 or what fleet mix and traffic levels are currently expected.
- **Geographical constraints** include the local topography around Schiphol airport, including digital elevation model which can influence propagation of noise and emissions through space. However, in case of Amsterdam, this impact is expected to be low.
- **Meteorological constraints** were derived from the past ten years of weather observations at (or near) Schiphol airport and focus on wind speed, direction, temperature, humidity, and atmospheric pressure.
- **Demographical constraints** are represented by the local population in the area. Information on the number of households, size of each household and exact location of each household has been used.

- **Legal constraints** were accounted for in the form of noise and emissions metrics used for reporting. These metrics have been aligned with existing reporting requirements in the Netherlands.

The use of all four of the research techniques mentioned on the previous page was not feasible for every one of the measures that form part of this research. Table 1 shows which research technique(s) were used to quantitatively assess the impact of each measure.

Measure/research method	Qualitative analysis		Quantitative analysis	
	Desktop research	Expert judgement	Fast time simulation	Environmental modelling
Accuracy of traffic delivery	✔	✔	✔	Fuel only
Tracking of tubes	✔	✔	✔	Noise & fuel
Climb/descent gradient	✔	✔	✔	Noise only
Horizontal/vertical spacing	✔	✔		

Table 1 Analysis methods used in the research

Assessment of measures

III Accuracy of delivery

III.1 Qualitative analysis

III.1.1 Description of the measure

The following section provides a summary of findings related to accuracy of traffic delivery to the Schiphol TMA.

In this report, "Accuracy of traffic delivery" means the time difference between the estimated arrival time of a flight at the initial approach fix and the actual arrival time of the flight at the Schiphol TMA entry fix. If the difference between the two is small (i.e. the accuracy of delivery is good) then the approach controller can form the arrival sequence with less effort, compared to situations where the aircraft are being delivered to the Schiphol TMA less accurately, requiring more sequencing actions to be carried out by the controller (and executed by the pilot). The four Schiphol TMA entry fixes considered in this study are ARTIP (northeast), SUGOL (northwest), RIVER (southwest) and ZUDOS (southeast).

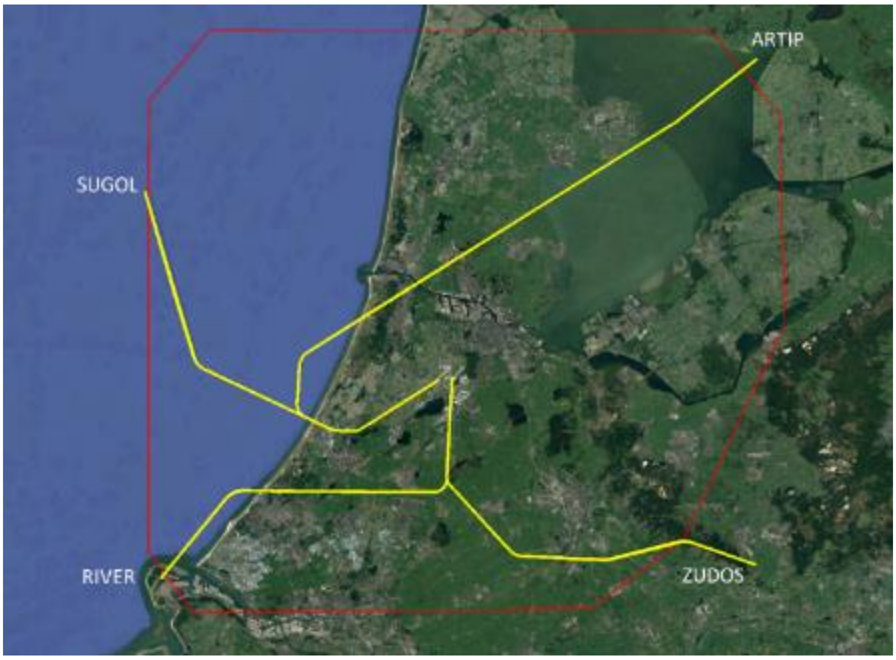

Figure 1: The four Schiphol TMA entry fixes considered in this study (example for 2 runway northerly arrivals)

As the full implementation of DARP programme expects to use tubes from the Schiphol TMA entry fix to the runway, speed control remains the only sequencing technique available to the approach controller to secure safe and efficient arrival sequence. Unlike current operational practice, the use of vectoring is not envisaged for standard operational situations in 2035. This means that by the time the approaches are served to the runway exclusively through the tubes, the delivery of inbound traffic to the Schiphol TMA needs to become accurate enough. This is envisaged to be achieved by development of advanced ATM tools (such as extended arrival manager) and merging the inbound traffic outside the Schiphol TMA.

However, the initial implementation step (2025) assumes that some degree of vectoring within the Schiphol TMA would be needed before the pre-requisites for the full-tube concept are fully established. Therefore, one of the aims of this research was to understand delivery accuracy thresholds at which ATCOs are likely to switch to vectoring. As the tubes concept will be novel to most of the ATCOs, the expected minimum delivery accuracy threshold may be more stringent than the actual threshold at which ATCOs are still able to operate the tubes concept instead of vectoring.

The scope of this research focusses on the effect of the accuracy on the operations in Schiphol TMA. External factors influencing accuracy of delivery, such as poor delivery from neighbouring FIRs to FIR Amsterdam, are not considered.

III.1.2 Key mechanisms and interdependencies

The accuracy, with which the ACC controller can hand over the flight to the approach controller, can influence a number of aspects discussed in the following sections.

III.1.2.1 Approach sequencing methods applied by the controller

If, during the peak arrival period, the flights are being delivered with inadequate accuracy of delivery then the approach controller needs to ensure that flights are maintaining safe and efficient separations within the Schiphol TMA to allow for maximised runway throughput and minimised arrival delays. In general, the three methods available to the controller in this case are:

- Speed control, where the aircraft would be spaced laterally by adjusting speeds of the leading and following aircraft;
- Vectoring, where the following aircraft would be vectored to ensure proper lateral distance from the preceding aircraft; and
- Airborne holding at IAF, which may be used as a last resort during difficult scenarios with poor accuracy of delivery and/or other worsening factors in place (emergencies, weather, pilot error).

The choice and application of suitable sequencing methods will depend, amongst other factors, on the accuracy of traffic delivery. It is expected that in the initial stages of DARP implementation (envisaged for 2025) the arrival tubes concept should be operable with the use of speed control and occasional vectoring (with airborne holding being implemented as a fall back solution for unforeseen situations).

In 2035, however, the start of the tubes are expected to be moved up to Schiphol TMA entry fix, with more sequencing taking place in the higher airspace. Together with additional ATCO supporting tools, improved aircraft performance and improved ATFM tools, the 2035 arrival tubes system is expected to be workable using exclusively speed control to sequence the arriving aircraft within the Schiphol TMA in normal situation.

III.1.2.2 The amount of delay incurred by a flight during the approach

As explained above, the amount and type of sequencing required will depend (among other items) on the accuracy of delivery. If any of the sequencing methods are applied then the flight will incur delay. Whether it is caused by a speed reduction, by being vectored or by being put into a hold, this delay will contribute to the overall inefficiency of the system.

III.1.2.3 Additional track miles flown as a result of sequencing methods applied

One of the possible results of an inadequate accuracy of delivery is that some of the flights would have to fly additional track distances, either in the holding pattern or in the vectoring area. Any additional distance flown negatively impacts fuel burn and associated emissions, both of which can also be translated into monetary costs for the airline.

III.1.2.4 Size of vectoring area(s) needed to handle the peak traffic

The vectoring areas, designated for ensuring proper separations between the arriving aircraft before they enter the arrival tube, need to be established taking into account a number of factors. Most importantly these include potential conflicts with other arrival streams and with departing traffic. This significantly limits the geographical boundaries within which flights can be vectored. Additionally, there is a trade-off between accuracy of traffic delivery, size of the vectoring area and the need to use airborne holds. If the size of the vectoring area is not sufficient to ensure required separations between arrivals delivered with inadequate accuracy of delivery, then one or more such flights will be held in a holding pattern before entering the TMA. In other words, the less accurate the delivery of traffic to the Schiphol TMA, the greater the geographical areas within the Schiphol TMA that will need to be dedicated as vectoring areas unless the flights go into the hold.

III.1.2.5 Length of arrival tubes

While in the initial stages of DARP implementation (envisaged for 2025) the inaccuracies in traffic delivery can be mitigated by vectoring, this is no longer envisaged for the full implementation estimated at 2035. By 2035 the flights will be operating using the full extent of the arrival tube, spanning from the Schiphol TMA entry fix down to runway threshold. This means that speed control will become the primary method for ensuring safe and efficient sequence of arriving traffic. As the speed is essentially a function of distance covered over a time period, it is the available track distance on each tube that will define how easy or difficult it will be to sequence aircraft using speed control only. For example, the longer arrival tubes (such as ARTIP to runway 06) provide much longer track distance over which the aircraft can decelerate (or even accelerate) to ensure the optimal arrival sequence.

However, other arrival routes are significantly shorter (such as RIVER to runway 06) and there might not be enough track distance to allow efficient speed control between the runway and Schiphol TMA entry fix during periods of significantly decreased accuracy of delivery. This implies that the accuracy of delivery does not necessarily need to be the same at all Schiphol TMA entry fixes and, in general, less adequate accuracy would be better handled for arrivals scheduled to operate over longer arrival tubes.

III.1.2.6 Maximum number of tubes joined at once

Besides the factors mentioned above, the achievable, sustainable and reliable accuracy of delivery might contribute to decision on what tube design will be adopted. Currently, there are four entry fixes for the new Schiphol TMA which are expected to serve either two, or a single landing runway. While in case of dual runway operations each runway serves traffic from two Schiphol TMA entry fixes (and only two tubes need to be combined for the arrival runway), in case of single runway operations the traffic from all four Schiphol TMA entry fixes has to be combined into a single stream of traffic. There are multiple ways in which this can be achieved.

The current concept foresees that for northerly operations on single arrival runway, the arrival tubes from ARTIP, SUGOL and RIVER will be joined into a single point. This combined stream of traffic will then continue towards the runway 06, picking up traffic from ZUDOS at approximately 10NM before the threshold. Merging the traffic from three different tubes in a single point may be considered more challenging than merging traffic from two tubes. Additionally, the insertion of ZUDOS arrivals to the main stream at just 10NM before touchdown assumes the traffic at the ARTIP/SUGOL/RIVER merge point will already be perfectly sequenced. This, in turn, may push the need for proper sequencing higher upstream these three tubes. So, in order for this proposed layout to work, we believe that a better level of accuracy is required.

An alternative method of joining the four arrival tubes assumes the two easterly streams (ARTIP, ZUDOS) are joined into a single stream. Simultaneously, the two westerly arrival streams (RIVER, SUGOL) are joined into a single stream. The resulting two streams are then combined into a single tube at around 10NM from the runway threshold. In this concept, it is always only two streams of traffic that are being merged. This allows for less stringent requirements on traffic delivery as the number of flights that need initial sequencing will be lower than in case of the three-tubes-merge concept. Additionally, the track distances from Schiphol TMA entry fix to runway are much more balanced in this concept, providing roughly similar distances for application of speed control.

The two possible methods (described above) for serving a single arrival runway were developed with ATC operability in mind. As of publication of this report, the 'three-streams merge' is considered the preferred option[1], due to the lower number of inbound/outbounds intersections and lower associated ATCO workload.

III.2 Quantitative analysis

III.2.1 Approach and assumptions

The quantitative analysis of potential mechanisms influencing (or influenced by) the accuracy of delivery was based on carrying out a series of sensitivity tests using the fast time simulation model of the future Schiphol TMA.

III.2.1.1 Fast time simulation model

The key assumptions (on top of those listed in general model description in Annex 4) valid for the scenarios used for sensitivity testing are as follows:

- An (almost) ideal sequence of arriving aircraft was established, leading to no (or only marginal) sequencing delays per flight and peak runway throughput. Performance of the system with this sequence was considered a performance at a (near) perfect accuracy of delivery. This was used as a baseline (reference) scenario for comparison against scenarios with varying accuracies of delivery.
- The timestamps over Schiphol TMA entry fix, recorded in the baseline scenario, were randomised to introduce +/- 15, +/-30, +/-45, +/-60 and +/- 90 seconds variations in time over Schiphol TMA entry fix, to simulate potential inaccuracies in delivery and resulting “bunching” of flights. The +/- 90 seconds variation was only applied to scenarios related to envisaged 2025 operating concept.

[1] Results of RTS1 Schiphol TMA real-time simulations.

- The randomisation of Schiphol TMA entry fix times was based on a normal distribution, using a 2-sigma approach, which means that 95% of the traffic was simulated within the bounds of the inaccuracy being tested. For example, in case of 2 sigma approach applied to +/-60 seconds variations, the 95% of varied timestamps will fall within +/- 60 seconds from their original time. To ensure that the remaining 5% of cases do not exhibit unrealistically high deviations from their original Schiphol TMA entry fix time, the bounds of the probabilistic function were capped at six sigma. In other words, for the +/- 60 seconds variation, there were 5% of records with their difference against the original Schiphol TMA entry fix time being more than +/-60 seconds but less than +/-180 seconds.
- In 2025 simulation runs, speed control, vectoring and airborne holding were all used (in this order of preference) to manage the arrival sequence. Vectoring areas for the simulation were provided by LVNL and their overview is provided in Annex 6.
- In 2035 scenario runs, the vectoring areas and airborne holdings were removed, and speed control was used as the only sequencing technique. If required, aircraft were allowed to re-accelerate within the Schiphol TMA to maintain required spacing.
- Departing traffic was assumed to operate on departure tubes until reaching 6,000ft. After passing 6,000ft, the departing traffic was directed to its destination aerodrome. The set of 233 destination aerodromes available in the original flight plans was simplified to 17 proxy aerodromes. For example, instead of modelling all airports in the far east, a single representative airport in the region was chosen.
- The departing traffic was required to meet the minimum altitude restrictions on the tube, however, if the aircraft performance and traffic situation permitted, the flight was allowed to climb faster than the maximum climb gradient envisaged in the departure tube.
- Absolute traffic peak (2A & 2D runway configuration) departure peak (1A & 2D runway configuration) were modelled for both northerly and southerly operating directions. The arrival peak combination (2A & 1D runway configuration) was not modelled as it shares the same key characteristics with the absolute traffic peak scenario (2A & 2D runway configuration) but less departures. From this perspective, the absolute traffic peak (2A & 2D runway configuration) can be considered the worst dual arrival runways scenario (in terms of traffic complexity), and the departure peak (1A & 2D runway configuration) can be considered the worst single arrival runways scenario (in terms of traffic complexity). In all scenarios modelled, the FTS engine was actively monitoring departure flows to be able to intervene where conflict with arrivals might have occurred.
- 10 randomised simulation runs were performed for each tested scenario and the results were then aggregated. Sample of 10 runs was considered a reasonable trade-off between the time needed to calculate the scenarios and process the results and the statistical relevance of averaged results. This study required running of hundreds of scenarios[2] to address various combinations of airspace measures tested, runway operating directions, traffic samples or time horizons. It would not be possible to complete the agreed scope of the study in time if a greater number of simulation runs were executed for each scenario.

III.2.1.2 Development of individual scenarios

The baseline FTS model was modified to allow sensitivity testing of individual airspace measures. The parameters for testing, as well as the key assumptions and set-up for each set of scenarios were agreed between Egis and

[2] This research investigated 156 individual scenarios, requiring a total of 588 AirTOp runs and 96 AEDT runs.

DARP representatives during regular weekly calls. The approach, assumptions and initial results for each investigated measure were presented to DARP representatives for comments and the feedback received during the progress review calls was reflected in the scenario set-up prior to production of the final results. Detailed assumptions and approach to testing sensitivity of individual measures is provided in respective sections later in this document.

III.2.2 Results of sensitivity testing for 2025 scenarios

Sensitivity tests were run for +/- 15, +/-30, +/-45, +/-60 and +/- 90 seconds variations in time over Schiphol TMA entry fix for 2A & 2D and for 1A & 2D scenarios on both northerlies and southerlies.

III.2.2.1 Average sequencing delay per flight (2025)

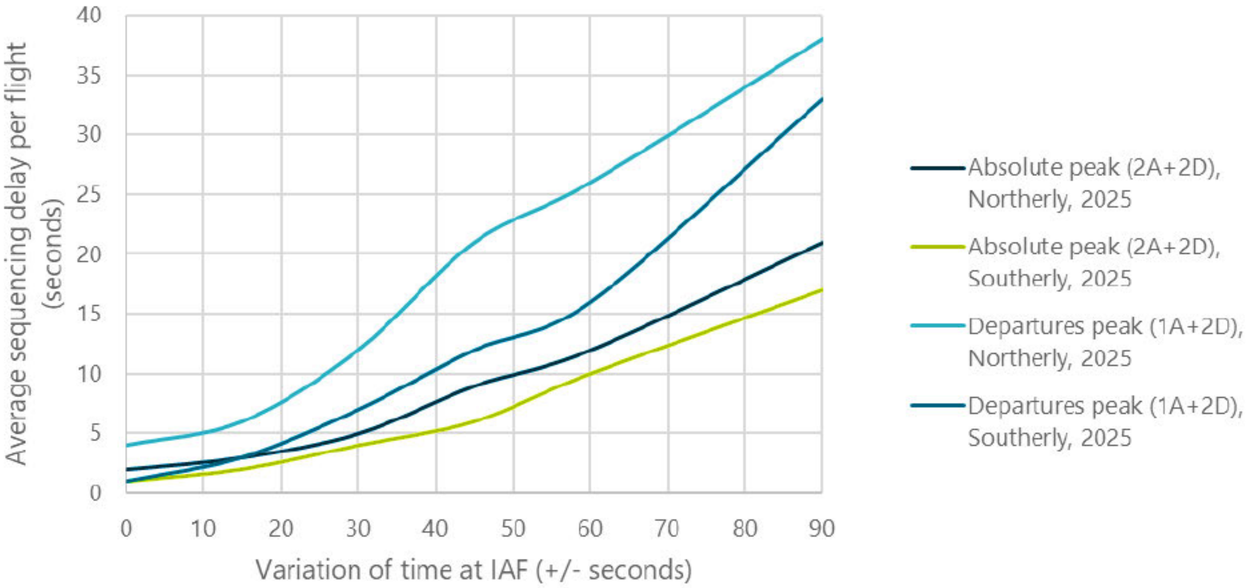

Figure 2: Average sequencing delay per flight (2025)

Average sequencing delay per flight (seconds)			Variation of time at Schiphol TMA entry fix					
Year	**Direction**	**Configuration**	**0s**	**+/-15s**	**+/-30s**	**+/-45s**	**+/-60s**	**+/-90s**
2025	Northerly	Absolute peak (2A+2D)	2	3	5	9	12	21
2025	Southerly	Absolute peak (2A+2D)	1	2	4	6	10	17
2025	Northerly	Departures peak (1A+2D)	4	6	12	21	26	38
2025	Southerly	Departures peak (1A+2D)	1	3	7	12	16	33

Table 2: Average sequencing delay per flight (2025)

Sequencing delay, measured as any delay incurred by an arrival between Schiphol TMA entry fix and runway threshold, is a feasible indicator of efficiency of arrival operations inside the Schiphol TMA. Sequencing delay includes delay related to ensuring safe and efficient arrival sequence. As such, it can include delay caused by speed control, vectoring delay, or delay spent in airborne holding pattern.

The simulation results confirm that sequencing delay increases with deteriorating accuracy of delivery. There seems to be a threshold at around 20-30 seconds (of variation in EAT adherence) after which the sequencing delay starts to increase at a faster pace compared to the rate of increase at better accuracy of delivery. While the traffic randomised with 15 and 30 second variations at Schiphol TMA entry fix can be managed with no or minimal vectoring, the scenarios aimed at testing 45, 60 and 90 second accuracy of delivery show increased used of vectoring, especially at RIVER and SUGOL, with (in the 10 randomised runs) some of the 90 second accuracy scenarios experiencing flights entering the hold. For illustration, see Annex 8 containing visual representations of trajectories flown by arrivals for each simulation scenario.

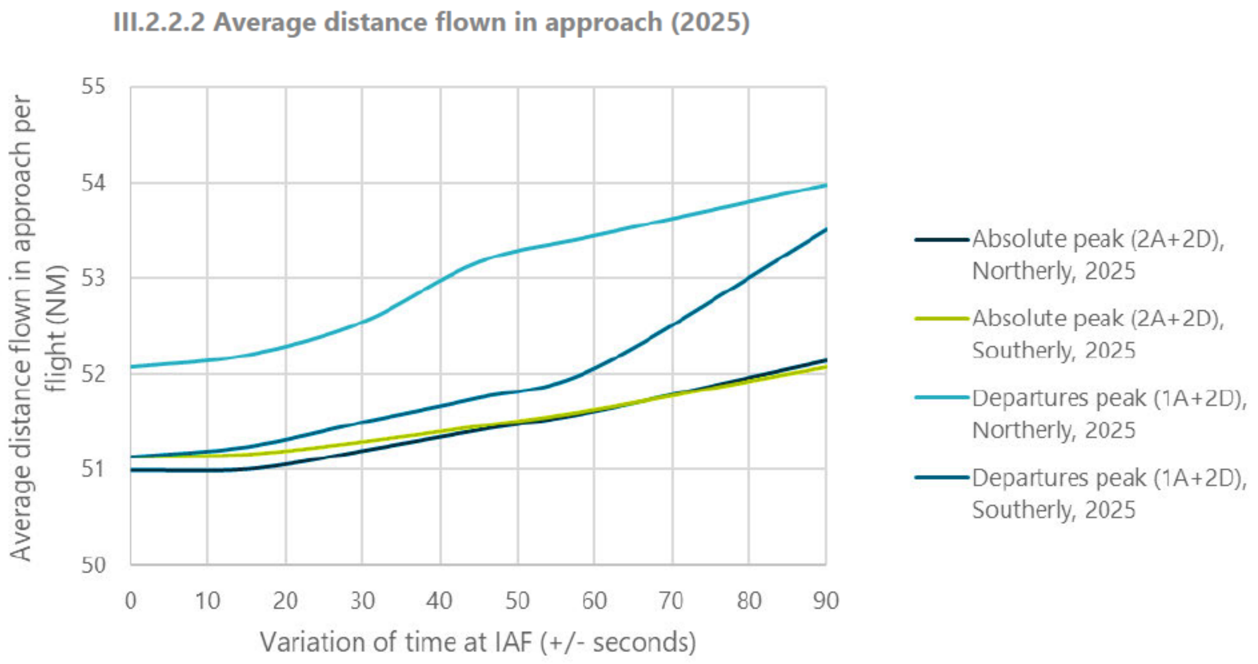

Figure 3: Average distance flown in approach (2025)

Average distance flown in approach (NM)			Variation of time at Schiphol TMA entry fix					
Year	**Direction**	**Configuration**	**0s**	**+/-15s**	**+/-30s**	**+/-45s**	**+/-60s**	**+/-90s**
2025	Northerly	Absolute peak (2A+2D)	51.00	51.01	51.20	51.42	51.61	52.14
2025	Southerly	Absolute peak (2A+2D)	51.14	51.16	51.29	51.46	51.63	52.08
2025	Northerly	Departures peak (1A+2D)	52.07	52.19	52.54	53.17	53.44	53.98
2025	Southerly	Departures peak (1A+2D)	51.13	51.23	51.49	51.75	52.05	53.51

Table 3: Average distance flown in approach (2025)

The average distance flown in approach measures the total distance flown by a flight between the Schiphol TMA entry fix and runway threshold. The graph above broadly mirrors the graph for the sequencing delay – because some of the sequencing can be achieved through vectoring, which, in turn, increases the distance flown. All four series of the graph above increase at roughly similar trend with increase in variation introduced to accuracy of delivery.

However, the arrivals to a single runway when on southerly operations in situations with the worst accuracy of delivery (variation of more than +/-60 seconds) show a greater rate of increase in the average distance flown. This indicates that more vectoring was required to handle the situation, which, in turn, led to greater arrival distances per flight. In fact, several of the randomised runs in this particular scenario saw flights using the full extent of the vectoring area at RIVER and SUGOL.

Again, the full situation is represented in Annex 8, which shows the arrival trajectories simulated under various parameters for all the scenarios mentioned above.

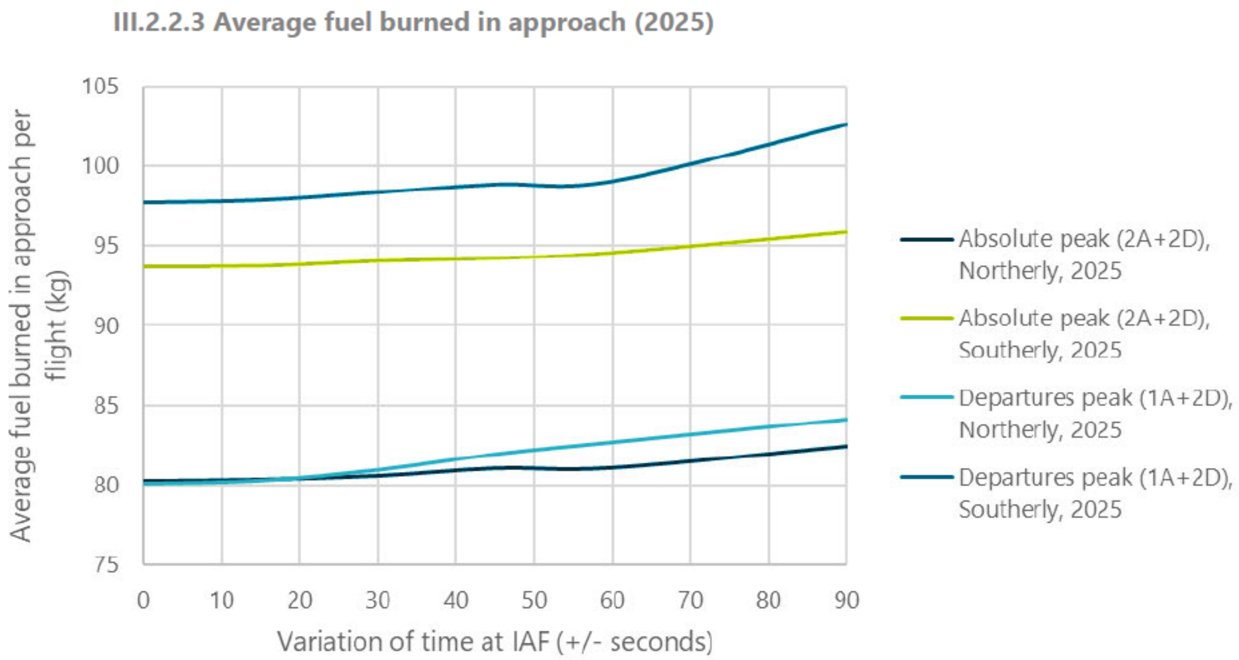

Figure 4: Average fuel burned in approach (2025)

Average fuel burned in approach (kg)			Variation of time at Schiphol TMA entry fix					
Year	**Direction**	**Configuration**	**0s**	**+/-15s**	**+/-30s**	**+/-45s**	**+/-60s**	**+/-90s**
2025	Northerly	Absolute peak (2A+2D)	80.30	80.39	80.62	81.08	81.11	82.42
2025	Southerly	Absolute peak (2A+2D)	93.67	93.72	94.03	94.20	94.56	95.85
2025	Northerly	Departures peak (1A+2D)	80.07	80.26	80.93	81.92	82.67	84.11
2025	Southerly	Departures peak (1A+2D)	97.69	97.85	98.34	98.85	99.05	102.60

Table 4: Average fuel burned in approach (2025)

The average fuel per flight burned during approach calculates the fuel burned between the Schiphol TMA entry fix and the runway threshold using the BADA performance model, taking into account aircraft weight, altitude restrictions on the tube and speed constraints imposed by the ATCO to ensure safe and efficient arrival sequence. The resulting fuel consumption is not a direct function of the distance flown but it does take into account the different fleet mix present in the four traffic scenarios simulated. The differences are small, however, regardless of the sensitivity test carried out.

The above table could be converted to average CO2 produced by each arrival flight by multiplying the weight of fuel by a factor of 3.15[3], leading to approximately 280 kg of CO2 produced by a single arrival to EHAM using the arrivals tube system[4].

[3] EUROCONTROL Standard Inputs for Economic Analyses (December 2020, Edition 9.0)

[4] As the "traditional" arrivals were not modelled in this research it is not possible to provide comparison of estimated 280 kg of CO_2 produced by tube system arrival against the same arrival using the existing operating concept. However, the difference between the two is expected to be minor.

III.2.3 Results of sensitivity testing for 2035 scenarios

Sensitivity tests were run for +/- 15, +/-30, +/-45 and +/-60 seconds variations in time over Schiphol TMA entry fix for 2A & 2D and for 1A & 2D scenarios on both northerlies and southerlies. The +/-90 seconds variation was not considered necessary to test.

III.2.3.1 Average sequencing delay per flight (2035)

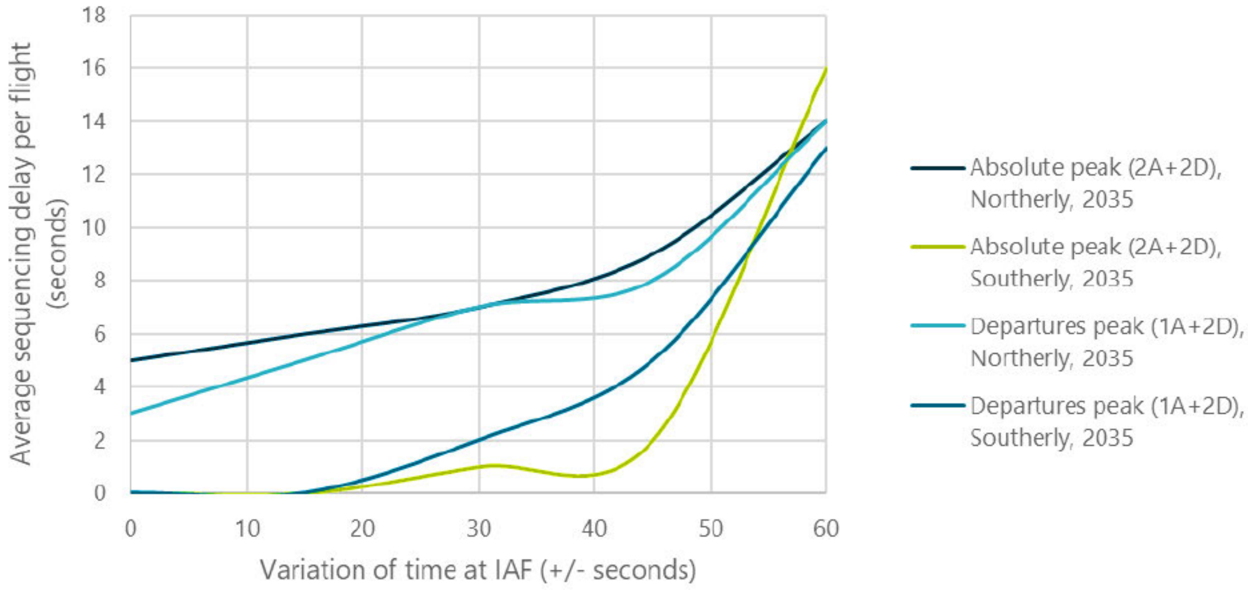

Figure 5: Average sequencing delay per flight (2035)

Average sequencing delay per flight (seconds)			Variation of time at Schiphol TMA entry fix				
Year	**Direction**	**Configuration**	**0s**	**+/-15s**	**+/-30s**	**+/-45s**	**+/-60s**
2035	Northerly	Absolute peak (2A+2D)	5	6	7	9	14
2035	Southerly	Absolute peak (2A+2D)	0	0	1	2	16
2035	Northerly	Departures peak (1A+2D)	3	5	7	8	14
2035	Southerly	Departures peak (1A+2D)	0	0	2	5	13

Table 5: Average sequencing delay per flight (2035)

Similar to the findings for the 2025 scenarios, the 2035 sequencing delay is higher for single runway operations. This comes from a fact that in single runway operations all the arrivals need to be formed into a single arrival sequence, while in the case of two-runway operations, two independent arrival streams can be formed to sequence the arriving traffic. Hence, in single runway scenario, any speed control imposed on a flight is likely to cause a greater knock-on effect on other flights, in comparison with to two-runway scenarios.

As no vectoring areas or regular holding patterns (at IAF) were assumed for 2035 FTS scenarios, speed control is the only measure that can be used to separate the traffic. This means that the system needs to be operated with as great an accuracy of delivery as possible, to reduce the need for additional speed control. Looking at the graph above, the system seems to be reasonably stable up until 20-30 seconds of variation in time at Schiphol TMA entry fix. Starting from 45 seconds variation, however, the system seems to start breaking apart, with sequencing delays rising considerably in all scenarios tested. The +/-60s variation even required occasional use of holds at IAF to mitigate some extremes in randomised times at Schiphol TMA entry fix. Although it occurred relatively infrequently, the occasional use of holds increased the average sequencing delay substantially.

III.2.3.2 Average distance flown in approach (2035)

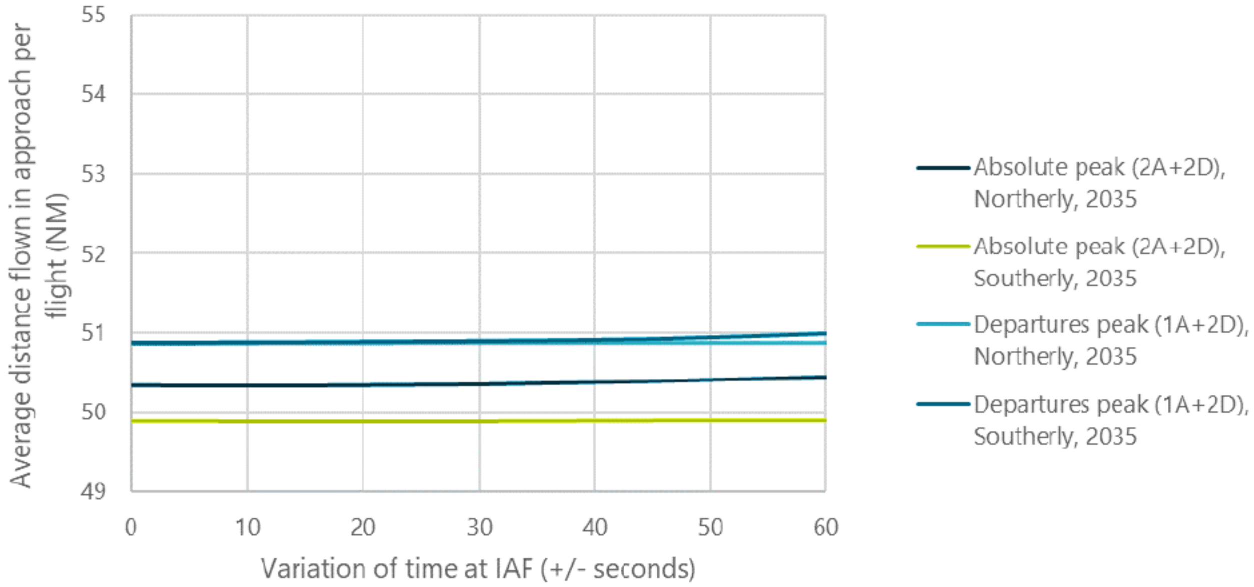

Figure 6: Average distance flown in approach (2035)

Average distance flown in approach			Variation of time at Schiphol TMA entry fix				
Year	**Direction**	**Configuration**	**0s**	**+/-15s**	**+/-30s**	**+/-45s**	**+/-60s**
2035	Northerly	Absolute peak (2A+2D)	50.34	50.34	50.35	50.39	50.44
2035	Southerly	Absolute peak (2A+2D)	49.88	49.88	49.88	49.89	49.89
2035	Northerly	Departures peak (1A+2D)	50.86	50.87	50.88	50.88	50.88
2035	Southerly	Departures peak (1A+2D)	50.87	50.88	50.90	50.92	50.99

Table 6: Average distance flown in approach (2035)

As there is no regular use of holding or vectoring envisaged for the 2035 scenarios, the distances flown remain essentially identical regardless of variation in time at Schiphol TMA entry fix. This sub-section has been provided only for comparison with the 2025 data. As there is no vectoring and almost no holding in the 2035 scenarios, the average distance flown by arriving flight in the Schiphol TMA is marginally lower than in 2025 scenarios (compared against 2025 scenarios with 0 seconds variation in accuracy of delivery).

III.2.3.3 Average fuel burned in approach (2035)

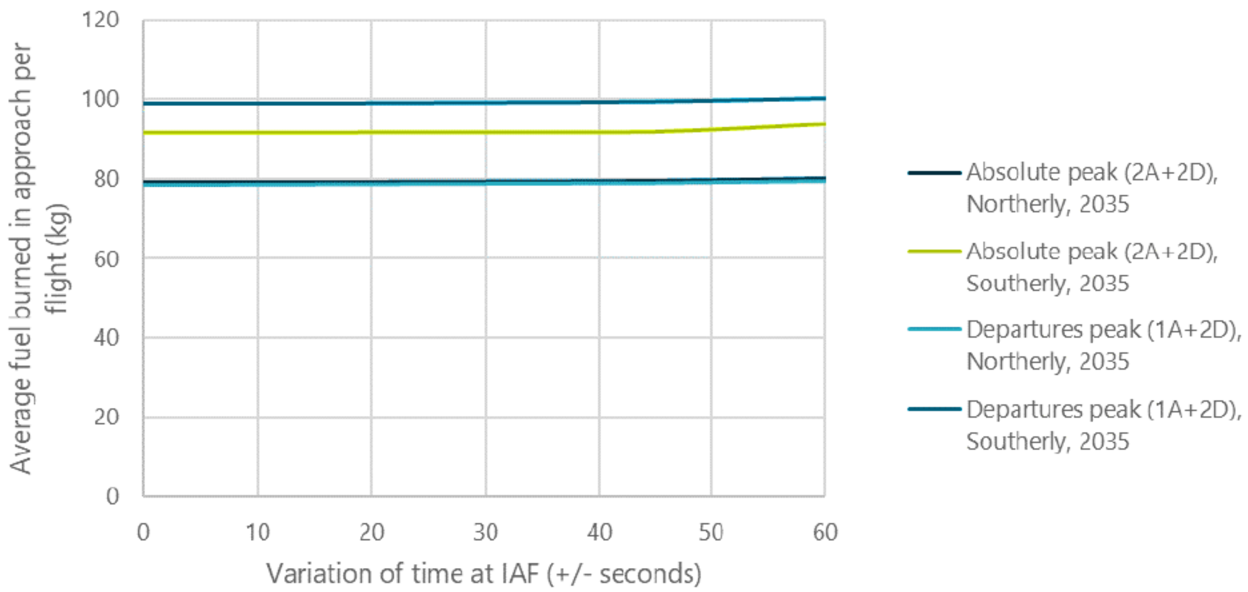

Figure 7: Average fuel burned in approach (2035)

Average fuel burned in approach (kg)			Variation of time at Schiphol TMA entry fix				
Year	**Direction**	**Configuration**	**0s**	**+/-15s**	**+/-30s**	**+/-45s**	**+/-60s**
2035	Northerly	Absolute peak (2A+2D)	79.41	79.38	79.52	79.69	80.21
2035	Southerly	Absolute peak (2A+2D)	91.79	91.78	91.85	91.94	93.67
2035	Northerly	Departures peak (1A+2D)	78.63	78.83	79.01	79.22	79.77
2035	Southerly	Departures peak (1A+2D)	98.87	98.9	99.10	99.38	100.24

Table 7: Average fuel burned in approach (2035)

Because fuel burned is primarily a function of distance flown, the figures in the table and graph above show minimal variation. The differences are more noticeable than in the previous section (distance flown in approach) however, because the speed control is applied to various flights in all scenarios considered, which leads to different approach speeds with different fuel burn.

Ultimately, this sub-section has also been provided for comparison with 2025 data only.

III.2.3.4 Flights with sequencing issues (2035)

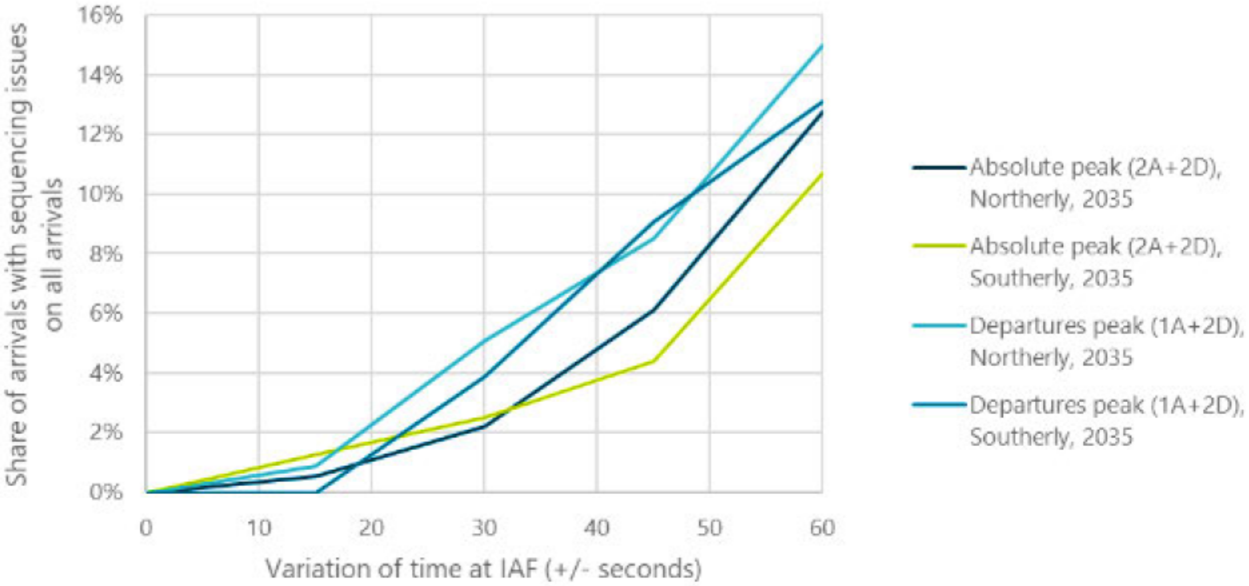

Figure 8: Flights with sequencing issues (2035)

% of arrivals with sequencing issues			Variation of time at Schiphol TMA entry fix				
Year	**Direction**	**Configuration**	**0s**	**+/-15s**	**+/-30s**	**+/-45s**	**+/-60s**
2035	Northerly	Absolute peak (2A+2D)	0.0%	0.6%	2.2%	6.1%	12.8%
2035	Southerly	Absolute peak (2A+2D)	0.0%	1.3%	2.5%	4.4%	10.7%
2035	Northerly	Departures peak (1A+2D)	0.0%	0.9%	5.1%	8.5%	15.0%
2035	Southerly	Departures peak (1A+2D)	0.0%	0.0%	3.9%	9.1%	11.7%

Table 8: Flights with sequencing issues (2035)

It is possible to set the simulation engine to report any events in which additional arrival sequencing actions had to be performed. For example, when a flight was added to runway arrival sequence list but the trailing flight was found not to have space to be sequenced correctly. In such cases, the speeds of both flights were adjusted to ensure proper separations were achieved by the time the flights got close to each other, and to ensure as efficient a runway arrival sequence as possible (on top of accuracy of delivery, this would require hand-over conditions in actual operation). Counting the number of these occurrences can provide an indication on how many potential conflicts might be triggered by inaccurate delivery and what degree of speed control might be required to resolve them. It should be noted that all flights in all simulation runs adhered to the proper separations, but the number of sequencing issues seems to increase significantly for any variation greater than +/-15 seconds for single runway arrivals and for variations greater than +/- 30 seconds for dual runway arrivals.

III.3 Summary of the key findings for accuracy of delivery

III.3.1 Initial implementation (2025)

Simulation results confirm that sequencing delay increases with deteriorating accuracy of delivery. There seems to be a threshold at around 20-30 seconds (of variation in EAT adherence) after which the sequencing delay starts to increase at a faster pace compared to the rate of increase of better accuracy of delivery. Using the currently proposed design of the tubes system, northerly operations seem to lead to greater sequencing delay. Additionally, scenarios with a single runway used for arrivals lead to even greater sequencing delay than scenarios where arrivals are served by two runways. This implies that the sensitivity of the system to any disruption is greatest when all the arriving traffic operates towards the single runway.

Total distance flown by an arrival in the Schiphol TMA starts to increase substantially once the accuracy of delivery deteriorates to more than +/- 60 seconds. This indicates increased a need to use vectoring areas when the speed control measures alone are no longer able to guarantee safe and efficient arrival flow.

III.3.2 Full implementation (2035)

As was the case with 2025 scenarios, the sequencing delay in 2035 remains higher for single runway operations. This comes from the fact that in single runway operations all the arrivals need to be formed into a single arrival sequence, while in the case of two runway operations, two independent arrival streams can be formed to sequence the arriving traffic. Therefore, in a 2035 single runway scenario, any speed control imposed on a flight is likely to cause a greater knock-on effect on other flights, compared to two runway scenarios.

The 2035 system seems to be reasonably stable up until +/- 20 to +/- 30 seconds of variation in time at Schiphol TMA entry fix. However, starting from +/- 45 seconds variation, the system seems to start breaking apart, with sequencing delays rising considerably in all scenarios tested. In fact, the +/-60s variation required occasional use of holds to mitigate some extremes in randomised times at Schiphol TMA entry fix.

The number of sequencing issues seems to increase significantly for any variation greater than +/-15 seconds for single runway arrivals and for variations greater than +/- 30 seconds for dual runway arrivals.

It can be concluded that with the proper accuracy of delivery, the 2035 concept should be easier to execute compared to a 2025 concept that includes vectoring and holding on more regular basis. However, the pre-requisite for this is that the accuracy of delivery does not get any worse than +/- 30 seconds from the estimated arrival time at Schiphol TMA entry fix.

IV Tracking of departure tubes

IV.1 Qualitative analysis

IV.1.1 Description of the measure

One of the key airspace building blocks listed in the Draft Preferential Decision of the Dutch Airspace Redesign Programme (DARP) is the use of "tubes" in approach airspace. A tube in this respect is equal to the current SID with minimum and maximum altitude constraints. The future operational concept plans for the approach and departure tubes being used to bring the traffic into and out of the airport using a set of pre-defined "tunnels in the sky".

Operation of the tubes concept is dependent on the implementation of Performance-Based Navigation using RNAV and RNP or optimised wake vortex separation based on RECAT-EU or pair-wise time-based separation. Weather is expected to be one of the key detrimental factors affecting the operation of the tubes system.

Departure tubes are intended to be used for continuous climb operations in intermediate airspace, avoiding interference with approaching traffic. They are designed for the average climb performance of the majority of aircraft, leaving out only a limited number of aircraft types, and their flight profiles should follow the Noise Abatement Departure Procedures (NADP). NADP2, for example, aims to reduce noise[5] in residential areas surrounding airports in the region 1,800-3,000ft altitude. Currently aircraft are required to follow the SIDs up to 3,000 ft due to noise considerations, then either maintain to follow the SIDs until reaching the TMA exit point or (depending on traffic situation) be given ATC instructions to TMA or FIR exit points.

Use of the tubes concept can be partially abandoned for safety reasons in cases of sudden occurrences of adverse weather, an unpredicted loss of visibility, runway closure or other technical and operational reasons. In case of disruptions and exceptional circumstances, it is generally preferred that the tubes concept continues to operate with limited capacity. Depending on the situation, appropriate mitigating measures such as vectoring or flow restrictions might be applied.

In the initial implementation phase, targeting 2025, departing flights are expected to remain within the departure tube until reaching at least 6,000ft. After that, the flight might be vectored directly to a TMA or FIR exit or other point, assuming there is no conflict with other traffic. When the tubes system is fully implemented, targeting 2035, departure operations are expected to remain similar to the initial implementation, such that vectoring above 6,000ft will be permitted on a case-by-case basis.

Unlike conventional SIDs and STARs, where the altitude limitations are defined more loosely, the tube concept has been defined with a limited number of altitude conditions to reach 3D spacing of routes. In the case of departure tubes, this means that flights will operate on a continuous climb vertical profile until reaching at least 6,000ft. If operationally possible, the upper vertical limit on the departure tube may be dropped to allow a flight unlimited climb.

[5] Depending on exact topography of the area around the airport, NADP1 profile may, in some specific cases, provide more noise respite than NADP2. This is driven by the location of individual settlements and their distance from the airport. In general, NADP1 alleviates noise close to the aerodrome while NADP2 alleviates noise more distant from the aerodrome (ICAO Doc 8168 Aircraft Operations).

IV.1.2 Key mechanisms and interdependencies

Operation of the tubes system is expected to be sensitive to several key influential factors:

IV.1.2.1 Complexity of the local airspace

The shape, length, and position of the tubes need to reflect the characteristics of the local airspace. Therefore, the more constraints that are imposed on the tubes system by the surrounding environment, the more complex the tubes system will be. This complexity brings potential implications for both the ATCO and the pilot's ability to operate the tubes efficiently. Considering the requirement for the departures to stay within the tube until at least 6,000ft, the direction of other traffic flows, potential risks of conflict or active military areas will all contribute the local airspace complexity and potentially limit the options for vectoring departures above 6,000ft.

As the departure tubes lead to different TMA exit points located at a roughly similar distance from the airport, the complexity of the operating environment is likely to *decrease* as the altitude at which the flight can leave the tube increases. For example a 10,000ft threshold would be located further from the airport and higher above arrival traffic flows than a 6,000ft threshold, potentially reducing overall complexity. The downside of this option is likely to be decreased horizontal flight efficiency, due to additional miles being flown in the tube and decrease of hourly capacity due to varying speeds and required longitudinal separation.

IV.1.2.2 Vertical profiles chosen on arrival and departure tubes

The vertical dimension of the tube is defined by the minimum and maximum applicable climb gradient, with the upper restriction potentially being lifted if both the operational situation and aircraft performance permit it. However, the selection of applicable vertical gradients for the tube affects how many aircraft will potentially be unable to operate within it and will also affect the point at which aircraft reach 6,000ft. Steeper vertical profiles for a tube will bring the 6,000ft point closer to the airport, potentially reducing the noise impact on local communities at a cost of higher fuel burn for airspace users. Keeping the vertical gradient of the tube shallow would take noise impacts away from the airport but might affect a greater number of people. Research into the relationship between the vertical profile of the tube and the associated noise impact is presented in Section V of this document.

IV.1.2.3 Fleet composition

The fleet mix at the airport will have a major influence on the selection of vertical profiles for the tubes, which will, in turn, impact fuel burn, emissions and noise. The vertical gradient selected needs to allow the majority of the fleet to operate safely and comfortably under a wide range of operating conditions. For example, a combination of adverse weather conditions and high take off mass with a steep vertical gradient may prevent some aircraft from operating on the tube. Such aircraft would have to be dealt with individually, potentially producing more noise and emissions to avoid traffic already established on existing tubes.

It is worth noting that the majority of aircraft types unable to meet the required climb performance are likely to be older wide-body aircraft, which also produce considerably more noise and CO_2. It may be desirable to define the vertical dimension of the tube based on either the lowest performance and/or the noisiest aircraft type which has a significant presence in the fleet, to ensure these types can operate in the tube without additional environmental impact beyond the expected minimum.

In summary, aircraft fleet composition influences the appropriate vertical dimension of the tube, which in turn affects noise and emission impacts by determining the point at which aircraft will reach 6,000ft.

IV.1.2.4 Weather

The tubes concept is expected to be sensitive to weather. Local adverse weather ('storms') in the vicinity of the airport are likely to prohibit use of the tubes, either partially or completely, as it is neither safe nor efficient to operate a tube through a localised storm near the airport. Similarly, the possibility to vector departures above 6,000ft will be impaired if a tall cumulonimbus cloud covers the area between the tube and the desired "direct to" point.

IV.1.2.5 Trade-off between flight efficiency and noise

The point at which the aircraft can be vectored (currently assumed to be 6,000ft) needs to balance the trade-off between noise and fuel burn/emissions. The sooner a departure is released from the tube (i.e. receives "direct to" another point) the more fuel will it save, with a resulting positive impact on emissions. However, the number of people potentially suffering from aircraft noise may also increase because the aircraft would operate outside the tube, potentially at low altitudes (depending on when exactly it left the tube) or over populated areas. Conversely, keeping aircraft in the tube for as long as possible would help to ensure that flights avoid noise-sensitive areas but would also limit the potential for reductions in track miles, fuel and emissions.

The currently assumed vectoring altitude of 6,000ft is broadly in line with similar initiatives in place elsewhere in the world. For example, in the UK a 7,000ft threshold is used in noise impact assessments as an altitude at which the aircraft noise does not cause significant disturbance. There is however pressure from local communities in the UK to increase the threshold of 7,000ft up to 10,000ft. In any case, 6,000ft can be considered a reasonable starting point for more detailed assessment of what the "suitable altitude" ought to be.

As part of this research, we investigated the sensitivity of the tubes system to departures leaving the tube earlier (at lower altitudes) or later (at higher altitudes) than the currently assumed 6,000ft. The results of this quantitative exercise are provided in the following chapter, and further in Annex 8.

IV.2 Quantitative analysis

IV.2.1 Approach and assumptions

The *quantitative* analysis of potential mechanisms influencing (or influenced by) the altitude used as a threshold for the vectoring of departures in the tube was based on carrying out a series of sensitivity tests using the fast time simulation model of the future Schiphol TMA concept design. Noise impacts were calculated through a dedicated environmental model by using key outputs from the fast time simulation model.

IV.2.1.1 Fast time simulation model

The key assumptions used for the fast time simulations scenarios employed for sensitivity testing were[6]:

- Departing traffic was assumed to operate in departure tubes until reaching the pre-defined altitude. For the purpose of the sensitivity tests, altitudes of 3,000ft, 4,000ft, 5,000ft, 6,000ft, 7000ft, 8000ft and 9,000ft were each tested individually (i.e. in each scenario, all departures were vectored after reaching the same altitude, which was set as a parameter for the model). Additionally, a scenario where the flights followed the departure tube in full (i.e. until the departure fix) was also tested.

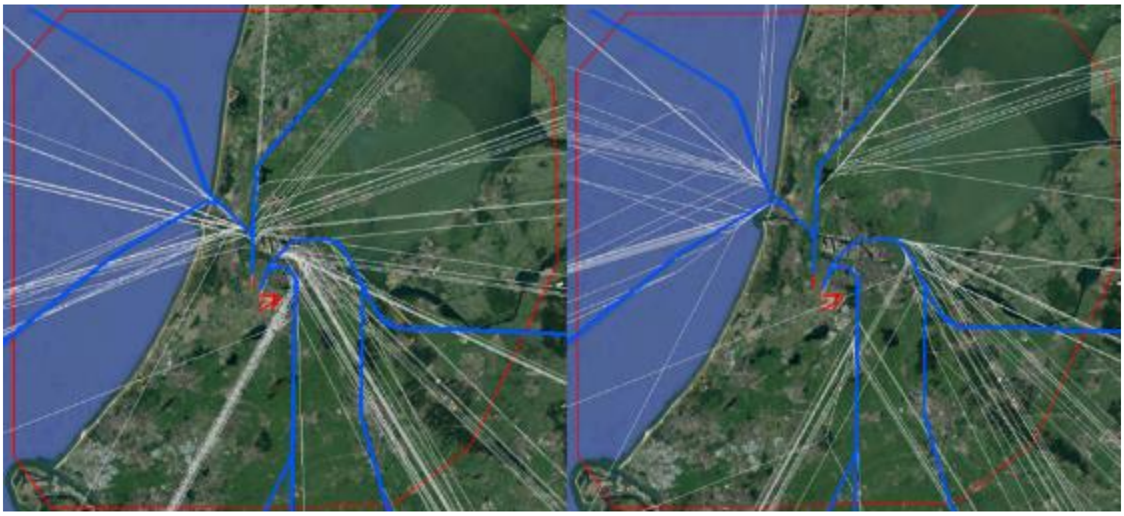

Figure 9: Example of departure traffic being vectored at 3,000ft (left) and at 8,000ft (right)

- After passing the specified altitude, the departing traffic was vectored directly to its destination aerodrome. Please note that the set of 233 destination aerodromes available in the original flight plans was simplified to 17 proxy aerodromes – for example instead of modelling all airports in far east, a single representative airport was chosen for the region.
- The departing traffic was required to meet the minimum altitude restrictions on the tube, although, if the aircraft performance and traffic situation permitted then the flight was allowed to climb faster upper altitude restriction on the tube was dropped.
- The “direct to” command was issued after the aircraft passed the reference altitude. Combined with pilot reaction time and aircraft handling characteristics, the altitude in which the aircraft actually started its turn was typically 200ft to 300ft higher than the reference altitude.

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[6] These assumptions are in addition to those listed in the general model description in Annex 4.

- Variability in aircraft take off weight, affecting climb and noise performance, was introduced based on the great circle distance from EHAM to the destination airport. These distances were categorised into short, medium, and long bands and appropriate haul was assigned to the flight.
- For arrivals, an (almost) ideal sequence of arriving aircraft was established, leading to no (or marginal) sequencing delays per flight and peak runway throughput.
- Absolute traffic peak (2A & 2D runway configuration[7]), departure peak (1A & 2D runway configuration) and arrivals peak (2A & 1D configuration) were all modelled for both northerly and southerly operating directions.
- A single run was carried out for each scenario (i.e. no randomisation of any variables took place).

IV.2.1.2 Environmental model

The key assumptions used for the environmental simulation scenarios used for sensitivity testing were[8]:

- A copy of the aircraft trajectories from the fast time simulation model was imported into the environmental model. This ensured 1:1 replication of FTS flight trajectory profile (latitude, longitude, altitude, and timestamp sampled in 10 seconds intervals), aircraft type, and haul category (short/medium/long).
- Departure aircraft type profiles were adjusted to replicate NADP2 departure procedure.
- As the FTS scenarios were run with different traffic schedules, the traffic levels in the environmental model were upscaled to match the estimated number of daily flights (07:00:00 - 18:59:59) in 2025 time horizon.
- The simulations were run with no noise cut-off altitude (i.e. noise events generated in any altitude were added to the resulting noise contour).
- A single run was carried out for each scenario (i.e. no randomisation of any variables took place).
- The results of individual scenario runs (e.g. vectoring at 3,000ft, 4,000ft etc.) within each individual runway configuration and operating direction are comparable with each other. However, the results are not comparable across runway configurations because different distributions of traffic were observed in the traffic samples modelled for individual departure tubes.
- The population density model used in the research was provided by NLR and is the same population model used in the rest of the Dutch Airspace Redesign Programme, as well as in other transport applications executed by Dutch government. The model includes a series of points (one point for each household) with indicated number of inhabitants registered at the given location. As the model was provided in Amersfoort CRS (EPSG:28992), a conversion to WGS84 (EPSG:4326) was necessary to ensure compatibility with the other software tools used.

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[7] A description of the runway configurations modelled is provided in Annex 4.

[8] These assumptions are in addition to those listed in the general model description in Annex 4.

IV.2.2 Results of sensitivity testing for 2025 scenarios

Sensitivity tests were run for vectoring of departures occurring at 3,000ft, 4,000ft, 5,000ft, 6,000ft, 7000ft, 8000ft and 9,000ft. An additional scenario in which the departures followed the full tube was also tested. The tests were carried out for 2A & 2D, 1A & 2D and 2A & 1D configurations on both northerlies and southerlies.

IV.2.2.1 Average distance flown and fuel burned by a departure from EHAM (2025)

This metric measures the distance covered in the Dutch FIR by a departure from Amsterdam airport. It is measured from the moment the aircraft wheels rolled on the departure runway until the flight crossed the boundary of FIR Amsterdam. In seven of the eight scenarios modelled, the flights were vectored to the destination airport after reaching selected altitude. In the last scenario the flights operated along the full departure tube. Upon reaching the last point of the tube, the flights turned towards their destination airports.

Average distance (NM) flown by EHAM departure in EHAA FIR			Departures vectored at							
Year	Dir.	Configuration	3,000 ft	4,000 ft	5,000 ft	6,000 ft	7,000 ft	8,000 ft	9,000 ft	Full tube
2025	N	Abs. peak (2A+2D)	87.9	87.9	86.9	82.9	85.3	88.0	82.7	85.1
2025	S	Abs. peak (2A+2D)	78.8	77.8	81.6	77.8	81.2	81.5	83.1	83.8
2025	N	Arr. peak (2A+1D)	88.4	88.2	86.6	84.3	84.2	87.3	89.5	90.6
2025	S	Arr. peak (2A+1D)	80.2	81.3	84.9	80.1	81.7	86.6	87.6	92.2
2025	N	Dep. peak (1A+2D)	87.9	87.9	86.9	82.9	85.3	88.0	82.7	85.1
2025	S	Dep. peak (1A+2D)	78.8	77.8	81.6	77.8	81.2	81.5	83.1	83.8

Table 9: Average distance (NM) flown by EHAM departure (2025)

The results indicate that the shortest distance to the FIR boundary can be achieved when vectoring departures at around 6,000 feet.

This result seems counterintuitive, as one might expect that the sooner an aircraft turns towards its destination the shorter the distance it will cover. That expectation would be valid only if measured within a circle centred on the airport or when the full origin-destination distances are measured. In either case the distances flown would indeed increase with increasing vectoring altitude.

In our scenarios, we modelled the existing boundaries of EHAA FIR. The FIR itself has quite irregular shape, which adds complexity to our explanation of the results. As the aircraft climbs along the tube it receives a direct vector to the fixed destination point but the point at which the aircraft receives a "direct to" command changes depending on the tube design, operating direction, aircraft performance and altitude at which it is vectored to the destination. The "vectoring point" can therefore vary, but the destination point remains fixed, so there will in effect be *two* individual segments leading towards the destination airport (see Figure 10). Had the distance *to the destination airport* been measured at this stage, then the assumption that vectoring at lower altitude leads to shorter distances would still be correct. However, because we are measuring the distance within the FIR area we need to identify an intersection of a FIR boundary with the two segments mentioned above. Depending on the FIR shape, these intersections may either fall closer to or further away from Amsterdam airport, causing the total distance flown in EHAA FIR to be a function of two factors:

1. How soon after departure the aircraft was given a direct routing (an earlier direct at lower altitudes leads to a reduction in distance flown), and
2. How the FIR exit point moves depending on the altitude at which the aircraft received a direct routing to the destination.

While the first of these factors is quite intuitive, the second is more difficult to predict because it is a function of FIR geographical boundary. Additionally, the averages for distance flown, as reported in this report, are based on several traffic samples with varying distribution of destinations. The results which are valid for the tested traffic sample might therefore be different if tested with a different traffic sample (e.g. a switch from a winter to a summer schedule, featuring more holiday destinations, would likely contain more southerly departures which may shift the balance of the results as the southern boundary of the FIR would be intercepted more often).

The schematic below illustrates this explanation, in some cases:

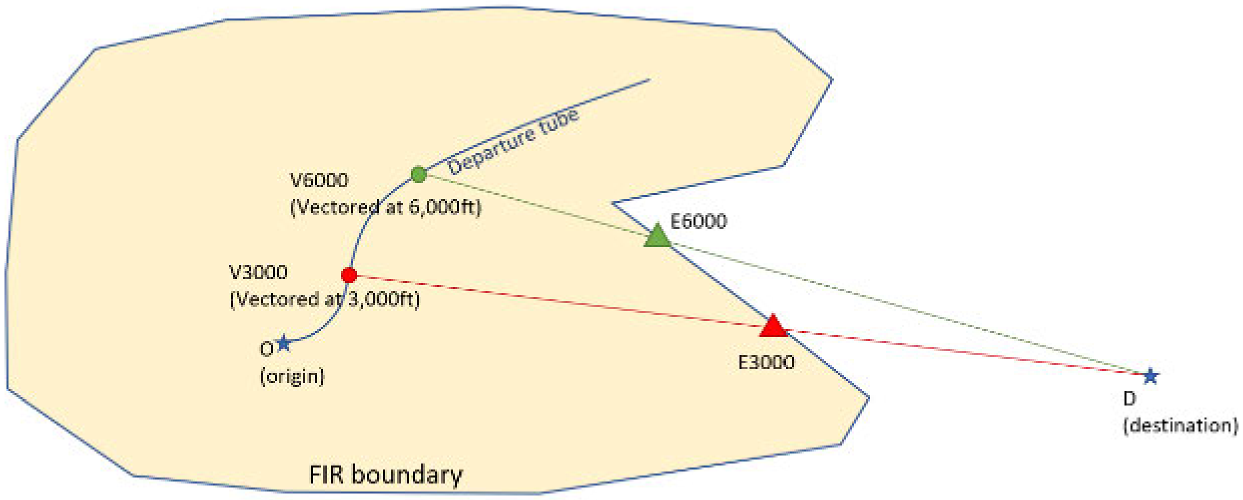

Figure 10: Diagram showing selected cases for calculation of distance flown by EHAM departure in EHAA FIR

The sum of distances from O to V_{3000} and from V_{3000} to E_{3000} is greater than the sum of distances from O to V_{6000} and V_{6000} to E_{6000}.

With this mechanism explained, it is possible to understand why the "sweet spot" in distances flown may occur with vectoring at 6,000ft, as shown in Table 2. This conclusion is however sensitive to the set of destination airports used.

Looking at simulated trajectories in more detail, we identified several examples of the above behaviour, two of which are presented in Figure 11.

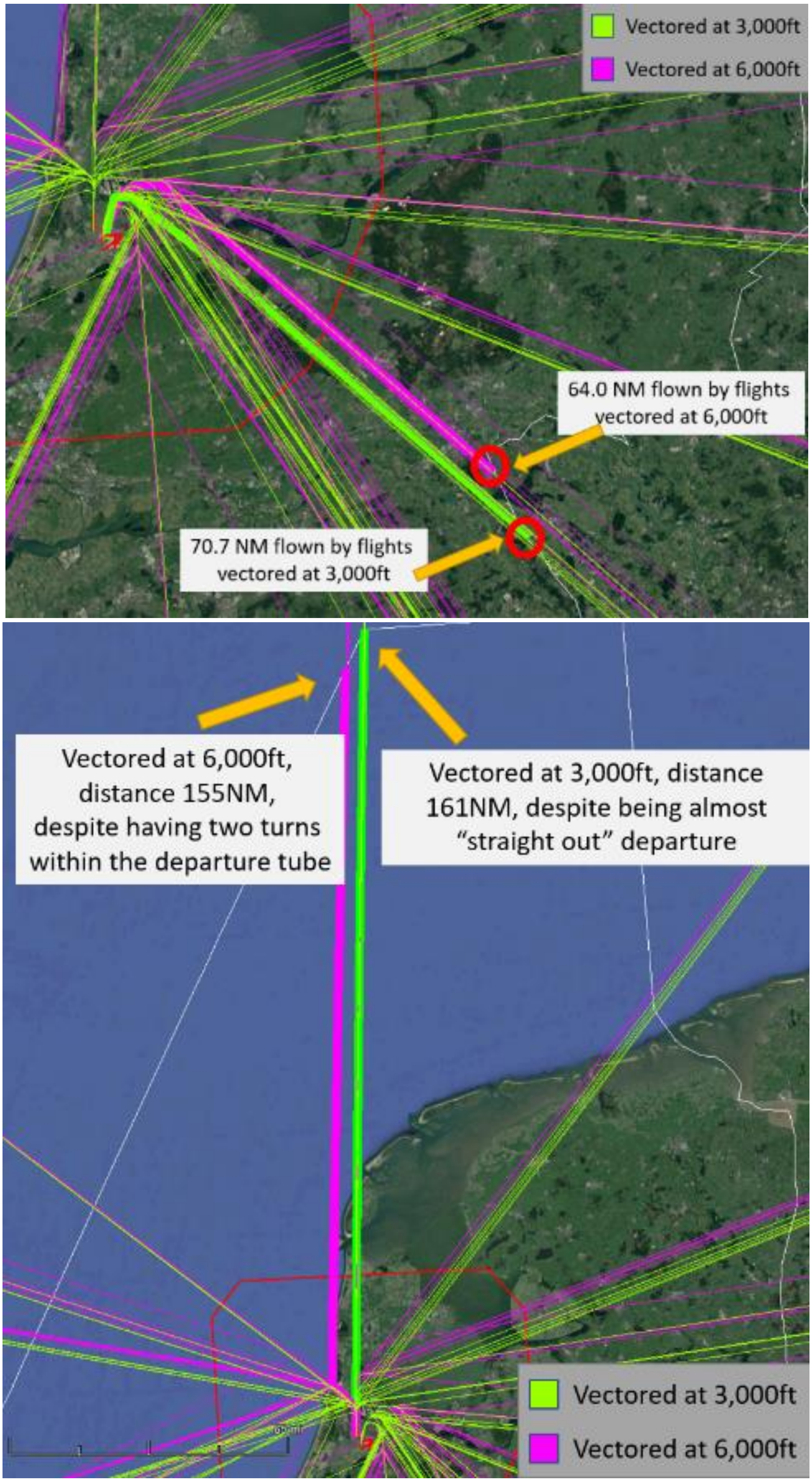

Figure 11: Example cases where departures vectored at 3,000ft flew longer track distance in EHAA FIR compared to departures vectored at 6,000ft

The amount of fuel burned in each scenario mirrors the trends in distances flown. The 6,000ft scenario resulted in one of the smallest average fuel burns across most scenarios, as shown in the table below. Using the conversion factor of 3.15 kg of CO_2 produced from one kg of burned aviation fuel, it may be derived that the average CO_2 production per single departure from Amsterdam airport would be around 3,200 kg (ranging from minimum of 2,800 kg to a maximum of 3,700 kg, depending on the scenario).

Average fuel burned by EHAM departure in EHAA FIR (in kg)			**Departures vectored at**							
Year	**Dir.**	**Configuration**	**3,000 ft**	**4,000 ft**	**5,000 ft**	**6,000 ft**	**7,000 ft**	**8,000 ft**	**9,000 ft**	**Full tube**
2025	N	Abs. peak (2A+2D)	1,010	1,010	1,000	950	980	1,010	950	980
2025	S	Abs. peak (2A+2D)	990	970	1,010	970	1,010	1,010	1,030	1,050
2025	N	Arr. peak (2A+1D)	1,100	1,100	1,070	1,040	1,040	1,080	1,110	1,110
2025	S	Arr. peak (2A+1D)	1,060	1,070	1,110	1,050	1,060	1,130	1,140	1,180
2025	N	Dep. peak (1A+2D)	1,010	1,010	970	950	980	1,010	950	980
2025	S	Dep. peak (1A+2D)	990	970	1,010	970	1,010	1,010	1,030	1,050

Table 10: Average fuel burned by EHAM departure in EHAA FIR (2025)

IV.2.2.2 Area and population impacted by 48dB noise contour (2025)

In terms of noise impact, the time-averaged L_{den} metric was used to calculate aircraft noise between 07:00:00 and 18:59:59 local time. Three noise contours were produced for each scenario modelled. These were 48dB, 45dB and 43 dB contours. This section presents results in a couple of metrics related to the noisiest 48dB contour. The same metrics (total contour area, contour area over the land and population within the contour) were calculated also for the remaining 45dB and 43 dB contours. However, the results for 45dB and 48dB show much greater variability and no strong conclusions could have been derived from the results. For completeness, the results of 43dB and 45dB noise contours are presented in Annex 8.

The basic metric to measure the change in aircraft noise is through the total area covered by the noise contour. In this case, the measure includes the entire area covered, regardless of whether it is inhabited, on land or over the sea. The results for most of the cases in the table below show a trend in reduction of the total area of the contour with increasing altitude at which the flights were vectored out from the FIR. As the departure peak scenarios (1A+2D) featured more departing aircraft compared to arrivals, the overall footprint of these scenarios is greater (as departures produce more noise than arrivals). Additionally, the greater number of departing traffic creates more concentration of flight tracks (for a longer period of time) which may lead to counterintuitive results in terms of increased noise footprint for 1A+2D scenarios.

48dB contour area (in km^2)			Departures vectored at							
Year	**Dir**	**Configuration**	**3,000 ft**	**4,000 ft**	**5,000 ft**	**6,000 ft**	**7,000 ft**	**8,000 ft**	**9,000 ft**	**Full tube**
2025	**N**	Abs. peak (2A+2D)	1,100	1,070	1,080	1,090	1,120	1,080	880	1,130
2025	**S**	Abs. peak (2A+2D)	1,090	1,080	1,040	1,050	970	910	920	1,110
2025	**N**	Arr. peak (2A+1D)	940	900	850	850	850	800	830	1,020
2025	**S**	Arr. peak (2A+1D)	1,030	1,040	1,020	1,010	930	950	960	1,300
2025	**N**	Dep. peak (1A+2D)	1,370	1,320	1,410	1,360	1,410	1,490	1,460	1,520
2025	**S**	Dep. peak (1A+2D)	1,280	1,280	1,250	1,300	1,260	1,190	1,210	1,410

Table 11: 48dB contour area (2025)

This can be explained by a trade-off between aircraft altitude, dispersion of tracks flown and density of operations on each route. In scenarios, where aircraft are vectored early, they follow the departure tube for a short period of time (a short distance) and are still at a low altitude when vectored to their destination. This means that the dispersion of tracks is happening relatively early during the departure procedure, but it is also causing more noise disturbance as the flights are still close to the ground and due to the dispersion, they are covering a larger area than they would if they all followed the departure tube longer.

Additionally, all 3,000ft vectoring points are located close to the airport (as the initial climb performance of the aircraft at lower altitudes is broadly similar), meaning that there are more overlapping tracks of vectored aircraft, and this adds to the overall noise footprint.

In order to allow comparison against similar research carried out in PlanMER document, the table below indicates % variation in results compared against existing practice (i.e. vectoring at 3,000ft).

48dB contour area (in km²)			**Departures vectored at**							
Year	**Dir**	**Configuration**	**3,000 ft**	**4,000 ft**	**5,000 ft**	**6,000 ft**	**7,000 ft**	**8,000 ft**	**9,000 ft**	**Full tube**
2025	**N**	Abs. peak (2A+2D)	100%	97%	98%	99%	102%	98%	80%	103%
2025	**S**	Abs. peak (2A+2D)	100%	99%	95%	96%	89%	83%	84%	102%
2025	**N**	Arr. peak (2A+1D)	100%	96%	90%	90%	90%	85%	88%	109%
2025	**S**	Arr. peak (2A+1D)	100%	101%	99%	98%	90%	92%	93%	126%
2025	**N**	Dep. peak (1A+2D)	100%	96%	103%	99%	103%	109%	107%	151%
2025	**S**	Dep. peak (1A+2D)	100%	100%	98%	102%	98%	93%	95%	110%

Table 12: 48dB contour area as % (2025)

As the vectoring altitude increases the flights are getting further away (and higher) from the airport, meaning that the higher noise levels (48dB contour) are more concentrated along the defined departure tubes. This creates a smaller noise contour area. The flights are then vectored at a higher altitude, leading to a greater dispersion of their flight tracks. This comes from the widening of "performance scissors" for various aircraft types – the higher the vectoring altitude, the greater variability in locations where various aircraft reach the required altitude. The dispersion of tracks therefore increases with vectoring altitude which, together with the increasing altitude, contributes to reduction in the area covered by the noise contour.

Finally, even if some of the dispersed tracks overlap, the cumulative impact on the noise contour is shown to decrease with increasing vectoring altitude. This can be observed when comparing the 48dB contour for a selected 3,000ft and 9,000ft scenario, as shown in the example in Figure 12.

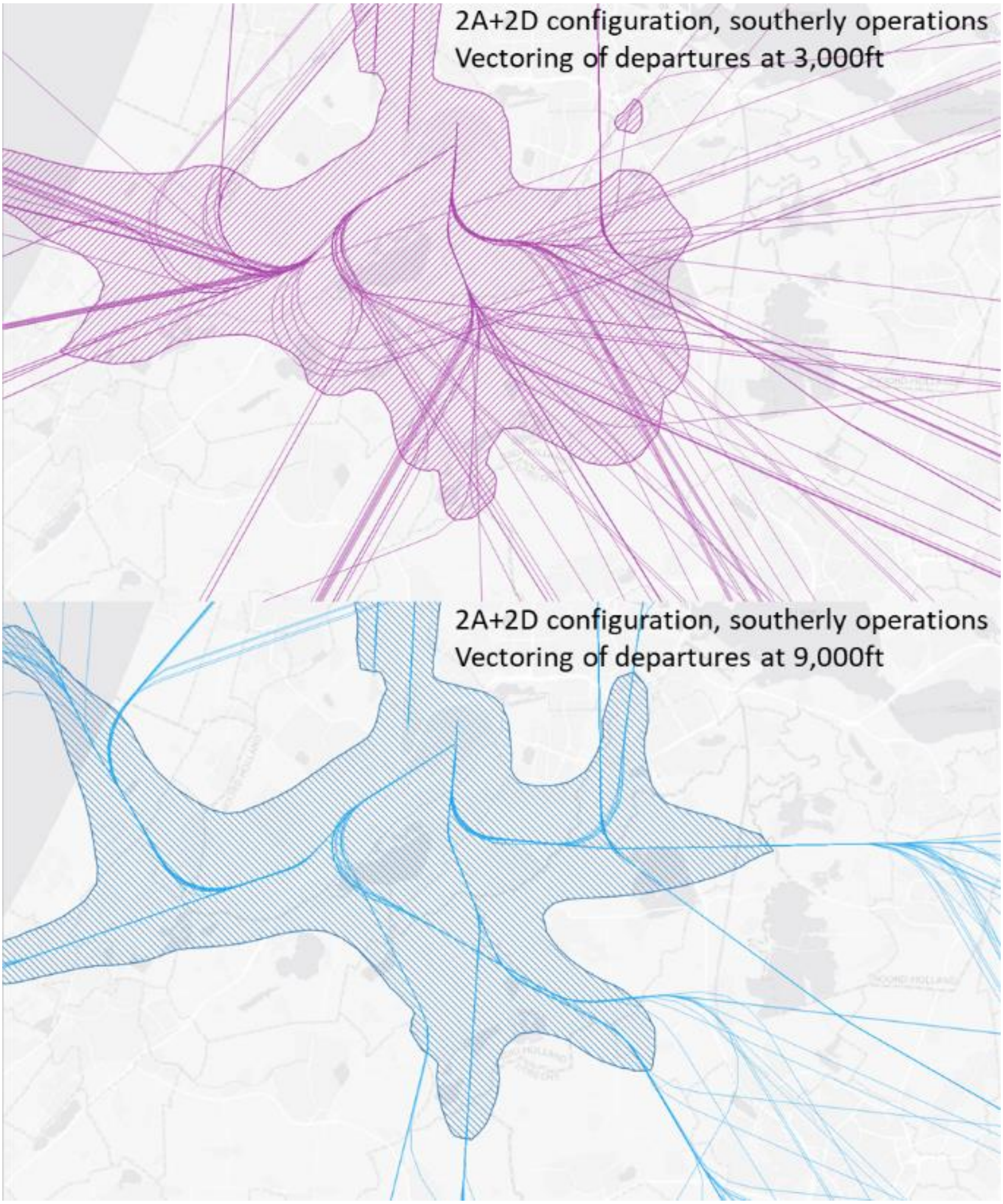

Figure 12: Comparison of example 48dB contour for flights vectored at 3,000ft and at 9,000ft

A separate case for discussion is operation alongside the full tube concept. The use of tubes allows traffic to be routed around the most noise-sensitive or densely populated areas. However, at the same time, the tube concept concentrates all traffic on the same set of routes, creating a higher density of operations along these tubes[9] compared to scenarios with vectoring of departures.

Finally, once aircraft reach the end of the tube (the departure fix) they start accelerating to cruise speed. This causes a localised widening of the noise contour at the end of the tube, visible in the Figure 4 below, as all the departures on such a tube start accelerating to cruise speeds at the same point. This phenomenon is not visible in the scenarios with departures vectored, because each departure follows its own direct route and there is no concentration of points at which aircraft accelerate to cruise speeds.

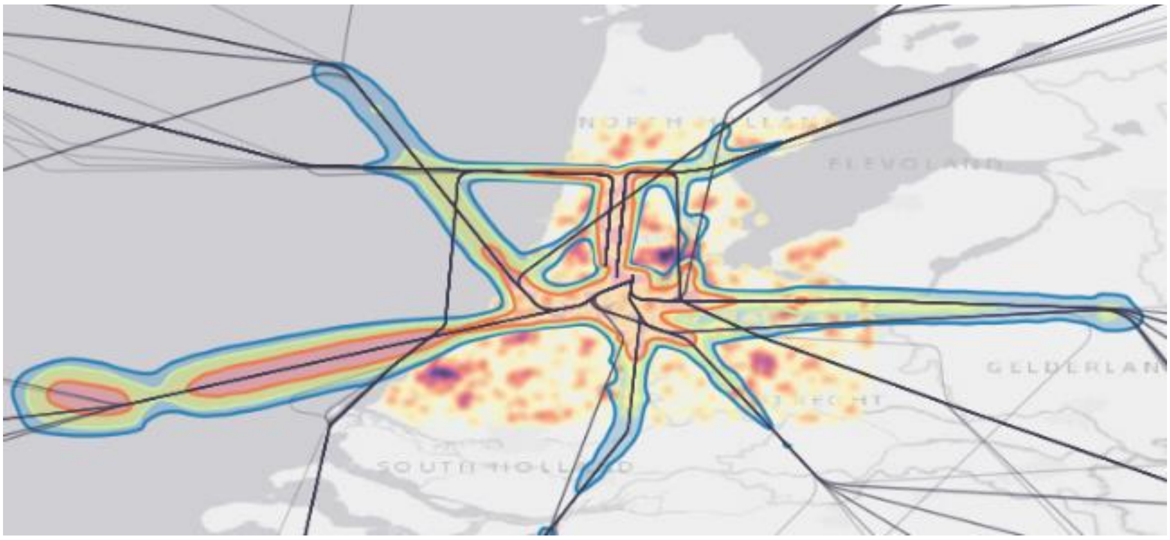

Figure 13: Example 48dB contour showing concentration of aircraft tracks along the tubes and "islands" of increased noise as there accelerate to en-route speed.

The full set of noise contours associated with various scenarios modelled are provided in Annex 8 at the end of this document.

Care should be taken when interpreting/comparing these results against each other. While it is possible to compare the results of various sensitivity tests associated with one particular runway configuration (for example, it is possible to compare contours for vectoring at 3,000ft and 4,000ft on 2A & 2D configuration on northerlies), it is not possible to compare noise contours belonging to different runway configurations or different operating directions. This limitation is due to the real-world traffic samples that were used with individual runway configurations and operating directions. Although the count of aircraft types and total number of flights in all simulated scenarios were harmonised as much as possible, the distribution of flights on individual departure tubes was not standardised. Only results for sensitivity tests within the same runway configuration and operating direction should therefore be compared against each other. For example, comparison of 3,000ft scenario on southerlies when in 2A & 1D configuration against the same scenario on northerlies is not possible because even though the runway configuration (2A & 1D) is the same, the runway ends are different and the distribution of flights on individual departure routes would also be different.

As substantial portions of noise contours span above the sea, where there are no people who may suffer from aviation noise, it makes sense to re-visit the total contour area metric with focus on area over the land only. Any

[9] In some European countries (the UK for example), local communities tend to argue that concentrating noise along the same route is worse for noise annoyance than dispersing the noise over a larger area.

portion of the contour that spanned across the water was therefore ignored and the resulting figure, provided in the table below, is representative of the area above the land covered by the noise contour.

48dB contour area over the land only (in km^2)			Departures vectored at							
Year	**Dir**	**Configuration**	**3,000 ft**	**4,000 ft**	**5,000 ft**	**6,000 ft**	**7,000 ft**	**8,000 ft**	**9,000 ft**	**Full tube**
2025	N	Abs. peak (2A+2D)	600	600	600	610	630	640	660	670
2025	S	Abs. peak (2A+2D)	660	640	630	640	650	650	650	660
2025	N	Arr. peak (2A+1D)	540	530	530	540	560	560	580	620
2025	S	Arr. peak (2A+1D)	530	530	520	540	540	560	570	630
2025	N	Dep. peak (1A+2D)	650	640	650	640	670	680	700	1,010
2025	S	Dep. peak (1A+2D)	690	670	650	660	680	690	690	710

Table 13: 48dB contour area over the land only (2025)

These results indicate that the best trade-off between increased noise resulting from low-altitude vectoring (and associated higher density of crossing tracks contributing to increased noise footprint) and increased noise resulting from higher concentration of flight tracks on the tube for a longer period of time (and resulting increase in noise footprint) occurs at the scenario in which the flights were vectored after passing 5,000ft.

5,000ft is therefore considered a threshold at which the traffic is high enough to allow for the noise reduction benefits of the dispersed tracks to be materialised, and not high enough to cause too much increase in noise caused by the prolonged concentration of flight tracks in the tube.

Although the area of the noise contour is a standard indicator, it does not provide insight into the potential impact of noise on actual people. We have therefore calculated the number of people living inside the 48dB contour using population data provided by NLR. Summary results are provided in the table below.

48dB contour - population (millions)			Departures vectored at							
Year	**Dir**	**Configuration**	**3,000 ft**	**4,000 ft**	**5,000 ft**	**6,000 ft**	**7,000 ft**	**8,000 ft**	**9,000 ft**	**Full tube**
2025	N	Abs. peak (2A+2D)	1.08	0.94	0.86	0.86	0.84	0.84	0.84	0.77
2025	S	Abs. peak (2A+2D)	0.35	0.32	0.33	0.34	0.34	0.37	0.36	0.77
2025	N	Arr. peak (2A+1D)	0.64	0.57	0.53	0.53	0.53	0.53	0.53	0.54
2025	S	Arr. peak (2A+1D)	0.30	0.29	0.30	0.32	0.32	0.32	0.34	0.34
2025	N	Dep. peak (1A+2D)	1.20	1.09	1.00	1.03	0.99	0.99	0.99	1.07
2025	S	Dep. peak (1A+2D)	0.38	0.37	0.37	0.39	0.39	0.40	0.43	0.43

Table 14: 48dB contour – population (2025)

The results of this high-level population analysis are broadly aligned with the findings on the total size of the contour above areas of land. Leaving the tube at 5,000ft will lead to the smallest number of people living within associated noise contour. The noticeable difference in number of people associated with all three northerly runway configurations, for both 3,000ft and 4,000ft scenarios, comes from the fact that those departures take off towards the city of Amsterdam where the population density is higher.

IV.2.3 Results of sensitivity testing for 2035 scenarios

IV.2.3.1 Comparison against 2025 contours

Evaluation of the expected system performance in 2035 started with a comparison of the starting assumptions between the 2025 and the 2035 scenarios.

In terms of the departing traffic in 2035, it was assumed that departures would still be vectored to their destination after passing an altitude threshold. For arrivals, the 2025 scenarios were modelled with perfect accuracy and no vectoring/holding and the same set of assumptions apply for 2035, i.e. a full tube concept would be used, leading to same set of arrival trajectories as modelled in 2025 scenarios.

The main two areas where the assumptions between 2025 and 2035 change substantially are aircraft separations and fleet composition.

In terms of aircraft separations, these are relevant for FTS modelling of operational performance of various actors in the ATM chain, but for noise modelling it does not matter what separations were used. Instead, it matters how many flights operated to/from the airport during a selected period (in our case 12 hours). Traffic levels for the 2035 simulations were therefore increased to be reflective of annual 2035 traffic levels when measured between 07:00:00 and 18:59:59.

In terms of fleet composition, several aircraft types modelled 2025 were replaced by new (and quieter) aircraft types to be modelled in 2035 (as described in Annex 5). It is recognised that PlanMER document assumes average annual reduction in the noise of the fleet of 1% per year. This assumption could not be modelled in our research directly because the noise characteristics of available aircraft performance models are pre-set in the modelling software used. Obtaining relevant data to update the noise characteristics of individual aircraft types in our modelling software would require substantial effort and additional assumptions.

With this new set of assumptions, a number of scenarios were run and compared against their relevant counterparts in the 2025 family of scenarios. The results, in terms of increase of noise contour area, are shown in Table 15.

% area difference vs 2025	2D & 1A (Northerly)			2D & 2A (Northerly)		
	43dB	45dB	48dB	43dB	45dB	48dB
3,000ft	6.6%	7.8%	12.0%	6.9%	13.9%	7.3%
4,000ft	7.1%	7.5%	13.7%	-	-	-
5,000ft	7.4%	7.8%	14.9%	-	-	-
6,000ft	6.7%	9.7%	8.3%	8.0%	14.6%	8.7%
7,000ft	7.3%	10.4%	7.4%	-	-	-
8,000ft	7.3%	9.6%	8.1%	-	-	-
9,000ft	6.7%	8.9%	15.2%	-	-	-
Full tube	5.8%	6.8%	14.5%	6.0%	9.3%	20.7%

Table 15: Difference in 2025 contour area against 2035 results[10]

The observed increase in contour area was generally between 5% and 15%, with one specific instance growing by more than 20%. This increase is not as large as it may first appear[11]: because the area is measured in squared units the seemingly important increase of 10% does not look great when visualised properly. The image below compares the 2025 contour for 2A & 2D scenario when operating on northerly direction with departures following the full tube. This was the scenario that resulted in the biggest rate of change (+20.7% in contour area in 2035), yet the differences, when plotted on map, appear marginal to the eye.

[10] Scenarios for 2A & 2D configurations on Northerly direction, with vectoring at 4,000ft, 5,000ft, 7,000ft, 8,000ft and 9,000ft were not run for 2035. Given the small differences observed for vectoring at 3,000ft, 6,000ft and full tube scenarios it was concluded that the remaining scenarios are highly unlikely to lead to any major differences in contour size against 2025 data.

[11] Imagine a square covering 100km^2. The edges of this square would each be 10km. Increase in area by 10% would lead to a new square, covering 110km^2. However, the edges of this new square would be only 10.49km (a square root of 110km).

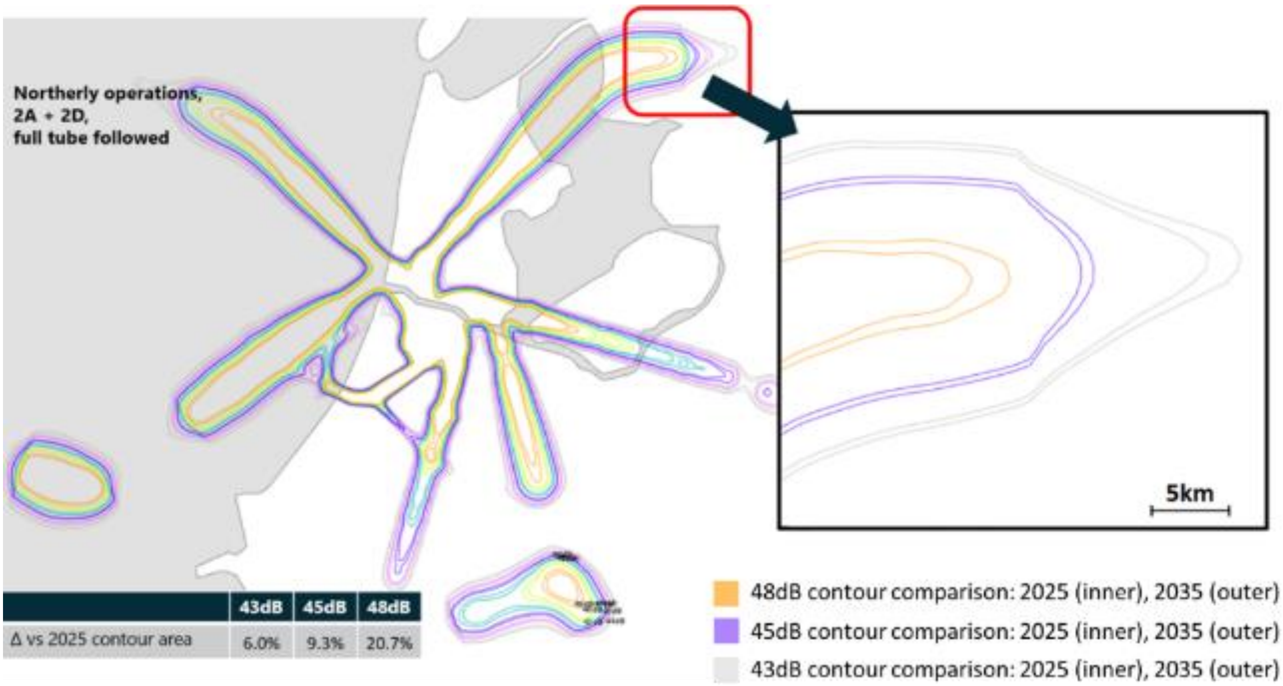

Figure 14: Visualisation of differences in 2025 and 2035 noise contours

An analysis of possible reasons for the minor differences identified three main factors responsible for the small increase in the noise contours:

- The 2035 scenarios featured identical set of destination airports as were used for 2025. Without a route development forecast for 2035 (and associated flight schedule) the existing 2025 flight schedule was used and upscaled to meet 2035 traffic levels. Introduction of new/removal of existing destinations for the 2035 time horizon would change directions in which the flights headed when being vectored to destinations, which would influence the shape of the contours.
- The traffic increase between 2025 and 2035 is relatively small. According to PlanMER, the increase in annual traffic between 2025 and 2035 horizons is only 7.8%.
- Fleet renewal trends are expected to result in a quieter fleet. As indicated in Annex 5, there are several fleet changes that are likely to happen and contribute towards reduction in aircraft noise. By 2035:
  - Older (and noisier) aircraft types will be phased out by more recent (and quieter) types.
  - Noisy turboprop aircraft operating in lower altitudes will be replaced by modern regional jets. These will not only have quieter engines but will also operate in higher altitudes (compared to turboprops), therefore reducing the noise even further.
  - Airlines will move away from extra large (and noisier) wide bodied aircraft. Instead, these will be, where possible, replaced by smaller, quieter, and more cost-efficient narrow bodies in "extended range" modification.

In summary, the additional noise resulting from the small increase in traffic numbers envisaged between 2025 and 2035 seems to be partly mitigated by fleet replacement strategies. Using the same set of destination airports for both the 2025 and 2035 scenarios, the resulting increase in noise contours in 2035 is expected to be only marginal. It was therefore agreed that the analysis of 2035 noise impact does not need to be expanded beyond its existing scope.

IV.3 Summary of key findings for tracking of tubes

IV.3.1 Initial implementation (2025)

The results indicate that the shortest distance to the FIR boundary can be achieved when vectoring departures to their destinations at around 6,000 ft. The total distance flown in any FIR is a function of two mechanisms:

(1) how soon after the departure the aircraft was given direct routing to its destination, and
(2) how the FIR exit point moves depending the altitude and therefore position at which the aircraft received a direct routing to the destination point.

With these two mechanisms in mind it is possible to conclude that these two influences are best balanced at 6,000ft (i.e. there are benefits from both the reduced distances in the Schiphol TMA and as a result of FIR shape). This conclusion is sensitive to the set of destination airports used in the analysis.

Simulations suggest that, when measured above land areas, the best trade-off between increased noise resulting from low-altitude vectoring (and associated higher density of crossing tracks contributing to increased noise footprint) and increased noise resulting from higher concentration of flight tracks on the tube for a longer period of time (and resulting increase in noise footprint) occurs at the scenario in which the flights were vectored after passing 5,000ft. 5,000ft is therefore considered a threshold at which the traffic is high enough to allow for the noise reduction benefits of the dispersed tracks to be materialised, and not high enough to cause too much increase in noise caused by the prolonged concentration of flight tracks in the tube.

Additionally, earlier vectoring spreads trajectories of essentially all aircraft types early on, however, later vectoring (at higher altitudes) primarily spreads the better performing aircraft (which can achieve the required altitude faster and typically also cause less noise) while the weaker aircraft take longer until they reach the vectoring altitude.

The results of this high-level population analysis are broadly aligned with the findings on the total size of the contour above areas of land. Leaving the tube at 5,000ft will lead to the smallest number of people living within associated noise contour. The noticeable difference in number of people associated with all three northerly runway configurations, for both 3,000ft and 4,000ft scenarios, comes from the fact that those departures take off towards the city of Amsterdam where the population density is higher.

IV.3.2 Full implementation (2035)

Comparison of selected 2035 contours against their respective 2025 counterparts showed limited increase in 2035 noise contours. The additional noise resulting from the small increase in traffic numbers envisaged between 2025 and 2035 seems to be partly mitigated by fleet replacement strategies. Using the same set of destination airports for both the 2025 and 2035 scenarios, the resulting increase in noise contours in 2035 is expected to be only marginal. It was therefore agreed that the analysis of 2035 noise impact does not need to be expanded beyond its existing scope.

V Climb and descent gradients

V.1 Climb gradient

V.1.1 Qualitative analysis

V.1.1.1 Description of the measure

Departure climb is one of the most important stages in the flight of the aircraft where the horizontal speed, vertical climb gradient, flight time, climbing mode and a set of flight performance parameters have important influence on the whole climb stage. Therefore, the research on the climbing stage of aircraft can clarify the mechanisms that influences how much noise is a departing aircraft going to make, depending on the climb gradient (and other parameters) chosen.

V.1.1.2 Key mechanisms and interdependencies

Aircraft climb gradient

The climb gradient that the aircraft is capable of achieving is typically influenced by several factors, including number of engines[12] , aircraft weight, wind direction and speed, ambient temperature and pressure, flap setting, power setting, aircraft type and aerodrome elevation (ICAO, Continuous Climb Operations (CCO) Manual; ICAO Document 9993). Therefore, there is no “universal” recommended climb gradient. Instead, the considered climb gradient on a departure tube should take into account all of the above and lead to a reasonable range of gradients able to accommodate the majority of traffic at the aerodrome in question.

An outbound flight, climbing to the cruise level, can influence its climb gradient in two ways. Firstly, if the aircraft needs to maintain the speed during the climb, the pilot has to reduce the rate of climb. Secondly, if the pilot wants to maintain the rate of climb, the aircraft has to reduce its indicated speed.

The indicated speed during climb ranges between 200kt and 250kt up to FL100, then the rate of climb is reduced in order to accelerate and reach a speed between 250kt and 320kt to finally increase again the rate of climb up to cruise level. As each aircraft has its own unique limitations due to the engine thrust performance, the climb performance differs depending on aircraft type. Very heavy aircraft climb at a rather low rate, especially at the beginning of their long-haul flights. Recent two-engine business jets are rather light and climb at a rate higher than previous generation of airliners. Finally, two-engine turboprop aircraft are less well-performing than jets but can also climb at a very high rate at rather low speed.

Due to regulatory requirements, twin-engine aircraft need to be more over-powered than four-engine aircraft in order to cope with a single engine failure on take-off, since they would have 50% of their power remaining compared to 75% for a four-engine aircraft. This means that with all engines functioning as normal, twin-engine aircraft can usually climb faster than four-engine aircraft.

From an ATCO perspective, if the controller asks for too high a rate of climb then he shall expect that the pilot will drastically reduce the speed in order to reach the cleared rate. On the other hand, if the controller asks for

[12] Two-engine aircraft climb faster than 3 or 4 engine aircraft when both engines are operating as they have greater excess thrust to cater for the engine out condition

a very high indicated speed, he shall expect that the pilot will drastically reduce the rate of climb in order to maintain the cleared speed. As the aircraft must not approach its stall speed, an operational margin is often added in order to protect the aircraft from stall in case of an unexpected change of the wind speed and/or direction.

From route planning perspective, designing tubes with steeper climb gradients will cause the aircraft to operate out of the airport with a faster climb but at lower horizontal speeds. In addition, because an aircraft is always able to reduce its climb gradient but is not always able to increase its rate of climb (due to aircraft performance, route design, conflicting traffic etc), the required minimum climb gradient has a significant influence on operations and provides an opportunity to decrease traffic complexity in the sector. If every flight operated on its own climb gradient, different aircraft would reach different altitudes at different points, requiring more attention from the radar controller. Finally, setting a minimum climb gradient enables more strategically separated routes to be developed, because route planers can work with an assumption that all (or the majority of) aircraft will operate at altitudes at or above the minimum required altitude at each point in the tube.

Trade-off between climb gradient and noise

A steeper climb concentrates noise impacts closer to the airport. Depending on whether a departure was carried out using NADP1 or NADP2 (or alternatively one of the two legacy ICAO departure procedures) the shape of the noise contour can vary. However, in each case the total noise energy remains broadly the same, with the areas benefitting from noise respite change depending on the departure procedure used. Comparison of NADP1 and NADP2 procedures is provided in the two figures below.

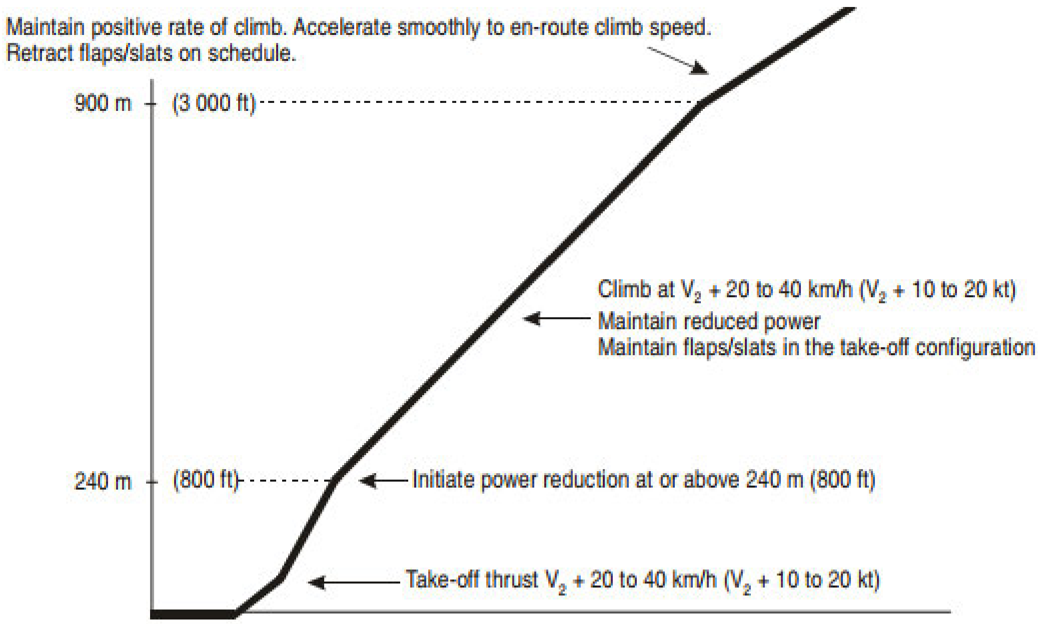

Figure 15: NADP1 procedure alleviating noise close to the aerodrome (ICAO Doc 8168)

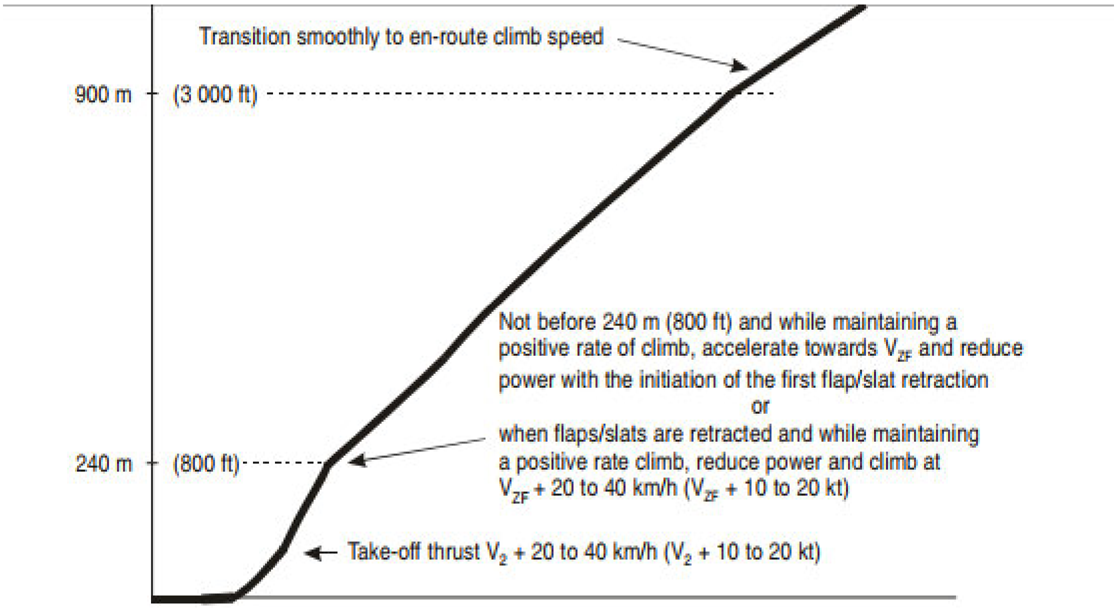

Figure 16: NADP2 procedure alleviating noise close to the aerodrome (ICAO Doc 8168)

On the other hand, if minimum and maximum altitude restrictions are defined on the departure tube then the concept of reducing the noise by increasing the climb gradient might not always work as expected, because some aircraft may need to operate with maximum possible thrust settings to reach even the lowest altitude restriction. Such an operation would be far from optimum climb settings and may lead to greater noise output (caused by maximum thrust of the engine). Similarly, those aircraft that could have climbed faster while still utilising their optimum climb settings would have to adhere to maximum altitude restrictions, which would keep them closer to the ground for a prolonged period. Again, this might have implications on the size of the noise contour.

These sources of uncertainty were investigated as part of the quantitative analysis, and the results are provided later in the document.

Trade-off between climb gradient and fuel burn

In the absence of other operational restrictions, the steepest possible climb gradient would provide the best benefits in terms of fuel economy. However, the cost of the departure also includes engine degradation and time between maintenance overhauls, so to prolong engine maintenance intervals and reduce engine overhaul costs airlines typically do not use full throttle take-offs and climbs. Additional parameters (such as the airline cost index) also influence the most economical climb profile used by the airline.

Handling of non-compliant aircraft types

Depending on how steep a climb gradient will be defined[13] for the use in the tube concept at EHAM, there may be some aircraft types that will not be able to meet the required gradient. The number of such flights is likely to vary depending on aircraft take-off weight, atmospheric conditions on the day of operations and airline operating procedures. If the pilot identifies a flight as being unable to meet the required climb gradient, his only option might be to reduce aircraft take-off weight by offloading some baggage or reducing the number of passengers. It is our view that such situations would not happen frequently, as the airline planning department would plan such an aircraft type to/from Amsterdam to ensure it is able to meet the required climb parameters

[13] The design should cater for most part of the time

with the expected payload in the expected weather conditions. For airlines based at Amsterdam, however, a series of discussions and additional analyses will be required to understand what share of their fleet might be capable of operating on selected climb gradients. Some airports, which require steeper climb gradients on some of their SIDs (mostly for obstacle clearance purposes) do offer alternative SIDs to pilots of less well-performing aircraft. Such alternative SIDs may be longer but better placed for the operation of aircraft with a lower maximum climb gradient. In any case, the failure to meet a required climb gradient under normal conditions would always be identified on the ground, enabling the situation to be addressed before the flight takes off.

A different case would be an "engine out" situation during and/or after the take-off. To ensure safe aircraft operations even during engine out situations, each aircraft is certified to meet the minimum engine out climb gradient of 2.4%, 2.7% and 3.0% for two, three and four engine aircraft respectively. In some situations, the maximum take of weight may need to be limited by the certification criteria to meet the minimum engine out climb gradient. Additionally, to ensure obstacle clearance while allowing for aircraft performance degradation and less-than-optimum pilot technique, the gross gradients are reduced by 0.8%, 0.9% and 1.0% respectively to calculate a net gradient. This net gradient is then published in the AFM performance data and used in actual operations. Engine out situations are relatively rare, however, and are rarely considered the primary factor when designing a new SID. Typically, a procedure for engine-out situations would be developed and published with climb gradients in the AIP.

V.1.2 Quantitative analysis

V.1.2.1 Approach and assumptions

Quantitative assessment of impacts of changing the climb gradient was carried out using a combination of fast time simulation model (to model various aircraft climb profiles) and environmental simulation software (to assess any changes in noise contours resulting from varying the climb gradient).

The key assumptions made (on top of those listed in general model description in Annex 4) for the scenarios used for the sensitivity testing of climb gradients are:

- Arrival operations were deactivated in both models (i.e. for testing the impact of changing climb gradients, only departure operations were simulated).
- 2025 FTS model is used as a baseline for all scenarios presented in this section.
- Three distinct groups of scenarios were conducted, each of which differed in a number of assumptions:
    - **First set of scenarios**: These assumed that aircraft will operate exactly *on the gradients based on current performance range of EHAM traffic* for each tube. Each tube is defined by bottom and upper vertical boundaries, i.e. by minimum and maximum altitude at individual waypoints of the tube. Additionally, there is a "nominal altitude" defined on each tube, based on assumed altitude achievable by 50% of assumed traffic. This was also modelled as part of the first set of scenarios. Aircraft with an abundance of power reduced their climb to operate exactly on any one of the three vertical trajectories described (bottom, upper or nominal). Aircraft with insufficient performance climbed using their maximum power to get as close to the prescribed vertical profile as possible.
    - **Second set of scenarios**: These assumed that aircraft will operate using one of the three tested climb gradients (10%, 13% and 15%) for the initial portion of climb (up to 10,000ft), before reducing their climb rate to reach the *nominal* altitude at the last point of the tube. Aircraft with an abundance of power reduced their climb to reach the "nominal altitude" at the end of the tube; Aircraft with insufficient performance climbed using their maximum power to get as close to the prescribed vertical profile as possible.
    - **Third set of scenarios**: These assumed that aircraft will operate using one of the three tested climb gradients (10%, 13% and 15%) for the initial portion of climb (up to 10,000ft), before reducing their climb rate to reach the *minimum* altitude at the last point of the tube. Unlike in the previous two sets of scenarios, in this set aircraft with an abundance of power commenced their climb immediately after take-off with an aircraft-specific optimum climb profile; Aircraft with insufficient performance still climbed using their maximum power to get as close to the prescribed vertical profile as possible.
- Depiction of the "low", "mid" and "high" ends of the tube is provided below.

Figure 17: "Low", "Mid" and "High" ends of the tube

- An overview of different assumptions used for different sets of scenarios described above is provided in the following table:

Assumptions	First set of scenarios	Second set of scenarios	Third set of scenarios
Initial climb profile up to 10,000ft	As per current performance range of EHAM traffic	10%, 13%, 15%	10%, 13%, 15%
Climb profile between 10,000ft and the last point of the tube	As per current performance range of EHAM traffic (Low, mid, and high)	Aiming for the "mid" end of the tube	Aiming for the "low" end of the tube
Handling of overpowered aircraft	Reduce climb to meet climb gradient defined by the tube design	Reduce climb to meet climb gradient defined by the tube design	Unrestricted climb
Handling of underpowered powered aircraft	Climb at maximum possible climb rate	Climb at maximum possible climb rate	Climb at maximum possible climb rate

Table 16: Climb gradient - differences in simulated scenarios

- No speed restrictions were applied to departing traffic.
- NADP2 departure procedure was used by departing traffic in all scenarios modelled.
- The simulation engine calculated appropriate climb profile for each flight; taking into account the initial climb gradient (up to 10,000ft), climb gradient between 10,000ft and the end of the tube, aircraft weight and other aircraft performance characteristics.
- Variations in aircraft weight were simulated by assigning all flights into three distinct categories (short haul, medium haul, long haul) based on the great circle distance to destination. There three haul categories then defined take-off weight (and associated flight performance) assumed in the simulation.
- In cases where aircraft performance did not allow the minimum altitude restriction to be reached by using the chosen climb gradient, the flight was marked as non-compliant. A count of all non-compliant departures was then expressed as % of all departures, to understand what proportion of traffic might have difficulty operating with the gradient tested.
- The aircraft performance data used in these calculations contained "normal" and "maximum" values. The simulation engine could use any of these values as long as the resulting vertical profile met the altitude restrictions on the tubes. In other words, some aircraft were simulated with climb speeds outside of their nominal values but still within the safe limits of the flight envelope.
- The impact of weather was disregarded (i.e. no weather was simulated during descent operations).
- Departures were following the tube to its last point (i.e. no vectoring of departures).

V.1.2.2 Results from the first set of scenarios

The aim of the first set of scenarios was to set the boundaries as to how far could noise contours would span if the aircraft operated along the bottom and top edges of the departure tube. Additionally, a profile representative of 50% of departing traffic was also modelled to check how this contour fits within the two extreme cases (low edge of the tube, high edge of the tube). Aircraft with an abundance of power reduced their climb to operate exactly on one of the three vertical trajectories described above. Aircraft with insufficient performance climbed using their maximum power to get as close to the prescribed vertical profile as possible. The top and bottom boundaries of the tubes, together with the nominal vertical profile are visualised in the figure below. These are the profiles modelled in the first set of scenarios.

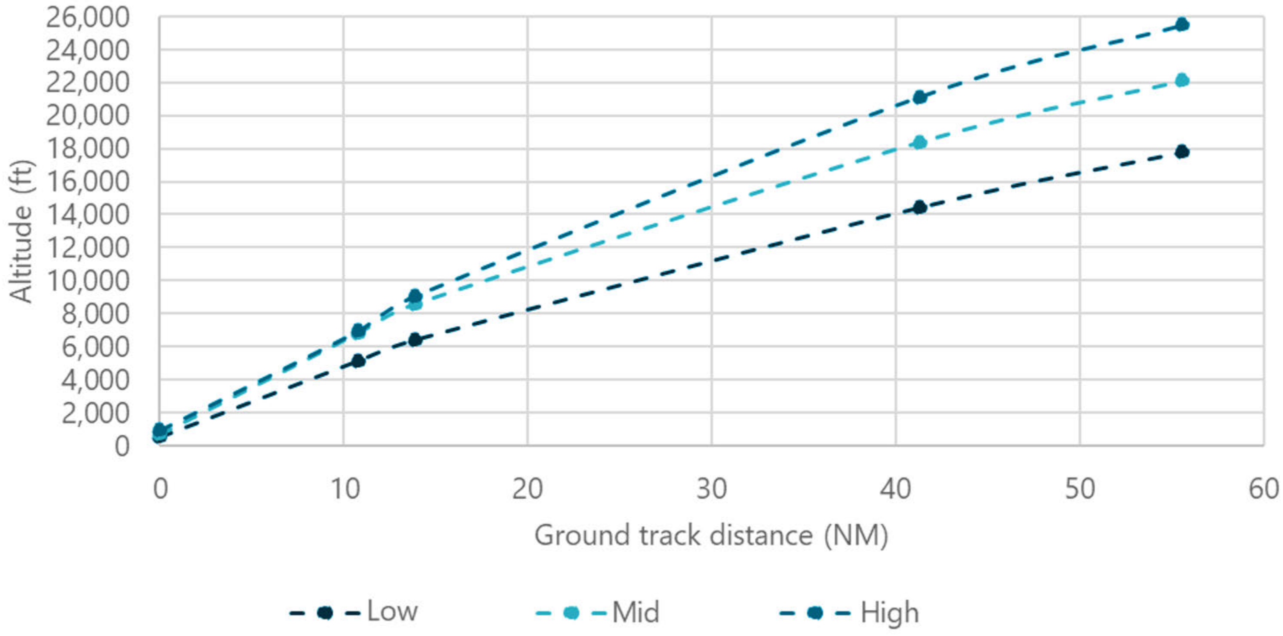

Figure 18: Gradients for the first set of scenarios

Analysis of the resulting noise contours suggests that operating along the bottom edge of the tube is likely to lead to the smallest noise contour. This perhaps counter-intuitive result can be explained by the fact that even the "low" gradient is still reasonably steep, and less thrust is required for an aircraft to adhere to such a gradient. In addition, aircraft which could have climbed faster were kept exactly on the defined vertical profile with reduced thrust (although not necessarily with greater fuel-efficiency, because climbing along the "low" gradient takes more time, during which the aircraft burns more fuel).

Conversely, when aircraft were simulated using the top edge of the departure tube, the size of noise contour increased substantially, mainly because more aircraft were operating using their maximum climb settings to achieve the steep climb gradient. This led to greater thrust, producing more noise, thus enlarging the contour. In terms of fuel efficiency, this profile is closer to what aircraft manufacturers declare to be the most fuel-efficient climb-out procedure.

Contour area (in km2)			First set of scenarios		
Configuration	Direction	Contour	Bottom edge of the tube	Nominal profile	Upper edge of the tube
2D	Northerly	48dB	400	410	500
2D	Northerly	45dB	830	870	1,180
2D	Northerly	43dB	1,760	2,010	2,820
2D	Southerly	48dB	400	400	510
2D	Southerly	45dB	900	940	1,260
2D	Southerly	43dB	1,600	1,730	2,590

Table 17: Contour areas from the first set of scenarios

As part of this analysis minimum gradients were also investigated. The worst performing aircraft turned out to be the 777-200 with a "long-haul" payload, which achieved only 4.9% initial climb performance. When tested with a much smaller payload (designated as "short haul") however, the climb performance of the 777-200 started to reach average climb performance in the traffic sample. All the other aircraft types managed to operate within the vertical bounds of the tube, as indicated in the figure below. In this example, ARNEM 18L departures were requested to climb with a minimum climb gradient of 10% until reaching 10,000ft.

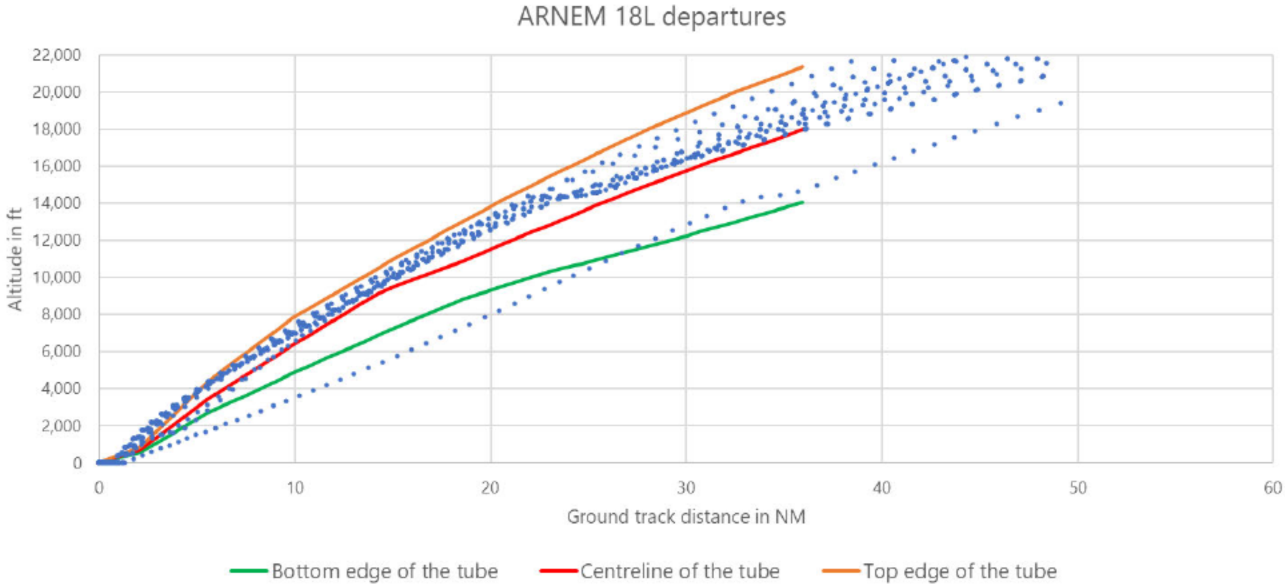

Figure 19: Example of departure profiles meeting the vertical dimensions of the tube

V.1.2.3 Results from the second set of scenarios

The results of the previous analysis (the first set of scenarios) indicted that the majority of aircraft are capable of operating on the lowest of the three tested gradients, as derived from current performance range of EHAM traffic, between ground and 10,000ft. A second, more challenging set of scenarios was therefore derived based on the assumption that by increasing the climb gradient in the early stages of flight it should be possible to concentrate the noise closer to the airport and reduce the size of overall noise contour. For this reason, the flights were asked to climb using 10%, 13% and 15% gradients to 10,000ft and then aim for the "mid altitude" at the last point of the tube. As before, aircraft with an abundance of power reduced their climb to operate exactly on one of the three vertical trajectories described above. Aircraft with insufficient performance climbed using their maximum power to get as close to the prescribed vertical profile as possible.

An example of the vertical profiles modelled, together with their comparison against the tubes based on current performance range of EHAM traffic can be found in the image below. As before, the profiles vary slightly on a tube-by-tube basis, due to the need to account for crossing arrival traffic and/or other local specifics.

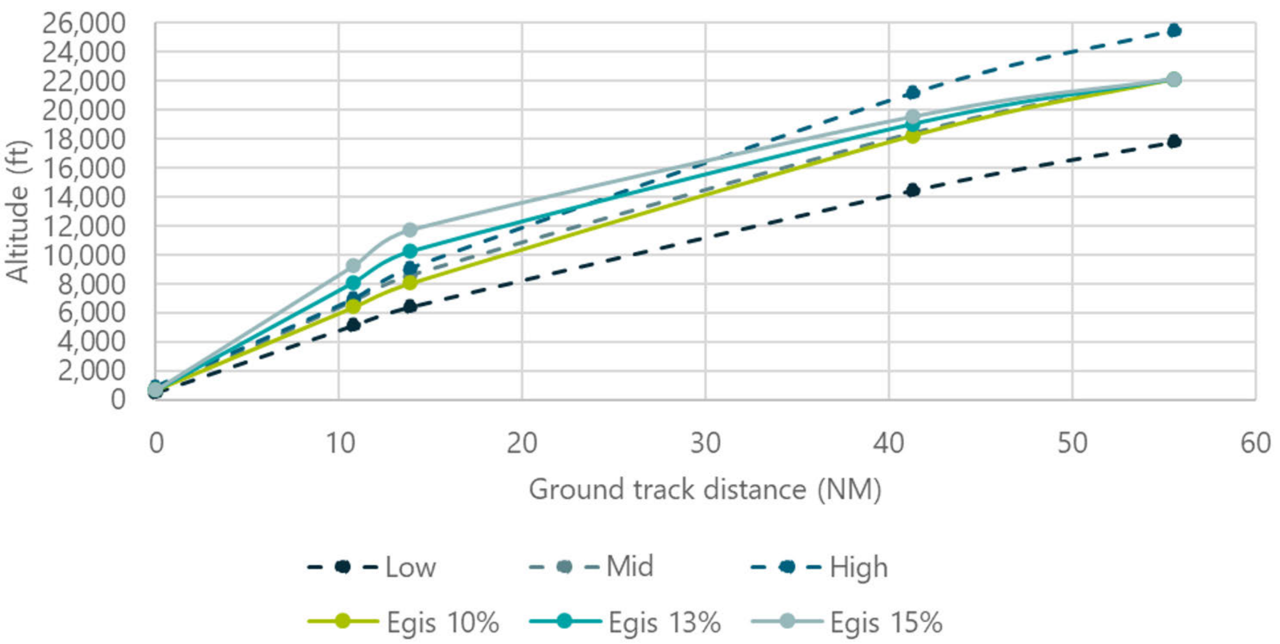

Figure 20: Gradients for the second set of scenarios

A comparison of the resulting noise contours against those from the previous set of scenarios (the first set of scenarios, as described in the previous section) confirms the expectation that increasing the initial climb gradient reduces the size of the noise contour. If we assume that 50% of the traffic can be expected to operate the "mid" profile, then this could serve as a suitable baseline profile for the benchmarking of contour areas.

An analysis of the resulting noise contours against each other confirms the expectation that increasing the climb gradient will concentrate the noise closer to the airfield. The loudest, 48dB contour in particular seems to benefit substantially from increased gradients (up to 10,000ft) in the vicinity of the airport. This brings aircraft to the required altitude faster, making them perceived as less noisy by an observer further away from the airport.

Climbing initially using a 10% gradient leads to the smallest 48dB contour but also the largest 43dB contour. Climbing using the second gradient tested (15%) leads to larger 48dB contour (comparable with that of nominal profile scenario) but the 43dB contour seems to be the smallest out of all contours tested. Finally, climbing using the steepest, 15% gradient leads to the largest 48 dB contour.

Contour area (in km2)			Comparison			
Configuration	Direction	Contour	Nominal profile	Initially 10%, then aiming "mid" end of the tube	Initially 13%, then aiming "mid" end of the tube	Initially 15%, then aiming "mid" end of the tube
2D	Northerly	48dB	410	330	400	490
2D	Northerly	45dB	870	640	660	790
2D	Northerly	43dB	2,010	1,260	1,060	1,150
2D	Southerly	48dB	400	350	390	420
2D	Southerly	45dB	940	710	670	700
2D	Southerly	43dB	1,730	1,370	1,270	1,220

Table 18: Contour areas from the first set of scenarios

V.1.2.4 Results from the third set of scenarios

The results of the previous analysis (second set of scenarios) indicated that an unexpectedly high number of flights were unable to meet selected combinations of initial and subsequent climb gradients, the final set of scenarios was based on modified assumptions where all aircraft were aiming at the "low" end of the tube after passing 10,000ft, in order to maximise the number of compliant aircraft.

Additionally, in the third set of scenarios aircraft were allowed to climb faster if their performance exceeded the minimum climb gradient. This was based on assumption that airlines, if allowed, would prefer to operate the most fuel-efficient departure procedure. According to several sources reviewed[14], the full-thrust climb profile offers the most fuel economy for unrestricted climb. However, the cost of the departure also includes engine degradation and time between overhauls, so the airlines typically apply take-off de-rates and climb de-rates to prolong engine maintenance intervals and reduce engine overhaul costs.

In the simulation model, two values for aircraft climb performance exist. The Normal performance, which was, for the purpose of our analysis, assumed to correspond to airline preferred climb rate (combining fuel and engine cost). Additionally, there is the Maximum performance value, which we let the simulation use in situations where the aircraft was unable to meet the required climb profile using the Normal settings. Of the three sets of scenarios simulated for departure climb gradient, this third set can be considered closest to operational practice.

The profiles tested in this set of simulations are provided in the figure below and marked as Egis 10%, 13% and 15%. Note the aircraft aimed for the lowest point of the departure tube after the initial climb phase was over.

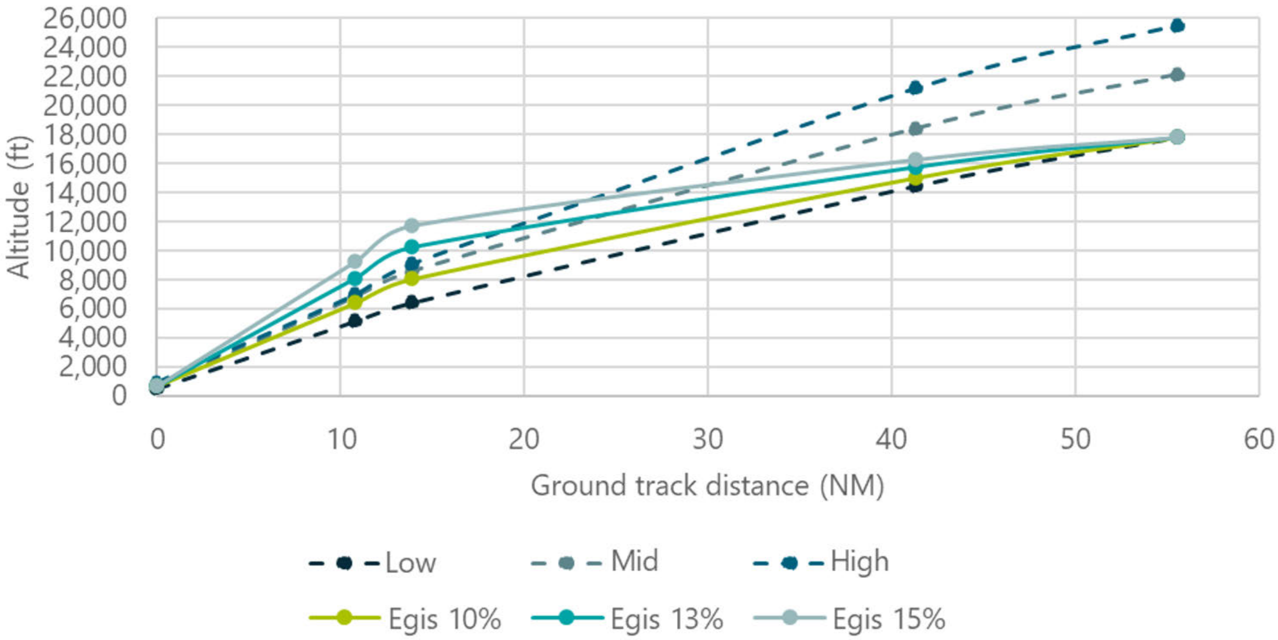

Figure 21: Gradients for the third set of scenarios

The contour area measured in this set of scenarios increased for all contours measured (compared to the first and second set of scenarios). This increase is driven by two factors. Firstly, by allowing aircraft to operate on an unrestricted climb profile, the aircraft that previously operated exactly on the required vertical profile now climb with steeper gradient (the maximum achievable "nominal" gradient), thus requiring more thrust and producing

[14] For example, a statement from Boeing:
https://www.boeing.com/commercial/aeromagazine/articles/qtr_4_08/article_05_3.html

more noise. Secondly, the decision for the aircraft to aim for the "low" end of the departure tube after passing 10,000ft causes some aircraft to operate closer to the ground then they would if they aimed for the "mid" or "high" end of the tube. However, increasing the target altitude at the end of the tube would lead to an additional increase in flights unable to operate on the modified climb profile and would increase the share of flights having to operate using maximum (not optimum) climb thrust, which would also contribute to contour expansion.

It is not necessarily the initial climb performance that has more influence on noise contours, but rather the performance in later climb stages. In other words, most aircraft in the tested sample can climb reasonably steeply immediately after departure, but the higher they get the weaker climb performance they have, which requires more thrust to be used. Where aircraft did fail to achieve the required gradient, this was more often in the later stages of the departure rather than shortly after take-off.

Contour area (in km2)			**Third set of scenarios**		
Configuration	**Direction**	**Contour**	**Initially 10%, then aiming "low" end of the tube**	**Initially 13%, then aiming "low" end of the tube**	**Initially 15%, then aiming "low" end of the tube**
2D	Northerly	48dB	390	470	500
2D	Northerly	45dB	830	890	890
2D	Northerly	43dB	1,780	1,770	1,820
2D	Southerly	48dB	390	440	470
2D	Southerly	45dB	900	820	860
2D	Southerly	43dB	1,600	1,400	1,400

Table 19: Contour areas from the third set of scenarios

Finally, any flight unable to meet the required minimum altitude restriction on a tube was logged and a simple statistic was produced to show the relationship between increase in the climb gradient and % of departures in the traffic sample unable to operate along such gradient. The results, presented in the figure below, are averages for both northerly and southerly operations combined, weighted by the number of flights. The curve starts at a 4.9% climb gradient (identified as the maximum climb gradient achievable by a 777-200, as the worst performing aircraft in the sample). Less than 1% of departures were unable to meet the 10% initial climb gradient, as represented by the 777-200 in the sample. As the gradient increases other, predominantly older wide-body aircraft start failing to achieve it. If the initial gradient was set up to 15% then more than 10% of the departures would struggle to operate on it. An overview of typical departure climb profiles by aircraft type is provided in Annex 8.

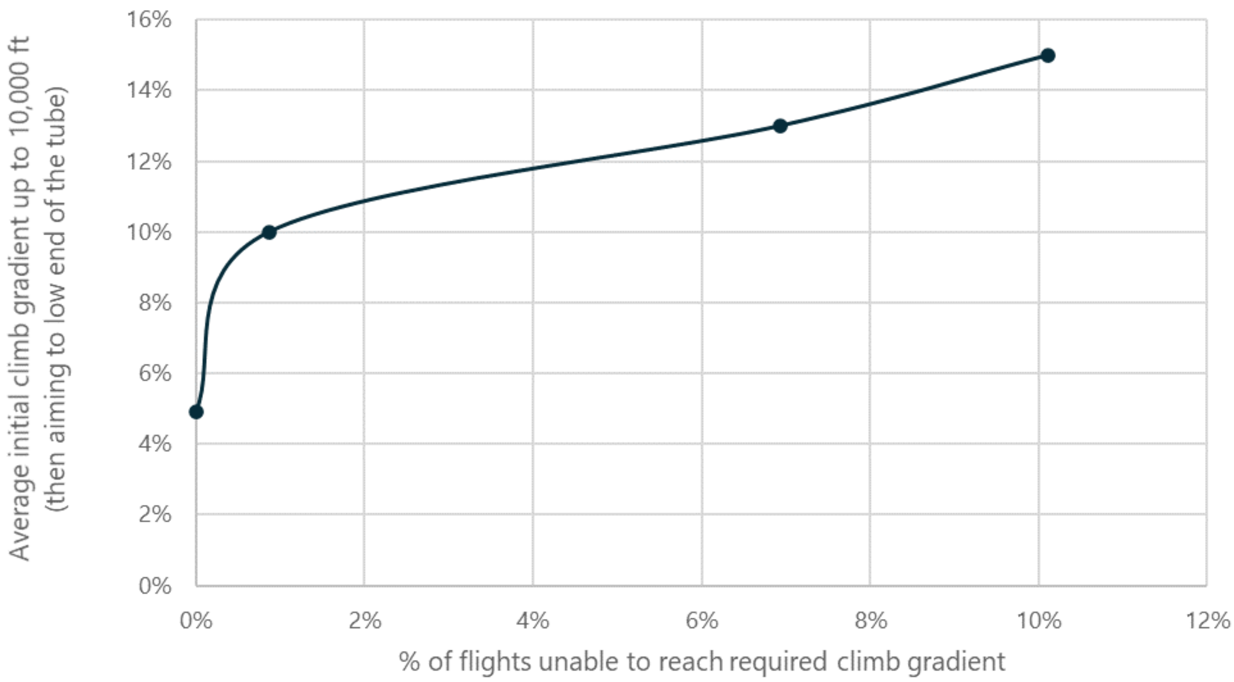

Figure 22: Relationship between increase in climb gradient and share of aircraft not capable to fly it

It is worth highlighting that all the simulations carried out for the climb gradient measure (regardless of scenario) were carried out using the default BADA performance model, which does not contain some of the most recent aircraft types, and even the types that are included do not contain all performance variants of the given type. It is therefore reasonable to expect that by 2025 (and certainly by 2035) the fleet performance will improve, with older generations of aircraft with poor performance being replaced by more efficient types, and therefore the share of aircraft unable to operate on the selected climb gradient is likely to reduce over time.

V.1.2.5 Additional findings

Differences in noise contours

While running the climb gradient scenarios, we overlaid some of the contours over those previously produced during the analysis of the tracking of tubes measures to cross-check whether, in selected comparable scenarios, the contours were identical. In some cases we noted a difference in contour shape and size. An investigation into the causes of this revealed that some of the contours for the climb gradient measure are likely to have been underestimated because to allow unrestricted climb the arriving traffic was not simulated. This resulted in some contours having shorter lobes in some of the climb gradient scenarios, compared to the corresponding tracking of tubes scenarios for which both arriving and departing traffic was simulated.

In a few occasions, the outbound traffic needs to follow a tube that leads below an inbound tube such that fewer unrestricted climbs can occur, because the departure traffic on these tubes would have to fly below the arrival tube before being allowed an unrestricted climb. This elongation of the departure level segment manifests as a longer (larger) lobe of the respective noise contour.

For example, during northerly operations, a BERGI departure from 36L, heading north-west, leads below an arrival tube for ARTIP arrivals to 06. This requires BERGI departures to operate longer in lower altitudes, causing more noise and fuel burn.

In a southerly mode, an analogous situation might occur when ARNEM departures from 18L need to fly below ZUDOS arrivals to 18C. However, the small number[15] of ARNEM departures in the tested traffic sample did not cause too many interactions with arrivals – although this could change if the traffic on ARNEM departures were to increase.

[15] 16% of all departures operated from runway 18L to ARNEM

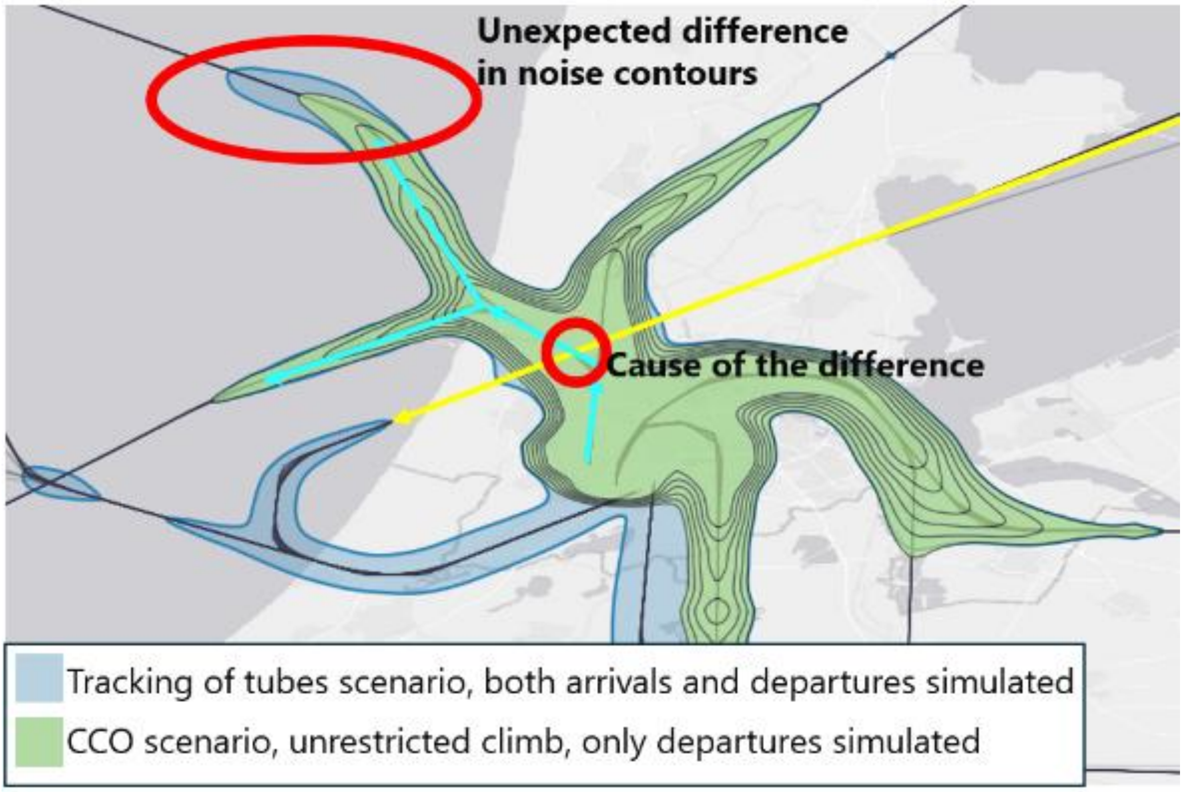

Figure 23: Unexpected difference in noise contours

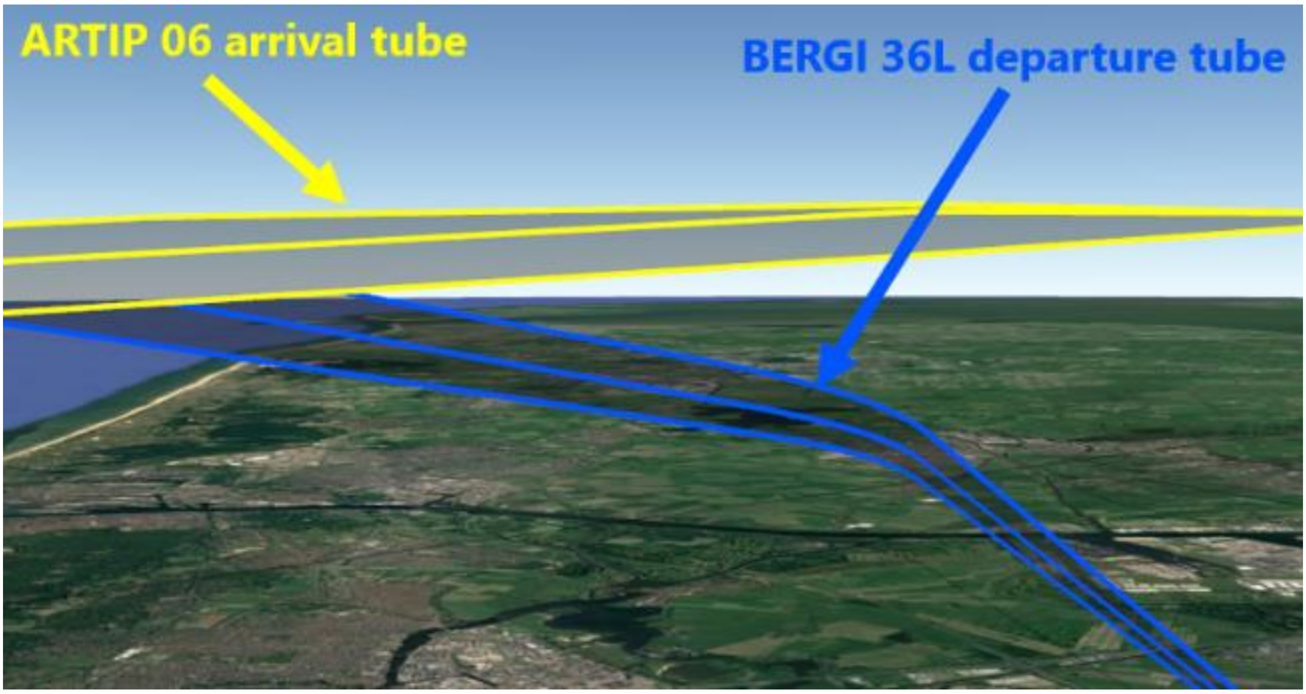

Figure 24: Cause of unexpected difference in noise contours

Sensitivity of noise contours to take-off thrust

As part of the quantitative assessment we were asked a question on sensitivity of noise contours to reduction in take-off thrust. To answer the question, we took a single trajectory of a departure flight and compared the noise contour produced with full take-off and climb thrust against a noise contour produced with 10% reduction in both take-off thrust and climb thrust.

For the purpose of this example, we have selected one departure of Boeing 737-800 taking off from runway 36L and following SUBRO departure route. The same flight was simulated with both full and reduced thrust. Both runs followed the same trajectory and altitude profile - 13% gradient up to 10,000ft followed by climb to reach the "low" end point of the tube.

As this scenario contained only a single movement, it was necessary to utilise a noise metrics from the family of "single event noise metrics" to understand the potential noise contours. As DARP currently does not recognise single event noise metrics we decided to use L_{Amax} metric (also referred to as Maximum Sound Level). L_{Amax} is the highest sound level measured during a single noise event (such as an aircraft fly by), in which the sound level changes value as time goes on. This means, the L_{Amax} metric is fundamentally different to L_{den} metric used in the rest of this report and the two are not directly comparable.

The results in the table below show clear reduction in contour area associated with reduced thrust departure. Visual comparison of resulting contours is provided on the next page.

	Contour areas (sq km)		
	43dB L_{Amax}	45dB L_{Amax}	48dB L_{Amax}
Full take-off and climb thrust	1,973	1,669	1,266
10% reduction in T/O and climb thrust	1,697	1,423	1,033
Difference	**-14%**	**-15%**	**-18%**

Table 20: Reduction in contour size as a result of reduced thrust

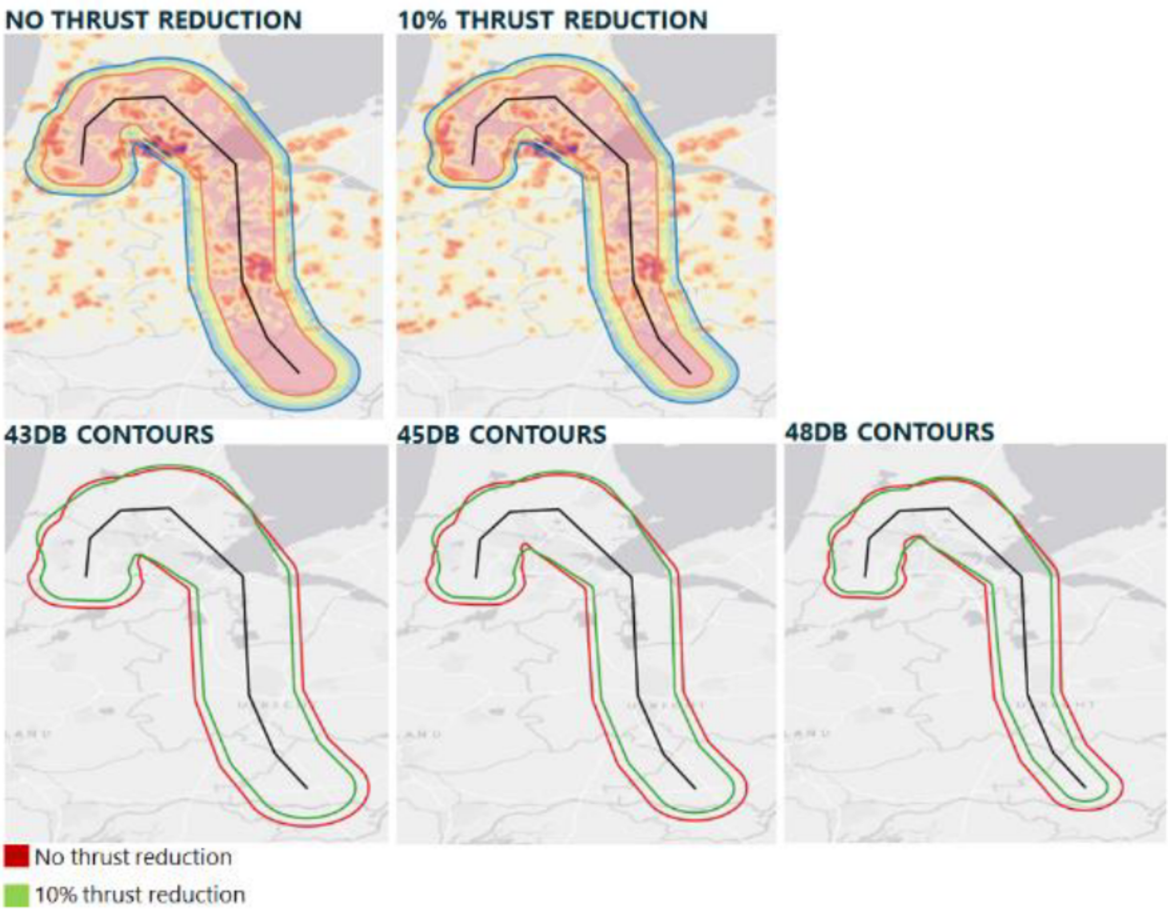

Table 21:Reduction in contour size resulting from reduced thrust

V.1.3 Summary of key findings for climb gradient

Based on the simulation results[16], an initial climb gradient of 13% should be achievable by more than 50% of the traffic.

It is not only the initial climb performance that has influence on noise contours, but also the performance in later climb stages. In other words, most aircraft in the tested sample can climb reasonably steeply immediately after departure, but the higher they get the weaker climb performance they have, which requires more thrust to be used. Where aircraft did fail to achieve the required gradient, this was more often in the later stages of the departure rather than shortly after take-off.

After passing FL 100 the aircraft should reduce its climb gradient. Operating alongside the currently considered upper edge of the tube is likely to lead to increased noise footprint compared to other options, such as following the bottom edge of the tube.

Based on the above, the most feasible climb profile (achievable by more than 50% of traffic and with the greatest potential for noise reduction) would consist of an initial climb gradient of 13% up to FL100, followed by a gradient that would enable traffic to reach the Low or Mid altitude constraint at the end of the tube.

The actual aircraft performance in 2025 or beyond is expected to be better than the performance of aircraft in these simulations. The actual size of the noise contours and the real % of non-compliant aircraft is therefore likely to be smaller than indicated in this research. These results are based on no-wind scenarios and the assumption that airlines will train their pilots in how to operate steeper departures efficiently.

Some departure tubes are restricted by inbound tubes crossing above them. Such crossing tubes limit the unrestricted climbs of outbound traffic and increase the area of the noise contours by keeping these departures closer to the ground for a longer period of time.

[16] The BADA performance tables implemented in AirTOp simulation model are not necessarily reflective of all possible combinations of performance parameters. In reality, different take-off weight, engine model, engine performance and thrust settings, departure procedures or other factors may apply.

V.2 Descent gradient

V.2.1 Qualitative analysis

V.2.1.1 Description of the measure

In the past, aircraft conducted approaches by alternating level segments with descent segments. This procedure had an adverse impact on both fuel consumption and noise, so a continuous descent approach procedure has been developed in which the aircraft approaches airport on a continuously descending trajectory. Today, a 3-degree descent gradient is usually considered optimum for a CDO profile although the ideal angle may differ depending on the fleet mix operating at the given airport, as well as the design of arrival routes and local topography.

The purpose of this section is to analyse the potential impacts of introducing CDOs at Amsterdam airport with 2.0, 2.5 and 3.0 degree descent gradients respectively.

V.2.1.2 Key mechanisms and interdependencies

Of all the factors that influence the selection of a suitable descent gradient (aircraft performance, lateral dimensions of the tubes (length, turns) and obstacle limitation surfaces), aircraft performance is by far the most limiting factor. Although the benefits of CDO in terms of fuel saved and noise reduction are indisputable, there is a cost to be paid in terms of the reduced options for speed control to maintain safe and efficient separations, especially with higher descent gradients. This is less of an issue during the beginning of the descent, where the aircraft is still high enough in en-route airspace and the need to apply speed restrictions tend to be smaller in both frequency and magnitude but it becomes a more restricting factor as the aircraft approaches the Schiphol TMA, at which point several other factors come into play.

Due to different aircraft weights and handling characteristics, top of descent is not identical for all aircraft types. In our research we have observed variations of +/- 20NM in location of the top of descent, depending on aircraft type. This was measured on FL280, and it can be assumed that at higher FLs the variation would have been even greater than 20NM. This variation needs to be reflected in planning of the overall descent procedure, as the descent can start as far as 100NM from the airport - quite often in the neighbouring FIR.

Different aircraft types also have different minimum and maximum operating speeds at different altitudes. Larger aircraft might need to fly with flaps and slats extended to adhere to a requirement to keep low speed because of smaller (slower) leading aircraft. At the same time, that leading aircraft might be flying closer to its maximum permittable speed for the given flight envelope.

Different aircraft have different aerodynamic characteristics, with modern types optimised for the least drag, enabling benefits in the departure phase of flight. During descent however, these aircraft typically struggle to descend and decelerate at the same time. If such an operating mode is even possible, the rate of deceleration is typically small and does not provide an ATCO with enough opportunities to control the arriving sequence of traffic using speed control alone. To compensate for the aerodynamic cleanliness of modern airframes, some airports use intermediate level segments to allow the aircraft to decelerate before continuing its descent. However, the strategy for handling flights unable to maintain both the required descent ratio and speed restrictions vary from airport to airport. While some airports allow the aircraft to operate on the lateral trajectory as planned, adhering to the maximum possible descent gradient the aircraft is able to maintain while also meeting speed restrictions, other airports simply vector the non-compliant traffic out of the main flow[17].

Steeper descent gradients have the potential for reducing the noise contour in the vicinity of the airport. For an observer standing at a fixed location, the noise from aircraft approaching at greater descent angle would be lower than noise from aircraft approaching at lower descent gradient because at any given distance from the airport the former would be higher than the latter. Additionally, the steeper the descent gradient the less engine thrust will be required, which also reduces the fuel burned during descent. The ideal descent gradient should allow aircraft to descend with a thrust at (or very near to) idle. Due to the wide range of aircraft performance characteristics, however, no single ideal descent gradient can be defined. Whatever gradient will eventually be adopted for implementation at Amsterdam will need to balance aircraft performance characteristics with route design requirements, ATCO operating practices and the projected noise footprint.

The analysis in the following section aims to explore and further clarify some of the interdependencies identified above.

[17] In the UK, a new Low Noise Arrivals Metric (LNAM) is supposed to address the issue of continuous descent carried out by low-drag modern aircraft type. More detail on LNAM is provided in Annex 1.

V.2.2 Quantitative analysis

V.2.2.1 Approach and assumptions

A quantitative assessment of the impacts of changing the descent gradient was carried out using a combination of fast time simulation model (for assessment of the share of flights that were unable to meet the descent gradient or speed restrictions) and environmental simulation software (to assess changes in noise contours resulting from varying descent gradient).

The key assumptions made for the scenarios used for sensitivity testing of descent gradients, in addition to those listed in the general model description in Annex 4, are:

- Departure operations were deactivated in both models, i.e. for testing impact of changing descent gradient, only arrival operations were simulated.
- The 2.0-, 2.5- and 3.0-degree descent gradients were tested as they had the greatest promise of being suitable for a majority of aircraft types. Gradients between 3.0 and 4.49 degrees are considered for steeper approach (see section VIII.2.3 Slightly steeper glide path in the Annex 2) and gradients above 4.5 degrees require aircraft and crew certification/training.
- The three gradients tested in this analysis were used to re-calculate altitude restrictions on individual points of the tube.
- Two options were tested:
  - Proper continuous descent, and
  - Descent with level segments at 10,000ft (starting at Schiphol TMA entry fix). After the level segment the flight continued its descent using the chosen gradient (i.e. with steeper gradient the level segment was longer; with shallower gradient the level segment was shorter).
- Jet aircraft started their descent from FL280, turboprops from FL230.
- Speed restriction on Schiphol TMA entry fix was set to no more than 300kts. Originally the model was developed with speed restriction of 250 kts on entry into the TMA. During model testing process it was discovered that a small number of flights were entering the TMA at speeds marginally greater than 250kts (ie. 252kts, 254 kts etc.). To ensure these flights are not counted towards the total number of flights unable to follow the tested descent gradient (as the difference against target restriction of 250kts was marginal), the speed restriction on the entry into the TMA was increased to 300kts.
- Speed restriction at the first point of the tube beyond Schiphol TMA entry fix was set to 250kts.
- The simulation engine calculated appropriate top of descent for each flight; taking into account the initial FL, aircraft weight and other aircraft performance characteristics. A descent profile was calculated to ensure the flight manages to comply with the speed/altitude restrictions along the arrival tube.
- In cases, where aircraft performance did not allow adherence to one or multiple speed/altitude restrictions, an aircraft descent vertical profile was established as close to the requested tube vertical profile as possible, given aircraft limitations. The flight was marked as non-compliant, and the reason for non-compliance was recorded (issues related to adherence to speed restrictions on individual segments of the tube(s) and issues related to descent gradient were both logged and analysed).
- The aircraft performance data used contain “normal” and “maximum” values. The simulation engine could use any of these values as long as the resulting vertical profile met the altitude/speed restrictions on the tubes. In other words, some aircraft were simulated with speeds and/or descent rates that were above their normal speeds / descent rates but still within the safe limits of the flight envelope.

- Impact of weather was disregarded (i.e. no weather was simulated during descent operations).
- Arrivals were served to the Schiphol TMA with perfect accuracy of delivery.

V.2.2.2 Results of sensitivity testing for descent gradient scenarios

As expected in the qualitative analysis, the noise contours of arrival operations shrink with increasing descent gradient. This was the case for all the scenarios modelled and the results are presented in the table below. The quieter the contour is, the greatest rate of reduction in contour size can be expected by increasing the gradient. For example, in case of 48 dB contour, the changes between 2.0- and 2.5-degree gradients is between 7% and 15%. However, with the quietest 43db contour, the contour area can shrink by up to 30%.

Configuration	Direction	Contour	Descent gradient				
			2.0°	2.5°	3.0°	2.0° with LS at 10,000ft	3.0° with LS at 10,000ft
2A	Northerly	48dB	131	127	122	132	122
2A	Northerly	45dB	226	203	191	226	191
2A	Northerly	43dB	332	295	266	331	266
2A	Southerly	48dB	201	184	174	200	174
2A	Southerly	45dB	306	286	267	304	268
2A	Southerly	43dB	442	383	351	424	351
1A	Northerly	48dB	109	101	97		
1A	Northerly	45dB	215	166	149		
1A	Northerly	43dB	302	257	216		
1A	Southerly	48dB	149	132	123		
1A	Southerly	45dB	256	232	211		
1A	Southerly	43dB	367	316	290		

Table 22: Contour area (in km^2) for tested descent gradients, including options with level segments

Interestingly, there seems to be practically no impact on noise arising from the existence of 10,000ft level segments after Schiphol TMA entry fix. These are high enough not to cause any disturbance from arrival flights as the arrival noise starts to be audible (i.e. manifests itself on the noise contours) when the aircraft is at an altitude of less than 7,000ft. These 10,000ft level segments are still useful for representing the deceleration of aircraft descending on 3.0-degree gradient.

The only case for which the size of the noise contour with the level segment differs notably from the noise contour without the level segment is for southerly operations with 2.0-degree gradient (e.g. SUGOL arrivals to 18R), as illustrated in Figure 25. In this case however, the difference in contour size is a function of both ground track distance and the 2.0-degree gradient which brings aircraft lower than with the existing concept (9,200 ft at SUGOL with 2.0 gradient vs 10,000ft at Schiphol TMA entry fix with the currently proposed tubes concept). As this happens only above the sea. however, it is considered irrelevant for noise impact.

A full set of detailed results from this section are provided in Annex 8.

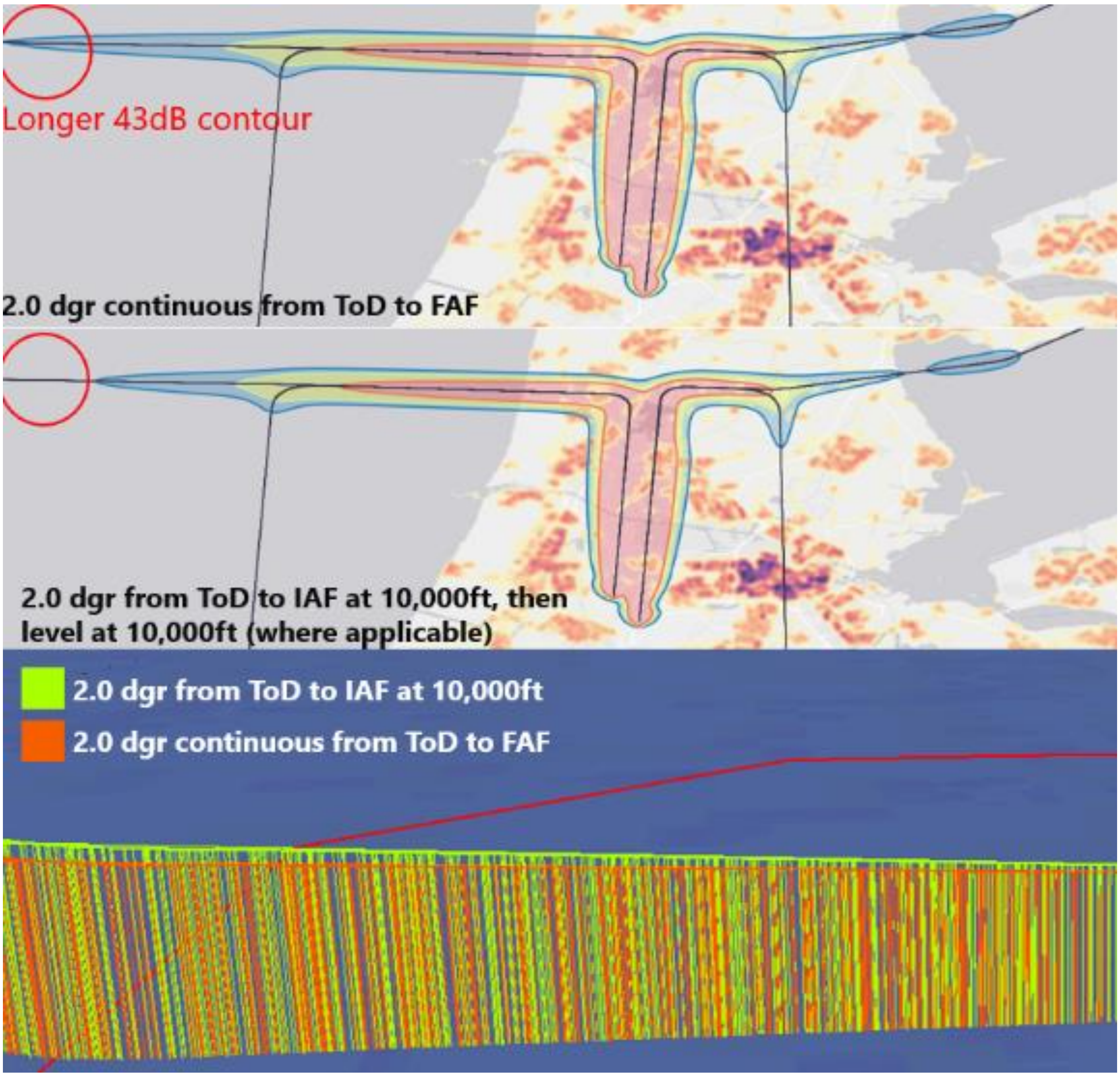

Figure 25: Selected difference in CDO contours explained

V.2.2.3 Aircraft unable to operate on the selected descent gradient

Our quantitative assessment also investigated also the proportion of aircraft unable to operate on selected gradients and the reasons for them not being able to meet the altitude restrictions imposed by various gradients on the tube waypoints.

Using the default aircraft performance model in the simulation tool (based on BADA performance calculations) we measured the number of issues related to speed restrictions on individual segments of the tube(s) and the number of descent gradient issues as a percentage of total number of arrivals in the traffic sample. Different runway configurations/orientations were modelled using different traffic samples but the general conclusions from all of these simulation runs are consistent across all runway configurations.

The 2-degree gradient can be adhered to by all aircraft in the simulation. The 2.5-degree gradient starts to cause a small number of descent rate issues, while all the aircraft can adhere to speed restrictions on various waypoints. At 3.0-degree gradient, no more than 4% of simulated aircraft had difficulty adhering to either speed restrictions or descent rate, with the aircraft types most affected being newer smaller jets, mostly A318/319 and newer versions of B737.

Issues related to meeting the speed restrictions issues[18] disappeared in the scenario with a 3-degree descent gradient and 10,000ft level segments, suggesting that the length of those segments allowed the aircraft to decelerate to meet the speed restriction on the following waypoint(s). A summary of quantitative results for number of speed control issues and descent gradients is provided in the Table 23.

Configuration	Direction	Metric	2.0°	2.5°	3.0°	2.0° with LS at 10,000ft	3.0° with LS at 10,000ft
2A	Northerly	Speed control issues (% of arrivals)	0.0%	0.0%	3.9%	0.0%	0.0%
		Descent rate issues (% of arrivals)	0.0%	0.6%	3.9%	0.0%	3.9%
2A	Southerly	Speed control issues (% of arrivals)	0.0%	0.0%	1.2%	0.0%	0.0%
		Descent rate issues (% of arrivals)	0.0%	0.0%	1.9%	0.0%	1.9%
1A	Northerly	Speed control issues (% of arrivals)	0.0%	0.0%	1.7%		
		Descent rate issues (% of arrivals)	0.0%	0.6%	3.3%		
1A	Southerly	Speed control issues (% of arrivals)	0.0%	0.0%	1.2%		
		Descent rate issues (% of arrivals)	0.0%	2.5%	3.1%		

Table 23: % of arrivals with speed control or descent rate issues on individual segments of the tube(s) - for selected descent gradients

[18] This relates to speed restrictions on individual points of the tube. This does not relate to speed control measures applied by ATCO to ensure proper separation.

V.2.3 Summary of key findings for descent gradient

The 2-degree gradient can be adhered to by all aircraft in the simulation. The 2.5-degree gradient starts to cause a small number of descent rate issues, while all the aircraft can adhere to speed restrictions on various waypoints. At 3.0-degree gradient, no more than 4% of simulated aircraft had difficulty adhering to either speed restrictions or descent rate, with the aircraft types most affected being newer smaller jets, mostly A318/319 and newer versions of B737.

The noise contours of arrival operations shrink with increasing descent gradient. The quieter the contour, the greater the rate of reduction in contour size that can be expected by increasing the descent gradient.

There seems to be practically no impact on noise arising from the existence of 10,000ft level segments after Schiphol TMA entry fix. These are high enough not to cause any disturbance from arrival flights as the arrival noise starts to be audible (i.e. manifests itself on the noise contours) when the aircraft is at an altitude of less than 7,000ft. These 10,000ft level segments are still useful for representing the deceleration of aircraft descending on 3.0-degree gradient.

The issue related to adhering to speed restrictions on individual tube segments disappeared in the scenario with a 3-degree descent gradient and 10,000ft level segments, suggesting that the length of those segments allowed the aircraft to decelerate to meet the speed restriction on the following waypoint(s).

VI Horizontal and vertical route spacing

VI.1 Horizontal spacing

VI.1.1 Qualitative analysis

This section looks into the potential for reducing horizontal spacing between the tubes in the terminal area, beyond the minima identified in ICAO Doc 4444 PANS Air Traffic Management.

The demand to increase capacity meant reconsidering the standard route spacing requirements based on conventional navigation devices. The use of GNSS, improved navigation performance of onboard navigation systems and more accurate surveillance systems enabled aircraft operations with lower separations. Since then, several studies were conducted in Europe and elsewhere looking into the horizontal spacing of routes.

The UK CAA, for example, conducted research into the possibilities of using PBN as an enabler to reduce route spacing. In order to support the UK Future Airspace Strategy (FAS) a re-design of UK terminal airspace and the wider introduction of ICAO's concept of Performance-based Navigation (PBN) was necessary. An essential proposed benefit of PBN was to enable the redefinition of route spacing between proximate departure and/or arrival routes and runway transitions. The application of PBN therefore required a commitment from aircraft operators to enhance their fleet capability (where necessary) to reflect the navigation performance capability and strategic objectives for the airspace.

Generic ICAO and EUROCONTROL studies have indicated a minimum spacing of 7 NM between routes. Although UK ANSPs have been able to design to less than this value, the assurance method employed (based on developing a Route Design Analysis Report (RDAR)) is manual and labour-intensive.

The traditional method of establishing route spacing has been through Collision Risk Modelling (CRM) supplemented by hazard identification and safety assessments. However, following a review of the previous work, the UK CAA concluded that the use of CRM to determine safe PBN route spacing in a complex tactically controlled airspace was inappropriate and that an alternative method was required.

The UK Civil Aviation Authority (CAA) and NATS worked collaboratively to develop a Loss of Separation Risk Model (LSRM) which assesses the safe spacing between PBN routes in a tactically controlled airspace environment based on the predicted number of losses of separation. This method was applied to data collected from existing RNAV 1 routes and specially designed operational trials and used to establish the predicated frequency of loss of separation associated with specific route spacings for different types of route designs and interactions.

The main difference between the LSRM and the traditional CRM approach is that the lateral track-keeping error distributions are used to estimate (for a particular traffic scenario) the number of losses of separation that would occur when aircraft are operating within their nominal navigation performance, rather than a lateral overlap probability i.e. risk of collision, for a pair of aircraft.

The UK CAA contracted DNV GL to support the independent review of the LSRM method and the analysis for each of the route interactions. Based on the report outcomes the UK CAA concluded that the method is sufficiently robust and is suitable for application in future PBN route developments in UK airspace. Details of the methodology are provided in the UK CAA CAP 1385.

As a result of the assessment, the minimum acceptable route spacing values were subject to sensitivity analysis, both in terms of the parameters such as Flow rate, Speeds, Across-track Speeds, Along-track Speeds and Length of Straight Segments and investigation of alternative fits to the lateral distributions. The parameters were chosen to be broadly applicable in a UK airspace context and therefore the minimum route spacing values can be directly applicable where the conditions and assumptions of this guidance were met.

The following summary information illustrates the comparative route spacing for each of the scenarios considered. The values presented must be subjected to an implementation safety assessment, and no spacing value shown in the table can be used without a local implementation safety assessment.

Description of the route interactions	Minimum acceptable route spacing (M_x)
Same Direction Parallel Straight Routes	MRS[19] + 0.8NM (3.8NM)
Opposite Direction Parallel Straight Routes	MRS + 1.2NM (4.2NM)
Moderate Turn Away when Leaving a Same Direction Parallel Straight	MRS + 0.9NM (3.9NM)
Joining a Same Direction Parallel Route with a 90° Turn	MRS + 0.9NM (3.9NM)
180° Wrap-around Turn Joining a Same Direction Parallel Straight	MRS + 3.4NM (6.4NM)
Same Direction Straight against the Apex of a 180° Wrap-around Turn	MRS + 2.9NM (5.9NM)
Same Direction Two Shallow Turns	MRS + 0.9NM (3.9NM)
Same Direction Two Moderate Turns	MRS + 1.2NM (4.2NM)
Two Opposite Direction Moderate Turns	MRS + 1.7NM (4.7NM)

Table 24: Minimum acceptable route spacing (CAP1385)

The results of the Loss of Separation Risk Model (LSRM) on route spacing segments described in the UK CAA CAP 1385 cannot be directly applied to Schiphol TMA. Nevertheless, the Heathrow and Amsterdam TMAs are both high density high complexity airspaces, so it can be assumed that a similar approach to that taken by the UK CAA could be successfully adopted in the Netherlands to derive acceptable specific local route spacings.

A reduction in horizontal route spacing minima may provide additional scope for further minor optimisation of the tubes concept, as it would reduce the width of the tubes and thus provide additional flexibility for route optimisation towards environmental sustainability. That said, we do not expect any new route spacing to substantially influence the overall efficiency of the concept as the tubes in the current concept are not running parallel to each other; in most cases they are more crossing each other. Localised improvements are likely to be

[19] In case of UK, the Minimum Radar Separation in this table is defined as 3NM in TMAs with suitable radar coverage.

enabled (e.g. shortening the length of a selected tube) but their contribution to the overall performance of the concept is expected to be minor.

VI.2 Vertical spacing

VI.2.1 Qualitative analysis

Despite investing significant effort researching potential initiatives aimed at the reduction of vertical route spacing in terminal airspace, we did not identify any such initiatives.

EUROCAE working group WG-85 is intended to look at reducing the vertical spacing between routes, but at the time of conducting this research the group was not conducting any activities related to vertical spacing. As an EUROCAE member Egis is monitoring this situation and we will be ready to provide updates to MINIENW whenever it might change.

Based on our theoretical knowledge of the subject, we believe that reducing the minimum vertical spacing between two tubes could introduce localised improvements in cases where vertical extent of the outbound tube is affected by a crossing inbound tube. The current tube concept contains several locations where the vertical extent of the departure tube is influenced by the inbound tube leading above. By reducing the tube vertical spacing it should be possible to reduce this impact, or even to establish the full vertical extent of the tube. In specific conditions, reduced vertical route spacing may also allow the altitude of affected tubes to be increased, thus bringing aircraft higher with a potentially beneficial impact on the noise contour below the tube.

VI.3 Summary of key findings for horizontal and vertical route spacing

The UK CAA has developed a suitable method to establish minimum acceptable horizontal route spacing based on the modern aircraft navigational capabilities (PBN). Reduction in horizontal route spacing minima may provide additional scope for further optimisation of some of the early route design concepts, as it would reduce the width of the tubes and thus could provide additional flexibility in the route optimisation towards greater environmental sustainability. However, it is not expected that any new route spacing standards would influence the overall efficiency and sustainability of the existing tubes concept at Amsterdam.

There does not seem to be any active research into the potential for reducing vertical spacing between the routes in the terminal airspace.

Conclusions

VII Conclusions

VII.1 Interpretation of effects of proposed measures with regards to planned implementation of the new Schiphol TMA in 2025

The effectiveness and sustainability of the initial implementation phase for the proposed tube concept at Schiphol TMA will depend on a number of key decisions to be made between now and 2025. This research provides initial insights into the impact of the four key measures in the scope of the project. Additional research may be needed to validate the results presented and/or to test the sensitivity of the same airspace measures against different conditions or assumptions.

For the “tracking of tubes” measure, the simulations suggest that the shortest distance to the FIR boundary can be achieved when vectoring departures to their destinations at 6,000 ft. In this case, the average distance of each EHAM departure covered inside the EHAA FIR would be between 78 and 84 NM per flight for southerly and northerly departures respectively. While these results are sensitive to the set of destination airports analysed, they suggest that leaving the tube at 6,000ft has the potential to maximise fuel savings in both the Schiphol TMA (by not following the full tube) and in the FIR (as the FIR shape influences where exactly the flight exits the FIR when being vectored).

Although exiting the tube at 6,000ft provides best fuel economy, exiting the tube at 5,000ft results in the smallest noise contour above the land area and the smallest number of people living within the noise contour. However, in terms of the extent of the noise contour and the number of people within it, the results for leaving the tube at 4,000ft and at 6,000ft are similar to those obtained for the 5,000ft scenario. This provides a good starting point for the consideration of these results against the results on distance flown, for which a “sweet spot” was observed at 6,000ft.

Investigation of the “accuracy of delivery” measure identified an accuracy variation of +/- 30 seconds to be the threshold at which the tubes concept starts to generate increasing sequencing delay. Below this threshold, the concept should be workable using speed control as the primary sequencing measure. Extensive use of vectoring is likely to be required after passing the threshold of +/-30 seconds variation in accuracy of delivery. If the accuracy of delivery deteriorates to more than +/-60 seconds then the occasional use of airborne holds may be required during peak traffic periods. The research concluded that northerly operations are slightly more challenging to accommodate, due to unequal length of the individual arrival tubes considered in this scenario, together with the need to merge three tubes at once.

Analysis of the “climb gradient” measure indicated that a 13% initial climb gradient to FL100 should be achievable by roughly 50% of airport traffic. Almost all simulated aircraft in the sample were capable of the steep initial climb, although some failed to comply with altitude restrictions at the later points of the tube. Due to improving aircraft technologies, the actual size of noise contours and the actual % of non-compliant aircraft is likely to be smaller than indicated in this research. The results are based on zero-wind scenarios and assume that airlines will train their pilots in how to operate the steeper departures efficiently. Further work is required to establish the impacts of varying take-off weights and wind strength on the climb performance.

Research of the "descent gradient" measure confirmed the prior expectation that the noise contour reduces with increasing gradient. While a 2-degree descent could be performed by all aircraft in the sample, 4% of arrivals would be unable to meet either the speed restrictions or descent rate criteria associated with a 3-degree descent. The introduction of intermediate level segments at 10,000ft seemed to alleviate this problem, by providing enough distance for flights to decelerate before continuing their descent.

VII.2 Interpretation of effects of proposed measures with regards to planned implementation of the new Schiphol TMA in 2035

One of the key changes in the full implementation of the concept relates to the use of tubes from the Schiphol TMA entry fix to the runway threshold. Unlike in the initial 2025 implementation, the use of vectoring and holding is not envisaged for the 2035 horizon and the sequencing of aircraft within the Schiphol TMA is therefore assumed to be carried out primarily by speed control measures.

As such, it was important to investigate the greatest inaccuracy threshold that would still enable the operation of the full tube concept with only speed control measures. The simulations indicate that the performance starts to deteriorate with accuracy variations greater than +/-15 seconds for single runway arrivals, and with variations greater than +/-30 seconds for dual runway arrivals. It can be concluded that, with the proper accuracy of delivery, the 2035 concept should be easier to execute compared to a 2025 concept that includes both vectoring and holding on a more regular basis.

In terms of the noise contours associated with 2035 operations, despite the 7-8% predicted growth of traffic between 2025 and 2035 the noise contours are not expected to grow substantially. This marginal growth can be attributed to fleet replacement, where older noisy wide-bodies and turboprops are expected to be replaced by newer and quieter types.

The climb gradient established using the 2025 traffic sample is likely still to be applicable in 2035. Due to expected technological advancements in aircraft design, the typical fleet in 2035 should be able to operate comfortably on any gradient established in 2025.

The same technological advances that will contribute to easier achievement of steeper climb gradient may cause additional challenges with adherence to steeper descent profiles. Despite the 3.0-degree descent profile providing the best fuel economy and smallest noise impact, more aerodynamic aircraft types may have more difficulties complying with steeper gradients in the future.

The last area of our research looked into the potential for reducing horizontal route spacing minima. While this may enable further optimisation of the early stages of some of the route design concepts by reducing the width of the tubes (and thus providing additional flexibility in the optimisation of routes for greater environmental sustainability) a high-level review of the existing tube concept at Amsterdam did not reveal any areas where introduction of the new route spacing standards would substantially influence the overall efficiency of the existent concept.

Annexes

VIII Annexes

VIII.1 Annex 1: Overview of similar concepts researched elsewhere in the world

While researching the airspace measures for this project, we identified a couple of similar concepts that either have been or are still being researched abroad. This section provides overview of these concepts.

VIII.1.1 Tubes concept

Concepts similar to the Tubes concept have been designed also in other parts of the world. In the subsections below, similar approaches in the UK and in the USA are described.

Dedicated arrival flow corridors - EUROCONTROL

As a predecessor of arrival and departure tubes, a concept of 'dedicated arrival flow corridors' was tested via Fast-Time Simulation (FTS) as part of Arrival Management and Trajectory Management to enable advanced Continuous Descent Approaches (CDAs) in a multi-airport Terminal Manoeuvring Area (TMA) in EUROCONTROL Experimental Centre in 2009[20]. It covered continuous descent operations to several European airports (Amsterdam, Dusseldorf, Cologne and Brussels), aiming at improved flight efficiency, reduced emissions and noise. These corridors were designed for feeding into entry points of involved TMAs. Arrival flow corridors were around 200 NM long, starting at the appointed ToDs (top of descent), covering approximately last 60 minutes of flights. In case of Schiphol airport, four TMA entry points were used. The study described the arrival flow corridors as ' … *long stretched dedicated arrival corridors, i.e. dedicated tunnels in the sky to accommodate arrival flows, were assumed that allow providing ATM service provision to arrival flows for hub airports with maximum efficiency, following continuous descent profiles, while metering and sequencing was applied using RNAV techniques*.'

Results of the simulations were summarised in "Results of FTS on Multi-Airport TMA operations in the core area of Europe" document. Key findings proved that continuous descent operations along the corridors has significant benefits, ensuring shorter flying times, though some issues stayed unsolved (e.g. interests of other airspace users, needs for such corridors for other airports at the same piece of airspace, sufficient capacity of corridors, etc.).

Letterboxes and gateways - NATS, UK

A UK CAA "Assurance Review" document[21] issued in 2018 works with the concept of tubes, letterboxes and gateways. The document defines the tubes as 3D flight routes, separating arrivals and departures. The benefits are expected in the area of environmental impact, ensured separation of arriving and departing flights, reduced

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[20] https://www.eurocontrol.int/sites/default/files/library/E3-WP5-D5.3.4-02-REP-V1.00-fts-on-multi-airport-tma-and-cda-report.pdf

[21] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/763085/nats-caa-feasibility-airspace-modernisation.pdf
https://www.caa.co.uk/Commercial-industry/Airspace/Airspace-change/Decisions-from-2018/London-Airspace-Management-Programme-Phase-2---ATS-Network/

controllers' workload, increased capacity, improved efficiency with less fuel burnt. Letterboxes are points in airspace where aircraft leave airport designed outbound (departing) tubes into NATS tubes (upper route airspace). Gateways are the points of transition from upper route airspace into airport designed approach procedures. The concept is envisaged to be applied between FL90 and FL305, with an option to specify letterboxes and gateways at FL70 for better manoeuvrability.

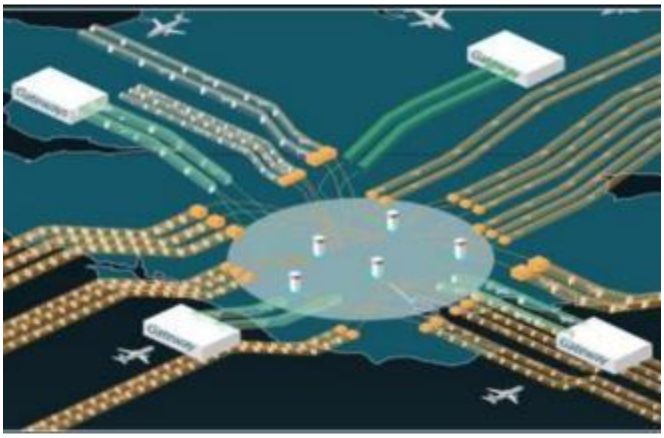


Figure 26: Concept of letterboxes and gateways. Source: NATS Feasibility Report into Airspace Modernisation in the South of the UK and the CAA Assurance into the NATS Feasibility Report

Conceptually, the "Gateways and letterboxes" system is similar to the "tubes" concept. Both of these systems rely on Performance Based Navigation, accurate delivery of traffic to the TMA and speed control as the primary means for managing aircraft separations and arrival sequencing. The key difference is that horizontal locations of letterboxes/gateways are lower than location of endpoints of the "tubes" - this is driven by local operating environments and interfaces with en-route network.

Flow corridors – NextGen, USA

Beyond Europe, a similar concept is described in the Concept of Operations for the Next Generation Air Transportation System document[22] (published in 2010) as

> '*a long "tube" of airspace that encloses groups of flights flying along the same path in one direction. It is airspace procedurally separated from surrounding traffic and special use airspace, and it is reserved for aircraft in that group. There is a minimum distance that traffic within the corridor must maintain from the edge of the corridor (i.e., "the corridor walls have some thickness").*'

These corridors should ensure procedural separation from other airspace, allowing for a high traffic density. They ensure that aircraft flying in the corridor do not interfere with the aircraft outside of them. Within the corridors, separations can be ensured by small changes of speed and trajectory. However, this concept is considered to be applicable in en-route airspace only – in combination with trajectory-based operations.

VIII.1.2 Accuracy of delivery

In order to enable arrival management concepts and solutions in a NextGen environment, ground based sequencing and scheduling functions have been developed in the US to support metering operations in the US National Airspace System. The study conducted by Shivanjli Sharma and John E. Robinson III: *"Methodology to Define Delivery Accuracy Under Current Day ATC Operations"* presents a methodology for determining the undelayed delivery accuracy for current day air traffic control operations. The method supports the definition of metrics that will allow development of near-future automation tools to successfully achieve desired separation

[22] https://www.hsdl.org/?view&did=747519

at metering points, enabling aircraft to meet their Scheduled Times of Arrival (STAs) while performing Performance-Based Navigation (PBN) procedures in the terminal area. The calculation algorithm was tested for four airports located in the USA and assured that the method can be utilized quickly and has the ability to function across various airspaces and adaptations.

Further to the calculation algorithm, John E. Robinson III and Jane Thipphavong, provide an insight on the advanced arrival management capability for terminal controllers, known as Terminal Sequencing and Spacing (TSS). The study *"Enabling Performance-Based Navigation Arrivals: Development and Simulation Testing of the Terminal Sequencing and Spacing System"* presents Terminal Sequencing and Spacing tool from proof-of-concept design to fully operational prototype. Simulations were again conducted at several US airports and incorporated a broad range of conditions. Two metrics were evaluated for these simulations: PBN Success Rate and Inter-Arrival Spacing Error. PBN Success Rate is a measure of performance that determines how frequently RNAV- and RNP-AR-equipped aircraft remained on their PBN arrival procedure without being vectored before reaching the end of the published lateral path. Inter-Arrival Spacing Error is a measure of performance that determines how precisely aircraft are spaced in time at the final approach fix. The study concluded that by using the Terminal Sequencing and Spacing tool, following performance can be achieved:

- The PBN Success Rate shows a definitive positive trend when TSS is used. It increases from 42% for today's operations to 68% for terminal metering only and to 92% for terminal metering with controller-managed spacing tools.
- The Inter-Arrival Spacing Error improves by 25–35% when TSS is used compared to not used.

VIII.1.3 Continuous climb and descent operations

VIII.1.3.1 Continuous climb

Continuous Climb Operations (CCOs) is an aircraft operating technique enabled by airspace design and instrument procedure design and facilitated by air traffic control (ATC). CCO allow aircraft to follow an optimum flight path that delivers environmental and economic benefits - reduced fuel burn and gaseous emissions, and reduced noise and fuel costs - without any adverse effect on safety.

CCO operations allow departing aircraft to climb continuously, to the greatest extent possible. Aircraft applying CCO employ optimum climb engine thrust and climb speeds until reaching their cruising levels. (ICAO, Continuous Climb Operations (CCO) Manual; ICAO Document 9993) Employment of this technique reduces intermediate level-offs and results in time being spent at more fuel-efficient higher cruising levels, hence significantly reducing fuel burn, and lowering emissions and fuel costs. (EUROCONTROL, Continuous climb and descent operations, n.d.)

According to ICAO Doc 9993, CCO offers the following advantages:

- more fuel-efficient operations.
- reduction in both flight crew and controller workload through the design of procedures requiring less ATC intervention.
- reduction in the number of required radio transmissions.
- cost savings and environmental benefits through reduced fuel burn and potentially aircraft noise mitigation through thrust and height optimization.
- potential authorization of operations where noise limitations would otherwise result in operations being curtailed or restricted.

Previous Egis work assessed various CCO and non-CCO climb profiles at one of the major European airports and compared them against each other. The study aimed to illustrate the differences in noise contour sizes and shapes on A319 aircraft type, as one of the most representative narrow-body jet.

For CCO flights, the climb gradient (or the steepness of the vertical profile) was found[23] to be crucial when comparing the contour sizes. When comparing the steepest[24] and the shallowest[25] CCO climb profiles of an A319 aircraft type, it was found that 65dB LA_{max} contour produced by the shallowest climb profile was larger by 71%[26] in terms of surface area than the 65dB LA_{max} contour produced by the steepest profile[27]. A comparison of 60dB contours indicated the same trend. The contour produced by the shallowest flight was larger by 52%[28] in terms of surface area. Moreover, the 65dB contour of the shallowest flight extended by 2.5NM further from the airport and the 60dB contour extended by 3NM further from the airport in comparison with the steepest flight contours. The study concluded that shallower climb gradients spread noise further from the airport.

The suitable climb gradient, and associated quality and quantity of CCOs depends on several factors.

Traffic levels

At Schiphol airport, the average time in level flight during climb out decreased significantly in 2020. This is in line with developments at other major European airports, where the share of CCO operations also increased. The dramatic reduction of traffic at these airports led to less complexity and density in the TMA airspace around these airports, allowing more opportunities for operating on ideal vertical trajectories without causing conflict with other traffic. Achieving high vertical efficiency is more challenging during peak traffic periods as air traffic controllers have less space to separate the traffic laterally, therefore vertical separation needs to take place to ensure sufficient capacity and maintain high safety levels by keeping required spacing between the aircraft.

The graph below illustrates the evolution of CCO operations at Schiphol in 2019 and 2020 (EUROCONTROL data).

[23] Results were produced using Aviation Environmental Design Tool (AEDT)

[24] Average climb gradient between take-off up to 6,000ft (60dB contour end) was 7.3 degrees

[25] Average climb gradient between take-off up to 6,000ft (60dB contour end) was 4.2 degrees

[26] The steepest flight created a 65dB contour area of 14 km^2 and the shallowest flight contour was larger by 10 km^2

[27] L_{max} metric was used for the comparison

[28] The steepest flight created a 60dB contour area of 29 sq km and the shallowest flight contour was larger by 15 km^2

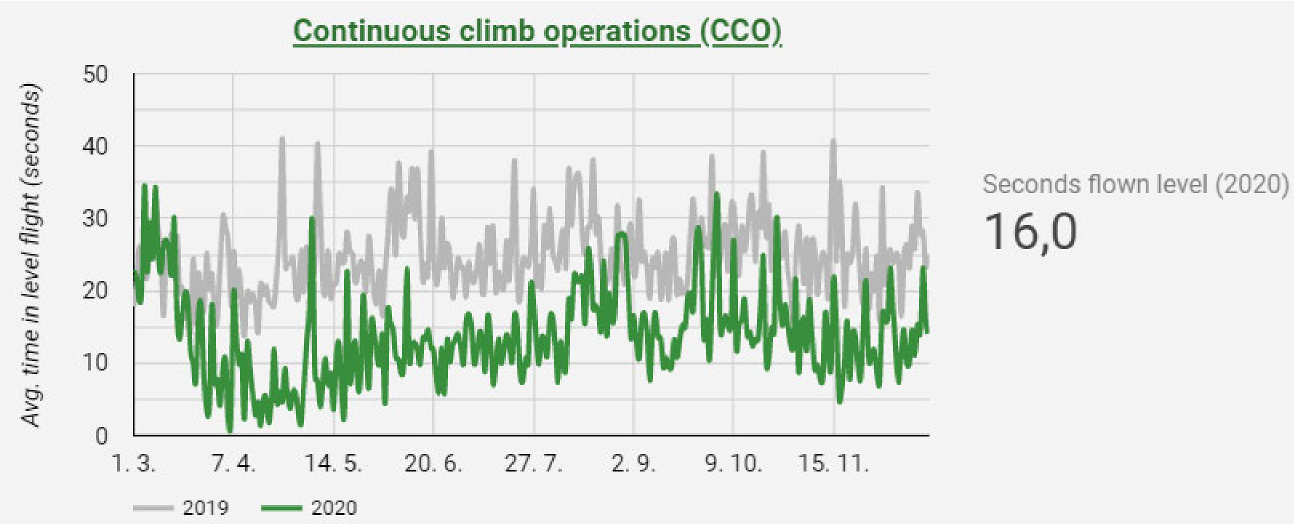


Figure 27: Evolution of CCO operations at Schiphol airport

Airspace complexity

The figure below shows that there is a relatively high amount of level flight during departure operations within the European core area, indicating a link between CCO and airspace complexity (EASA, n.d.). Only airports with average length of a level segment during departure climb procedure longer than 3NM are displayed in the figure below.

Figure 28: Traffic levels and level segment distance flown in 2019 during climb operations

The link between airspace complexity and distance flown level during climb was investigated further and is shown in the figure below. There seems to be a relationship where increasing airspace complexity is associated with longer distances flown level during departure climb-out. Given its airspace complexity score, LVNL is performing better in this metric compared to other ANSPs which either have similar (or lower) airspace complexity score and longer level segments during climb or have comparable length of level segments but lower airspace complexity. This situation provides a feasible starting position for further implementation of continuous climb procedures by 2025 which will further improve vertical efficiency of departures from Dutch airspace.

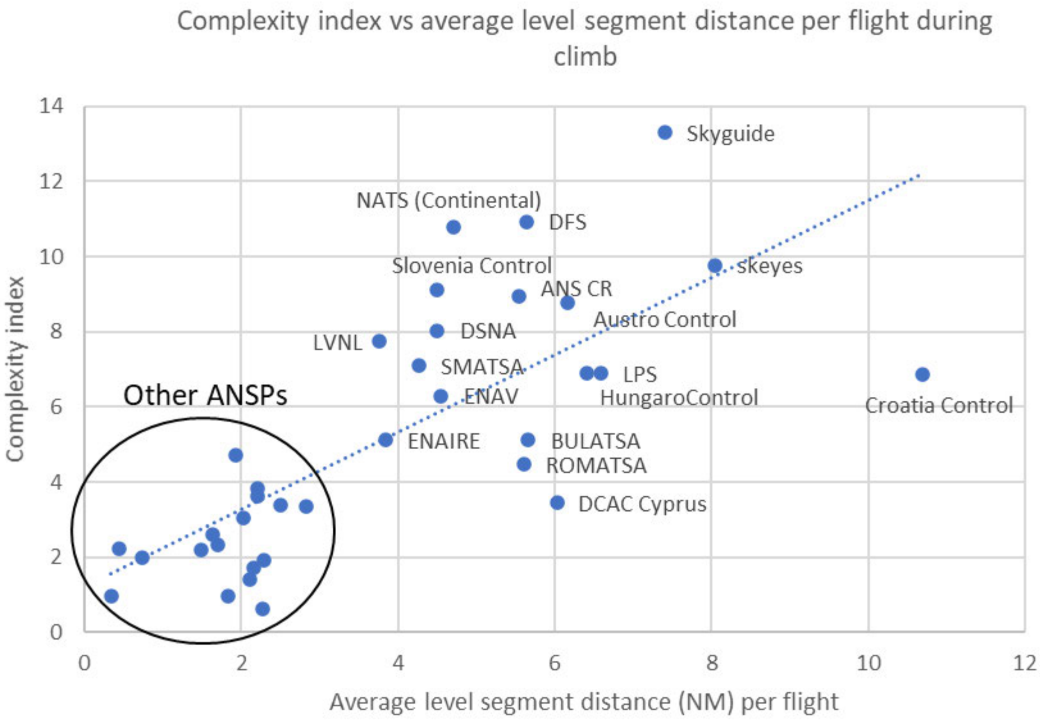


Figure 29: Complexity index vs level segment distance flown during climb operations

Weather

CCO operations are highly affected by weather, in particular, cumulonimbus clouds typically associated with storm activity should be avoided at all times, manoeuvrability may be reduced at lower altitudes during the climb phases of flight due to the often complex interaction between arrival and departure routes.

A previous Egis study looked at impact of storms at vertical flight efficiency during initial climb phases of flight. It revealed that in 2019, the typical departure flight in Netherlands operated 3.5 NM in a level segment. However, on days when a major storm[29] took place in Netherlands, the distance flown level during departure phase increased by 47% to 5.2NM.

A joint study on possible changes in frequency and intensity of storms and their impact on European aviation system in 2050 (carried out by Egis and UK Met Office in 2021) indicates that the situation at Amsterdam airport is likely to see little change with regards to frequency of storms. However, the intensity of storms is likely to increase, as a result of changing climate patterns. In other words, the number of storms near Amsterdam airport is likely to remain broadly constant between now and 2025, but if a storm occurs, its intensity is likely to be greater than intensity of a typical storm experienced today. This is likely to have adverse impact on operation of the Schiphol TMA concept.

[29] Major storm was defined as a storm with its Convective Available Potential Energy (CAPE) ranking in the top 5% of all measurements.

In 2018, EUROCONTROL conducted an ECAC-wide CCO and CDO analysis using 2017 traffic data, in order to estimate the potential network benefits of optimising the CCO and CDO in terms of fuel savings, emissions reduction and fuel costs.

For CCO, the study concluded that 94% of flights in ECAC currently fly CCO to FL (Flight Level) 100 while 74% fly a full CCO to Top of Climb (ToC). For those flights currently flying non-CCO profiles, the average time spent in level flight (before reaching the ToC) was 168 seconds; should these level segments be eliminated, these flights could have saved roughly 15kg fuel (or 48 kg CO_2 or 7 EUR) per flight. (EUROCONTROL, Continuous climb and descent operations, n.d.).

For non-CCO climb profiles, thrust settings change throughout the ascent to accommodate level segments. These changes in thrust impact noise at different stages depending on the number, length and altitude of level flight segments. Noise is redistributed as a result of the non-CCO departure profile. In the figure below (also produced by Egis as part of a different project), the 60dB and 65dB noise contours produced by flight D are of a similar size (in terms of area) as the steepest CCO profile, however the noise is redistributed as a result of thrust reduction during the level segment at 4,000ft (between 8-10NM from the airport) and applying higher thrust when climb is initiated again.

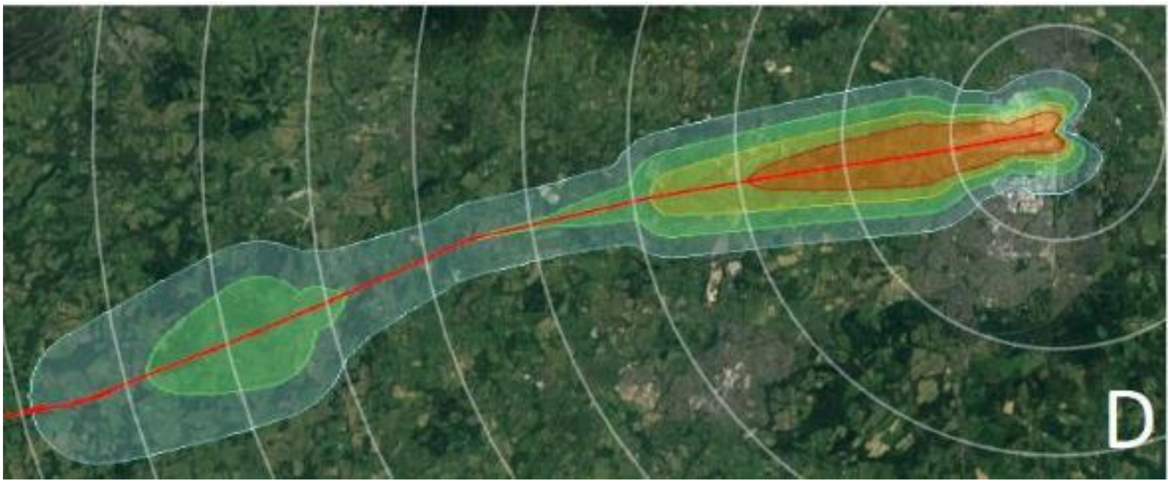


Figure 30: Noise (LA_{max}) produced by A319 on a non-continuous climb profile up to 6,000 ft

CCO profiles can provide significant benefits over non-CCO profiles if the aim is to keep the noise closer to the airport, potentially impacting smaller number of inhabited areas. Non-CCO profiles, however, can be also flown in a quiet manner. If level segments are carefully designed and placed into the climb profiles, the procedure can reduce noise over densely populated areas and shift it towards less populated ones. This would be suitable on the departure routes that cannot be routed around noise-sensitive areas for various operational reasons (e.g. proximity of danger or prohibited areas, active military zones, or potential conflicts with other routes).

The vertical profile during a non-CDO climb-out is not a “straight line” climb, but is based on various segments, where actions such as gear and flap retraction, engine thrust cut-back and acceleration take place. During an intermediate levelling off, the aircraft will operate at a sub-optimum altitude and operational mode and will fly a longer track than necessary at non optimum altitude, consuming more fuel. At lower altitude, the aircraft may not be able to operate in a clean configuration (flap setting) during a level off (depending on speed limitations). The higher air density at low level, added to the additional drag due to the extended flaps, typically requires additional energy. Levelling off at a higher intermediate altitude in a clean configuration is more efficient but it also reduces the amount of time the aircraft can operate at its optimum level. (ICAO, Continuous Climb Operations (CCO) Manual; ICAO Document 9993).

VIII.1.3.2 Continuous descent

Continuous Descent Operations (CDOs) are aircraft operating techniques enabled by airspace design, instrument procedure design and facilitated by air traffic control (ATC). CDO allow aircraft to follow a flexible, optimum flight path that delivers major environmental and economic benefits - reduced fuel burn, gaseous emissions, noise, and fuel costs - without any adverse effect on safety.

CDO operations allow arriving aircraft to descend continuously, to the greatest extent possible. With CDO, aircraft employ minimum engine thrust, ideally from top of descent, prior to the final approach fix (ICAO, Continuous Descent Operations (CDO), ICAO Document 9931, 2010). Employment of this technique reduces intermediate level-offs and results in flight time being spent at more fuel-efficient higher cruising levels, hence significantly reducing fuel burn, and lowering emissions and fuel costs (EUROCONTROL, Continuous climb and descent operations, n.d.).

According to ICAO Doc 9931, CDO offers the following advantages:

- More efficient use of airspace and arrival route placement.
- More consistent flight paths and stabilized approach paths.
- Reduction in both pilot and controller workload.
- Reduction in the number of required radio transmissions.
- Cost savings and environmental benefits through reduced fuel burn.
- Reduction in the incidence of controlled flight into terrain (CFIT); and
- Authorization of operations where noise limitations would otherwise result in operations being curtailed or restricted.

The Arrivals Code of Practice (published by Sustainable Aviation, United Kingdom's industry body) considers an arrival as a CDO if it contains, below an altitude of 6000ft: no level flight, or one/multiple phase(s) of level flight not longer than 2.5 nautical miles (NM). The angle of descent affects noise on the ground, and today the optimum CDO profile is defined in the Code of Practice as having a 3-degree descent angle. If an aircraft flies an extended level segment on descent (i.e. longer than 2.5NM) it is categorised as a non-CDO flight, requiring additional engine power to maintain level flight at a constant speed and thus creating more noise.

LNAM metric

CDO is the primary method of reducing noise experienced on the ground beneath arriving aircraft, and today, compliance rates at airports that implemented CDO are very high, suggesting a time for a review of the current CDO definition might have come. Egis was a part of the validation process of a new Low Noise Arrivals Metric (LNAM) developed by the UK Civil Aviation Authority's Environmental Research Consultancy Department (CAA ERCD) and tested by NATS. Whilst CDO operations are broadly effective, CAA ERCD's research identified that there are occasions when CDO does not distinguish the quietest flights. A CDO angle of descent can vary, and in some instances, arrivals can be categorised as CDO compliant but may not necessarily be low noise. For example, aircraft with a shallow angle of descent would have a larger noise impact on the ground compared to the target CDO (with a 3-degree descent angle). In general, non-CDO aircraft are considered to be noisier than CDO aircraft due to their extended level segments, but this is not always the case. On occasion, a shallow CDO profile can be noisier than a non-CDO aircraft with level flight at higher altitude. To better rate low noise arrival performance, two height boundary conditions were developed, creating three low noise categories. These three categories are defined as Cat A, Cat B, and Cat C, where Cat A is the quietest and Cat C the loudest.

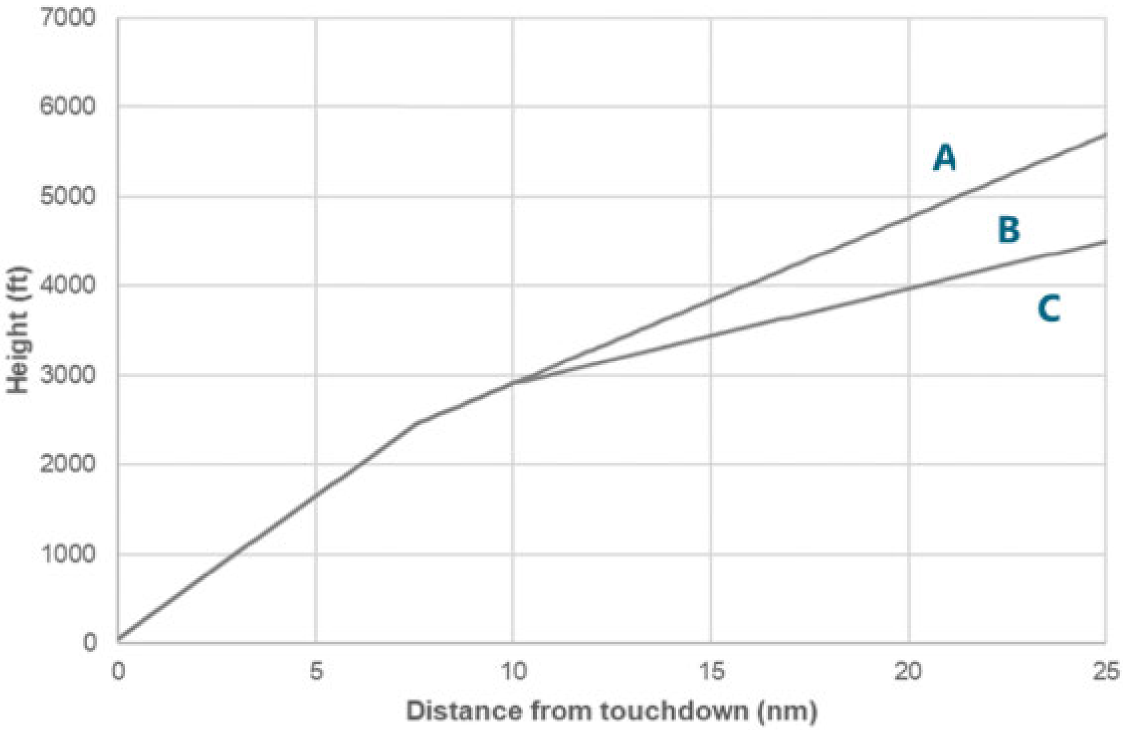


Figure 31: Flight categories for the proposed low-noise arrival metric (A- quietest, C-loudest category)

The new metric incentivises steeper initial/intermediate descent angles encouraging higher descent profiles, but not to the extent that would necessitate any changes in speed control or aircraft configuration.

In terms of measuring compliance against the metric, only CDO aircraft can be assigned a low noise arrival category. The lowest category entered on descent will define the low noise rating for each flight, therefore by means of an example, if an aircraft descends in Cat A for most of its approach but dips into Cat B momentarily, this aircraft will be assigned low noise arrival Cat B. A tolerance has been applied to the criteria to address uncertainties.

During CAA ERCD's initial research, it was identified that as well as permitting shallow angle approaches, the current CDO definition is not necessarily suitable for some modern aircraft types that require periods of shallow descent or level flight during the initial approach (at higher altitude) in order to reduce their speed. The current definition permits phases of level flight not longer than 2.5 NM – newer aircraft types may require phases of level flight longer than 2.5NM to help reduce their speed in the quietest manner. The idea moving forward is that airports operating CDO arrivals will monitor the metric and assess the proportion of flights classified as CDO and non-CDO within the three low noise arrival categories. The new metric has a potential to incentivise aircraft to descend at higher altitude whilst meeting the defined CDO criteria, and discourage level segments closer to the ground, thus reducing the arrivals noise. In the long-term, airports may consider monitoring and reporting compliance against the new metric as they do today with existing noise abatement procedures.

The suitable descent gradient, and associated quality and quantity of CDOs depends on several factors.

Traffic density

At Schiphol airport, aircraft now spend more time in level flight during arrival rather than during departure operations. The average time spent in level flight in 2020 was 16 seconds for departures and 104 seconds for arrivals, as depicted in the figure below. The average time of level segment decreased by approx. 50% with the drop of traffic due to the pandemic (EUROCONTROL, Continuous climb and descent operations, n.d.) suggesting there is a link between traffic density quality of continuous descent operations.

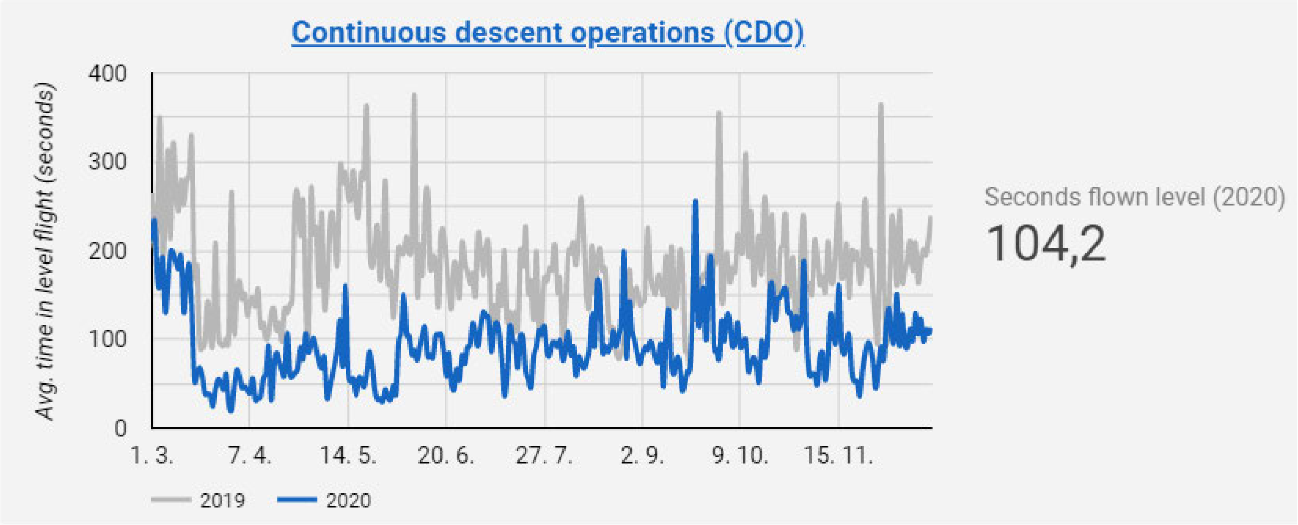


Figure 32: Continuous descent operations

Airspace complexity

The Figure 33 below shows that there is a comparably higher amount of level flight during descent operations within the European core area, indicating a link between CDO and airspace complexity (EASA, n.d.). Only airports with average level segment distance over 10NM are displayed in Figure 12.

Figure 33: Traffic levels and level segment distance flown in 2019 during descent operations

The link between airspace complexity and the distance flown in level segment is shown in Figure 36. The relationship between quality of continuous descent operations and airspace complexity seems even stronger than in case of continuous climb operations. However, LVNL's current performance in this metric seems on par with several other ANSPs, i.e. LVNL's performance with regards to airspace complexity in Netherlands is not significantly better (nor worse) than performance of other ANSPs with comparable airspace complexity. This could be down to the need to vector arrivals to the final approach fix (which may require disruption to the continuous descent profile) but additional research would be required to confirm or disprove this hypothesis.

Additionally, due to (comparably) small geographical extent of Netherlands, some of the continuous descents do start outside of LVNL's area of responsibility meaning that the quality of continuous descent approaches to Netherlands may be influenced also by high density/high complexity airspace of neighbouring ANSPs.

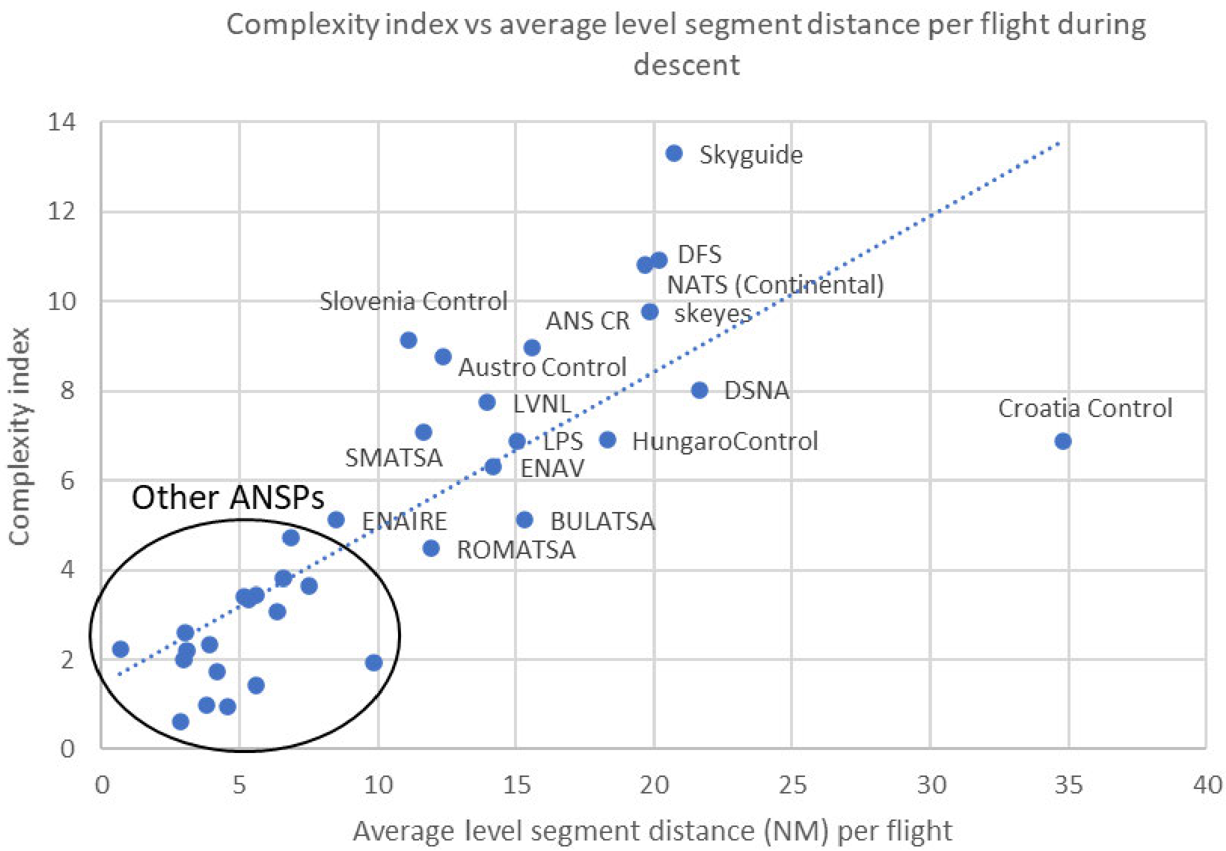


Figure 34: Complexity index vs level segment distance flown during descent operations

The amount of time flown level (a proxy for inefficiency) and consequently the amount of fuel savings available from optimizing the descent phase (CDO) of operations to Schiphol is significantly greater than the time flown level during the climb phase (CCO) or departures from Schiphol; therefore, indicating that airlines do fly reasonably efficient climb operations, but there is scope for improvement in CDO operations.

Weather

CDO operations are highly affected by weather, in particular, cumulonimbus clouds typically associated with storm activity should be avoided at all times, and manoeuvrability may be reduced at lower altitudes during the descent phases of flight due to the often complex interaction between arrival and departure routes.

Previous Egis study looked at impact of storms at vertical flight efficiency during descent phases of flight. It revealed that in 2019, the typical arrival flight in Netherlands operated 12.9 NM in a level segment. However, on days when a major storm[30] took place, the distance flown level during departure phase increased by 10% to 14.2NM. This historic data suggests that while initial concept implementation in 2025 may be able to cope better with occasional storms by having measures in place to allow vectoring around the storms, the efficiency of 2035 concept (where use of full arrival tubes is assumed instead of vectoring) is at risk from weather phenomena.

A joint study on possible changes in frequency and intensity of storms and their impact on European aviation system in 2050 (carried out by Egis and UK Met Office in 2021) indicates that the situation at Amsterdam airport is likely to see little change with regards to frequency of storms. However, the intensity of storms is likely to increase, as a result of changing climate patterns. In other words, the number of storms near Amsterdam airport is likely to remain broadly constant between now and 2025, but if a storm occurs, its intensity is likely to be greater than intensity of a typical storm experienced today. This is likely to have adverse impact on operation of the Schiphol TMA concept.

For CDO, the EUROCONTROL conducted an ECAC-wide CCO and CDO analysis using 2017 traffic data concluded that 41% of flights fly CDO from FL75 (the top of the noise CDO) while only 24% fly a CDO from Top of Descent (ToD – the top of the fuel CDO). For those flights currently flying non-CDO profiles, the average time in level flight from the ToD was 217 seconds, with per-flight savings estimated at 46kg fuel/145kg CO_2/20EUR. (EUROCONTROL, Continuous climb and descent operations, n.d.)

Egis CDO study

One of the previous Egis projects aimed at investigating the correlation between descent angle and size of the noise contours. Egis has analysed 60dB L_{max} contours from various descent profiles to determine the impact of aircraft flying at unnecessarily low altitudes. A320 and B789 aircraft type descents were analysed.
The noise footprint was calculated for three types of arrivals:

- a 'hypothetical' arrival profile, defined as the "ideal" vertical profile expected to be used during night time operations to minimise the noise to the greatest extent possible,
- a 'low noise' arrival (an actual, recorded arrival) flying a steeper profile similar to the profile the airport intended to introduce for night operations, and
- an 'outlier' arrival (an actual, recorded arrival) flying a shallower profile than the other aircraft.

The results confirmed reduction in size of the noise contour related to increase in vertical gradient on the approach path. The low noise arrivals and the hypothetical arrivals had a considerably smaller 60dB L_{max} noise footprint than the outlier aircraft.

The low noise arrivals had a smaller footprint than the outlier aircraft by between 4% and 41% depending on descent gradient and aircraft type.

The hypothetical arrivals had a smaller footprint than the outlier aircraft by between 10% and 38% depending on descent gradient and aircraft type.

As with the continuous climb measure, the detailed Dutch-specific assessment is planned for the final version of this report. In the interest of demonstrating the link between descent gradient and contour size, we provided

[30] Major storm was defined as a storm with a Convective Available Potential Energy (CAPE) ranking in the top 5% of all measurements.

an example from out previous analysis for a different client. The figure below (only tails of the contours are displayed) shows difference in noise contours produced by A320 descending on 2.7 degree gradient (see the blue "outlier arrival" contour) vs descent on 3.4 degree gradient (see the red "hypothetical arrival" contour). In this case, increasing the vertical gradient by 0.7 degree led to 11% reduction in contour size.

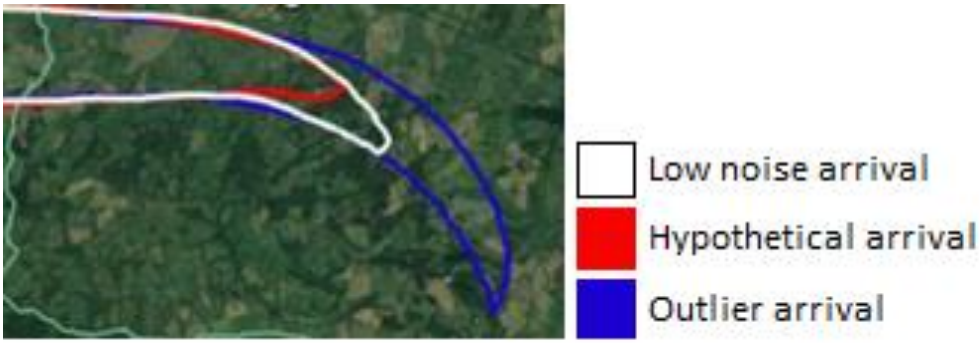


Figure 35: Tails of the 60dB LA_{max} contours for three different arrivals

VIII.2 Annex 2: Overview of other potentially relevant measures identified throughout desktop research

VIII.2.1 Enhanced arrival procedures

There are several new concepts of enhanced arrival procedures that have become feasible due to more precise navigation available, especially satellite-based (SBAS) and ground-based (GBAS) augmentation systems. The procedures considered in this section are:

- Enhanced Arrival procedures using Second Runway Aiming Point (SRAP);
- Enhanced Arrival procedures using Increased Glide Slope (IGS);
- Enhanced Arrival procedures using Adaptive Increased Glide Slope (A-IGS). A-IGS is an onboard-calculated approach slope optimising the slope given by ATC, to take into account the current conditions (Wind, aircraft mass, etc);
- Enhanced Arrival procedures using Increased Glide Slope to Second Runway Aiming Point (IGS-to-SRAP), each of those procedures being active in addition to a standard approach procedure.

All these procedures generally aim at reducing noise under the approach path as aircraft fly higher than the standard airport approach procedure. In addition, SRAP and IGS-to-SRAP may bring capacity benefits (increased runway throughput) as wake vortex separations can be reduced for some leader-follower pairs, when big aircraft fly on the lower glide and lighter on the upper one. On the contrary, IGS and A-IGS may have a negative impact on capacity as separations can never be decreased and these concepts increase spacing for some aircraft pairs.

A number of these procedures, especially SRAP, will require investigation from sustainability perspective. It is not clear how utilising two different glide paths to the same runway can affect changes in noise contours. Similarly, operating heavier aircraft on shallower glide path may require some additional thrust (that would lead to extra fuel burn/emissions) although this extra requirement may be offset by smaller fuel burn of lighter aircraft operating on steeper glide path. This relationship also needs to be investigated. However, based on the flight simulation of EUROCONTROL and Lufthansa Aviation training (LAT)[31] , IGS and SRAP concepts seem to be promising.

VIII.2.1.1 Enhanced Arrival procedures using Second Runway Aiming Point (SRAP)

SRAP introduces two different runway aiming points (active thresholds) on a single runway – one of them being located in a distance towards the end of the runway. This concept enables to reduce noise footprint impact in areas surrounding the airport. It can also lead to reduced runway occupancy time and/or taxi-in time.

[31] https://www.eurocontrol.int/news/flight-sim-arrival-procedure-promises-increase-runway-capacity-less-noise

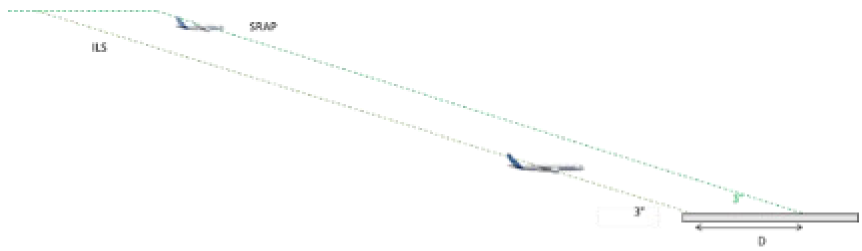
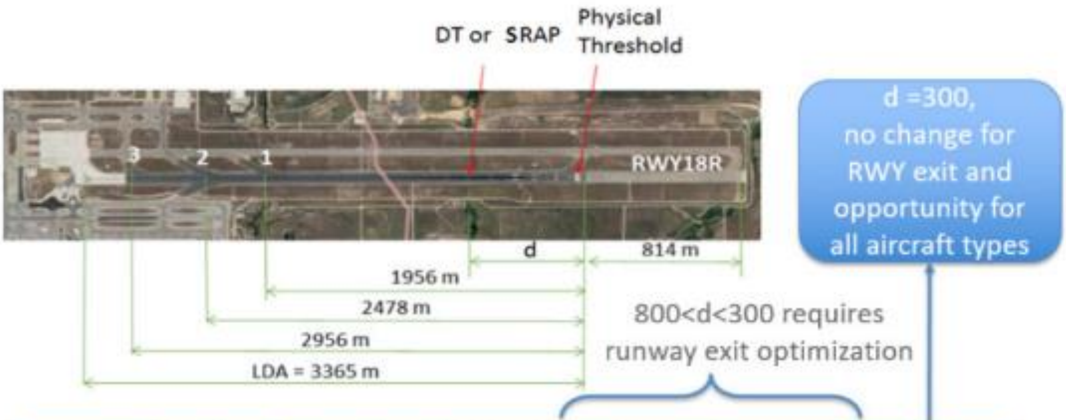


Figure 36: Enhanced arrival procedures: SRAP (Source: PJ.02-W2-14.2 /Release 10)

In order to allow SRAP, there must be a procedure published for the second aiming point and necessary visual aids, lights and ground markers have to be available. This procedure can be used when the runway length is sufficient and supported by appropriate runway exits. The glide slope for the SRAP is the same as for the nominal aiming point.



FLEET	E1	E2	E3	LDA	EAP 1000	EAP 800	EAP 600	EAP 300
Heavy			✓	✓	✗	✗	LDA	E3/LDA
Medium-Jet		✓	✓	✓	LDA	E3/LDA	E3/LDA	E2/E3/LDA
Medium-TH	✓	✓	✓	✓	E2/E3/LDA	E2/E3/LDA	E1/E2/E3/LDA	E1/E2/E3/LDA
Light	✓	✓	✓	✓	E2/E3/LDA	E1/E2/E3/LDA	E1/E2/E3/LDA	E1/E2/E3/LDA

Figure 37: Enhanced arrival procedures: Example of SRAP / Displaced Threshold (DT) concept in LEMD runway 18R used in SESAR validations (Source: PJ.02-02. D2.1.046)

All RWYs at Schiphol airport (besides RWY 04/22) should have sufficient RWY length for SRAP implementation for light and medium heavy aircraft. The suitability of the concept for heavy aircraft would need to be verified (landing distance requirements).

The second threshold displacement distance will need to be considered to ensure that the remaining part of the runway would be sufficient for all aircraft intended to use SRAP.

The SRAP concept should not negatively impact the airport capacity and therefore the runway exits will need to be assessed ensuring that SRAP will not increase Runway Occupancy Time and thus negatively impact the runway capacity.

VIII.2.1.2 Enhanced Arrival procedures using Increased Glide Slope (IGS)

IGS falls into interval between standard glide slope (3°) and 4.49° (4.50° and steeper slopes represent a steep approach concept for which aircraft shall be certified and the crew shall be trained and authorised). The two glide slopes can be operated simultaneously but aircraft using increased slope generates less noise (up to 3 dBA in approaches between 15 NM and 4 NM from the runway threshold) and also decreases the CO_2 emissions because the aircraft requires less thrust to maintain the increased glide slope.

Increased glide slope can also prevent from usage of aircraft autoland functions because IGS angle may be outside of the descent angle limitations for which the autoland function could be engaged. Therefore, it would be necessary to consult implementation of IGS with the airspace users in advance to ensure they would be able to use IGS and not compromising their safety procedures if the autoland function would not be available for IGS with the existing aircraft fleet.

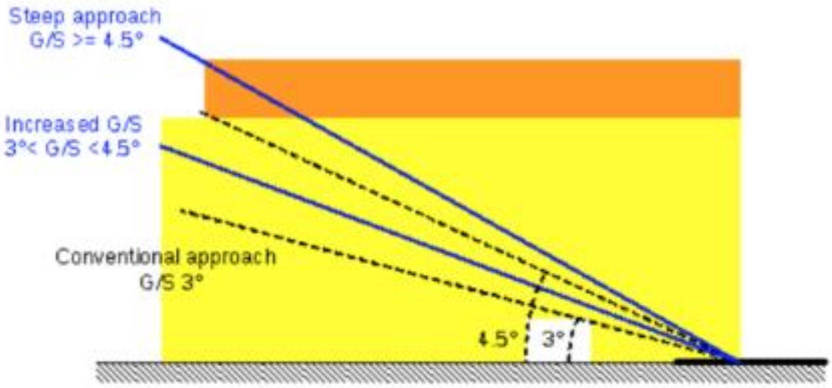


Figure 38: Enhanced arrival procedures: IGS (Source: SESAR PJ02-02-D2.1.046)

VIII.2.1.3 Enhanced Arrival procedures using Adaptive Increased Glide Slope (A-IGS)

A-IGS is a procedure performed by the pilot of an aircraft using on-board flight management function which dynamically calculates the slope according to aircraft characteristics (weight, configuration) and weather (e.g. wind, temperature, air pressure). This procedure aims to reduce noise and fuel burn and seems to be mostly beneficial for lighter aircraft in favourable weather conditions (head wind, higher-density air).

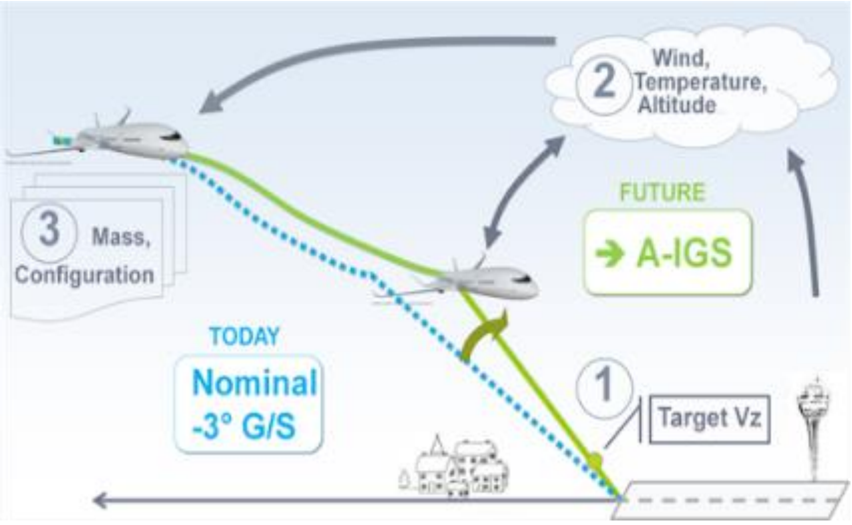


Figure 39: Enhanced arrival procedures: A-IGS (Source: ATAEGINA)

VIII.2.1.4 Enhanced Arrival procedures using an Increased Glide Slope to Second Runway Aiming Point (IGS-to-SRAP)

IGS-to-SRAP is a combination of the procedures mentioned above, applying two aiming points on the single runway, and approaching with increased glide slope. All the previously listed conditions (appropriate runway length, the gliding slope up to 4.49°, etc.) are maintained. Comparing to SRAP, IGS-to-SRAP should allow further reduction of noise impact, CO2 emission reduction and wake turbulence separations.

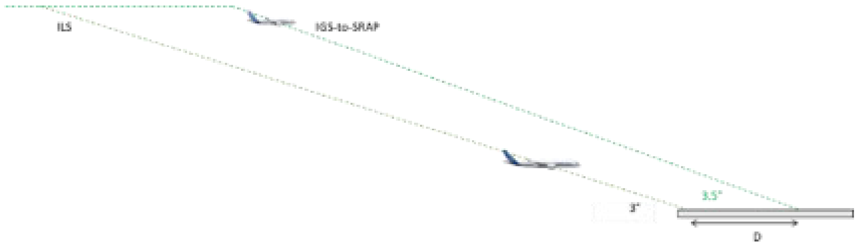


Figure 40: Enhanced arrival procedures: IGS-to-SRAP (Source: PJ.02-W2-14.2 /Release 10)

Introduction of any of the procedures listed in this section is likely to require revision of vertical gradients of currently proposed arrival tubes. Once arrival tubes are revised, impact on departure tubes and their lateral/vertical location needs to be cross-checked to ensure required separations are maintained.

VIII.2.2 Low Power – Low Drag Operations

Aircraft is considered to be operating in Low Power – Low Drag (LPLD) configuration when it maintains a 'clean' configuration for as long as safely possible, i.e. delaying the deployment of flaps, slats, undercarriage and air brakes. A 'cleaner' configuration generally requires lower engine thrust. An aircraft conducting a LPLD approach will generate less engine and less airframe noise.

LPLD is often used in conjunction with CDO. CDO is intended to keep aircraft higher for as long as possible and is acknowledged as being a leading potential technique for the mitigation of aircraft noise and greenhouse gases (GHG) emissions on approach to an airport.

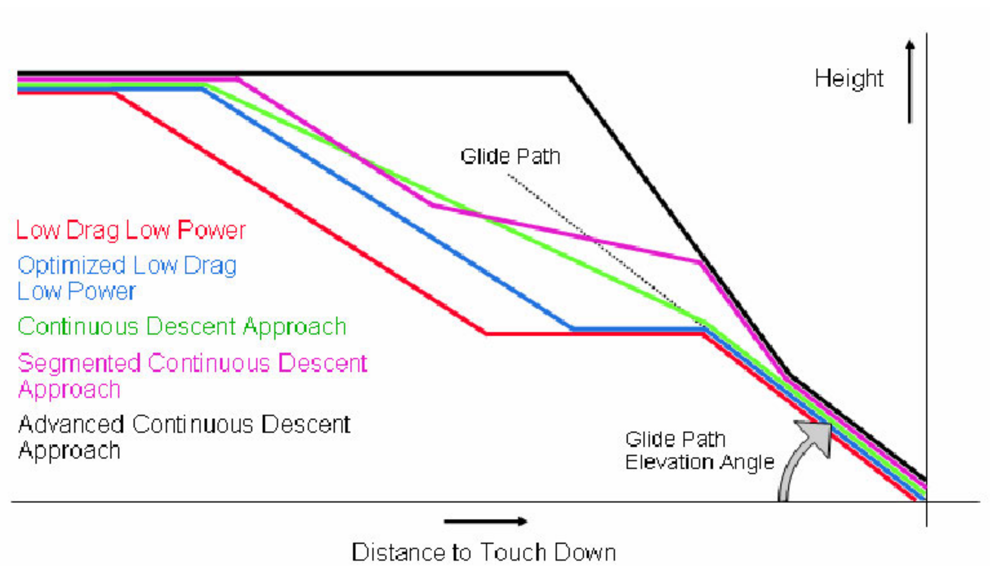


Figure 41: Low Drag Continuous Descent Operations (source: Aircraft Flight Procedure Design with Respect to Noise Abatement as well as Economical and Pilot Workload Aspects)

LPLD can lead to decreased noise levels without additional investments for either airport or aircraft operator. Results of other studies suggest that pilots of wide body aircraft lower their undercarriages earlier than pilots of narrow body aircraft and pilots familiar with the airport have tendency to lower undercarriages later. However, measurement of aircraft entering/exiting LPLD configuration is challenging and currently there seem to be no quick and easy solutions to allow airports measuring LPLD performance.

As LPLD is an aircraft operating procedure, it has no major implications on any of measures proposed for Schiphol TMA. Vertical gradients for arrival tubes will have to be reviewed to ensure that the majority of traffic can operate LPLD within these gradients.

VIII.2.3 Slightly steeper glide path

Slightly steeper glide with vertical gradient of 3.2° can be considered similar technique to IGS Enhanced Arrival Procedures, which use the interval 3° - 4.49°. Increasing the angle at which aircraft fly the final approach track to the runway aims to reduce the impact of noise during the final approach phase. Airports that have investigated and implemented slightly steeper glide paths have used a 3.2° glide path to stay within the aircraft’s certification specification. At 8NM prior to touch down, a 0.2° steeper glide path angle would result in an aircraft being 170ft higher than its usual height at this distance from the runway.

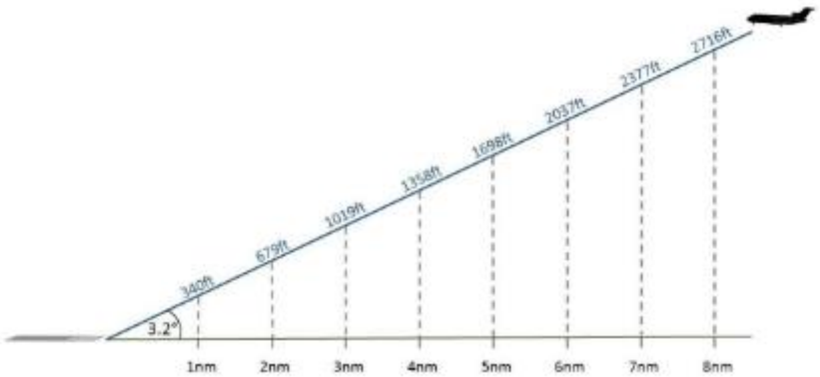


Figure 42: Slightly steeper glide path (Source: 3.2° Slightly Steeper Approach Trial Report, UK CAA)

Manoeuvrability of an aircraft, hence ability to descend using steeper glide path, may be reduced with presence of adverse weather (tailwind, stormy conditions, etc). Decision to maintain a specific configuration of aircraft might affect the rate of descent for certain aircraft types. When proposing this measure, it should be considered also that there is a number of aircraft that might not be certified to perform CAT III approaches with an angle of 3.2°.

As aircraft typically deploy their undercarriage at certain height, this measure leads to its deployment at shorter distance from the threshold, in line with intentions of LPLD measure.

Any change to glide path angle would require review of the proposed set of tubes within Schiphol TMA to ensure proper vertical separations are maintained.

VIII.2.4 Two-segment approach

An alternative concept to a slightly steeper approach is a two-segment approach. A two-segment approach adopts an intermediate approach phase flown at a steeper angle, before transitioning back to a standard 3° glide path. This could potentially provide noise benefits further out during the approach, without affecting the final approach phase.

There are several ways how the approach procedure could be flown: (1) the traditional stepped approach with level segments (which can, in some scenarios provide more noise respite than a traditional CDO), (2) traditional CDO and (3) approach procedure with variations of descent gradient. However, any reduction in noise footprint resulting from varying the approach angle depends on how steep the initial segment of the approach profile is. In any case, environmental modelling would be required to understand exact noise impacts.

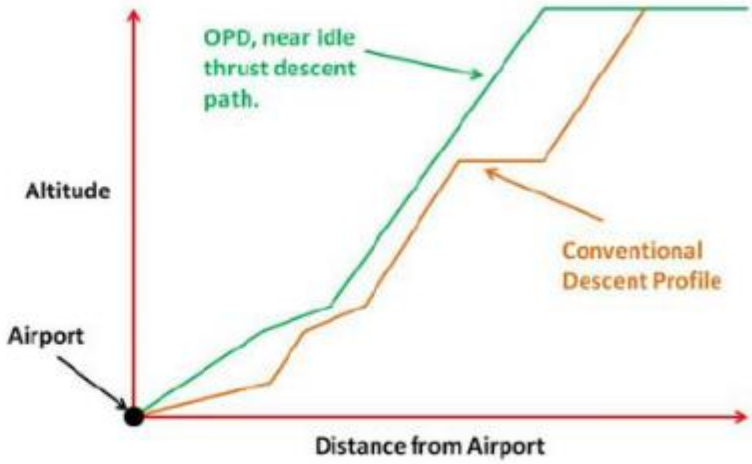


Figure 43: A two-segment approach (source: Optimized Profile Arrivals at Los Angeles International Airport, Clarke, John-Paul & Brooks, J. & Nagle, G. & Scacchioli, Annalisa & White, W. & Liu, Sandy)

Two segment approach has direct impact on all potential arrival measures, namely low power – low drag, angle of glide path and enhanced arrival procedures. Two segment approach can be coupled with increased glide slope during the first phase of the approach. Different arrival procedures will have different requirements on what the descent gradient should be and whether it should change throughout the descent. Low power – low drag operations might not be fully feasible for all aircraft types if the descent gradient is exactly specified, mainly because some modern aircraft types might struggle to descend and decelerating at the same time.

Primary impact on departure gradient or tracking of flights up to 6,000ft is considered low as two segment approach does not concern departure operations directly. Secondary impact on these measures might be present in case of conflict between arrival and departure streams of traffic. The tubes, as currently considered, assume single vertical gradient throughout the approach (within the extent of the tube). Introduction of two segment approach will likely require increase in vertical dimension of the approach tube - this may make it span close enough to existing departure tubes, which, in turn, will require the routes to be separated further - either horizontally or vertically. In such case, a major revision of the vertical gradients applicable for the tubes will be needed to account for different gradients utilised at different segments of the approach.

Two segment approach will impact the efficiency of wake-optimised arrival separation concepts. With certain combinations of descent gradients, atmospheric conditions, and aircraft types/performance it may not be feasible to stick to the most efficient separations.

Besides other measures, airline procedures and atmospheric conditions have to be taken into account when designing two segment approaches.

VIII.2.5 Minimum-Pair separations based on Required Surveillance Performance (RSP)

During peak hours all aircraft pairs, even if not constrained by any other separation standards (e.g., wake separations), should respect surveillance minima. This means that for airports with few or no Heavy aircraft imposing wake separation, increased throughput can only be achieved by the reduction of these surveillance separation minima. Moreover, the efficient use of time-based separation can only be achieved by allowing 2NM separation between pairs constrained by 2.5NM MRS (Minimum Radar Separation) in case of moderate and strong headwind on the straight-in final approach track.

Based on the results of SESAR PJ.02-03 validations, the reduction of the in-trail Minimum Radar Separation from 2.5NM to 2NM on final approach with a controller support tool (such as the ORD (Optimised Runway Delivery) tool) has fulfilled the criteria to achieve the maturity level. However, more validation activities, namely real time simulations, are required in order for the in-trail Minimum Radar Separation from 2.5 NM to 2NM on final approach without a controller support tool.

This concept has a potential to further reduce arrival-arrival separations in order to improve arrival throughput. As the throughput increases, aircraft that would have to spend more time in an airborne hold or be vectored will gain additional efficiencies through reduced track miles flown (and associated reduction in fuel and emissions).

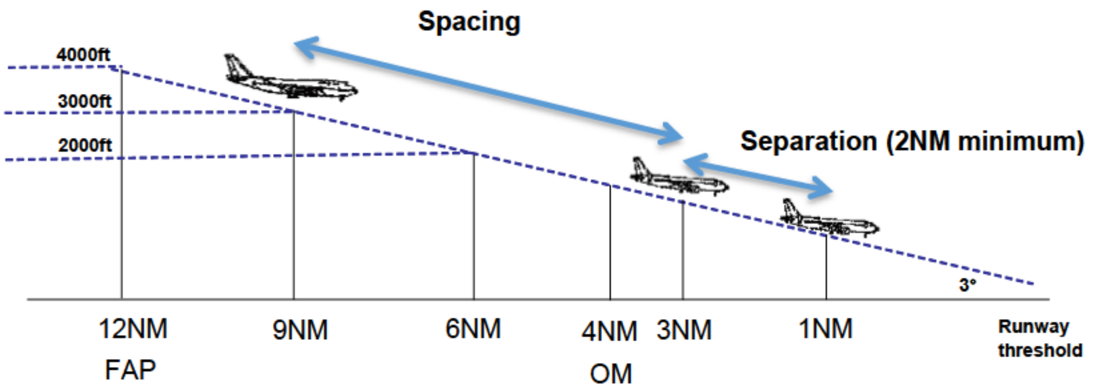


Figure 44: Differences in concepts of spacing vs. minimum separation (Source: SESAR PJ.02-03-D3.1.013)

FAA (Federal Aviation Administration) has introduced the concept at Memphis airport since November 2012 and achieved 15 percent increase in capacity[32] . More major airports have been included into the list since then[33].

VIII.2.6 Traffic optimisation on single and multiple runway airports

SESAR Solution PJ.02-08 'Traffic Optimisation on single and multiple runways' focuses on improving single and multiple runway airport operations by:

[32] https://www.faa.gov/newsroom/memphis-recat-increases-capacity-significantly

[33] https://www.faa.gov/other_visit/aviation_industry/airline_operators/airline_safety/safo/all_safos/media/2012/SAFO12007.pdf

- Increasing the capacity, predictability and punctuality as well as fuel efficiency through the management of an Integrated Runway Sequence, or with a combination of optimised runway configuration management and Integrated Runway Sequence in case of multiple runways;
- Increased Runway Throughput based on local ROT (Runway Occupancy Time) categorisation (ROCAT) and Increased Runway Throughput based on AROT (the time interval between the aircraft crossing the threshold and its tail vacating the runway) optimisation.

The one considered the most relevant for Schiphol TMA is 'Increased Runway Throughput based on local ROT characterization (ROCAT)' a concept that intends to reduce the in-trail separation on final approach with the aim of increasing runway throughput by taking into account the Runway Occupancy Time (ROT). The most constraining factor for the reduction of the separation is, together with the wake turbulence, the ROT; and therefore a new separation minimum could be computed based on the prediction of the ROT, the Minimum Radar Separation and the wake categorization separation.

ROCAT can increase runway throughput by up to 12% where the aircraft traffic mix is predominantly medium aircraft, especially where reduced wake separation using RECAT is inefficient due to the lack of wide-body aircraft types in the traffic mix.

VIII.2.7 Synchronization of departing traffic flows from multiple airports

The concept of synchronization of departing traffic flows from multiple airports aims to process the departure traffic flows interactions with traffic flows from adjacent airports within the same TMA.

As described by the SESAR Solution PJ.01-02 departure information is compiled and presented to the TMA Supervisor to allow adjustment to the departure flows and enable a more consistent and manageable delivery into the en-route phase of flight. The system also provides automated support to departure metering and/or coordination of dependent traffic flows from multiple airports. Where an excess of demand over capacity is predicted within the TMA that may negatively affect delivery of traffic into en-route, additional capacity, e.g. use of an alternate systemised route, should be made available where possible. Only if no further capacity can be added should demand be modified by changing the departure sequence from one or more airports.

This concept is potentially relevant for Schiphol TMA as (if) the traffic at Lelystad and Rotterdam increases.

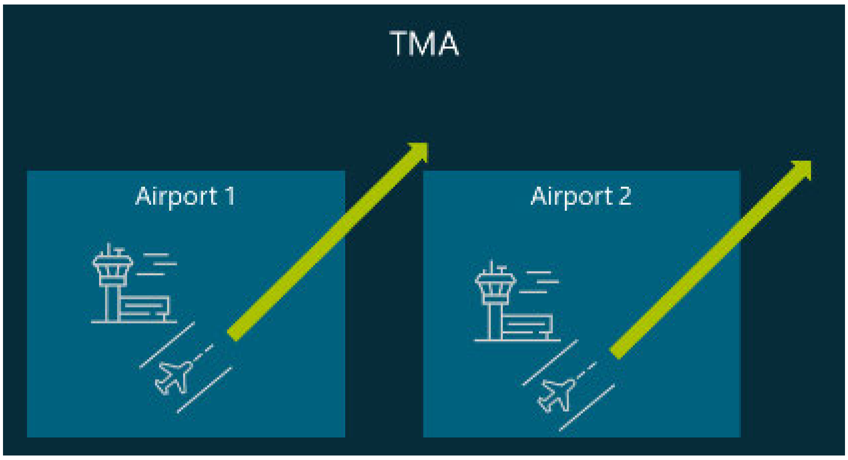


Figure 45: Synchronization of departing traffic flows from multiple airports

Synchronisation of departures from multiple airports could reduce ATCO workload as any two departures heading towards the same TMA exit point could be synchronized to minimize the risk of potential conflict. This could also have a minor impact on fuel burn and flight delays.

VIII.2.8 RNP less than or equal to 0.3NM

RNP 0.3 (or below) might provide space for minor optimisation of horizontal position of tubes envisaged within Schiphol TMA. These changes, when quantified, are likely to lead to reduction in distance flown and fuel burned, however, these improvements are likely to be very marginal. Greater concentration of RNP 0.3 trajectories may also lead to marginal changes in noise footprint.

As the route "buffer" will be smaller, more routes can fit into the same volume of airspace. In that case, re-evaluation of potential interactions between departure and arrival tubes will be needed; not only for airport-specific tubes, but also for all three airports combined. However, if the currently proposed route structure remains as is (i.e. no further optimisation of the tubes network is needed), the change to RNP 0.3 will not bring any significant operational benefits. In general, environmental implications are still unknown.

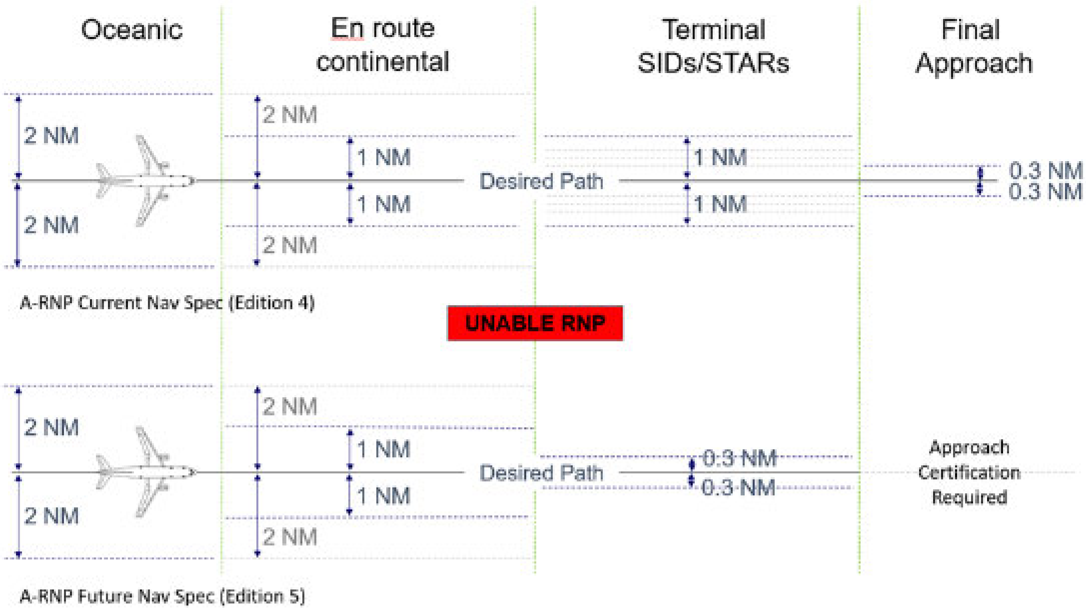


Figure 46: RNP less than or equal to 0.3 NM (source: pbnportal.eu, EUROCONTROL)

A-RNP is foreseen to be an enabler for independent parallel approach operations (Mode 1). For runway spacings with a minimum distance between runway centrelines of 2224m (4 x 0.3NM = 2224m), +/- 0.3 NM performance outside the FAF/FAP is required[34] being a significantly better performance than the +/- 1 NM provided by RNP APCH in the initial and intermediate phases of the approach.

[34] https://pbnportal.eu/epbn/main/Overview-of-PBN/PBN-Concept---Unpacked/PBN-Applications/Terminal-Operations.html?queryStr=a-rnp

VIII.3 Annex 3: Interdependencies between the investigated measures

As a number of additional, potentially interesting measures have been identified as part of this research, a mapping of impact of these measures on the existing set of measures considered by DARP was developed. This is presented in the tables below. Each table maps likely interdependencies between one of the main measures considered by DARP and a set of other measures identified in this research.

VIII.3.1 Accuracy of delivery – interdependencies with other measures

Potential measures of influence	Impact	Occurrence probability	How (mechanism) and to what extent can this potential measure influence delivery to the Schiphol TMA?
Letterboxes and gateways in the sky	high	low	This measure is technically similar to intended Tubes concept. As such, the impact on traffic delivery (or impact of traffic delivery on letterboxes/gateways) is considered similar to impact on the tubes concept.
Point merge	medium	high	In 2035 scenario, the merge point for inbound traffic is expected to be located outside the TMA. In combination with time-based operations, merging the traffic before reaching the TMA is expected to introduce significant benefits in traffic predictability, possibly opening the way for arrivals to operate on the full extent of the arrival tube (not possible in 2025 scenario due to the need to compensate for inaccuracies in traffic delivery by use of vectoring between TMA entry fix and 6,000 ft).
Wake turbulence separation optimisation - arrival concepts	high	medium	In order for the wake-optimised arrival separation concepts work efficiently, a timely, predictable and reliable delivery of traffic to the TMA is a pre-requisite to allow ATCO to form efficient aircraft pairs, be it time-based separation, pairwise separation or other. A flight delivered earlier than planned will have to be vectored to ensure proper separation from the leading flight, while a flight delivered late would lead to separation from the preceding aircraft being greater than required - this could then cause deterioration in runway throughput. However, investigating (quantifying) possible interdependencies of numerous wake turbulence separation techniques would be a project on its own.
Sequence optimisation and delivery in overlapping extended AMAN horizons within high complexity airspace environments	high	low	AMAN extended into en-route (and integrated with demand capacity balancing) would help with management of arrival streams where one (or more) aircraft failed to be delivered into TMA with required accuracy. By being able to "look" beyond TMA boundary, this system could be able to better predict EAT.
Enhanced arrival management to collaborate with non-local departure management	high	low	Potentially relevant for a TMA containing Schiphol, Lelystadt and Rotterdam, but since this topic is related to management of traffic more than to airspace structure, we'd propose not to evaluate it as part of our research. However, this concept has a potential to collect and process estimated times for all arrivals and departures in the TMA and then advise on the most optimal distribution of runways, SIDs, STARs and traffic flows. With regards to delivery to TMA measure, this concept could provide useful in constructing the arrival sequence of arrivals with poor accuracy of delivery, as the system would know how the expected accuracy of delivery of each flight evolves in time and could plan for this accordingly.

Potential measures of influence	Impact	Occurrence probability	How (mechanism) and to what extent can this potential measure influence delivery to the Schiphol TMA?
Coupled sequencing tool enhanced to better handle arrivals and departures	medium	low	Potentially relevant for a TMA containing Schiphol, Lelystadt and Rotterdam, but since this topic is related to management of traffic more than to airspace structure, we'd propose not to evaluate it as part of our research. However, the system should be able to support further optimisation of traffic delivered to the TMA with greater inaccuracy, as the system would likely have the information on changes in expected time of delivery in advance, thus allowing enough time for better optimisation of the arrival sequence.
Trajectory Based Operation	medium	medium	According to Airbus, TBO has a potential to reduce inaccuracy in traffic prediction calculations by 30-40% through sharing of detailed and timely updated 4d trajectory data with the key stakeholders. This should have beneficial effect on accuracy in traffic delivery and subsequent arrival stream.

VIII.3.2 Tracking of tubes – interdependencies with other measures

Potential measures of influence	Impact	Occurrence probability	How (mechanism) and to what extent can this potential measure influence issues/hotspots?
Enhanced arrival procedures	low	medium	All of the currently considered departure tubes have the "6,000 ft" point located well above any arriving traffic. This is down to the climb gradient being proposed greater than arrival gradient. Therefore, any vectoring from 6,000ft or above could take place without being influenced by roll-out of enhanced arrival procedures or steeper glide paths. The only combination of parameters that could lead to interference between arriving traffic and traffic leaving the tube at 6,000ft would be a situation with extremely high descent gradients and extremely low departure gradients being implemented at the same time.
Slightly steeper glide path	low	high	The only possible influence of introduction of steeper glidepaths on the need to follow SIDs to 6,000ft would be around interactions between arrival and departure streams of traffic. If the steeper glide paths end up being implemented, a careful assessment of potential conflicts of arrival/departure tubes will have to be performed.
Synchronization of departing traffic flows from multiple airports	low	medium	Synchronisation of departures from multiple airports provides opportunities for decreasing ATCO workload through minimisation of potential conflicts of two departures heading towards the same TMA exit point. If the two departures are heading towards the same exit point, one may be postponed on the ground for a while (incurring departure delays) to minimise the need to apply vectoring to keep the departures separated. A careful consideration will be needed to ensure that traffic at neither of the airports is unduly penalised (e.g. all Lelystadt or Rotterdam departures being always postponed ensuring synchronisation with Amsterdam traffic).
RNP less than or equal to 0.3NM	low	medium	Reduction of horizonal separations from 1NM to 0.3NM or less would have potential to make the "width" of the tubes narrower. This could provide limited options for further optimisation of the tubes. However, the overall impact is considered low, given the volume of airspace around the tube (potentially freed up by introduction of RNP<= 0.3) would be small.
Point merge	high	low	Point merge is considered a potentially high impact event as it is likely to take up large volumes of airspace, therefore potentially impacting several departure tubes and introducing additional constraints on possible vectoring from above 6,000 to TMA exit point. Either the "6,000ft point" and TMA exit point would have to be designed laterally outside of potential conflict with point merge traffic, or the separation would have to be enforced through vertical dimension - e.g. if the PM was established, the traffic may be able to leave departure tube not at 6,000ft but later.
Improved parallel approach operations using PBN	medium	low	Introduction of parallel approach operations using PBN will complicate options for assigning DCT to TMA exit point after climbing over 6,000ft. The departure will have to be clear of not just one, but two arrival streams of traffic spaced close to each other.
Wake turbulence separation optimisation - departure concepts	low	medium	Optimisation of the wake turbulence separation on departure may lead to greater departure throughput which may result in more aircraft operating on the same departure tube at a time. If the aircraft follow the departure tube longer, aircraft wake vortex separation on the tube might become the primary restrictive

Potential measures of influence	Impact	Occurrence probability	How (mechanism) and to what extent can this potential measure influence issues/hotspots?
			factor for smooth and efficient expedition of departures from the runway.
Enhanced arrival management to collaborate with non-local departure management	high	low	Potentially relevant for a TMA containing Schiphol, Lelystadt and Rotterdam, but since this topic is related to management of traffic more than to airspace structure, we'd propose not to evaluate it as part of our research. However, this concept has a potential to collect and process estimated times for all arrivals and departures in the TMA and then advise on the most optimal distribution of runways, SIDs, STARs and traffic flows. With regards to tracking of tubes up to 6,000ft, this concept could provide useful in identifying which flights could leave the tube towards the TMA exit point at what altitude without causing interference with other traffic.

VIII.3.3 Continuous climb operations – interdependencies with other measures

Potential measures of influence	Impact	Occurrence probability	How (mechanism) and to what extent can this potential measure influence climb gradient?
Enhanced arrival procedures	low	medium	Primary impact is considered low, as enhanced arrival procedures do not concern departure operations. Secondary impact on climb gradient might be present in case of conflict between arrival and departure streams of traffic. In such case, climb gradient might have to be changed to accommodate enhanced arrival procedures.
Slightly steeper glide path	low	high	Primary impact is considered low, as steeper glidepaths do not concern departure operations. Secondary impact on climb gradient might be present in case of conflict between arrival and departure streams of traffic, however, this is considered less probable, as "slightly steeper" in this context means a fraction of percent or degree and not a change in the climb gradient significant enough to warrant relocation of departure tubes.
Synchronization of departing traffic flows from multiple airports	medium	medium	If this measure is implemented, climb gradients utilised on tubes from all airports included in the synchronised departures operations will have to be set up taking into account operational differences between the airports involved, for example different fleet mix/aircraft performance. This may lead to vertical dimension of the departure tube to be greater than in case of a tube designed just for a single airport. Alternatively, departure gradients applied at different airports may be different, to account for local differences in climb performance. In any case, utilising synchronised departures concept would require additional review of potential conflicts with arrival traffic.
Point merge	high	low	Point merge is considered a potentially high impact event as it is likely to take up large volumes of airspace, therefore impacting several departure tubes and requiring the climb gradient on these tubes to be high enough to allow departing traffic to operate above the sequencing legs of the point merge. Alternative would be to let departures operate below the traffic arriving on the point merge, however, this would come at a cost of higher noise footprint and potentially increased fuel burn.
Enhanced terminal area for efficient curved operations	high	low	The goal of this measure is to use geometric vertical navigation guidance in the TMA (to simplify operations by removing the workload associated with the transition from barometric to geometric vertical navigation) together with the use of curved segments as close to the runway as possible to optimise procedures in terms of fuel consumption or noise abatement. This concept is expected to be relevant in far future (i.e. post 2035) and as such it is not suggested for further investigation. However., if implemented, it would require revision of climb gradients in line with navigational capabilities of aircraft and their flight performance - which (by the time the concept is implemented) are both likely to be significantly different to what they are now.
Wake turbulence separation optimisation - departure concepts	low	medium	Various wake turbulence separation techniques are considered in this measure. The expected mechanism of influence on climb gradient will be based on separation technique used, aircraft types being separated and their performance. In certain (less likely) combinations of these parameters it could potentially happen that two departures could be demanding to operate on the same departure tube, with the leading aircraft performance allowing slower climb than the climb rate achievable by the following aircraft. in such situation it would be necessary to

Potential measures of influence	Impact	Occurrence probability	How (mechanism) and to what extent can this potential measure influence climb gradient?
			identify suitable resolution technique - vectoring of either of the aircraft out of the tube, delaying the subsequent aircraft on the ground, or, modifying the vertical gradient of the tube to allow the aircraft with worse performance to operate on the bottom edge of the tube with the high performance aircraft potentially overtaking it using top edge of the tube while ensuring proper vertical separation.
Enhanced arrival management to collaborate with non-local departure management	high	low	Potentially relevant for a TMA containing Schiphol, Lelystadt and Rotterdam, but since this topic is related to management of traffic more than to airspace structure, we'd propose not to evaluate it as part of our research. However, this concept has a potential to collect and process estimated times for all arrivals and departures in the TMA and then advise on the most optimal distribution of runways, SIDs, STARs and traffic flows. With regards to climb gradient, this concept should be able to work with different climb gradients depending on the aircraft performance.
Fleet developments	low	medium	Impact of fleet is considered to be reflected through different fleet mixes planned to be used in the simulations. It was also agreed that impact of those aspects of fleet renewal that cannot be simulated (such as electric or hydrogen propulsion) will be assessed qualitatively only.

VIII.3.4 Continuous descent operations – interdependencies with other measures

Potential measures of influence	Impact	Occurrence probability	How (mechanism) and to what extent can this potential measure influence descent gradient?
Enhanced arrival procedures	high	medium	Different enhanced procedures will have different requirements on what the descent gradient should be. In other words, if the enhanced procedures are going to be implemented, the proposed vertical gradient needs to take this into account. In some cases, like SRAP, the variation in required vertical gradient can be significant.
Low power - log drag continuous descent operations	low	high	Experience from other airports (LHR, LGW) that introduced LPLD operations shows that no revision of existing vertical gradient was required. On-board speed management can be used to operate with the required vertical gradient. Moreover, introduction of "allowed ranges" of vertical gradients will ensure there is enough "room" for most of aircraft types to operate LPLD within the vertical extent of the arrival tube. A consideration needs to be made for potentially overly steep vertical profiles as some modern aircraft types may have difficulties decelerating and slowing down at the same time, while being on the tube, without exiting LPLD configuration.
Slightly steeper glide path	high	high	This measure is expected to have direct impact on descent gradient - as a result of introducing steeper glide paths, the descent gradient will have to increase.
Two-segment approach	high	low	If this enabler is going to be introduced, a major revision of the vertical gradients applicable for the tubes will be needed to account for different gradients utilised at different segments of the approach. The tubes, as currently considered, assume single vertical gradient throughout the approach (within the extent of the tube). However, two segment approach is likely to need greater vertical extent of the tube, potentially increasing number of conflicts with departure tubes.
Traffic optimisation on single and multiple runway airports	low	medium	Optimising runway throughput through introduction of aircraft categorisation based on runway occupancy times is unlikely to have impact on descent gradient. Regardless of the descent gradient used, the flare phase of flight (immediately before touch-down) is always carried out in level flight and in a speeds largely independent of the descent gradient used.
Point merge	low	low	If introduced, descent gradient will apply from the merge point to runway threshold. Therefore, the PM system would not have direct (or only low) impact on what vertical gradients will be declared between the merge point and the runway.
Noise abatement operational procedures: displaced landing thresholds	high	low	Introduction of displaced threshold would require changes to the descent gradient considered for the tube. If both the original and displaced thresholds were to be served through the same arrival tube, the high boundary of the rage of values considered for the descent gradient would have to be increased. However, real world implementations of displaced thresholds showed limited benefits in terms of noise footprint reduction - at a cost of reduced landing distance available (which might have a psychological effect on pilots).
Enhanced terminal area for efficient curved operations	high	low	The goal of this measure is to use geometric vertical navigation guidance in the TMA (to simplify operations by removing the workload associated with the transition from barometric to geometric vertical navigation) together with the use of curved segments as close to the runway as possible to optimise procedures in terms of fuel consumption or noise abatement. This

Potential measures of influence	Impact	Occurrence probability	How (mechanism) and to what extent can this potential measure influence descent gradient?
			concept is expected to be relevant in far future (i.e. post 2035) and as such it is not suggested for further investigation. However., if implemented, it would require revision of descent gradients in line with navigational capabilities of aircraft and their flight performance - which (by the time the concept is implemented) are both likely to be different to what they are now.
Wake turbulence separation optimisation - arrival concepts	high	medium	In order for the wake-optimised arrival separation concepts work efficiently, a timely, predictable and reliable delivery of traffic to the TMA is a pre-requisite to allow ATCO to form efficient aircraft pairs, be it time based separation, pairwise separation or other. With certain combinations of descent gradients, atmospheric conditions, and aircraft types/performance it may not be feasible to stick to the most efficient separations - mainly because some modern aircraft types have difficulties descending continuously and decelerating at the same time (especially if a LPLD requirement is in place). Depending on the choice of wake turbulence separation method, the descent gradient will have to be reviewed/adjusted to accommodate at least the most frequent aircraft pairs comfortably at majority of conditions.
Sequence optimisation and delivery in overlapping extended AMAN horizons within high complexity airspace environments	high	low	AMAN extended into en-route (and integrated with demand capacity balancing) would help with management of arrival streams where one (or more) aircraft failed to be delivered into TMA with required accuracy. By being able to "look" beyond TMA boundary, this system could be able to support CDOs from the ToD, while managing multiple ToDs at once.
Enhanced arrival management to collaborate with non-local departure management	high	low	Potentially relevant for a TMA containing Schiphol, Lelystadt and Rotterdam, but since this topic is related to management of traffic more than to airspace structure, we'd propose not to evaluate it as part of our research. However, this concept has a potential to collect and process estimated times for all arrivals and departures in the TMA and then advise on the most optimal distribution of runways, SIDs, STARs and traffic flows. With regards to descent gradient, this concept should be able to work with different descent gradients depending on the aircraft performance.
Fleet developments	low	medium	Impact of fleet is considered to be reflected through different fleet mixes planned to be used in the simulations. It was also agreed that impact of those aspects of fleet renewal that cannot be simulated (such as electric or hydrogen propulsion) will be assessed qualitatively only.

VIII.3.5 Horizontal spacing – interdependencies with other measures

Potential measures of influence	Impact	Occurrence probability	How (mechanism) and to what extent can this potential measure influence horizontal spacing?
Two-segment approach	high	low	Introduction of two segment approach will likely require increase in vertical dimension of the approach tube - this may make it span close enough to existing departure tubes, which, in turn, will require the routes to be separated further - either horizontally or vertically.
CAP 1385	high	low	The key recommendations for terminal airspace revolve around route spacing and define minimum acceptable route spacing in terminal airspace as "minimum radar separation + <0.8 NM; 3.4NM>, depending on the type of route interaction. Adapting recommendations from CAP1385 would require categorisation of proposed tubes into one of the nine categories available in CAP1385 and applying corresponding route spacing minima.
Minimum-pair separations based on required surveillance performance (RSP)	high	medium	introduction of this measure may be required if time based separation is to be used in strong headwind conditions. If implemented, the horizontal separation between aircraft pairs not restricted by the wake vortex separation might reduce, therefore allowing improved runway throughput.
Synchronization of departing traffic flows from multiple airports	low	low	Introduction of reduced horizontal spacing may provide opportunities for better optimisation of departure tubes from two different airports leading to the same TMA exit point.
RNP less than or equal to 0.3NM	high	medium	Introduction of this measure will make the tubes "narrower", allowing further lateral (and vertical) optimisation of position of the tubes. Having the confidence that the aircraft will fly within the pre-defined area will free up other parts of the airspace for minor adjustments.
Letterboxes/gateways in the sky	low	low	This concept is technically similar to concept of the "Tubes" - introduction would mean revision of suitable locations of gateways and letterboxes, but in general, it is expected these could remain roughly at the positions expected by the current "plus and cross" concept.
Point merge	medium	low	Introduction of point merge concept would take up much of the airspace volume. Such a major change of airspace infrastructure would require revision of locations of the tubes, incl. their horizontal spacing from each other and from the point merge.
PBN mixed mode operation	high	high	If the mixed mode concept is going to be adapted, the horizontal dimension of the tube would have to be designed to accommodate the aircraft with the worst intended navigational capabilities. So, the "target navigational capability" is likely to be the key driver for width of the tubes. This will, in turn, have impact on how far from each other can the tubes be located.
Improved parallel approach operations using PBN	high	low	This concept covers independent parallel approaches where PBN is used to increase segregation of arrival flows to the parallel runways, and to ensure a standard interception of the extended runway centreline. It relies on pre-defined trajectories prior to final approach and the application of RNP navigation specifications. The candidate solution addresses two options to join the PBN transitions: merging to a point or merging to an axis. Introduction of this concept could require "doubling" of the arrival tubes leading to parallel runways and revisiting the horizontal position of these tubes.

Potential measures of influence	Impact	Occurrence probability	How (mechanism) and to what extent can this potential measure influence horizontal spacing?
Wake turbulence separation optimisation - arrival concepts	high	medium	Required horizontal separation will be influenced by wake vortex separation between the leading and following aircraft type. In other words, if the optimised wake vortex separation is greater than the minimum radar separation then the larger of the two would have to be maintained. Optimised departure separation (REACT-EU or pairwise). However, impact of various separation techniques and separation matrixes would require a study on its own due to the breadth of the topic.
Wake turbulence separation optimisation - departure concepts	high	medium	
Wake turbulence separation optimisation - wake decay enhancing devices concept	medium	low	Wake decay enhancing tools may allow for reduced wake vortex separations through faster elimination of wake vortices. The technology is nearing maturity levels, but its direct operational impact remains largely unknown.

VIII.3.6 Vertical spacing – interdependencies with other measures

Potential measures of influence	Impact	Occurrence probability	How (mechanism) and to what extent can this potential measure influence vertical spacing?
Enhanced arrival procedures	high	medium	Different enhanced arrival procedures will have different requirements on what the descent gradient should be. Adjusting the descent gradient according to arrival procedure chosen will have impact on vertical spacing between arrival and departure tubes. Choosing vertical dimension of the tube wide enough to accommodate various arrival procedures and aircraft performance levels will likely lead to more interference with planned departure tubes.
Slightly steeper glide path	low	high	This measure is expected to have direct impact on descent gradient - as a result of introducing steeper glide paths, the descent gradient will have to increase - this will, in turn, require revision of vertical spacing between the tubes.
A two-segment approach	high	low	Introduction of two segment approach will likely require increase in vertical dimension of the approach tube - this may make it span close enough to existing departure tubes, which, in turn, will require the routes to be separated further - either vertically or horizontally.
Synchronization of departing traffic flows from multiple airports	low	low	Introduction of reduced vertical spacing may provide opportunities for better optimisation of departure tubes from two different airports leading to the same TMA exit point.
Letterboxes/gateways in the sky	low	low	This concept is technically similar to concept of the "Tubes" - introduction would mean revision of suitable locations of gateways and letterboxes, but in general, it is expected these could remain roughly at the positions expected by the current "plus and cross" concept
Point merge	medium	low	Introduction of point merge concept would take up much of the airspace volume. Such a major change of airspace infrastructure would require revision of locations of the tubes, incl. their vertical spacing from the point merge system
Enhanced terminal area for efficient curved operations	medium	low	The goal is to use geometric vertical navigation guidance in the TMA (to simplify operations by removing the workload associated with the transition from barometric to geometric vertical navigation) together with the use of curved segments as close to the runway as possible to optimise procedures in terms of fuel consumption or noise abatement. As this is a relatively early concept, its implications on possibility to reduce vertical spacing further are unclear. However, the impact is marked as "medium" as the hypothesis is that geometric altitude information will be significantly more accurate than currently used barometric altitude information, which is often dependent on mainly pressure and temperature and can sometimes provide skewed values. Introduction of geometric vertical navigation will significantly improve predictability of vertical position of the traffic, possibly allowing further reduction in vertical spacing.
WG-85 intentions			The latest revisions of WG-85 documents (available to us in WG85 working space) were not related to the topic of reducing vertical spacing. Therefore, the current intentions of WG85 in this domain remain unknown.

Potential measures of influence	Impact	Occurrence probability	How (mechanism) and to what extent can this potential measure influence vertical spacing?
Safety nets			While we agree safety nets will play an increasingly significant role in high density and high complexity scenarios, they themselves do not allow reduction in separations. They merely provide ATCO a last resort in case of loss of separation. Similar case would be ATCO tools, or modifications to HMI, or enhanced flow planning and control techniques - neither of which we consider in scope of this research. However, safety nets, ATCO tools and proper HMI set-up all contribute to ATCO comfort margin applied on top of required minimum separations to account for pilot reaction time, weather conditions, aircraft performance or other uncertain variables.
Fleet developments			Impact of fleet is considered to be reflected through different fleet mixes planned to be used in the simulations. It was also agreed that impact of those aspects of fleet renewal that cannot be simulated (such as electric or hydrogen propulsion) will be assessed qualitatively only.

VIII.4 Annex 4: Data, assumptions, and models used for assessment of quantitative performance of selected measures

The majority of quantitative research tasks in this study have been executed through the use of airspace/airport fast time simulation model(s) and environmental models. The results of any modelling activity are dependent on input data and assumptions used. This section provides overview of the key assumptions and data relevant to each model used.

VIII.4.1 Fast time simulation model, data, and assumptions

The fast time simulation model of Schiphol TMA has been developed in AirTOp.

AirTOp is the latest generation fast-time simulator capable of simulating almost any aspects of gate-to-gate aviation operations. Be it airport, TMA or en-route movements, passenger handling within the terminal building or even detailed aircraft turnaround and ground handling processes, AirTOp provides a single sophisticated solution that can be used to increase insight for almost all types of airport and airspace problems. AirTOp has been used worldwide by dozens of air navigation service provides, airports and civil aviation authorities for several years, and it has been also used by EUROCONTROL and FAA for airspace analysis.

AirTOp is a rule-based fast time simulator, which means that although it has some pre-defined operational concepts (like, for example, wake vortex separations), all the other actions it can simulate must be pre-defined as a set of conditions, triggering events or combination of the two. As a result, only the pre-defined rules can be triggered which means that it is not feasible to define, in a great level of detail, every potential situation that could occur in the modelled scenario. As such, fast time models are generally used to test a greater number of options before a subset of candidate solutions is brought forward for further testing (for example through real time simulations).

All the functionality of AirTOp is divided across several modules. The modules utilised for this research included airport ground module, TMA module and en-route module.

Using a combination of historic and current data, complemented with inputs and assumptions from DARP stakeholders, Egis developed a model that simulates airspace operations from the Schiphol TMA boundary (TMA entry fix) to runway threshold. In the opposite operating direction, departures are modelled from the runway threshold to crossing the boundary of the FIR Amsterdam. Full en-route operations or airport ground operations are not modelled.

In some scenarios, both arrival and departure flows are modelled. Where this is the case, the FTS engine is actively monitoring departure flows to be able to intervene where conflict with arrivals might have occurred. In such cases, the arriving traffic has priority, and the departures are either delayed on ground, or spaced vertically from the arriving traffic.

A baseline model has been developed for both 2025 and 2035 time horizons considered in this study. Selected parameters of the baseline model have then been modified to allow the model to test sensitivity of selected airspace measures. The table on the next page provides the list of the key data and assumptions used to develop the baseline model.

RTS1a and RTS1b traffic samples provided by LVNL were used for the model. These traffic samples were developed for a very specific purpose, namely to answer the research questions. Therefore, the necessary traffic situations were tailor-made within the sample and the traffic levels were increased to counter for a RTS-simulation-effect. Due to that the samples are not 100% realistic but are considered sufficient for this study.

AirTOp model	2025 time horizon	2035 time horizon
Waypoints	AIRAC 2107	
Airspace polygons	AIRAC 2107, provided by LVNL where required	
Airport database	AIRAC 2107	
Runway physical characteristics	LVNL AIP effective 07 Oct 2021	
Arrival and departure "tubes" (conceptual)	Provided by LVNL	
New waypoints	Provided by LVNL, added by Egis where required	
Fleet mix	2019 fleet mix assumed satisfactory match for 2025 traffic	Changes in fleet mix identified for 2035 scenario. Electric, hydrogen or other alternative propulsion methods not simulated as estimated to be low in numbers.
Traffic samples	Selected RTS1a and RTS1b traffic samples used where possible	RTS1a and RTS1b traffic samples upscaled to reach PlanMER runway throughput estimated in 2035 (where required), fleet mix changes applied
Aircraft performance model	EUROCONTROL BADA	
Primary configuration for departure peak	24 + 18L for departures and 18R for arrivals	
Secondary configuration for departure peak	36L+ 36C for departures and 06 for arrivals	
Primary configuration for arrival peak	24 for departures and 18R + 18C for arrivals	
Secondary configuration for arrival peak	36L for departures and 06 + 36R for arrivals	
Primary configuration used in 2 + 2 mode	24 + 18L for departures and 18R + 18C for arrivals	
Secondary configuration used in 2 + 2 mode	36L + 36C for departures and 06 + 36R for arrivals	
Minimum radar separation	3NM inside Schiphol TMA	2.5NM inside Schiphol TMA
Aircraft wake vortex separations	RECAT-EU	Pair-wise separation

AirTOp model	2025 time horizon	2035 time horizon
Schiphol TMA entry fix	at 10,000ft	
FAF	at 3,000ft	
Order of priority for arrival sequencing methods	Speed control, Vectoring, Airborne holding	
Vectoring of departing traffic to destination airport	After passing 6,000 if not in conflict with other traffic	
Sequencing of arrival traffic to ensure safe and efficient arrival stream after Schiphol TMA entry fix	Within bounds of vectoring areas provided by LVNL, use of airborne holding as a last resort	Speed control only
Weather	No significant weather phenomena simulated	

Table 25: Summary of the key assumptions for the fast time simulation model

VIII.4.2 Environmental model, data, and assumptions

Environmental impact of selected measures was quantified using the Aeronautical Environmental Design Tool (AEDT). AEDT is a software that models aircraft performance in space and time to estimate fuel consumption, emissions, noise, and air quality consequences. AEDT facilitates environmental review activities by consolidating the modelling of these environmental impacts in a single tool. AEDT is designed to model individual studies ranging in scope from a single flight at an airport to scenarios at the regional, national, and global levels. AEDT leverages geographic information system (GIS) and relational database technology to achieve this scalability and offers rich opportunities for exploring and presenting results. AEDT is approved by several civil aviation authorities as suitable tool for aviation environmental modelling.

A model of Schiphol airport and surrounding airspace has been developed in AEDT, using (where required), assumptions valid for airspace FTS model. A link between AirTOp FTS and AEDT environmental models has been established, allowing export of full set of aircraft trajectories from the fast time simulation model into the environmental model. This ensured 1:1 replication of FTS flight trajectory profile (latitude, longitude, altitude, and timestamp sampled in 10 seconds intervals), aircraft type, and haul category (short/medium/long). As the flights in the FTS model were assumed to operate on the centreline of the tube (minor lateral deviations in turns visible due to aircraft turn characteristics) there was no lateral dispersion of flight tracks modelled in the environmental model.

The AEDT model has been loaded with additional data and assumptions relevant for execution of environmental impact assessment. Summary of these data and assumptions is provided in the table below.

AEDT Modelling	2025	2035
Aircraft noise performance model used	ICAO Aircraft Noise and Performance Database (ANP)	
Aircraft flight performance and fuel burn models used	BADA4 (fallback to BADA3 where required)	
Noise calculation model	Aligned with ECAC.CEAC Doc 29	
Atmospheric absorption model	SAE-ARP-5534	
Airport layout used	as per AirTOp model	
Traffic modelled	as per AirTOp model	
Noise cut-off altitude	Not applied	
Emissions mixing height	3,000ft	
Aircraft approach and climb profiles	as per AirTOp model	
Population data	Provided by NLR. Conversion from Amersfoort CRS (EPSG: 28992) to WGS84 (EPSG: 4326) performed to align the data with CRS used in the rest of the models	
Average airport weather	Average of 2011-2021 weather	
Surface winds data	ISHD (TD3505) data from Bloemendaal, 15 km from EHAM. WMOID: 062470	
Upper air data	FSL radiosonde data from Valkenburg, 25km from the airport. WMOID: 06210	
Terrain data	SRTM3 DEM data	

Table 26 : Summary of the key assumptions for the environmental model

VIII.5 Annex 5: Expected changes in fleet mix by 2035

VIII.5.1 Context

This study focussed on answering a set of questions related to two distant time horizons, 2025 and 2035. As the time difference between the two is considered significant, it was necessary to reflect on potential evolution(s) in aircraft technology between now and 2035, especially with an aim to prepare two distinct fleet mixes for use in quantitative assessment tools utilised during this research.

It was agreed with DARP that the current fleet mix (as of 2019) would be acceptable as a proxy for 2025 fleet mix.

However, in order to arrive at 2035 fleet mix, a set of assumptions has been developed and applied on the 2025 fleet. The methodology and individual assumptions used are elaborated in this annex. The traffic levels used in the quantitative assessment are aligned with annual traffic projections indicated in PlanMER document.

VIII.5.2 Methodology and sources

Our approach to development of the 2035 fleet mix was based on following:

1. Identification of how many aircraft of what types are currently on option or on order with the few major carriers at EHAM. This information was achieved through Fleet Analyser provided by FlightGlobal.
2. Review of fleet evolution forecasts prepared by Boeing and Airbus. Although we consider these rather optimistic in terms of projected traffic levels, the overall trends in retirement and replacement of the most popular aircraft and aircraft families presented in these documents are considered accurate and were used extensively in our fleet projection.
3. Definition of fleet renewal process – using the information from points 1) and 2) above, we developed a "fleet renewal logic" that was applied to 2025 fleet mix. A very simplified version of this logic is presented in Figure 27 below.

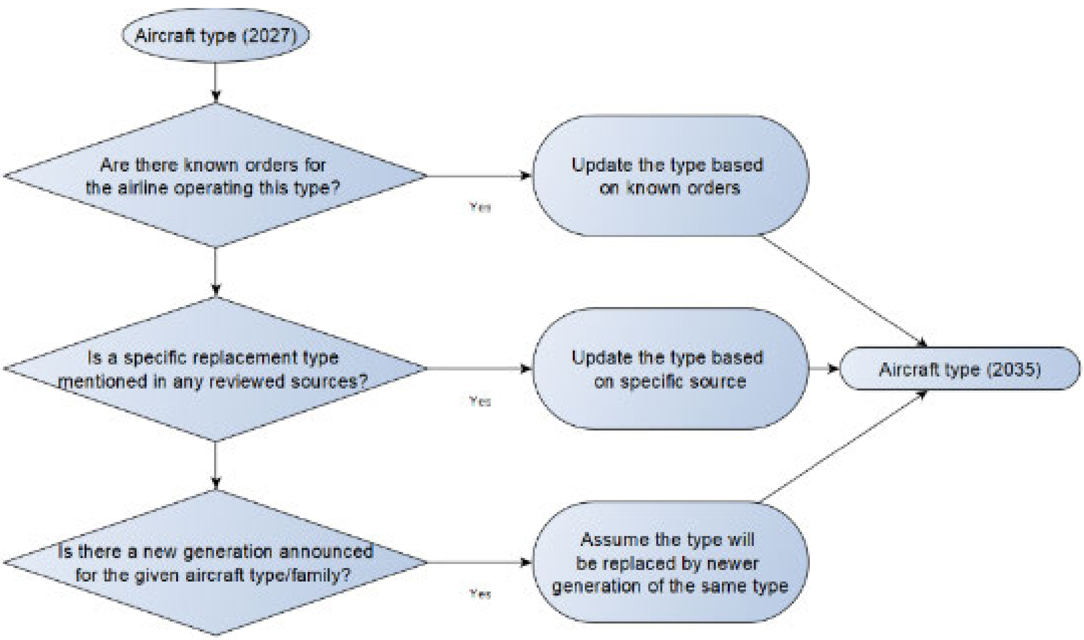


Figure 47: Methodology for the fleet renewal analysis

It should be noted that the purpose of this exercise was to develop a reasonable fleet mix to be used in conjunction with anticipated 2035 traffic levels in assessment of quantifiable impacts of the proposed airspace measures. As the quantification was done using off-the-shelf commercial products, which come with pre-defined set of aircraft using various performance models (BADA3, BADA4 or ICAO ANP) we were limited to use of these types only. This means that, for example, electric or hydrogen powered aircraft were not considered to be part of the 2035 fleet as there are currently no performance models that would allow us to simulate operations of these aircraft in the tools we used for quantitative analysis.

However, even if such aircraft were present in 2035 fleet, they are likely to be low in numbers and designed in a way that would allow them to operate with the procedures valid at the time of their introduction to the market. In other words, Egis does not expect the electric or hydrogen aircraft would require substantially different handling from ATC/ATM perspective than traditional jets and/or turboprops. However, the use of drones and UAM is likely to increase between now and 2035 and is likely to have influence on design of operations to/from Schiphol, especially in lowest altitudes.

Finally, the fleet mix projection does not take into account:

1. Possible changes in destinations served from EHAM (and their potential impact on aircraft used). This would require a significant amount of extra effort and is not considered in scope of this study.
2. Possible impact of global warming. Increased temperature may have impact on aircraft performance, potentially prolonging the take-off run and worsening the climb performance. It can also have impact on passenger's choice of destinations, i.e. increased demand for holidays in northern parts of Europe.
3. Potential entry of new airlines and/or bankruptcy of existing ones. Again, this would require a significant amount of extra effort and is not considered in scope of this study.

Summary of the key assumptions taken, together with relevant sources, is provided in the table on the next page.

ID	Assumption	Rationale	Source
1	Known KLM orders	Dutch flag carrier has announced orders of new 787s to replace their aging long-haul fleet and orders of next generation E195s to expand their regional aircraft fleet.	FlightGlobal fleet analyser
2	Known orders of Corendon, Transavia and TUI	These carriers have on orders new 737 Max 8 to expand their existing fleet.	FlightGlobal fleet analyser
3	Known orders of Vueling and Easyjet	Both low-cost airlines have significant number of A320 Neos and A321 Neos on order. These will partly replace and partly expand their existing fleet.	FlightGlobal fleet analyser
4	Renewal based on new generations of the existing fleet	For airlines with smaller share of operations at EHAM, as well as for minority aircraft types of the major carriers, we assumed that the existing line-up of aircraft will be gradually replaced with newer generations of the same aircraft type/family. For example, airlines which currently operate previous generation A320 were assumed to operate Neos by 2035.	https://www.lufthansagroup.com/en/themes/fleet-development.html
5	Older 777s replaced by 787s or A350s	Research showed a several airlines intend to replace the aging 777s by 787s and A350s, potentially benefiting from better fuel efficiency stemming from smaller MTOW due to use of lightweight carbon components.	https://www.outlookindia.com/newsscroll/sia-to-replace-b777-with-b78710-on-delhisingapore-route/1345984 https://www.ch-aviation.com/portal/news/103433-japan-airlines-to-replace-b777s-with-a350s-by-late-1q23
6	Significant extension of range and capacity of narrow body types (A321XLR)	Airbus predicts introduction of A321XLR will replace some of the wide-bodies and older long-haul narrow bodies (B767) on medium haul and shorter intercontinental routes.	https://simpleflying.com/airbus-a322-next-gen/
7	Noisy turboprops replaced by quiet small jets	Research showed several airlines across the world are retiring their turboprop fleet and introducing the latest generation of small regional jets, such as Bombardier C-Series or Embrearer E2.	https://www.arctictoday.com/northern-norways-wideroe-eyes-buying-jets/ https://time.com/5331213/propeller-era-over-airlines/ https://www.ch-aviation.com/portal/news/59958-latvias-airbaltic-to-replace-q400s-with-more-cseries https://financialpost.com/transportation/bombardier-cseries-ushers-in-new-era-of-super-quiet-jets
8	747 and 380 replaced by next gen. 777X	Boeing predicts the airlines that would still want an aircraft with similar capacity and range as retiring 747s and A380s would go for its new 777X that promises similar performance as the two older types that it is supposed to replace.	https://simpleflying.com/british-airways-747-retirement-plans/ https://simpleflying.com/boeing-777-10/
9	Phasing out of 4-engine long haul types	The trend visible over the last few years, where 4-engined aircraft were deemed less efficient (higher maintenance costs) and replaced with 2-engine equivalents is expected to continue into the future. Where possible, we replaced older 4 engine types (such as A340) with 2 engine models.	https://simpleflying.com/two-engines-vs-four-engines/
10	Cargo fleet replaced by current types that will be obsolete by 2035	It was assumed the airlines will buy the latest generation aircraft to replace their aging fleet. However, the aircraft that got replaced would still be airworthy and many of these would be converted to serve as cargo aircraft. We assumed there converted cargo aircraft would replace the oldest cargo types in Schiphol fleet, for example A300 Freighter.	https://www.flightglobal.com/flight-international/passenger-to-cargo-conversions-boom-but-can-it-last/142047.article

VIII.5.3 Proposed changes in the fleet mix

The 2025 fleet mix (equal to 2019 fleet) was used as a basis for development of 2035 estimates. The new fleet mix takes into account all of the assumptions from the previous section. Evolution of the fleet (by aircraft family) between 2025 and 2035 is presented in Figure 28 below. Noteworthy observations include:

- B737 and Embraer families are likely to retain their fleet share, however, the individual aircraft models are likely to be replaced by next generation alternatives,
- A320 family will increase its fleet share, mainly due to introduction of A321 XLR. However, shortest A318 is no longer envisaged to operate in 2035 scenario.
- B787 is likely to double its fleet share, mostly due to it being used as a replacement for retiring B777s, A380 or B747s.
- B777 family is likely to reduce its fleet share. Retiring aircraft will be likely replaced by other types (B787 or A350), with the new 777X model not being expected to be sold enough to compensate for the decrease in 777 fleet size.
- Several aircraft families are expected to disappear from skies above Amsterdam by 2035. These include: B747, turboprop aircraft, B767, B757, A380, A340 and cargo A300 Freighter.

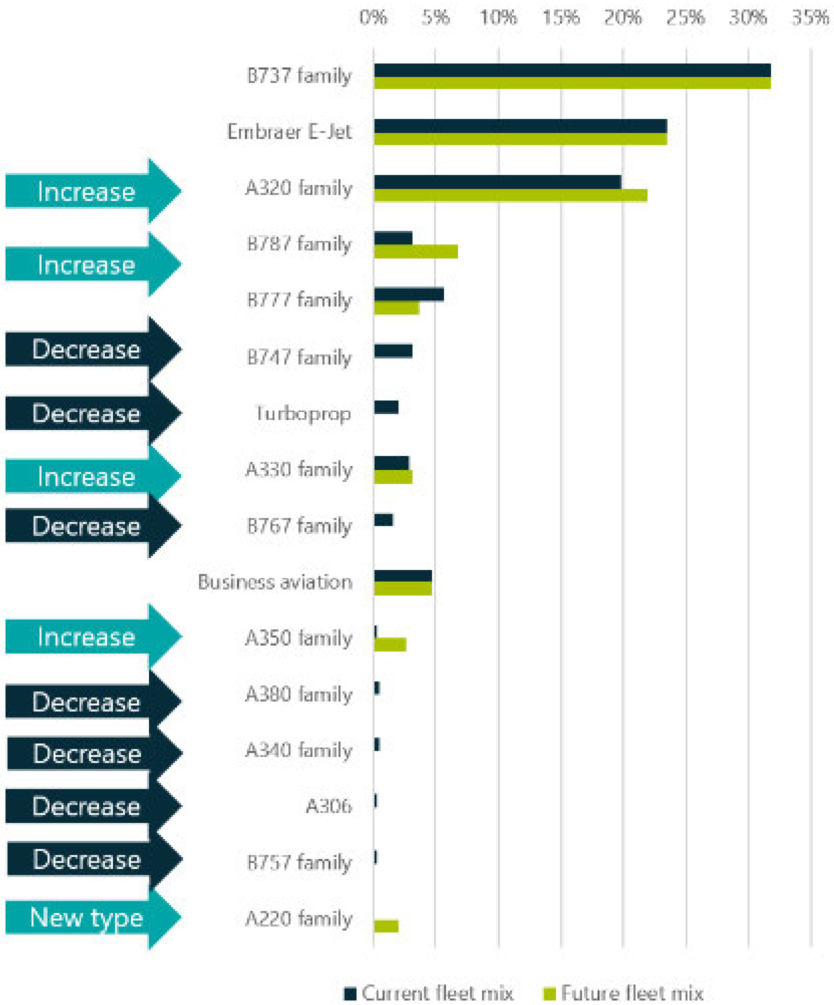


Figure 48: Anticipated fleet replacement patterns (2035)

VIII.6 Annex 6: Vectoring areas assumed in the model

The presence and size of vectoring areas for arrivals in 2025 scenarios have major impact on how well each concept can be operated. The greater the vectoring area, the more flights and delay can be absorbed within the Schiphol TMA. If the vectoring area is not large enough and if the accuracy of delivery is not adequate, some aircraft may end up in the holding pattern.

The details of vectoring areas for this study were provided by LVNL. These took form of simple sketches and were included in the fast time simulation model developed as part of this research. The information provided by LVNL is presented below.

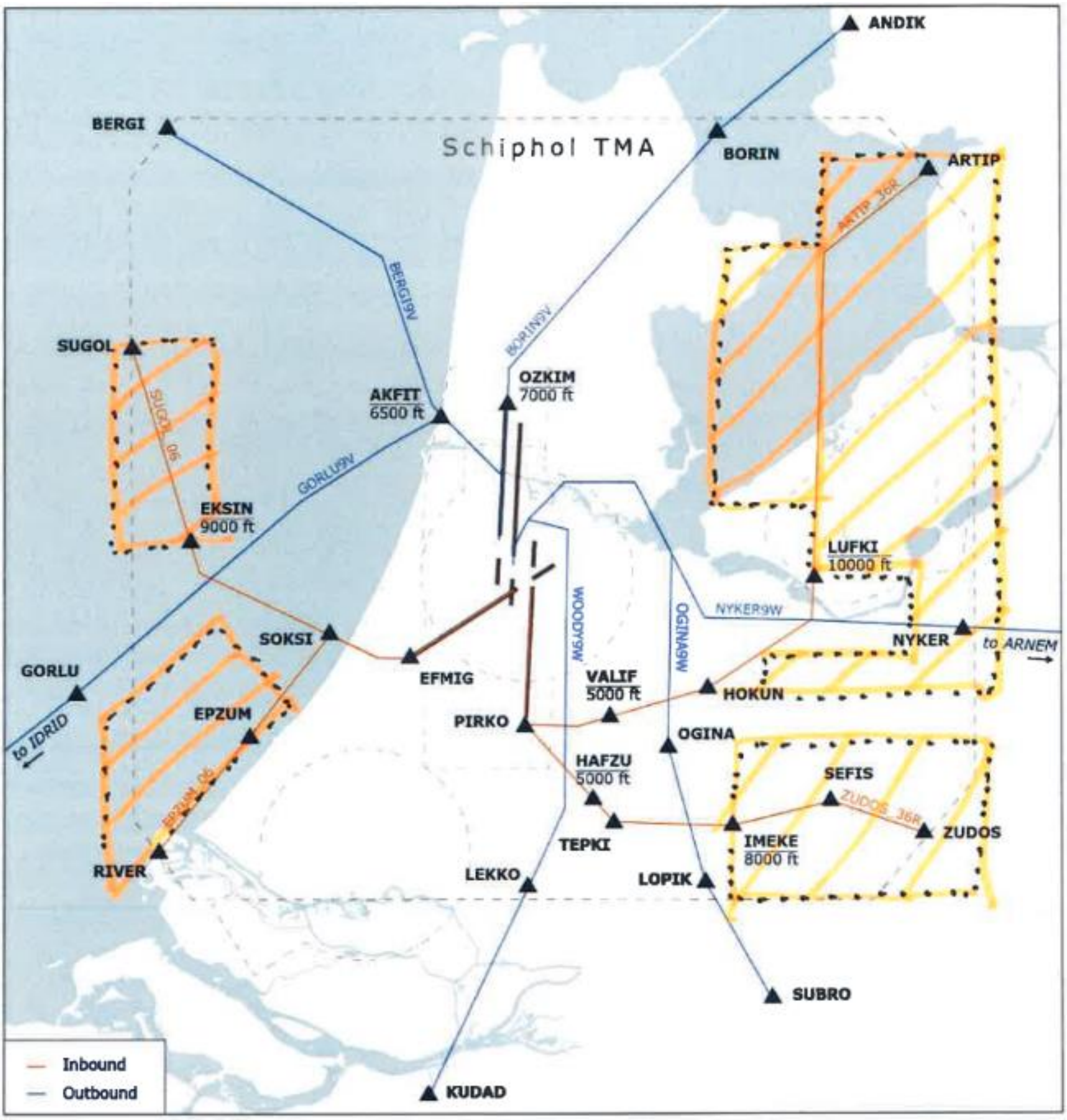


Figure 49:Vectoring areas provided by LVNL (exhibit 1)

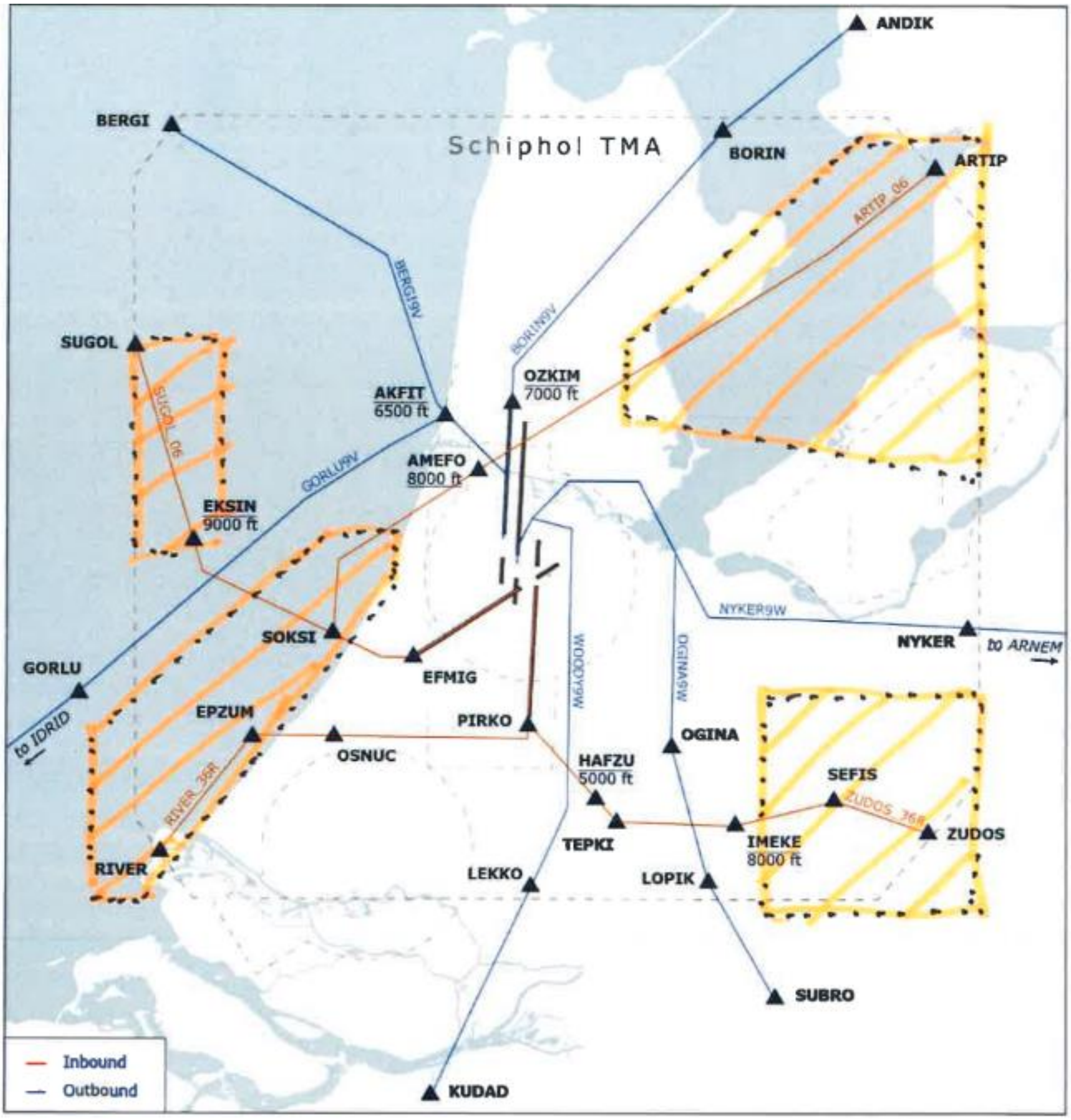


Figure 50: Vectoring areas provided by LVNL (exhibit 2)

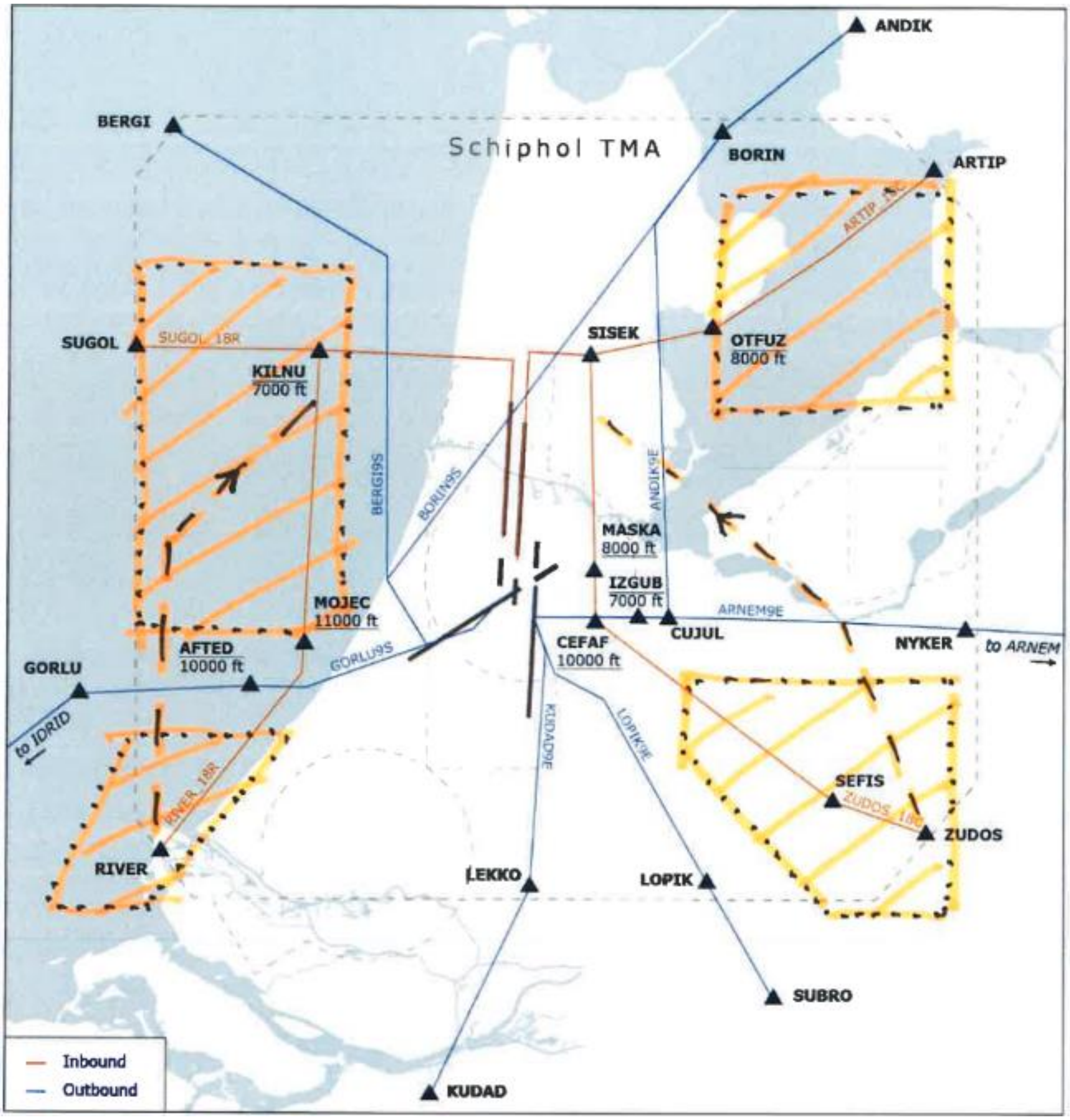


Figure 51: Vectoring areas provided by LVNL (exhibit 3)

VIII.7 Annex 7: Definition of metrics used in the research

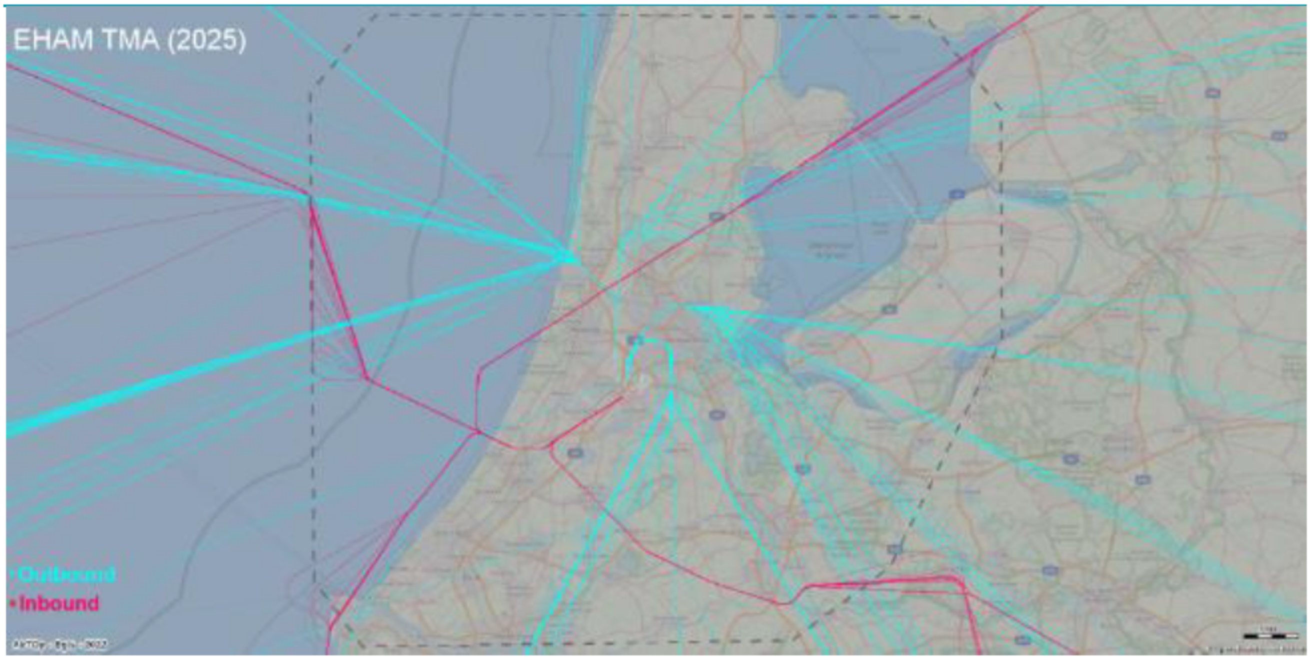
Metric	Definition	Units
Average distance flown by a departure in EHAA FIR	Average distance flown by an aircraft departing from EHAM achieved between start of take-off roll and crossing EHAA FIR boundary.	NM
Average burned by a departure in EHAA FIR	Average burned by an aircraft departing from EHAM achieved between start of take-off roll and crossing EHAA FIR boundary.	Kg
Average distance flown in approach	Average distance flown by arriving aircraft between Schiphol TMA entry fix and touchdown at EHAM.	NM
Average fuel burned in approach	Average fuel burned by arriving aircraft between Schiphol TMA entry fix and touchdown at EHAM.	Kg
Departure runway throughput	Count of lift-offs in 60-minute rolling period.	Count
Arrival runway throughput	Count of touchdowns in 60-minute rolling period.	Count
Average sequencing delay	Average delay per arriving flight incurred between Schiphol TMA entry fix and touchdown as a result of sequencing actions, such as speed control, vectoring or airborne holding.	Seconds
% of arrivals with sequencing issues	Count of events (expressed as % of arrivals) when additional arrival sequencing actions had to be performed by the simulation engine, for example, when a flight was added to runway arrival sequence list, but the trailing flight was found not to have space to be sequenced correctly.	%
L_{den} metric	Time-averaged noise metric calculated between 07:00:00 and 18:59:59 local time. Three noise contours were produced for each scenario modelled. These were 48dB, 45dB and 43 dB contours.	Contour
Total contour area	Total geographical area covered by noise contour	Km^2
Contour area over landside areas	Total geographical area covered by noise contour minus total area over water	Km^2
Population	Sum of people living within selected noise contour.	Millions

VIII.8 Annex 8: Detailed quantitative results

VIII.8.1 Accuracy of delivery (detailed results)

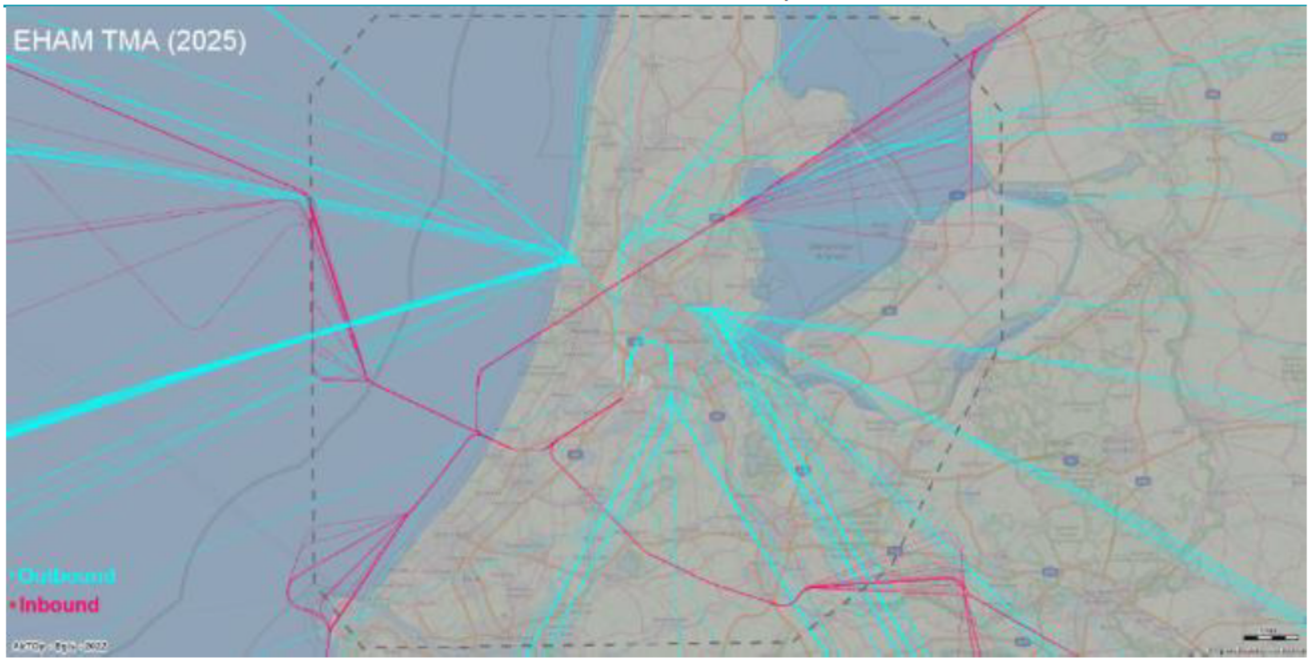
VIII.8.1.1 2025, Northerly, 1A & 2D

Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Northerly	1 arrival RWY, 2 departure RWYs	0s

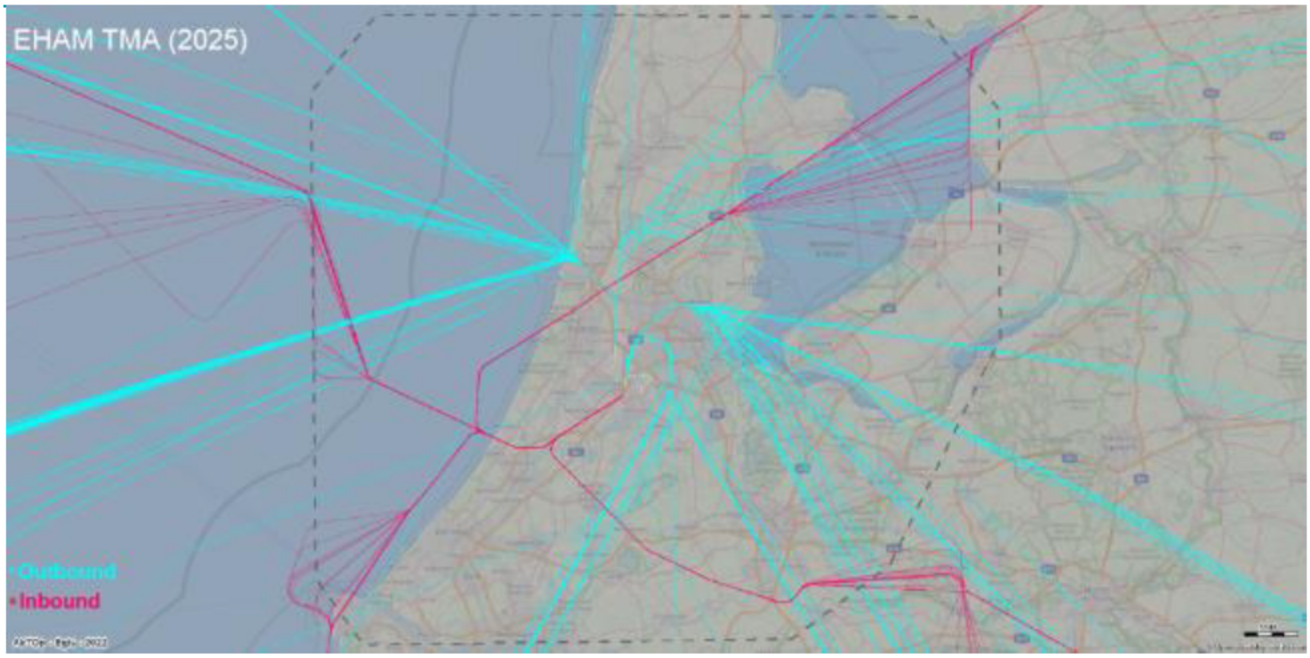


Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Northerly	1 arrival RWY, 2 departure RWYs	15s

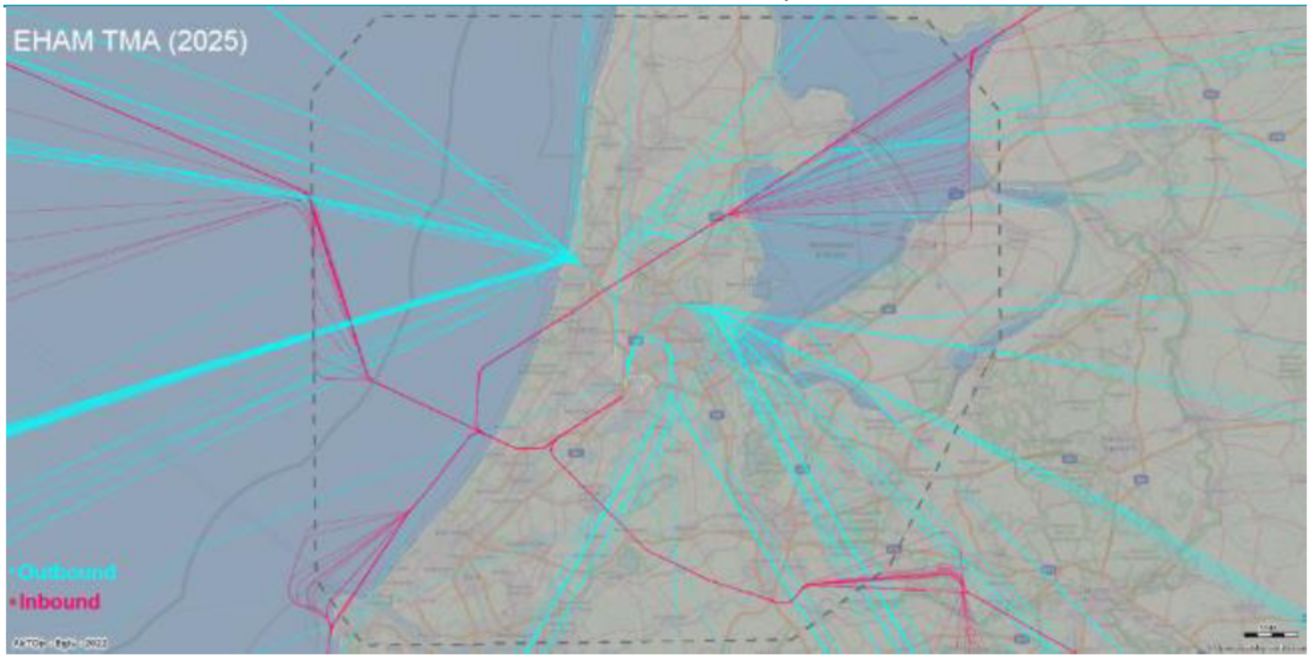
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Northerly	1 arrival RWY, 2 departure RWYs	30s



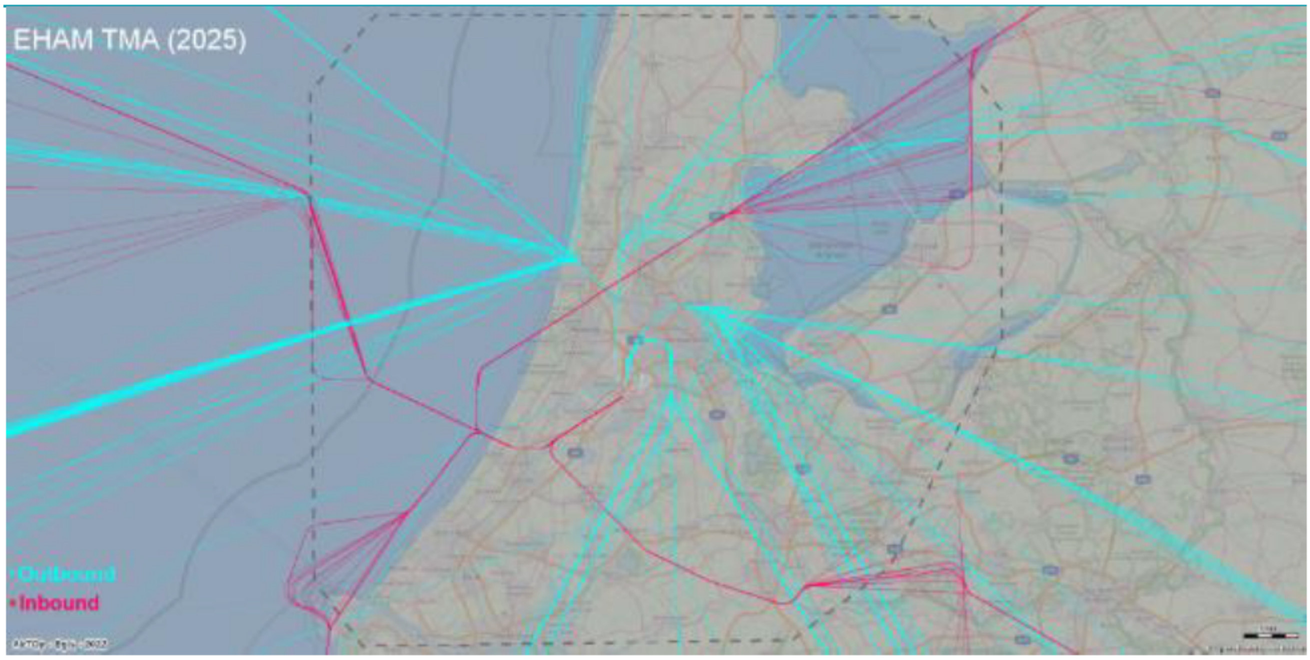
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Northerly	1 arrival RWY, 2 departure RWYs	45s

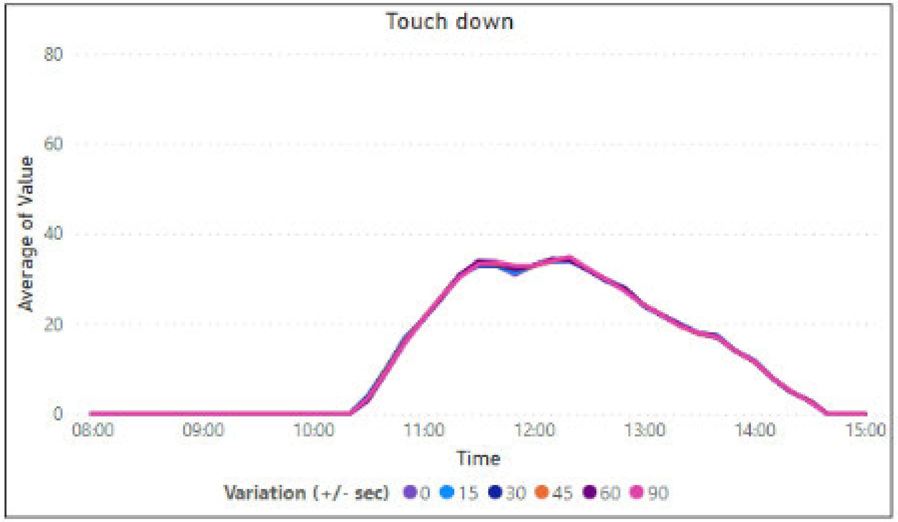


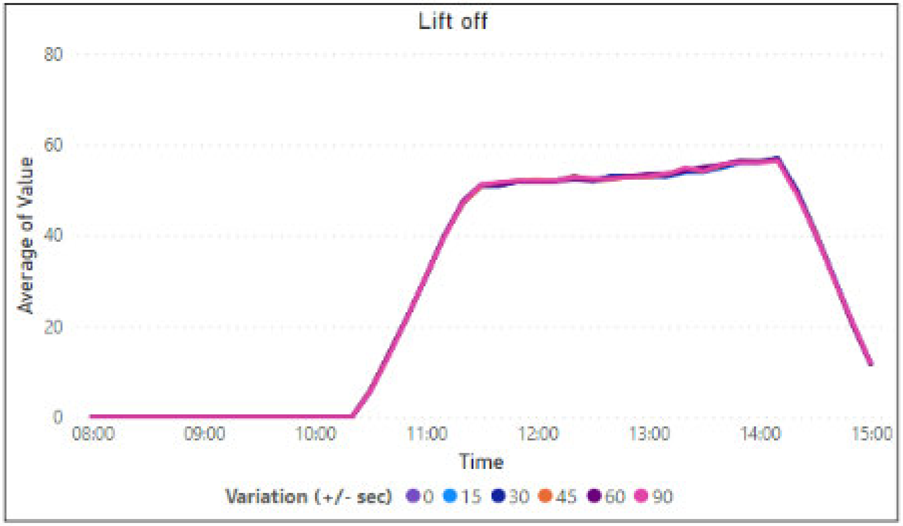
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Northerly	1 arrival RWY, 2 departure RWYs	60s

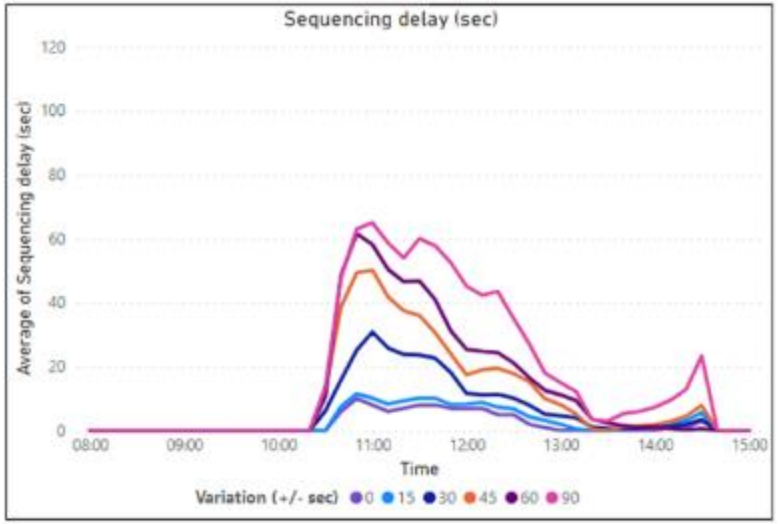


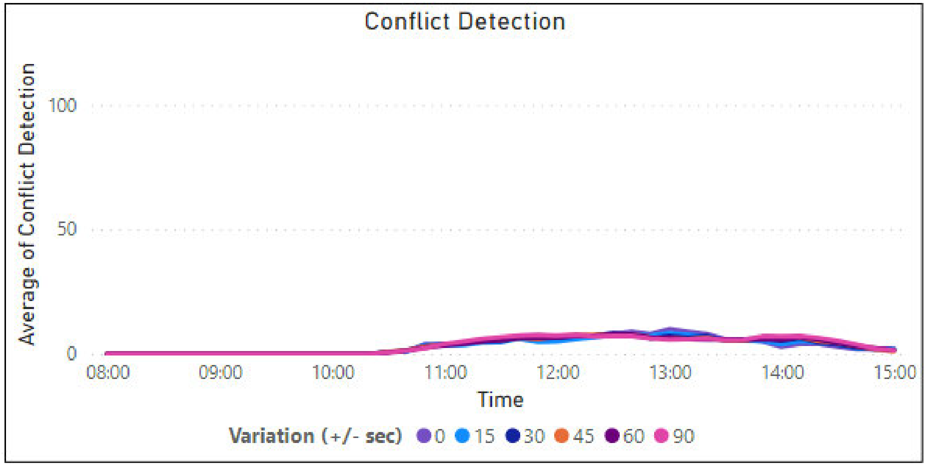
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Northerly	1 arrival RWY, 2 departure RWYs	90s




Touch down
80
60
40
20
0
Average of Value
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60 90

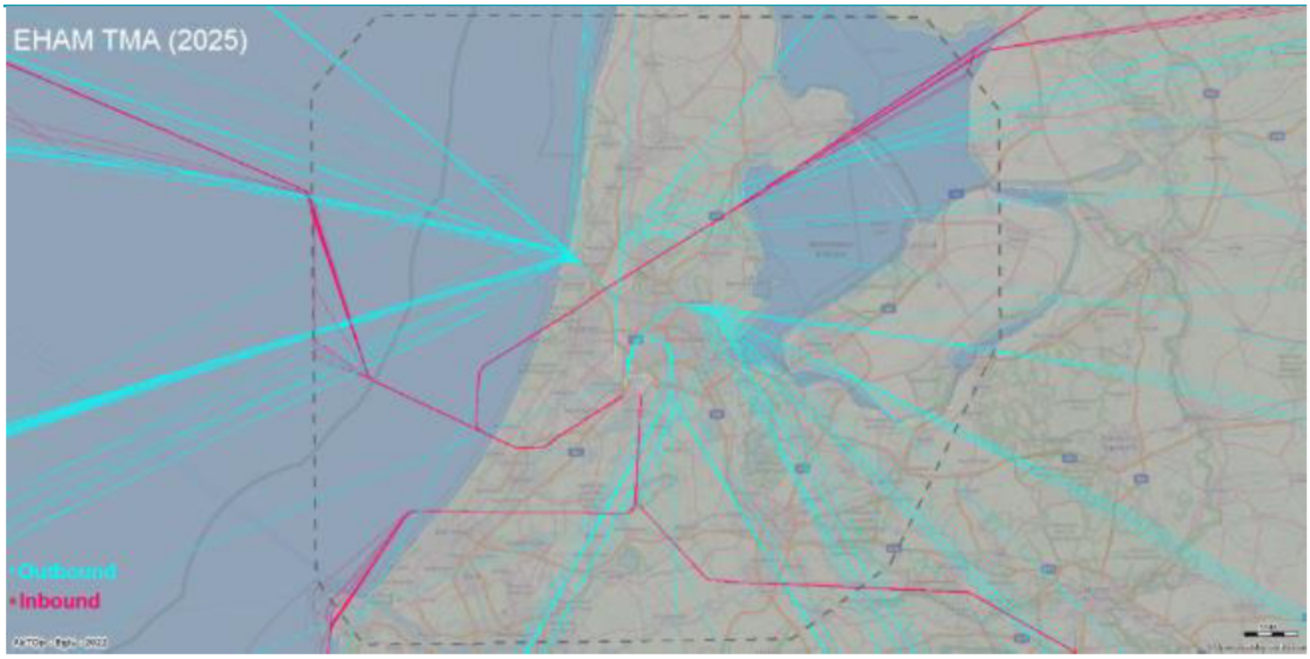

Lift off
80
60
40
20
0
Average of Value
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60 90


Sequencing delay (sec)
120
100
80
60
40
20
0
Average of Sequencing delay (sec)
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60 90

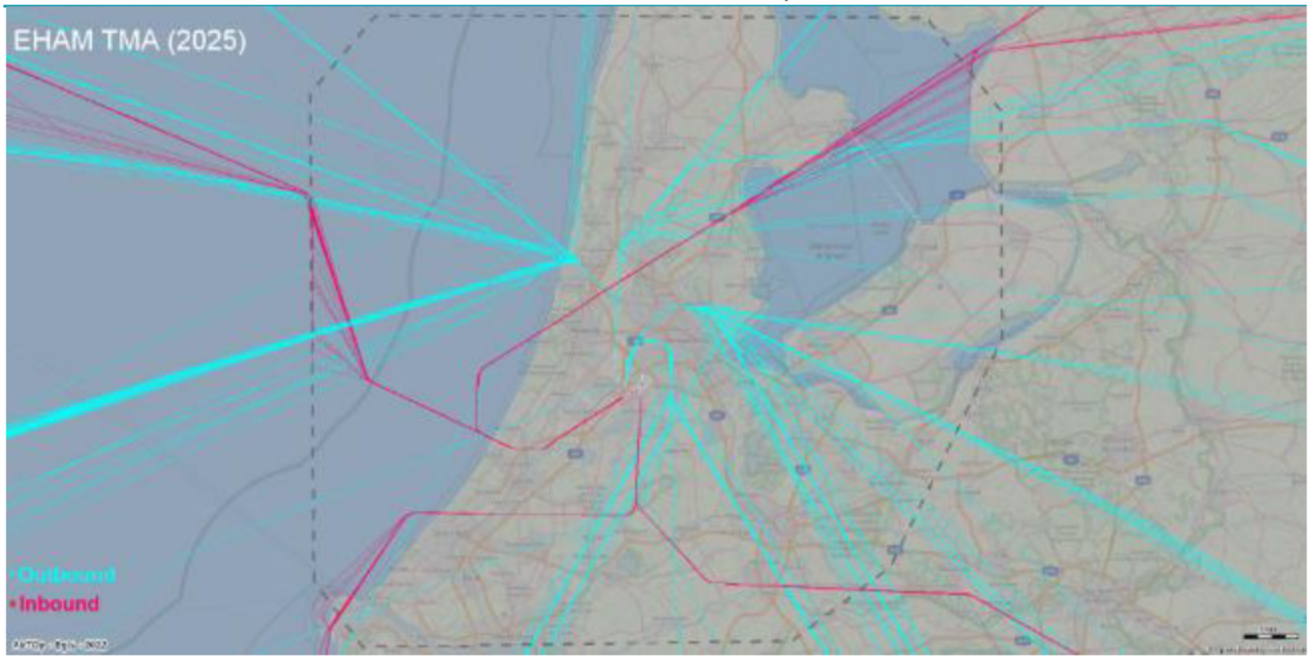

Conflict Detection
100
50
0
Average of Conflict Detection
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60 90

VIII.8.1.2 2025, Northerly, 2A & 2D

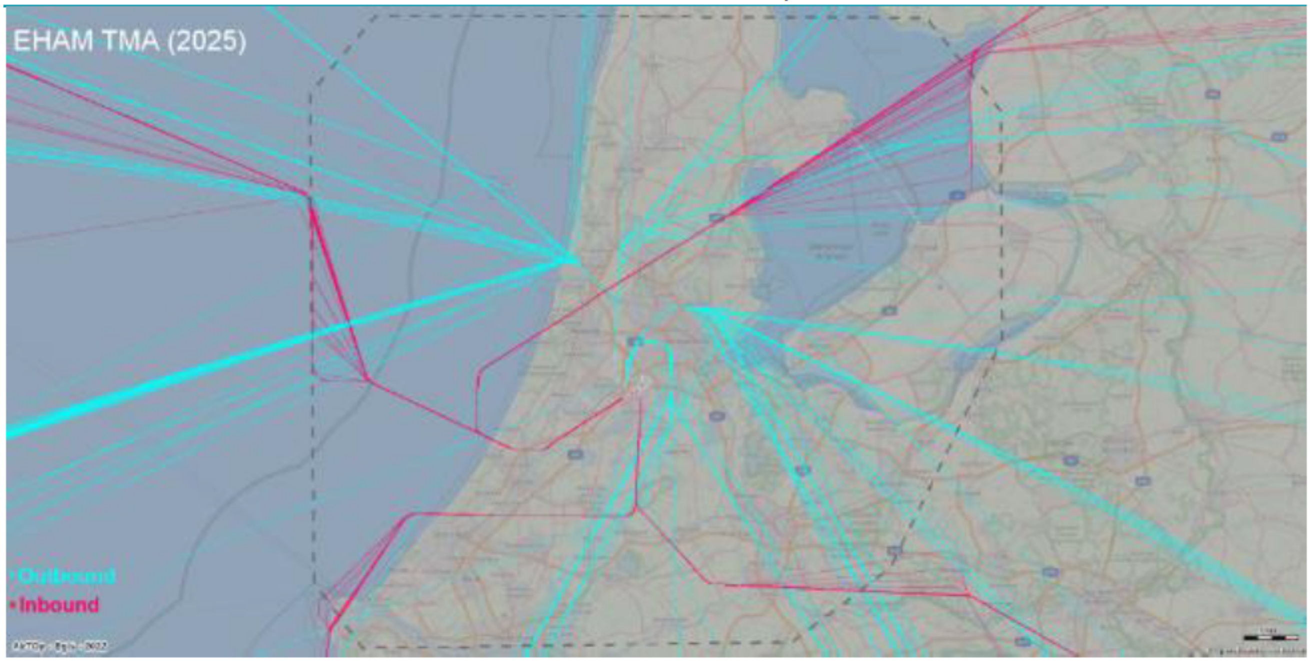
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Northerly	2 arrival RWYs, 2 departure RWYs	0s



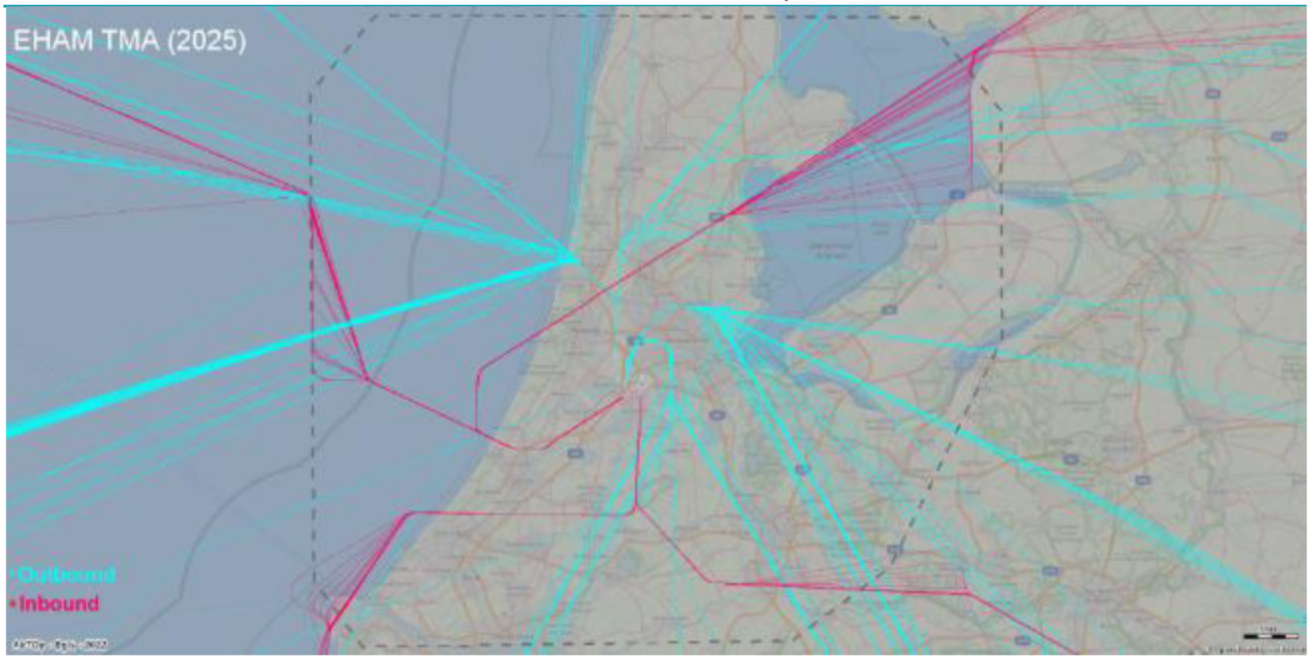
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Northerly	2 arrival RWYs, 2 departure RWYs	15s



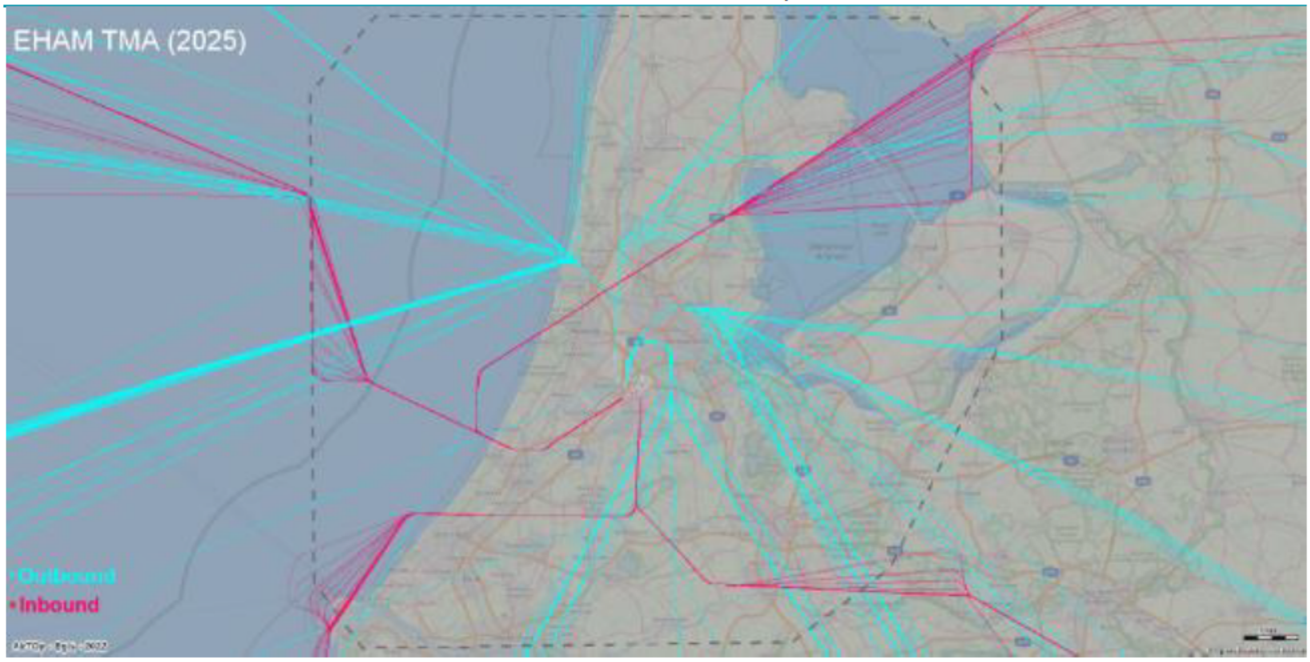
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Northerly	2 arrival RWYs, 2 departure RWYs	30s



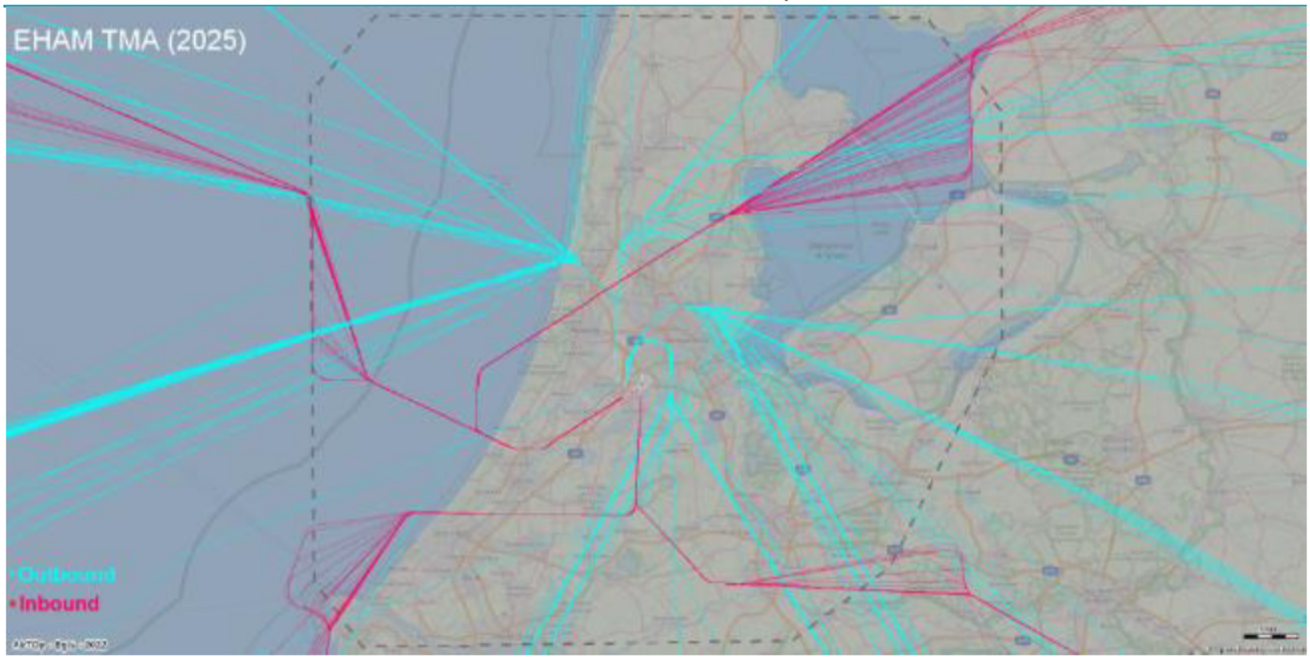
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Northerly	2 arrival RWYs, 2 departure RWYs	45s

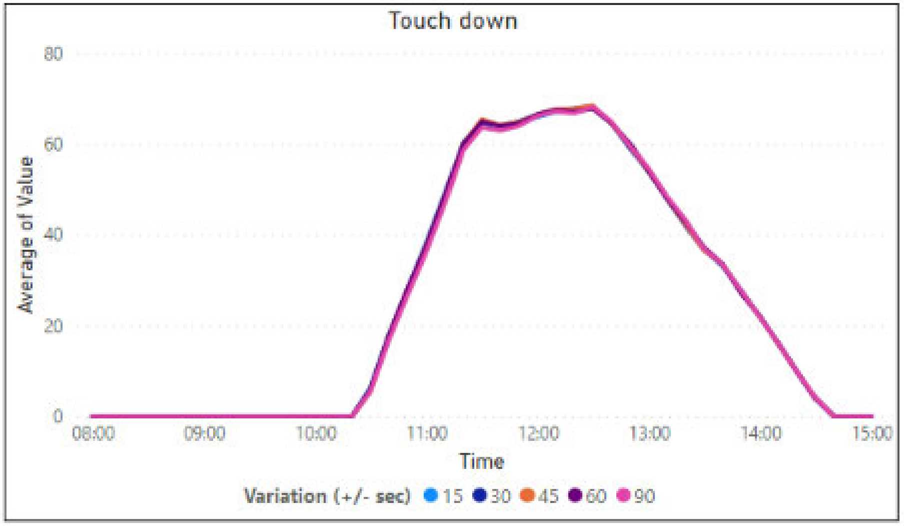


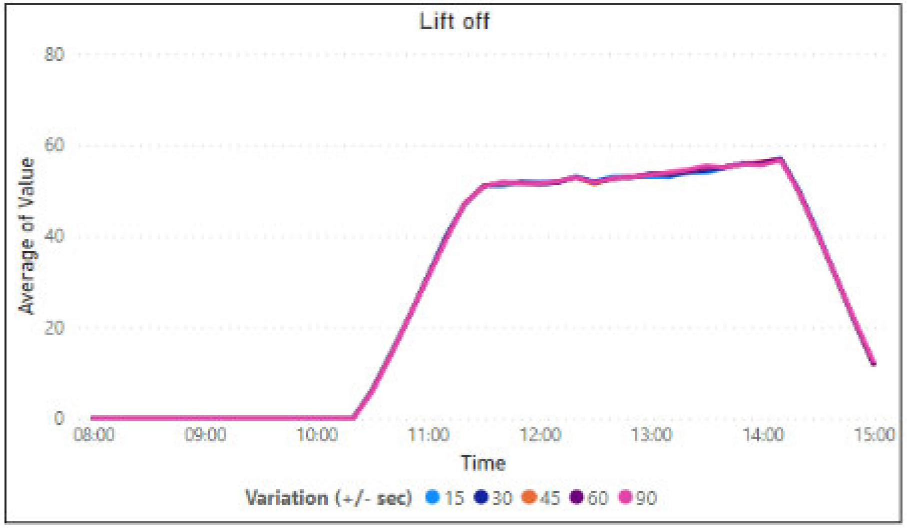
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Northerly	2 arrival RWYs, 2 departure RWYs	60s

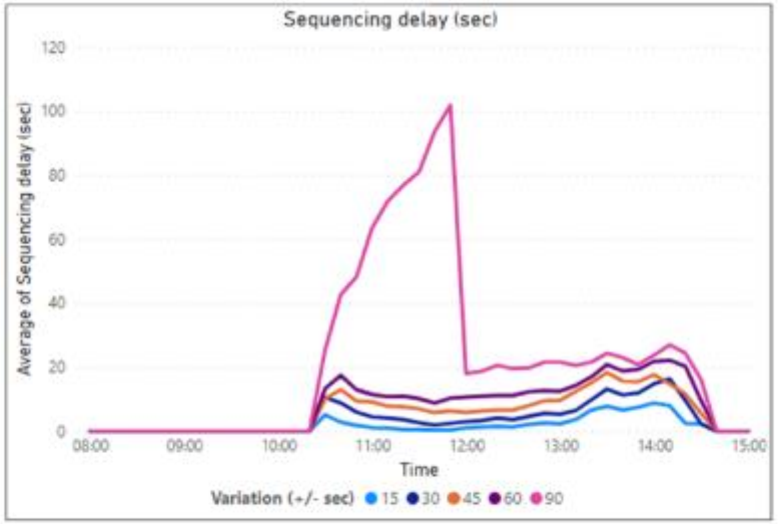


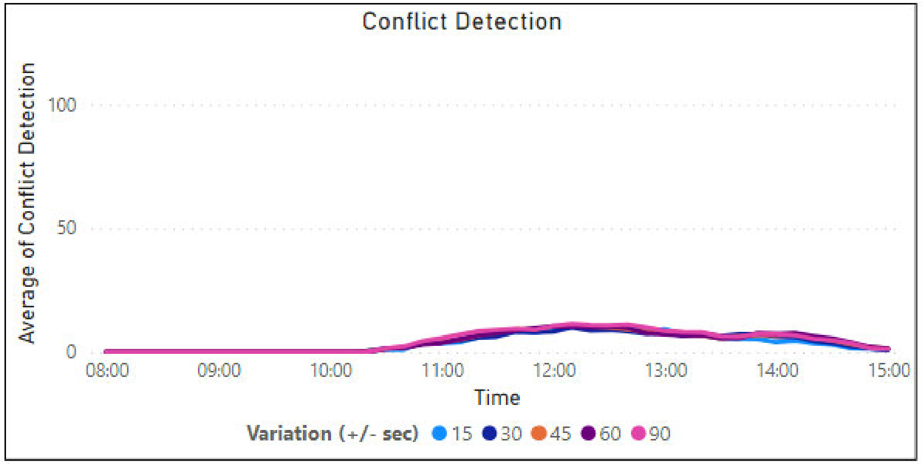
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Northerly	2 arrival RWYs, 2 departure RWYs	90s




Touch down
Average of Value
80
60
40
20
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 15 30 45 60 90

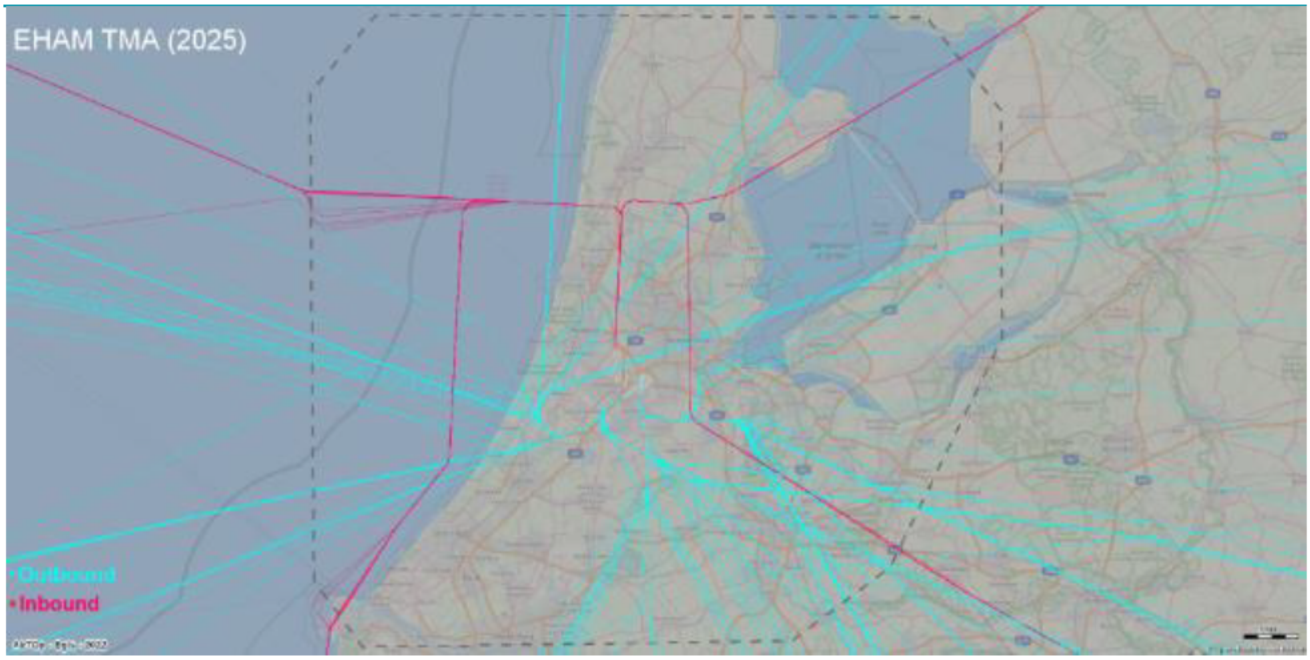

Lift off
Average of Value
80
60
40
20
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 15 30 45 60 90


Sequencing delay (sec)
Average of Sequencing delay (sec)
120
100
80
60
40
20
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 15 30 45 60 90

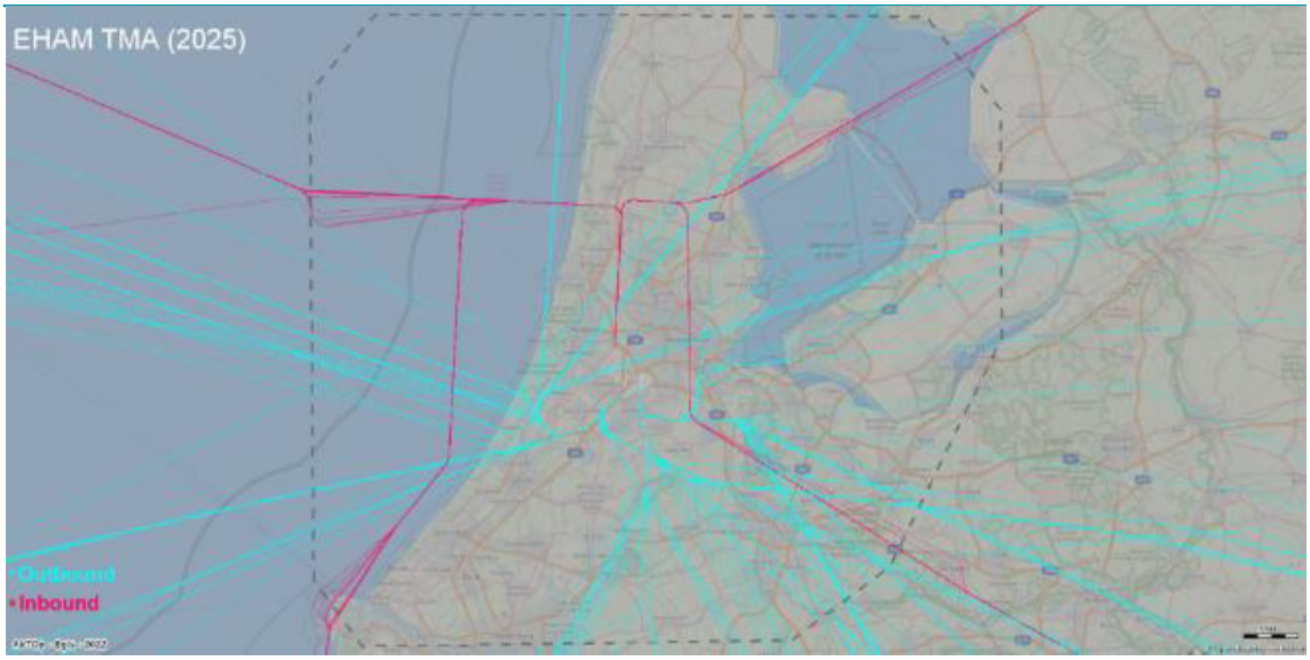

Conflict Detection
Average of Conflict Detection
100
50
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 15 30 45 60 90

VIII.8.1.3 2025, Southerly, 1A & 2D

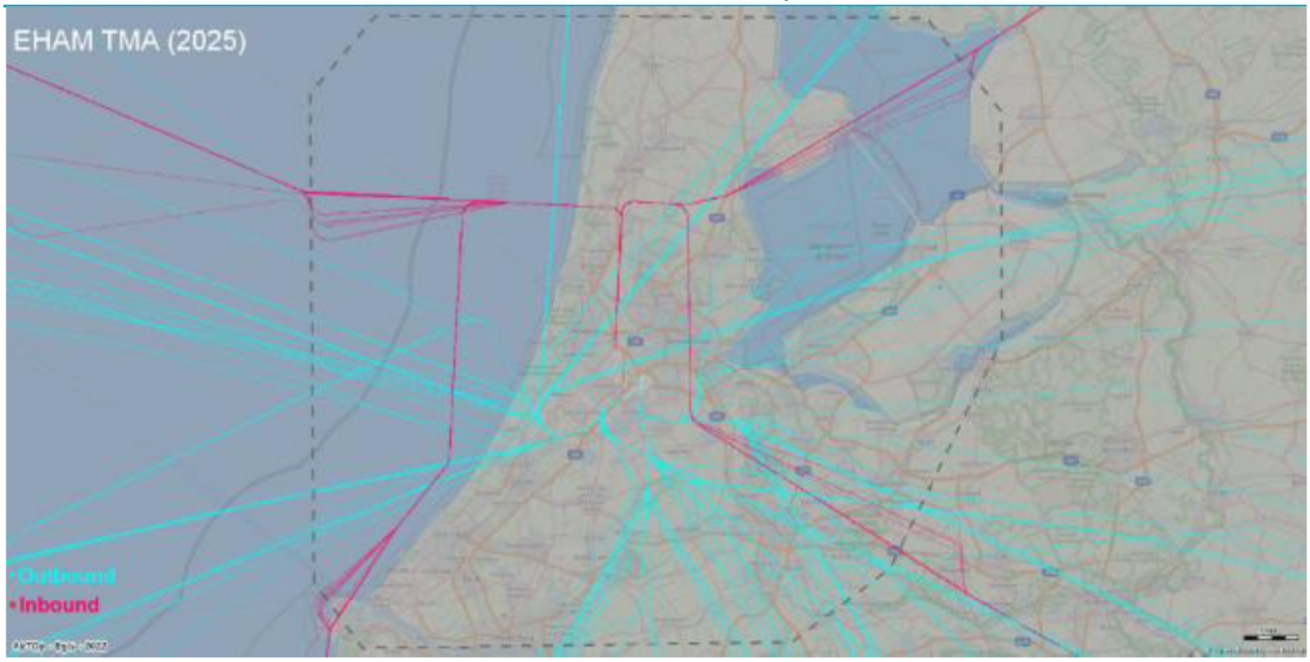
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Southerly	1 arrival RWY, 2 departure RWYs	0s



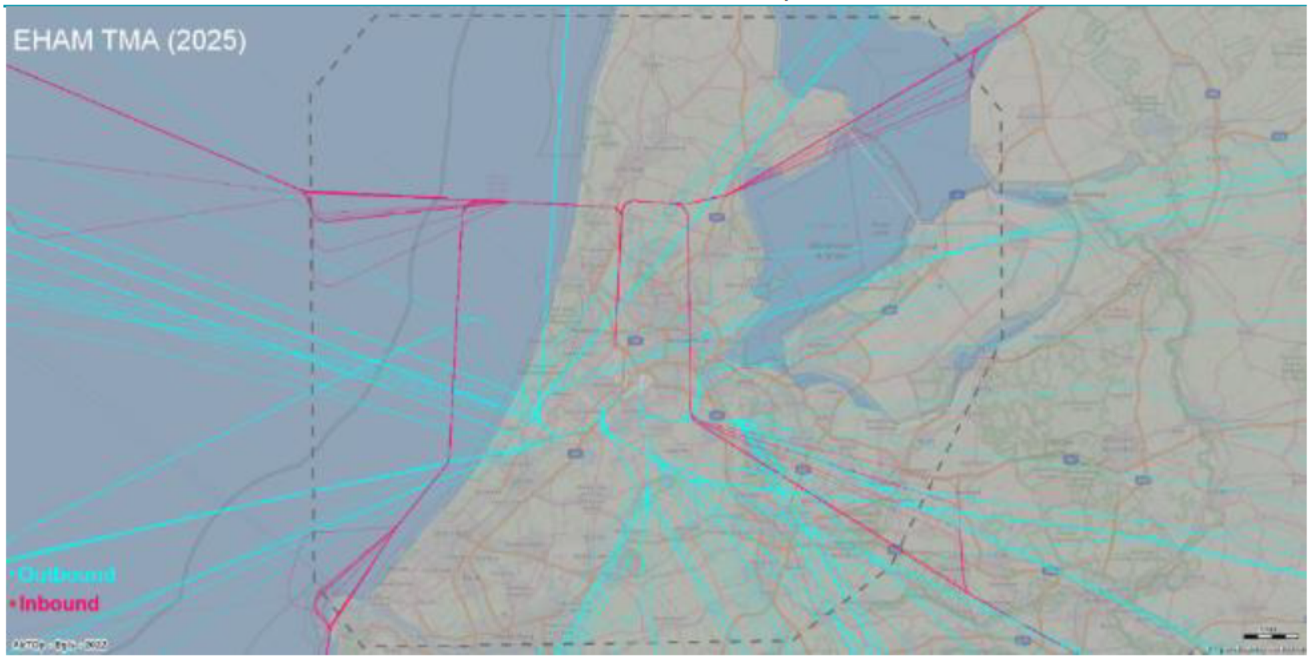
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Southerly	1 arrival RWY, 2 departure RWYs	15s



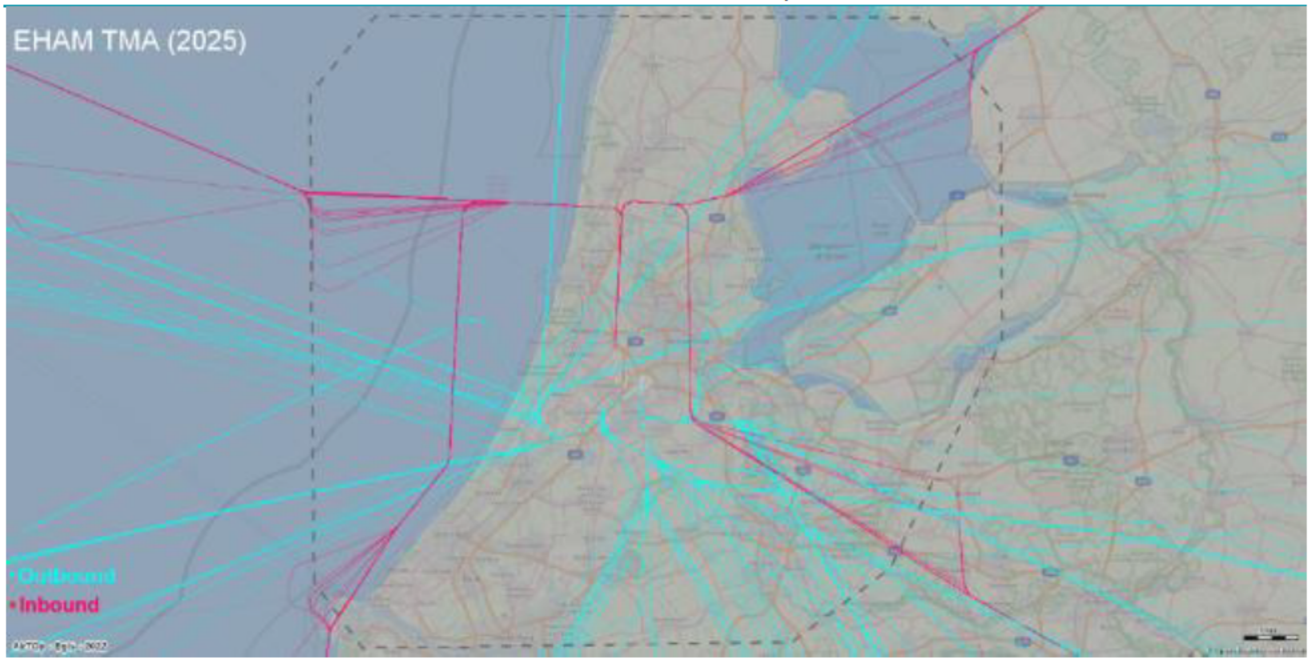
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Southerly	1 arrival RWY, 2 departure RWYs	30s



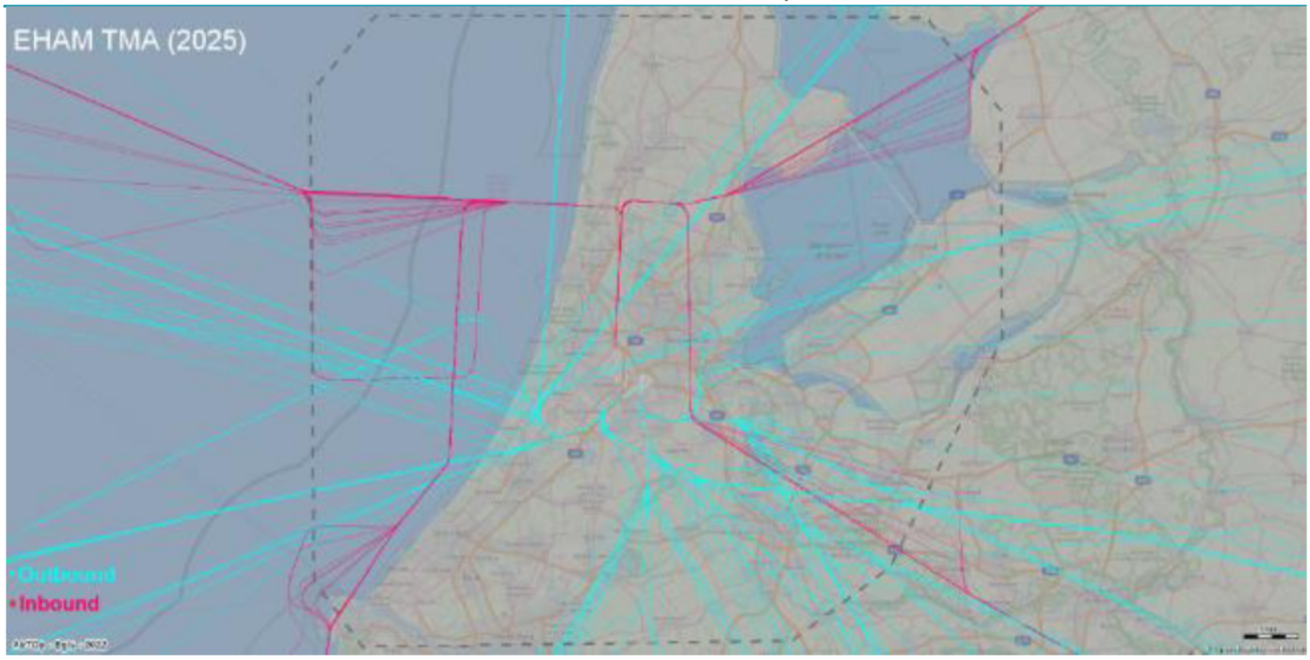
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Southerly	1 arrival RWY, 2 departure RWYs	45s

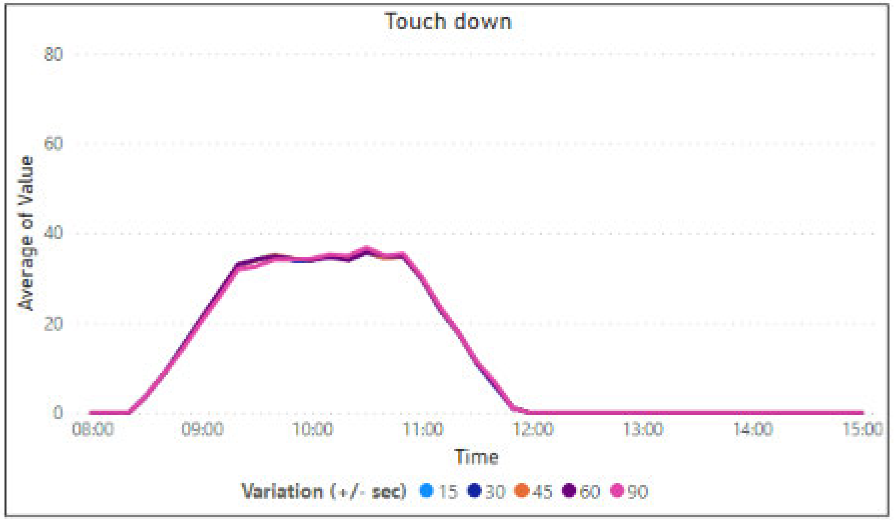


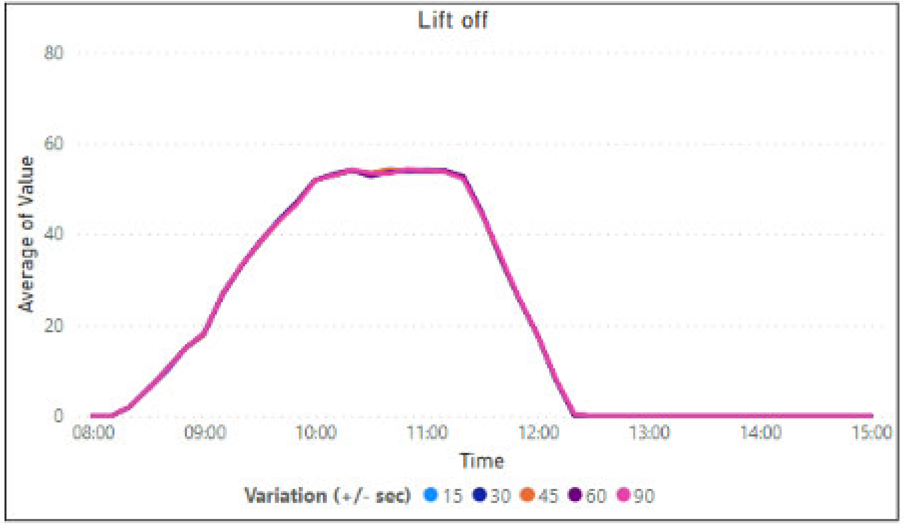
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Southerly	1 arrival RWY, 2 departure RWYs	60s

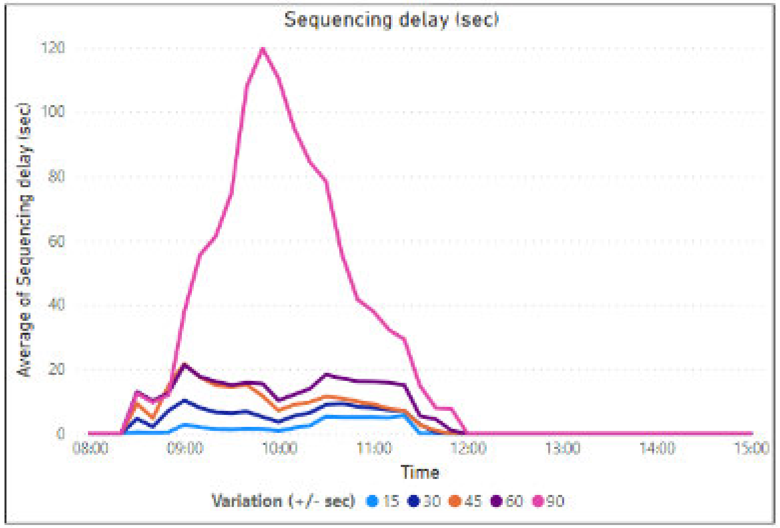


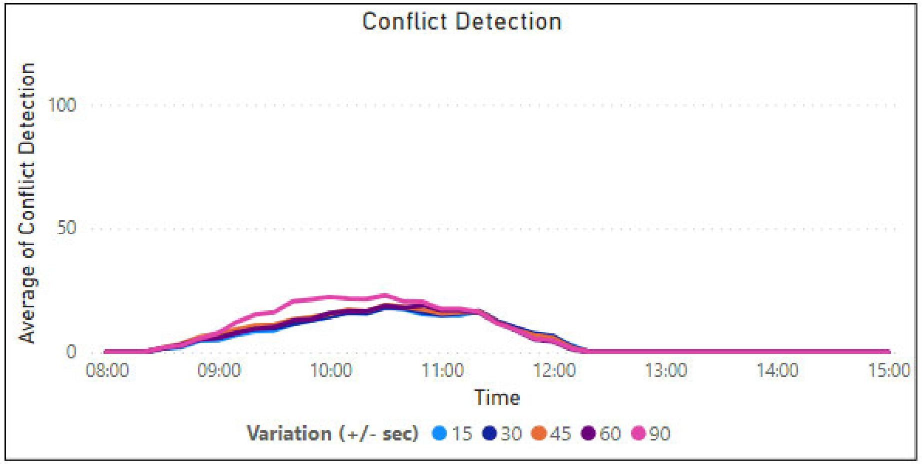
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Southerly	1 arrival RWY, 2 departure RWYs	90s




Touch down
80
60
40
20
0
Average of Value
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 15 30 45 60 90

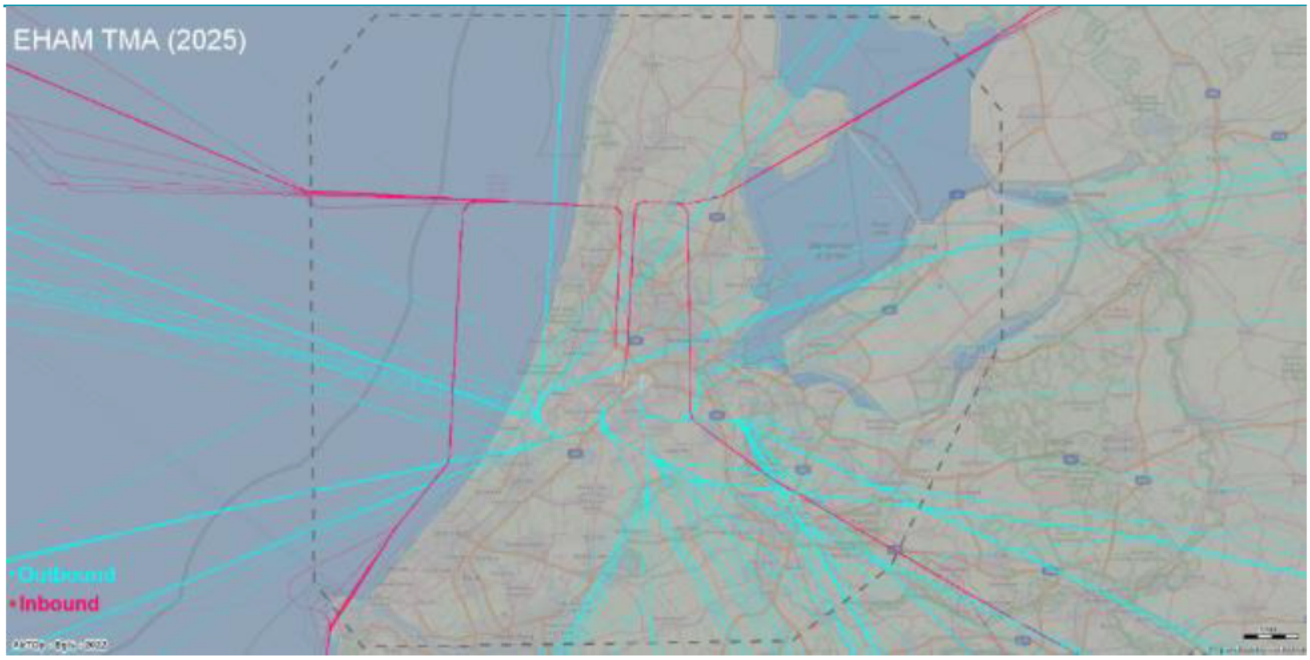

Lift off
80
60
40
20
0
Average of Value
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 15 30 45 60 90


Sequencing delay (sec)
120
100
80
60
40
20
0
Average of Sequencing delay (sec)
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 15 30 45 60 90

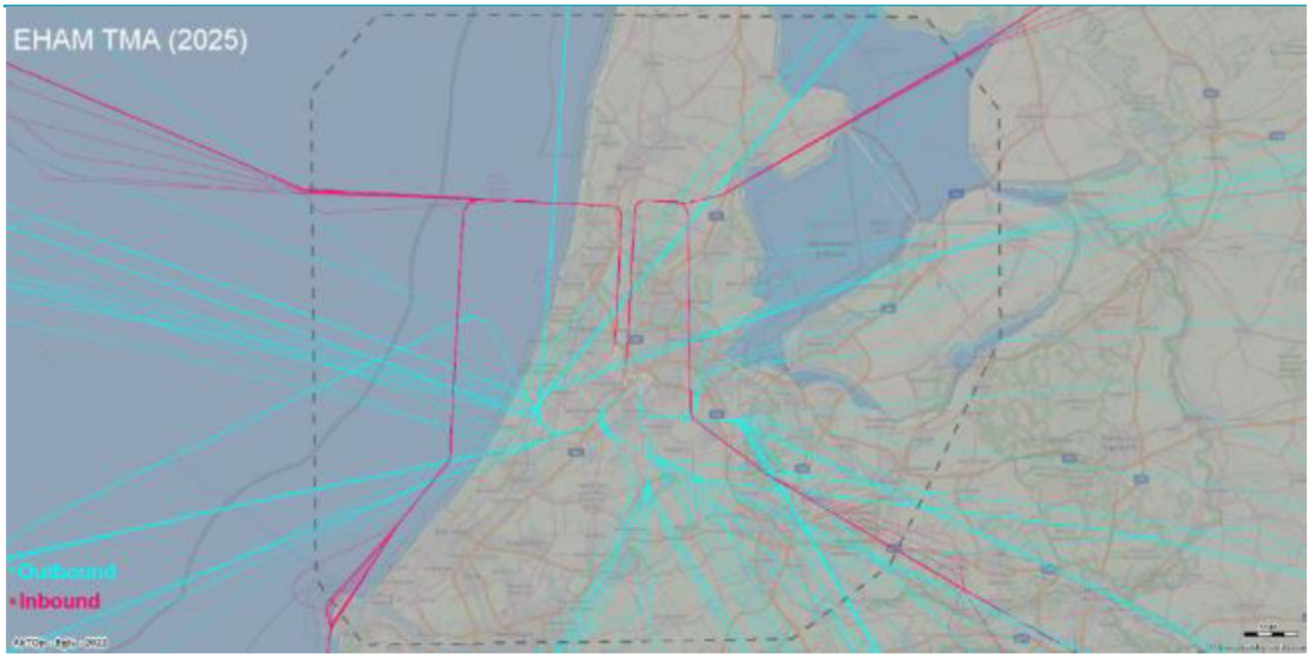

Conflict Detection
100
50
0
Average of Conflict Detection
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 15 30 45 60 90

VIII.8.1.4 2025, Southerly, 2A & 2D

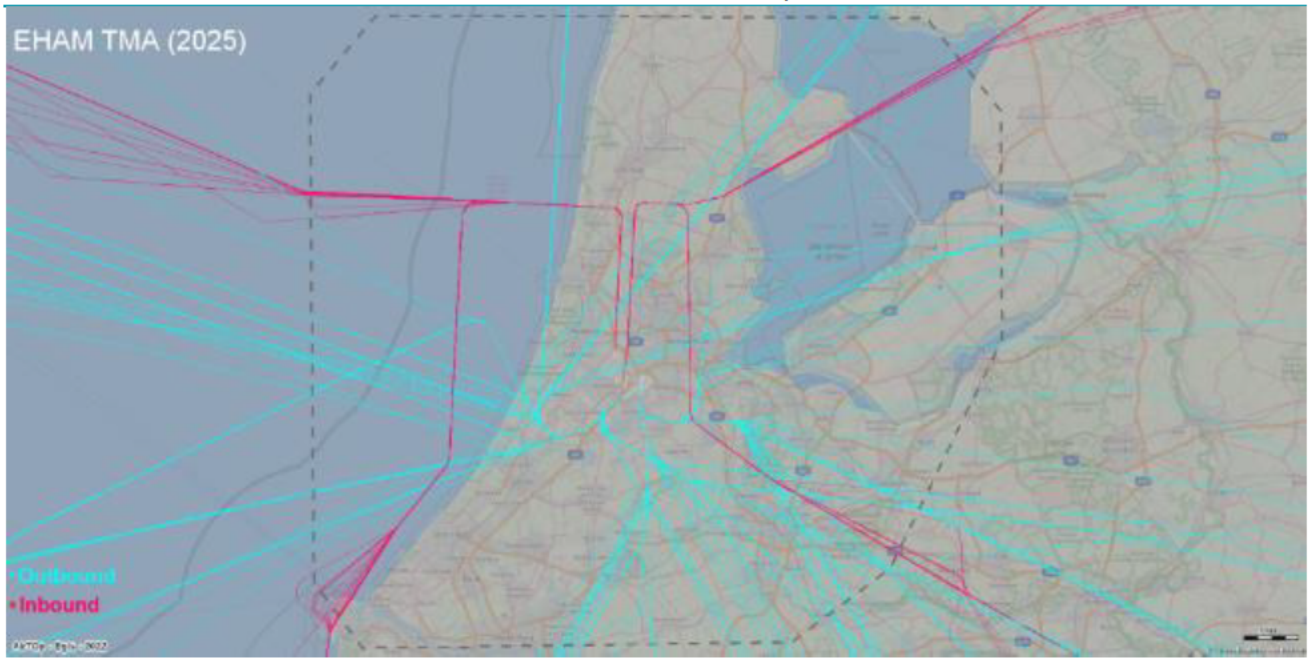
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Southerly	2 arrival RWYs, 2 departure RWYs	0s



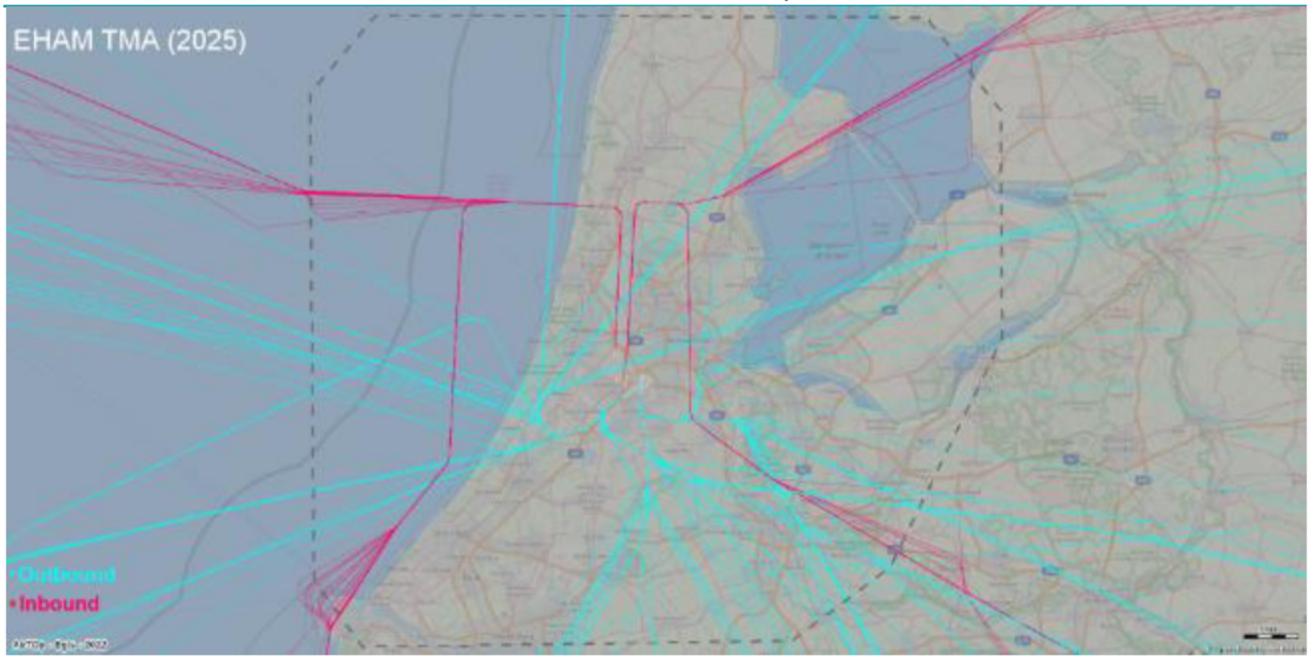
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Southerly	2 arrival RWYs, 2 departure RWYs	15s



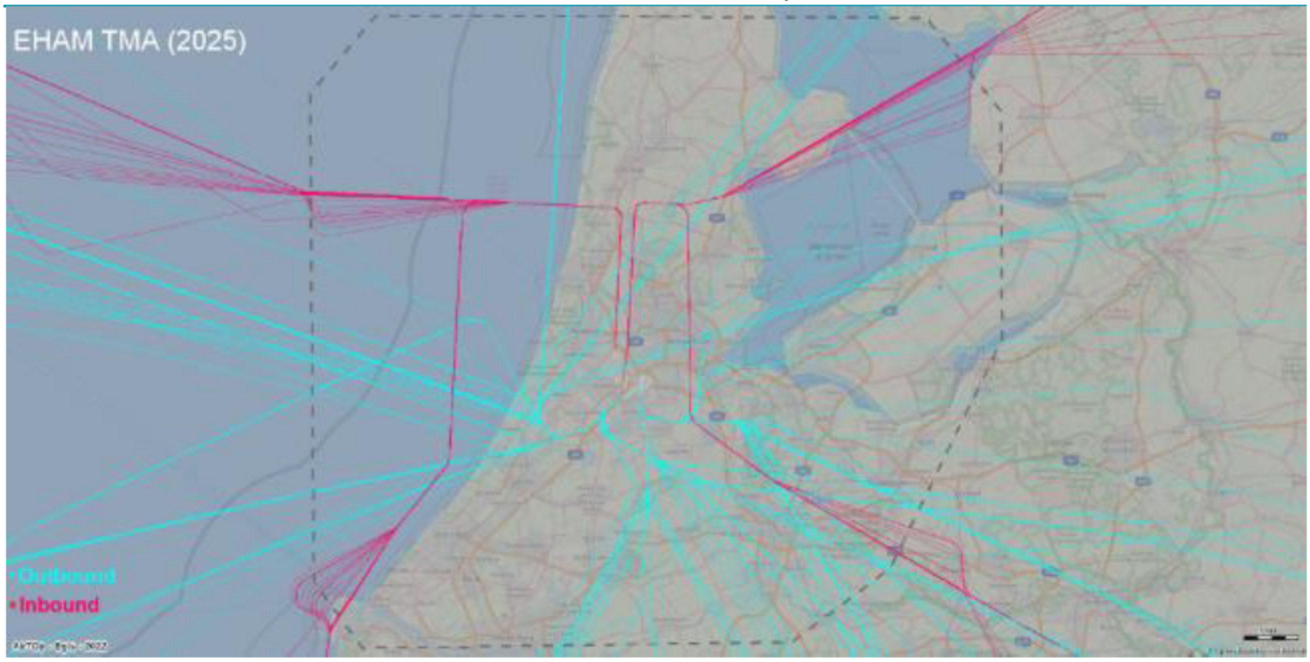
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Southerly	2 arrival RWYs, 2 departure RWYs	30s



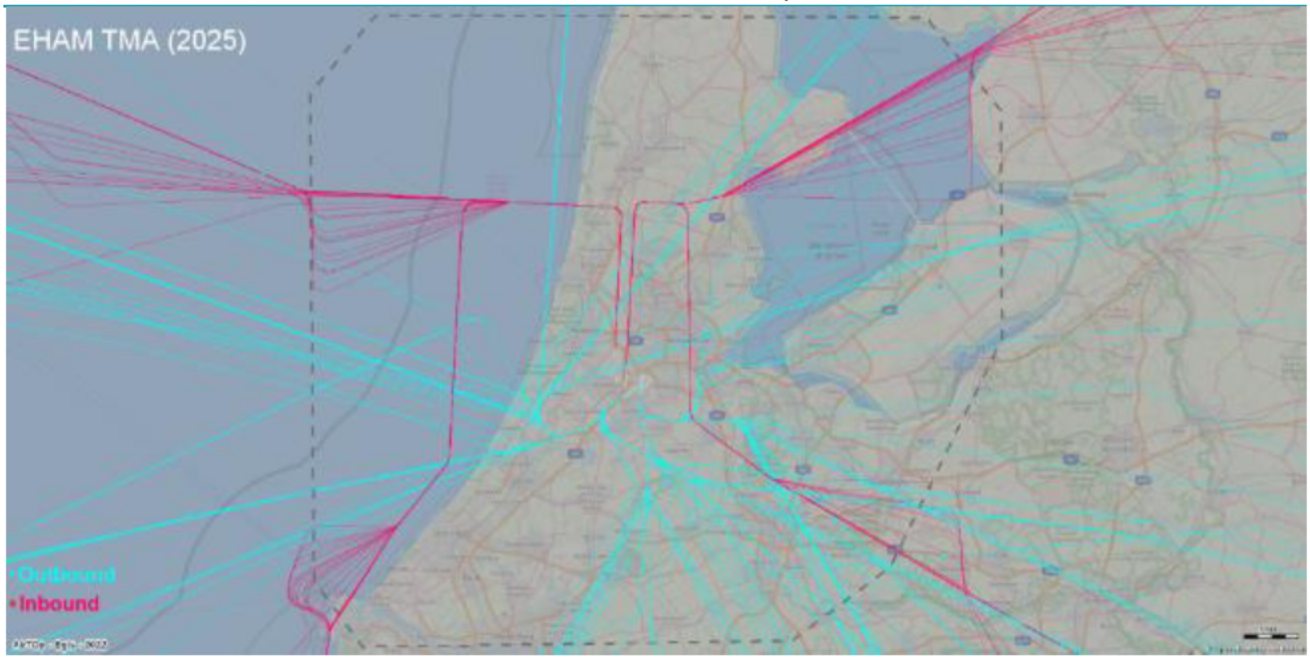
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Southerly	2 arrival RWYs, 2 departure RWYs	45s

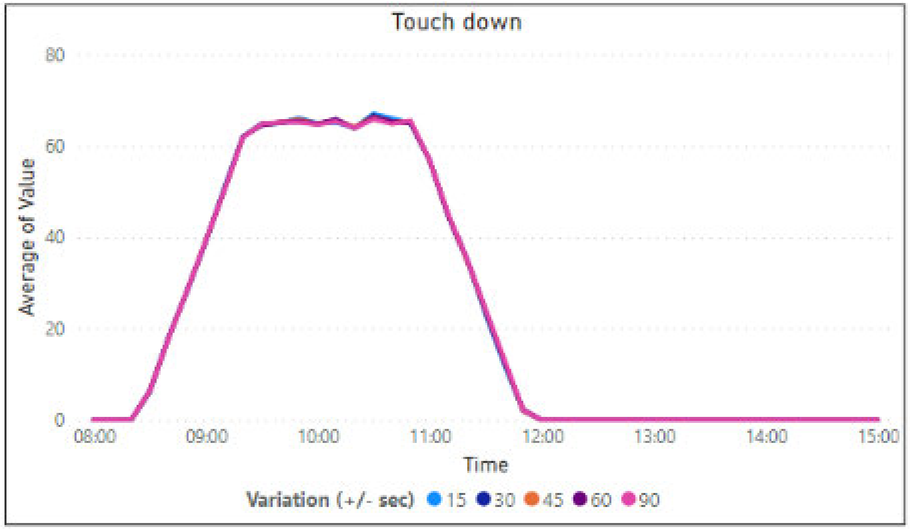


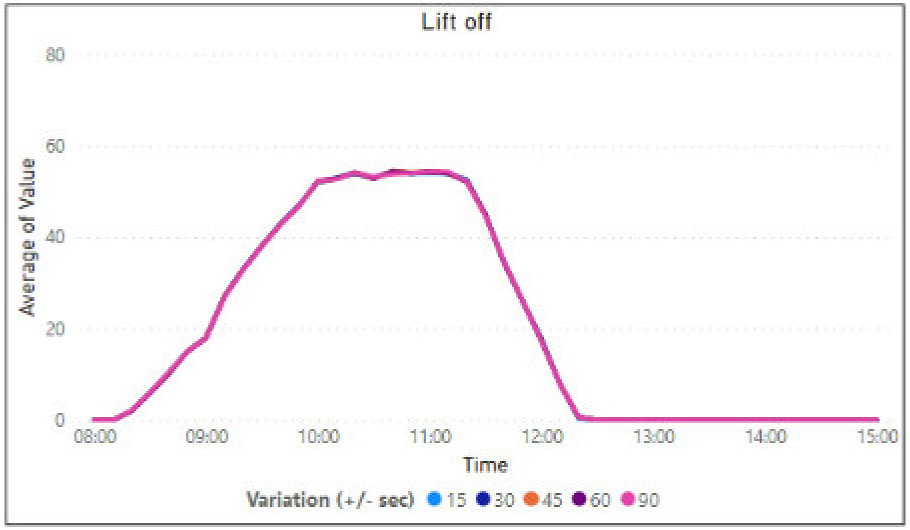
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Southerly	2 arrival RWYs, 2 departure RWYs	60s

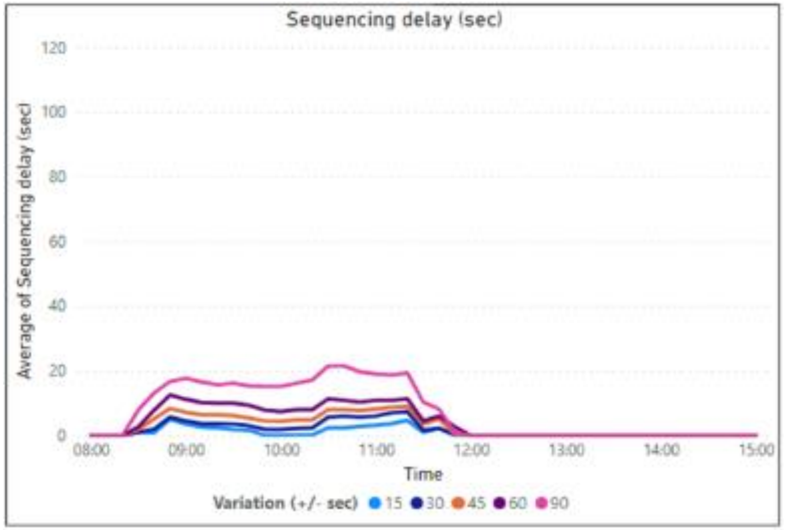


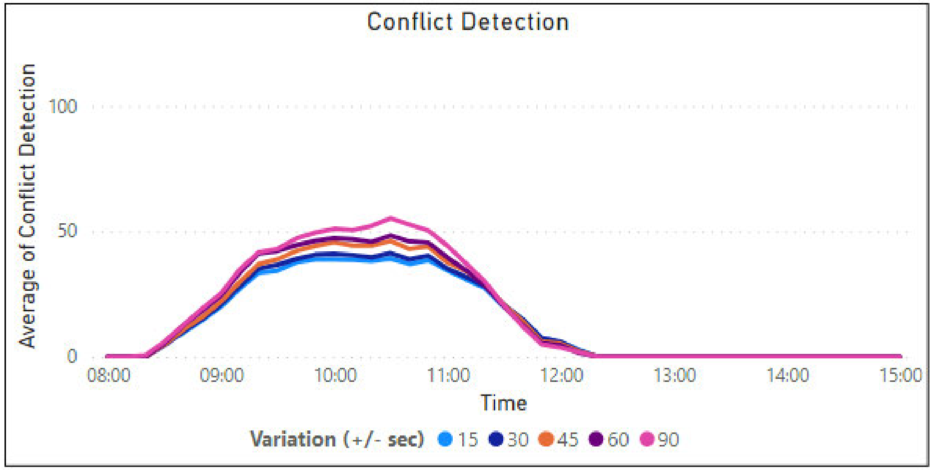
Scenario	Direction	Runway configuration	Accuracy of delivery
2025	Southerly	2 arrival RWYs, 2 departure RWYs	90s




Touch down
Average of Value
80
60
40
20
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 15 30 45 60 90

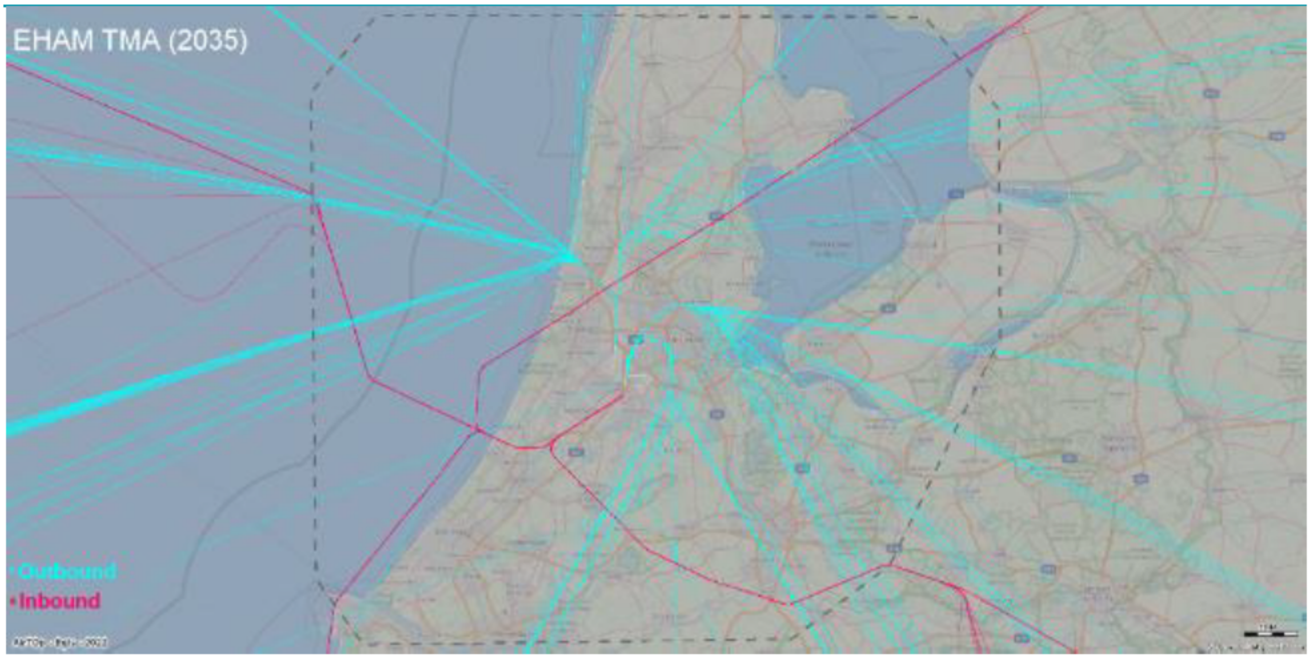

Lift off
Average of Value
80
60
40
20
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 15 30 45 60 90

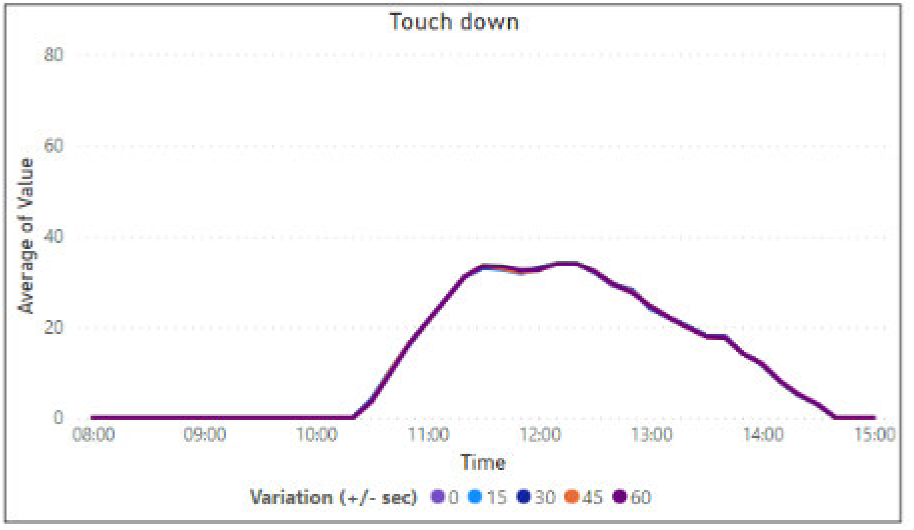

Sequencing delay (sec)
Average of Sequencing delay (sec)
120
100
80
60
40
20
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 15 30 45 60 90

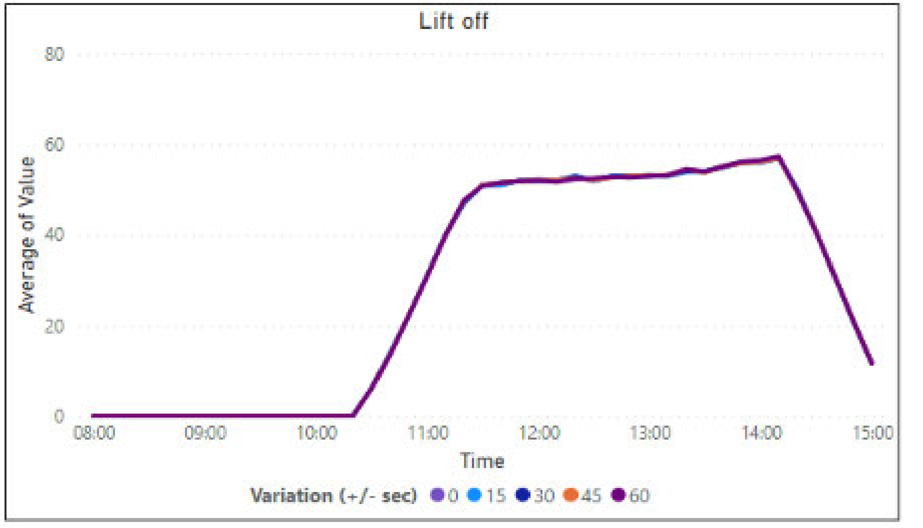

Conflict Detection
Average of Conflict Detection
100
50
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 15 30 45 60 90

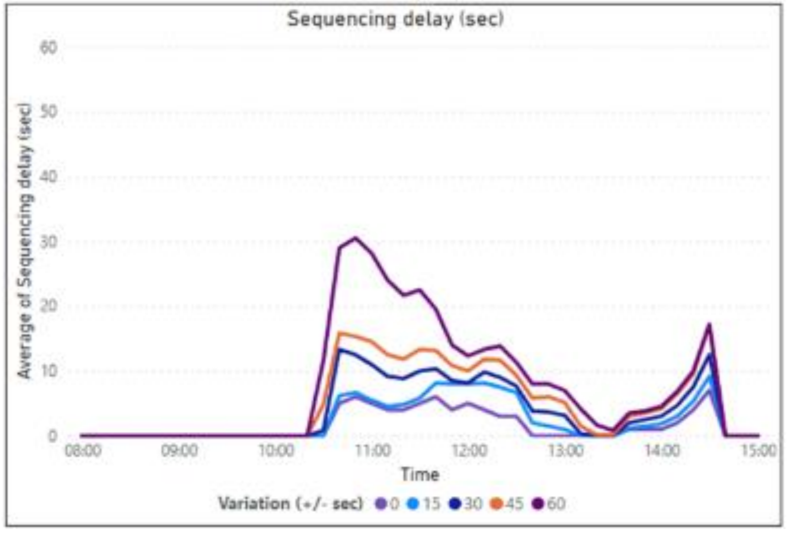
VIII.8.1.5 2035, Northerly, 1A & 2D

Scenario	Direction	Runway configuration	Accuracy of delivery
2035	Northerly	1 arrival RWYs, 2 departure RWYs	0s




Touch down
Average of Value
80
60
40
20
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60


Lift off
Average of Value
80
60
40
20
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60


Sequencing delay (sec)
Average of Sequencing delay (sec)
60
50
40
30
20
10
0
08:00
09:00
10:00
11:00
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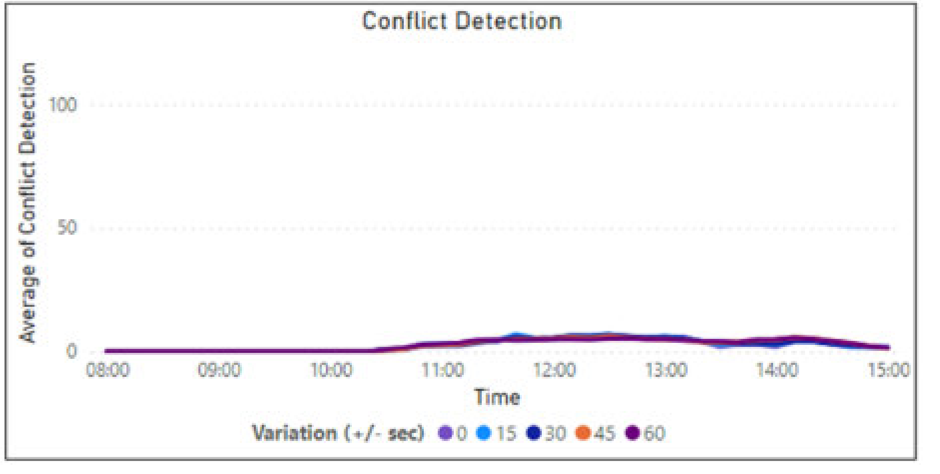
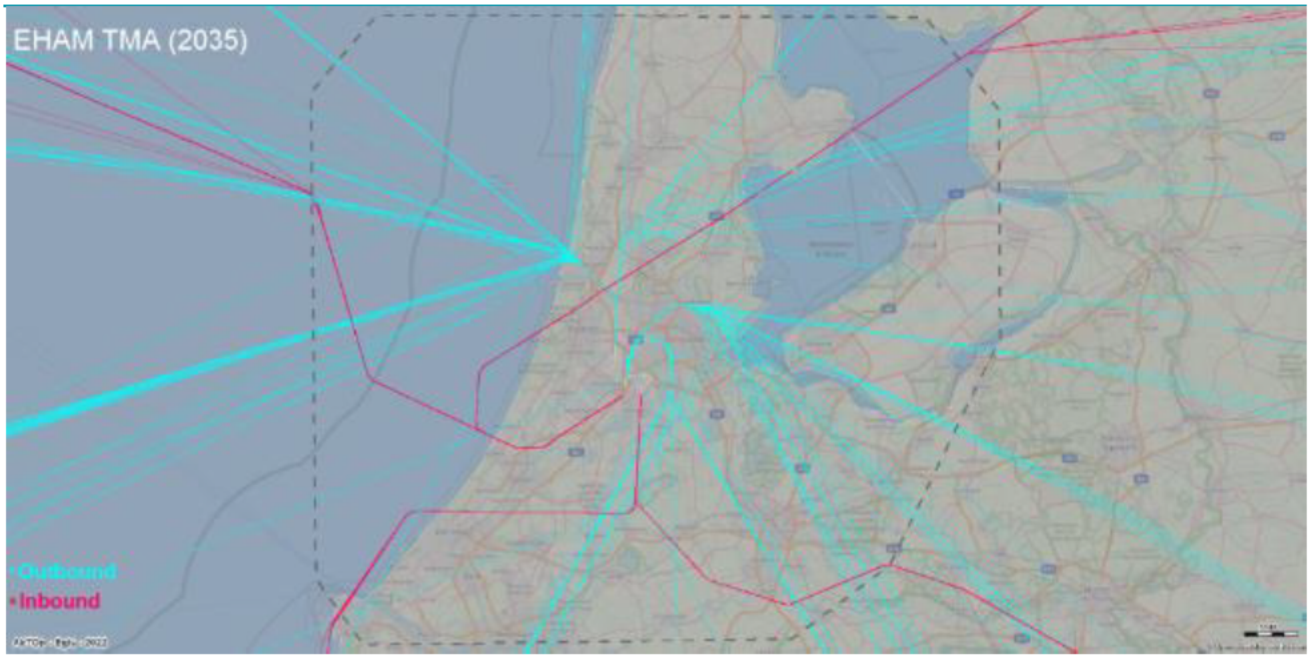
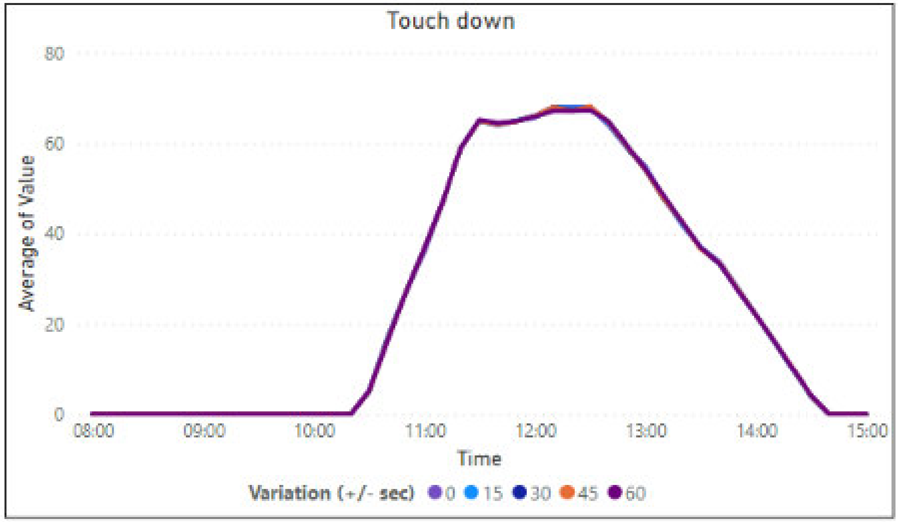
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60

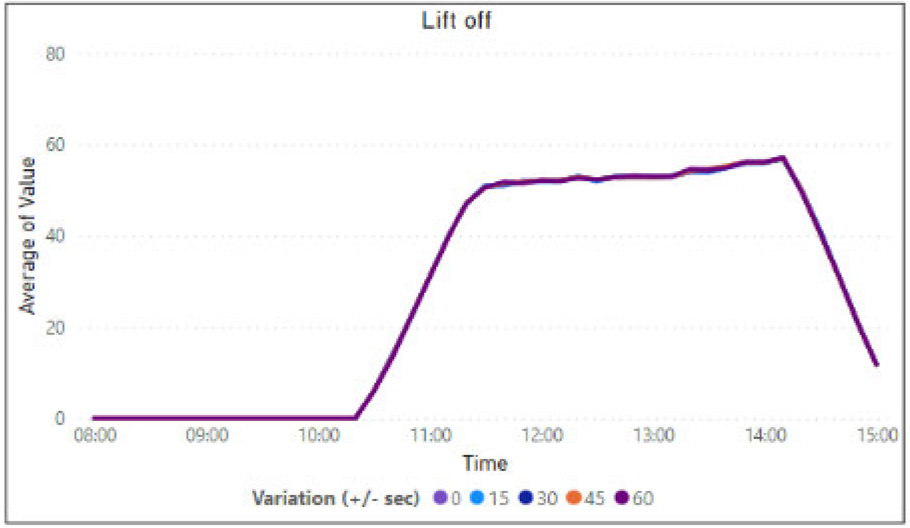

Conflict Detection
Average of Conflict Detection
100
50
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60

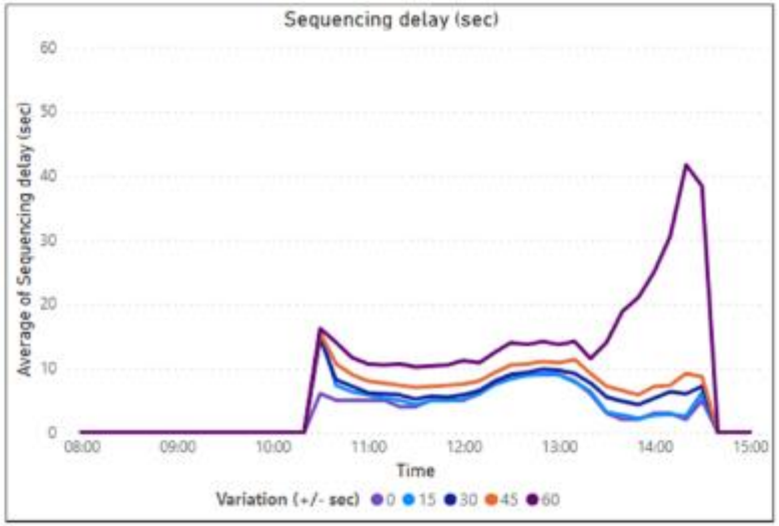
VIII.8.1.6 2035, Northerly, 2A & 2D

Scenario	Direction	Runway configuration	Accuracy of delivery
2035	Northerly	2 arrival RWYs, 2 departure RWYs	0s




Touch down
Average of Value
0
20
40
60
80
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60


Lift off
Average of Value
0
20
40
60
80
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60


Sequencing delay (sec)
Average of Sequencing delay (sec)
0
10
20
30
40
50
60
08:00
09:00
10:00
11:00
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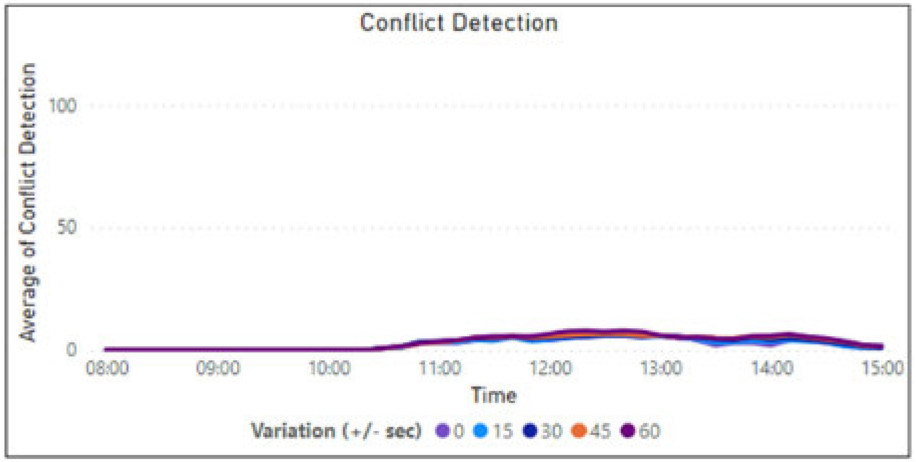
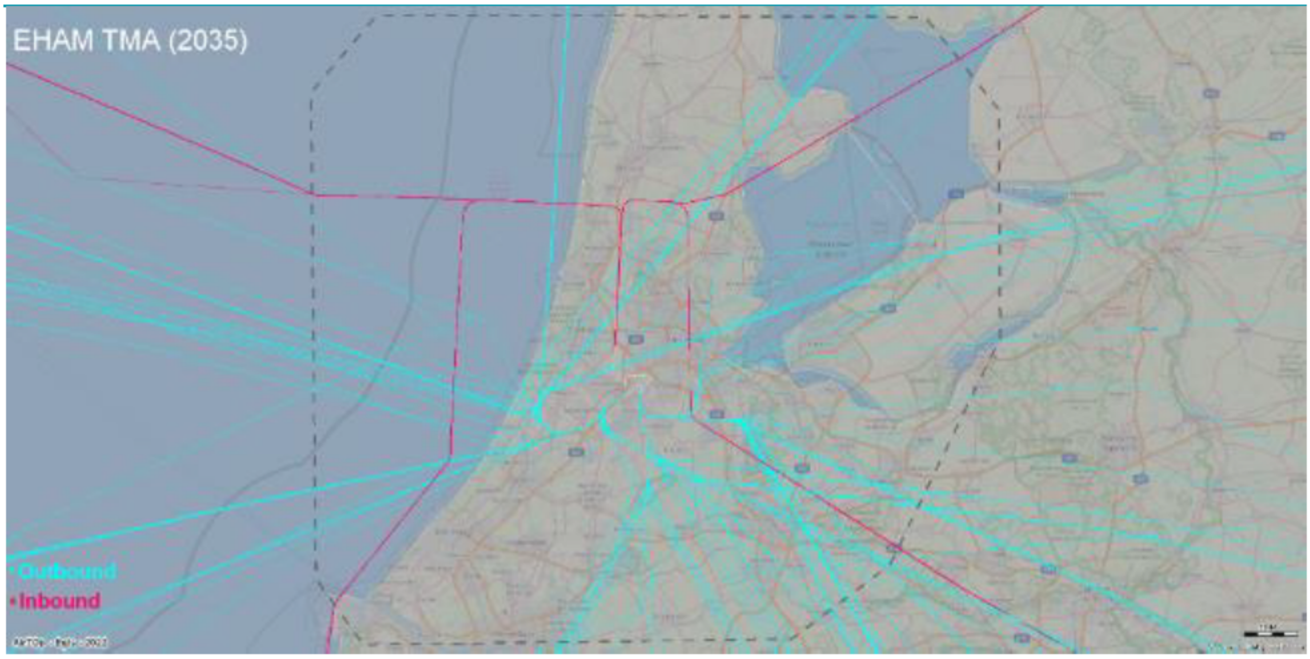
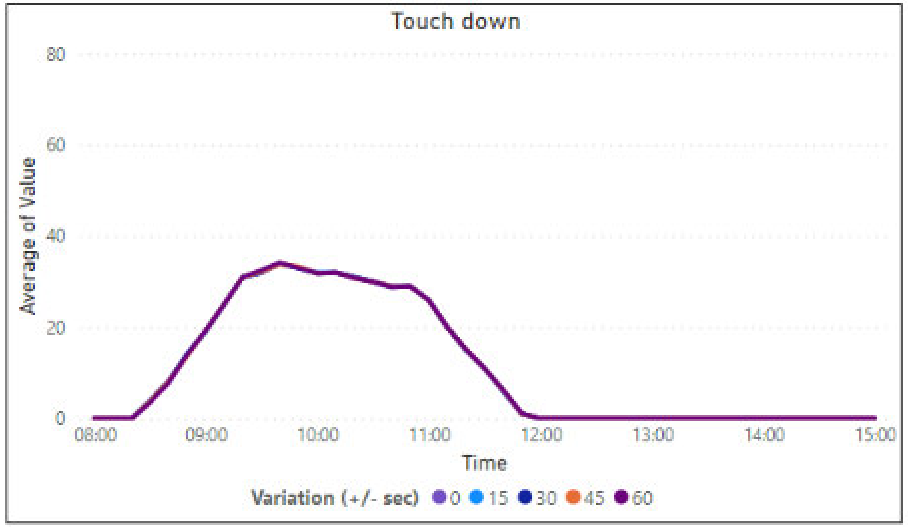
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60

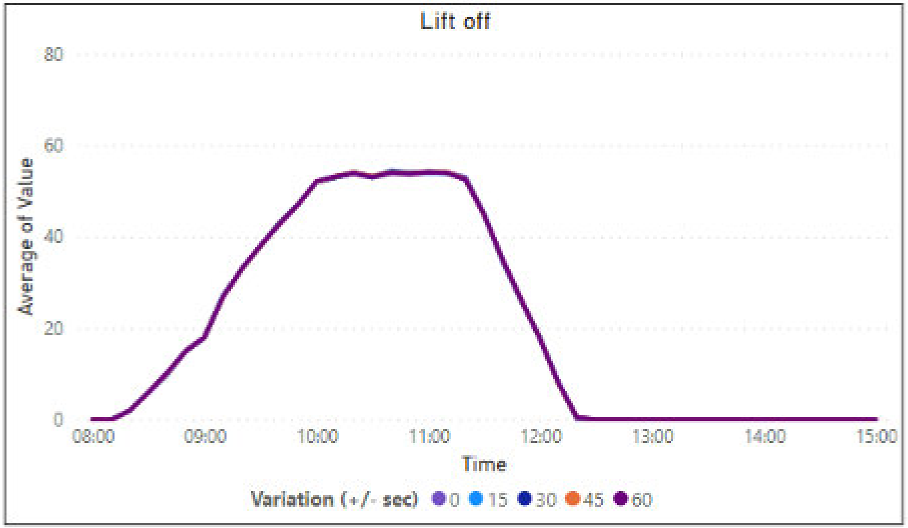

Conflict Detection
Average of Conflict Detection
0
50
100
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60

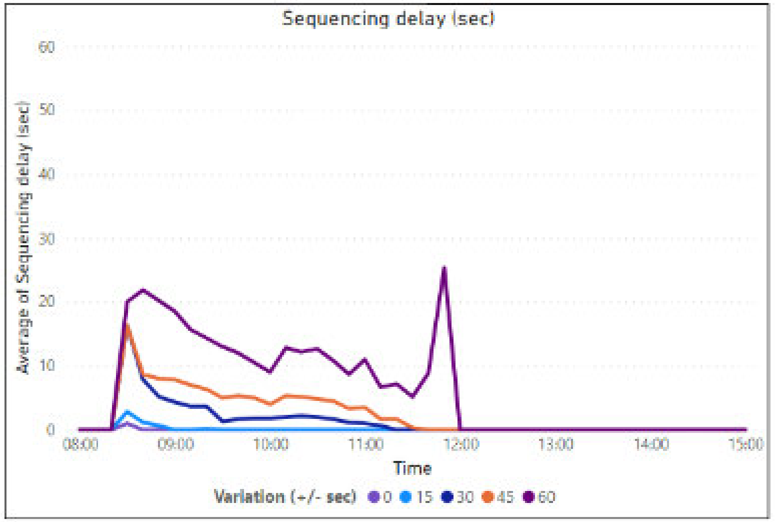
VIII.8.1.7 2035, Southerly, 1A & 2D

Scenario	Direction	Runway configuration	Accuracy of delivery
2035	Southerly	1 arrival RWYs, 2 departure RWYs	0s




Touch down
Average of Value
80
60
40
20
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60


Lift off
Average of Value
80
60
40
20
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60


Sequencing delay (sec)
Average of Sequencing delay (sec)
60
50
40
30
20
10
0
08:00
09:00
10:00
11:00
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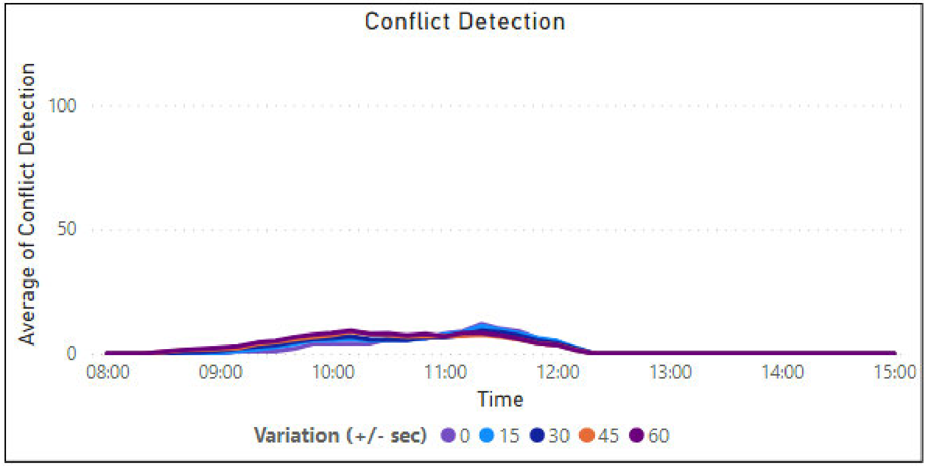
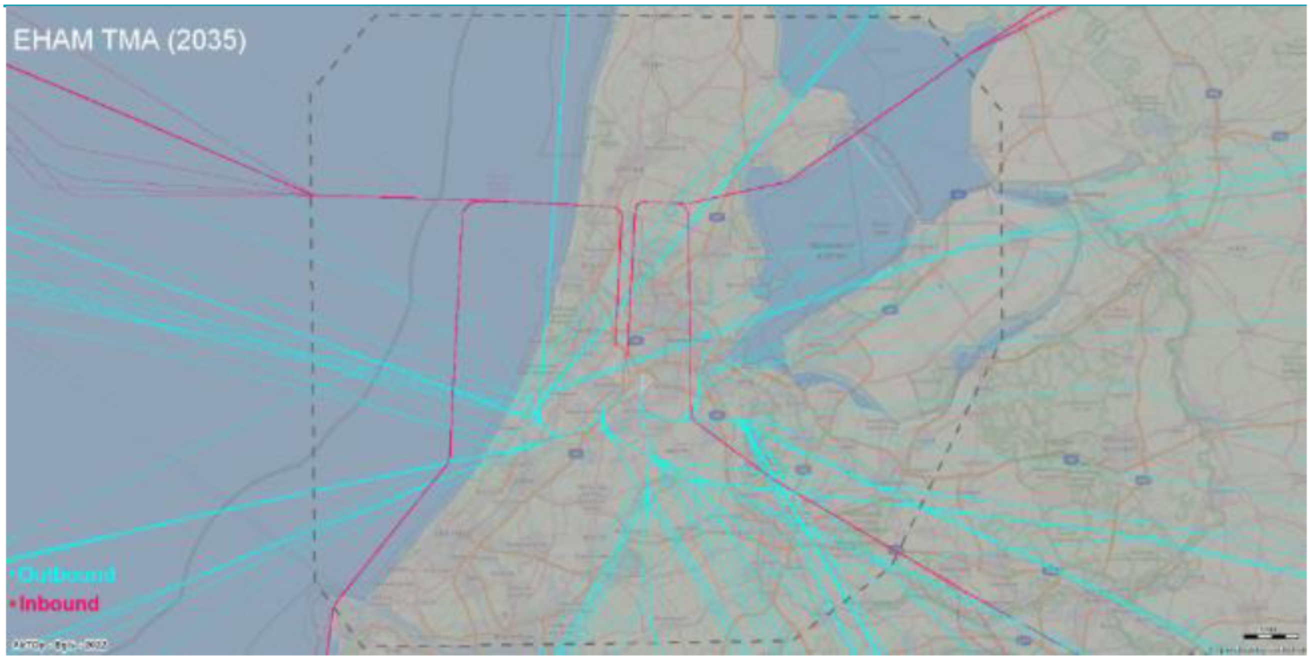
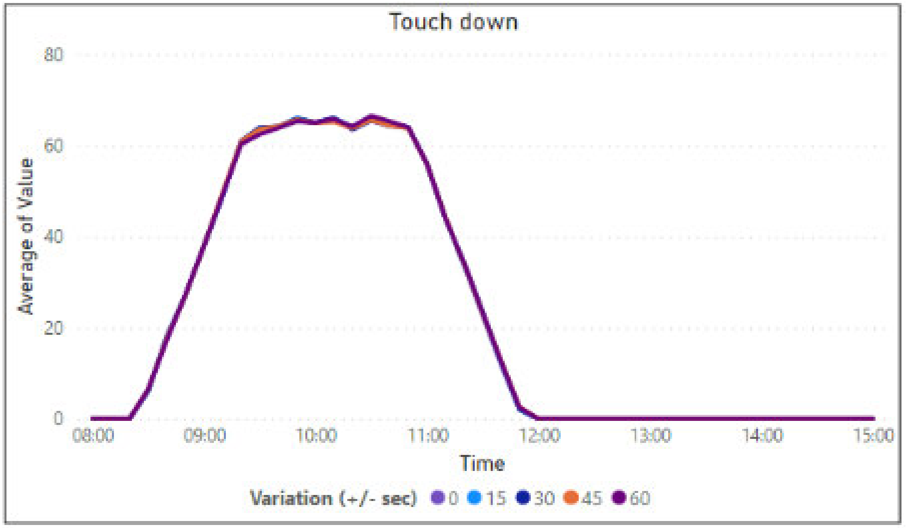
Time
Variation (+/- sec) 0 15 30 45 60

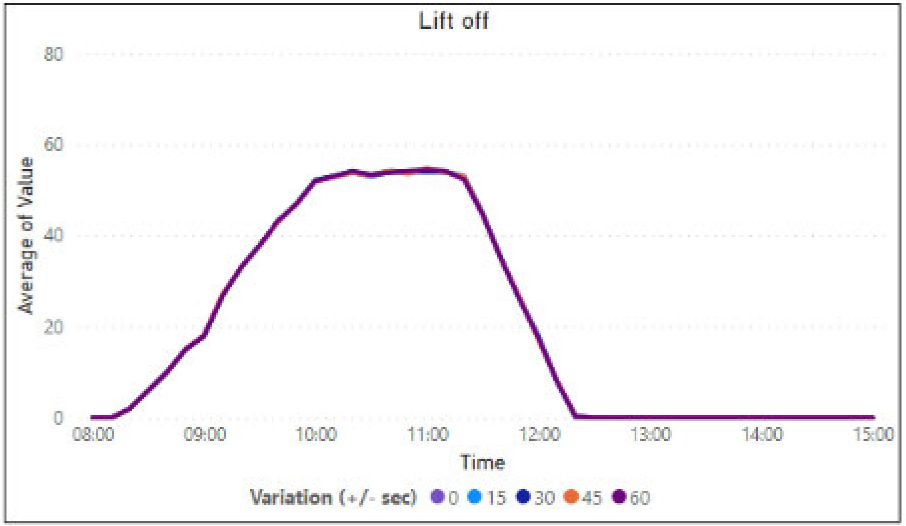

Conflict Detection
Average of Conflict Detection
100
50
0
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60

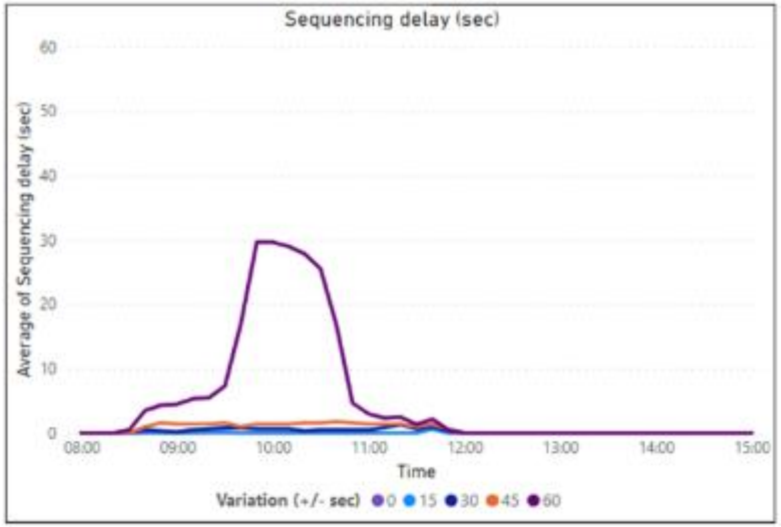
VIII.8.1.8 2035, Southerly, 2A & 2D

Scenario	Direction	Runway configuration	Accuracy of delivery
2035	Southerly	2 arrival RWYs, 2 departure RWYs	0s




Touch down
80
60
40
20
0
Average of Value
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60


Lift off
80
60
40
20
0
Average of Value
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60


Sequencing delay (sec)
60
50
40
30
20
10
0
Average of Sequencing delay (sec)
08:00
09:00
10:00
11:00
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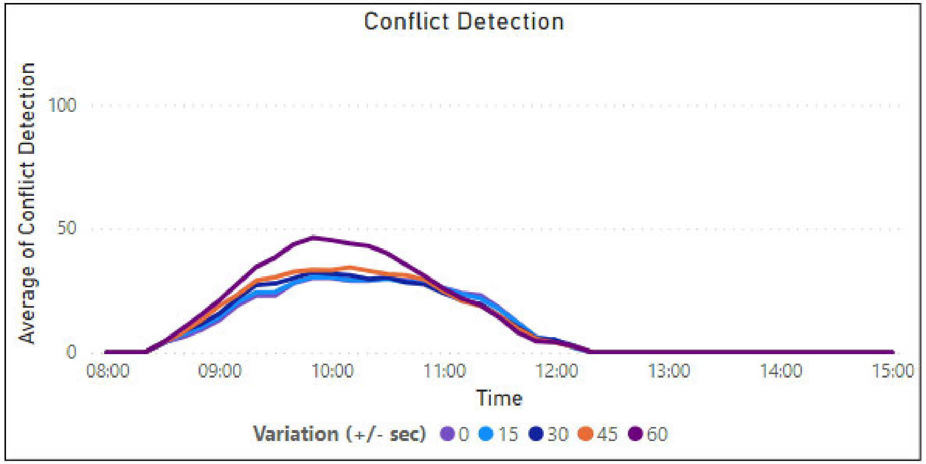
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60


Conflict Detection
100
50
0
Average of Conflict Detection
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
Time
Variation (+/- sec) 0 15 30 45 60

VIII.8.2 Tracking of tubes (detailed results)

VIII.8.2.1 Additional results for the 45 dB contour

45dB contour area (in km²)			Departures vectored at							
Year	Dir	Configuration	3,000 ft	4,000 ft	5,000 ft	6,000 ft	7,000 ft	8,000 ft	9,000 ft	Full tube
2025	N	Abs. peak (2A+2D)	3,150	3,070	2,980	2,510	2,460	2,590	2,740	3,740
2025	S	Abs. peak (2A+2D)	1,930	1,960	1,910	2,000	2,090	2,010	1,980	2,470
2025	N	Arr. peak (2A+1D)	3,260	3,210	2,300	2,280	2,260	2,290	2,280	2,850
2025	S	Arr. peak (2A+1D)	1,840	1,840	1,860	1,930	2,050	2,000	1,970	2,690
2025	N	Dep. peak (1A+2D)	4,420	4,440	4,370	3,980	3,820	3,890	4,050	4,910
2025	S	Dep. peak (1A+2D)	2,360	2,410	2,450	2,490	2,610	2,660	2,510	3,350

45dB contour area over the land only (in km²)			Departures vectored at							
Year	Dir	Configuration	3,000 ft	4,000 ft	5,000 ft	6,000 ft	7,000 ft	8,000 ft	9,000 ft	Full tube
2025	N	Abs. peak (2A+2D)	1,430	1,260	1,190	1,140	1,110	1,090	1,090	1,950
2025	S	Abs. peak (2A+2D)	1,040	1,060	1,010	1,020	1,010	1,030	1,060	1,240
2025	N	Arr. peak (2A+1D)	1,550	1,370	1,250	1,140	1,090	1,070	1,090	1,460
2025	S	Arr. peak (2A+1D)	840	830	850	860	880	900	930	1,260
2025	N	Dep. peak (1A+2D)	2,010	1,860	1,780	1,740	1,660	1,640	1,580	2,670
2025	S	Dep. peak (1A+2D)	1,220	1,280	1,290	1,230	1,220	1,230	1,240	1,700

45dB contour - population (millions)			Departures vectored at							
Year	Dir	Configuration	3,000 ft	4,000 ft	5,000 ft	6,000 ft	7,000 ft	8,000 ft	9,000 ft	Full tube
2025	N	Abs. peak (2A+2D)	1.51	1.43	1.39	1.46	1.36	1.34	1.38	1.63
2025	S	Abs. peak (2A+2D)	0.60	0.71	0.65	0.64	0.65	0.70	0.68	1.63
2025	N	Arr. peak (2A+1D)	1.37	1.21	1.11	1.01	0.93	0.90	0.90	1.04
2025	S	Arr. peak (2A+1D)	0.52	0.58	0.57	0.52	0.51	0.55	0.62	0.67
2025	N	Dep. peak (1A+2D)	1.65	1.63	1.67	1.69	1.75	1.76	1.70	1.88
2025	S	Dep. peak (1A+2D)	1.00	1.07	1.15	0.92	0.92	0.99	0.98	0.98

VIII.8.2.2 Additional results for the 43 dB contour

43dB contour area in km²			Departures vectored at							
Year	**Dir**	**Configuration**	**3,000 ft**	**4,000 ft**	**5,000 ft**	**6,000 ft**	**7,000 ft**	**8,000 ft**	**9,000 ft**	**Full tube**
2025	N	Abs. peak (2A+2D)	5,380	5,370	5,310	5,090	5,000	5,010	5,160	5,810
2025	S	Abs. peak (2A+2D)	3,160	3,150	3,220	3,290	3,330	3,390	3,330	4,240
2025	N	Arr. peak (2A+1D)	5,160	5,260	4,330	4,230	4,280	4,100	4,150	4,600
2025	S	Arr. peak (2A+1D)	3,060	3,090	3,080	3,160	3,280	3,370	3,200	3,980
2025	N	Dep. peak (1A+2D)	6,570	6,690	6,540	6,360	6,420	6,540	6,670	7,080
2025	S	Dep. peak (1A+2D)	4,170	3,930	4,020	4,180	4,320	4,310	4,420	5,340

43dB contour area over the land only in km²			Departures vectored at							
Year	**Dir**	**Configuration**	**3,000 ft**	**4,000 ft**	**5,000 ft**	**6,000 ft**	**7,000 ft**	**8,000 ft**	**9,000 ft**	**Full tube**
2025	N	Abs. peak (2A+2D)	2,460	2,330	2,230	2,200	2,200	2,140	2,070	3,240
2025	S	Abs. peak (2A+2D)	1,650	1,690	1,740	1,730	1,640	1,610	1,650	2,270
2025	N	Arr. peak (2A+1D)	2,380	2,310	2,310	2,150	2,130	1,980	1,930	2,340
2025	S	Arr. peak (2A+1D)	1,360	1,390	1,370	1,410	1,410	1,410	1,410	1,950
2025	N	Dep. peak (1A+2D)	3,030	3,000	2,860	2,790	2,910	2,940	2,890	4,000
2025	S	Dep. peak (1A+2D)	2,100	2,060	2,080	2,160	2,190	2,070	2,150	2,930

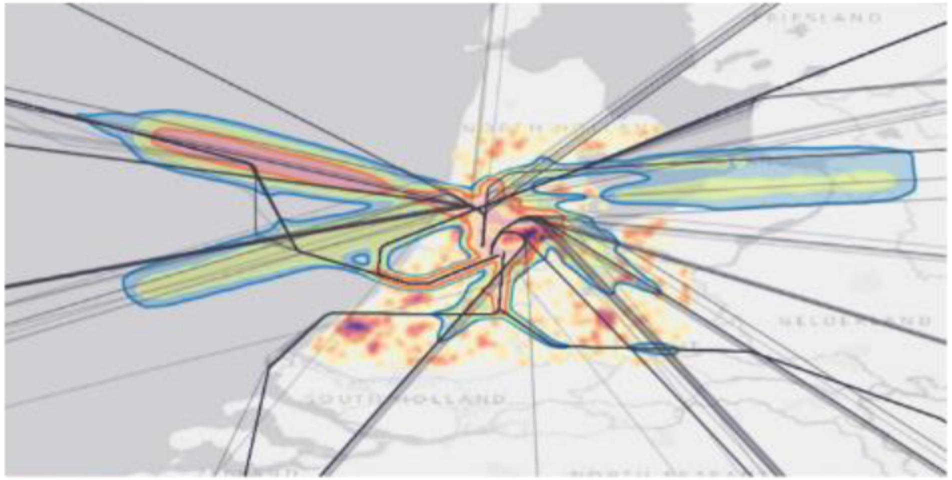
43dB contour - population (millions)			Departures vectored at							
Year	**Dir**	**Configuration**	**3,000 ft**	**4,000 ft**	**5,000 ft**	**6,000 ft**	**7,000 ft**	**8,000 ft**	**9,000 ft**	**Full tube**
2025	N	Abs. peak (2A+2D)	1.84	1.91	1.94	1.93	2.00	2.01	1.98	2.16
2025	S	Abs. peak (2A+2D)	1.38	1.46	1.60	1.51	1.29	1.39	1.45	2.16
2025	N	Arr. peak (2A+1D)	1.78	1.79	1.83	1.65	1.47	1.42	1.42	1.55
2025	S	Arr. peak (2A+1D)	0.98	1.00	1.02	1.11	1.04	1.11	1.26	1.08
2025	N	Dep. peak (1A+2D)	2.22	2.27	2.32	2.43	2.50	2.47	2.47	2.44
2025	S	Dep. peak (1A+2D)	1.66	1.80	1.91	2.00	1.99	1.93	1.86	1.79

VIII.8.2.3 Tracking of tubes, 2025, Northerly, 2A & 2D

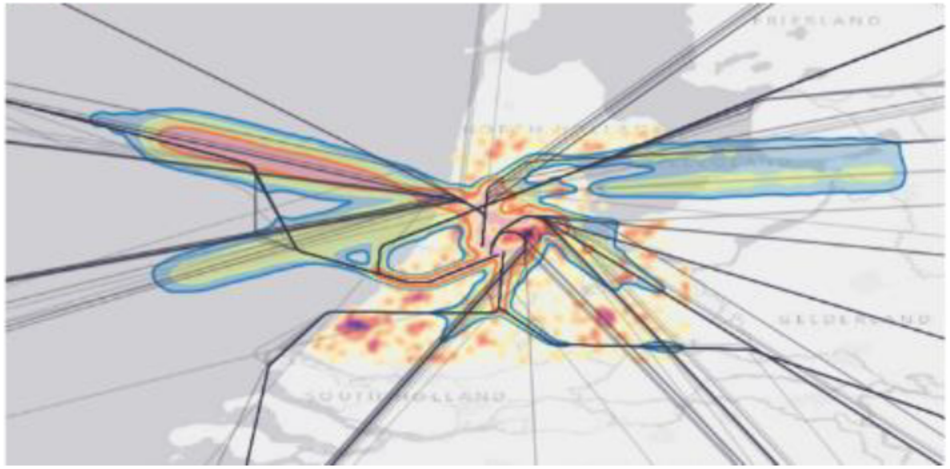
Scenario	Direction	Runway configuration	Tracking of tubes up to
2025	Northerly	2 arrival RWYs, 2 departure RWYs	3,000ft – 6,000ft

3000FT

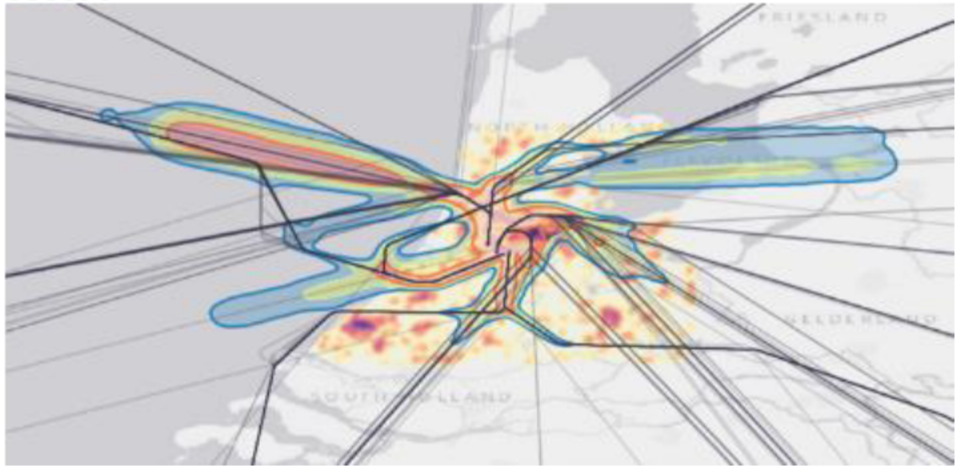
4000FT



5000FT

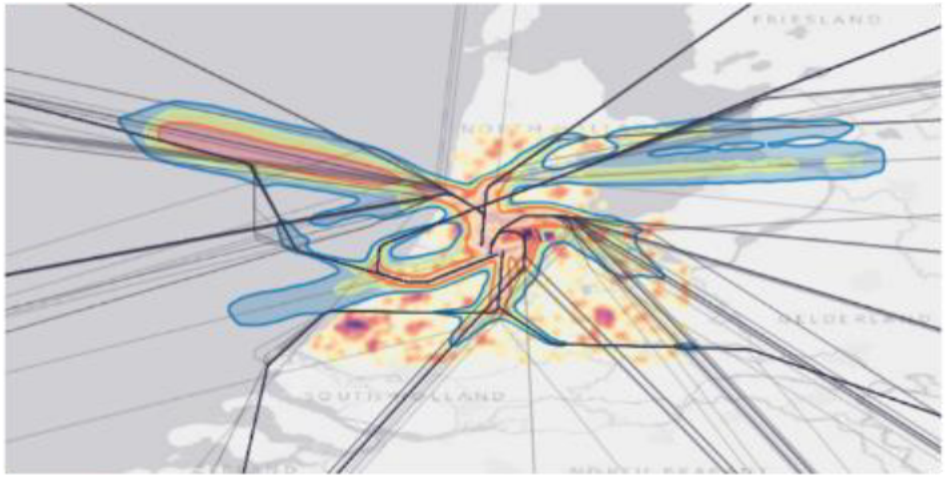


6000FT

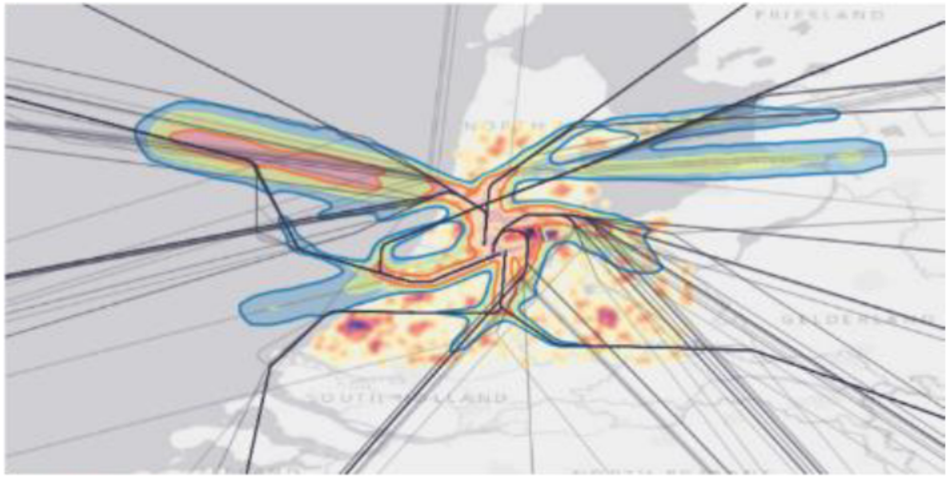


Scenario	Direction	Runway configuration	Tracking of tubes up to
2025	Northerly	2 arrival RWYs, 2 departure RWYs	7,000ft – full tube followed

7000FT

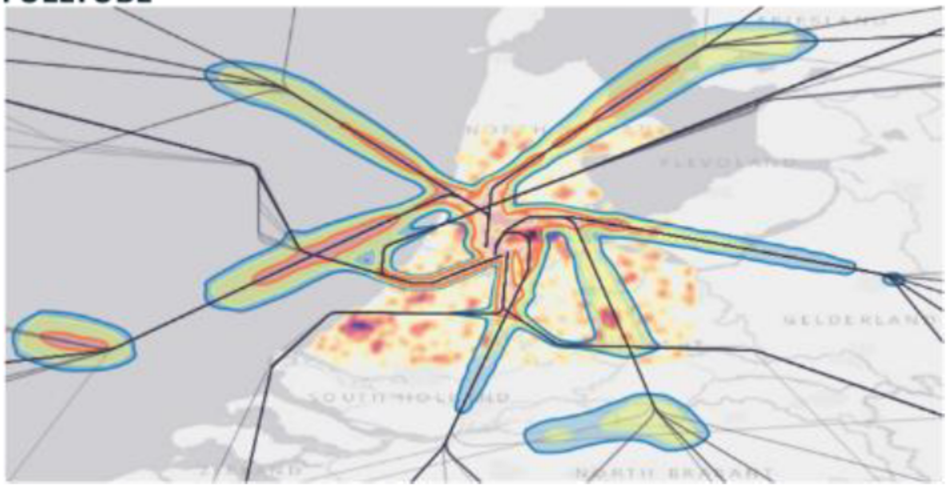


8000FT



9000FT

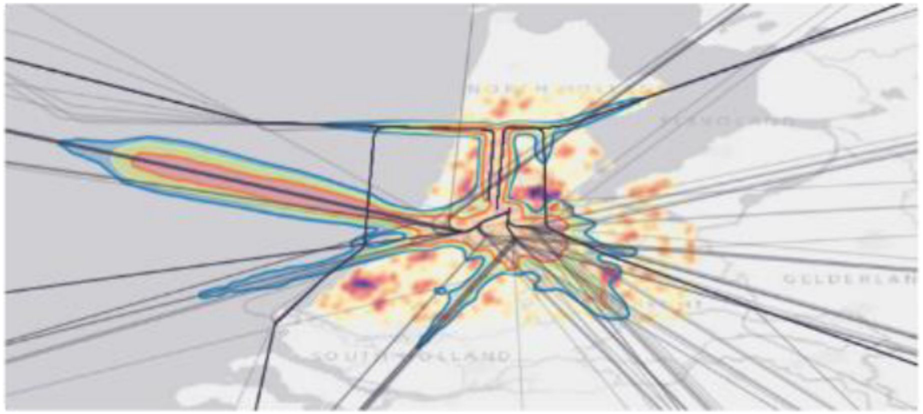
FULLTUBE



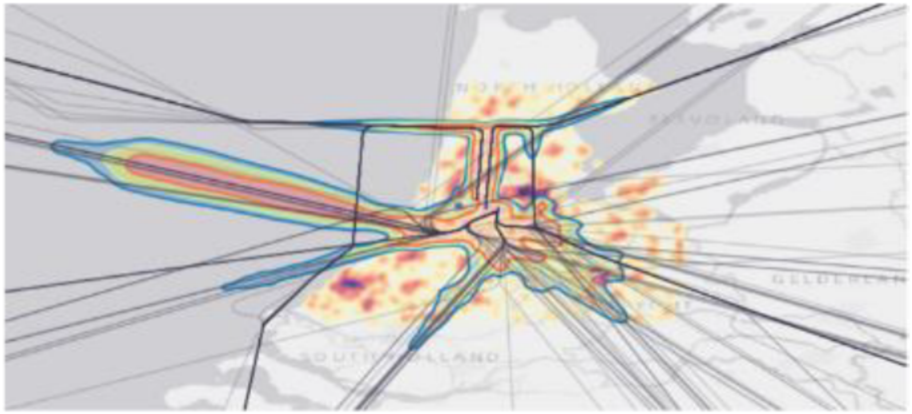
VIII.8.2.4 Tracking of tubes, 2025, Southerly, 2A & 2D

Scenario	Direction	Runway configuration	Tracking of tubes up to
2025	Southerly	2 arrival RWYs, 2 departure RWYs	3,000ft – 6,000ft

3000FT



4000FT



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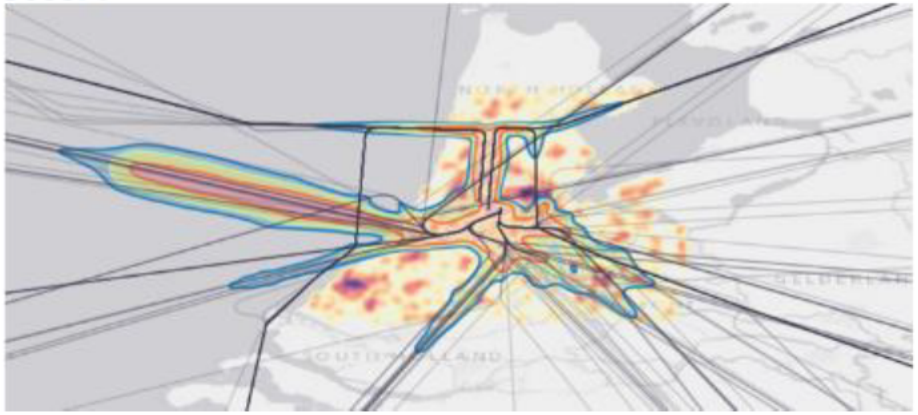

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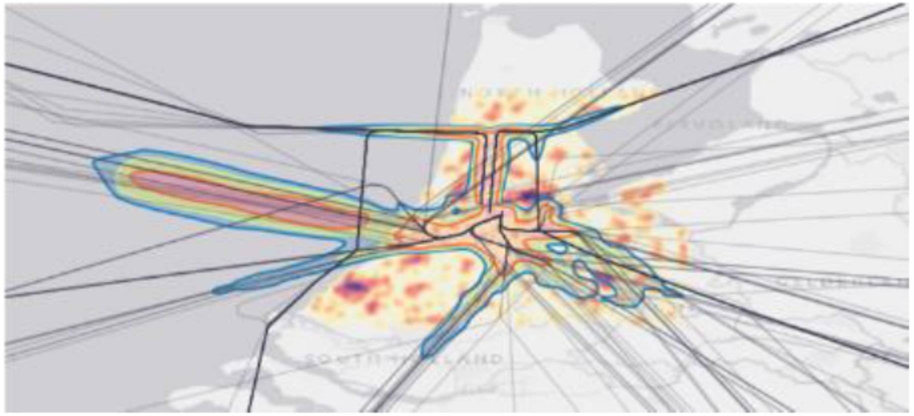
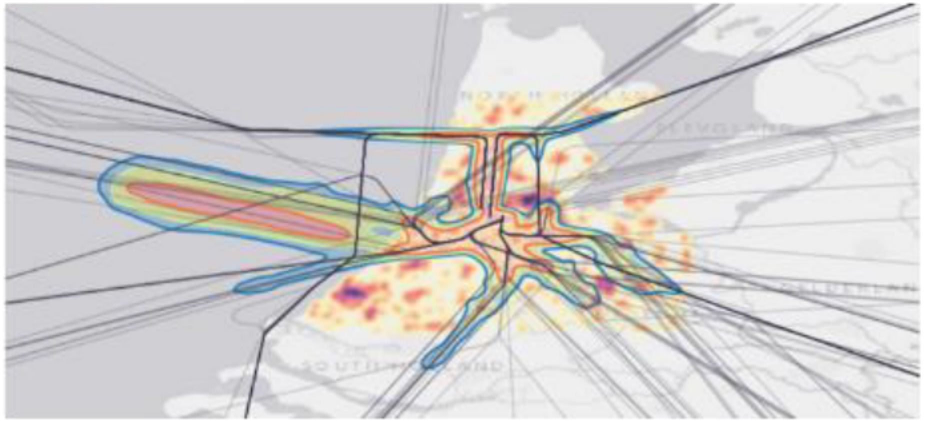
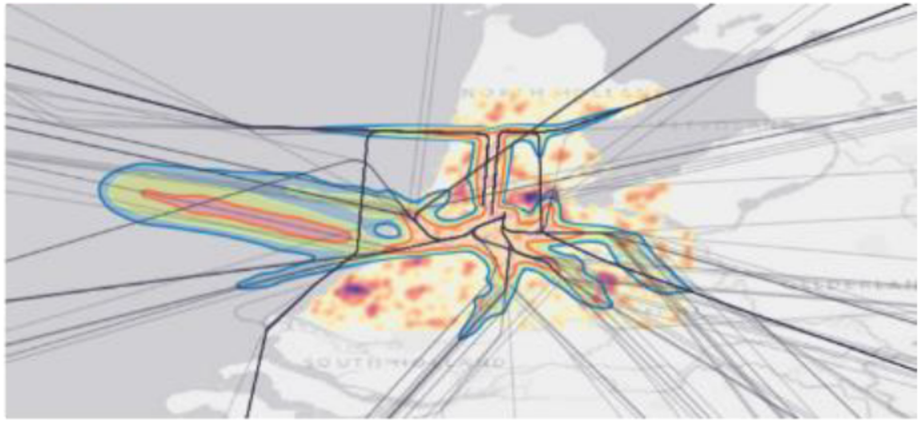


Scenario	Direction	Runway configuration	Tracking of tubes up to
2025	Southerly	2 arrival RWYs, 2 departure RWYs	7,000ft - full tube followed

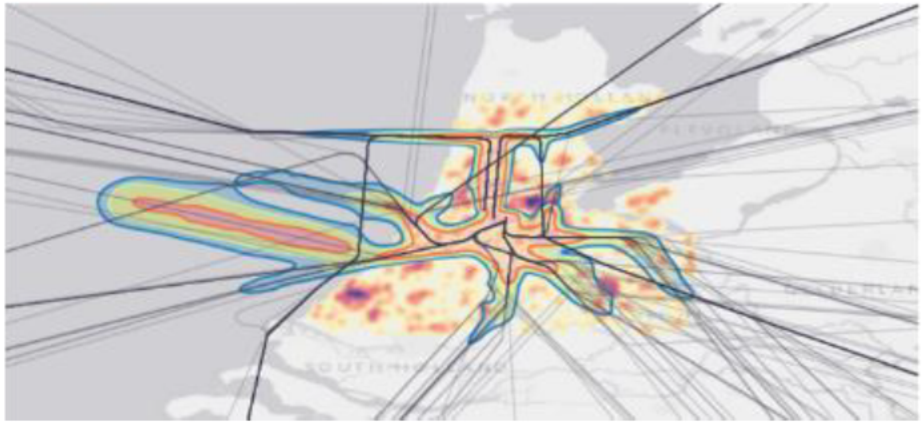
7000FT



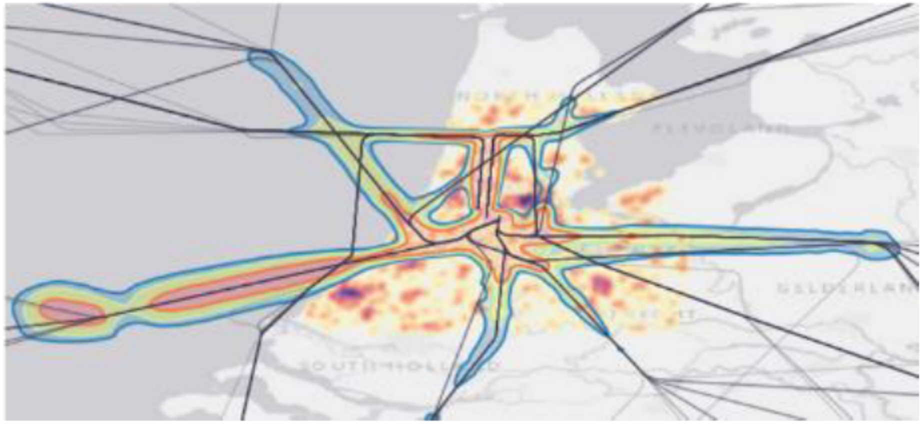
8000FT



9000FT



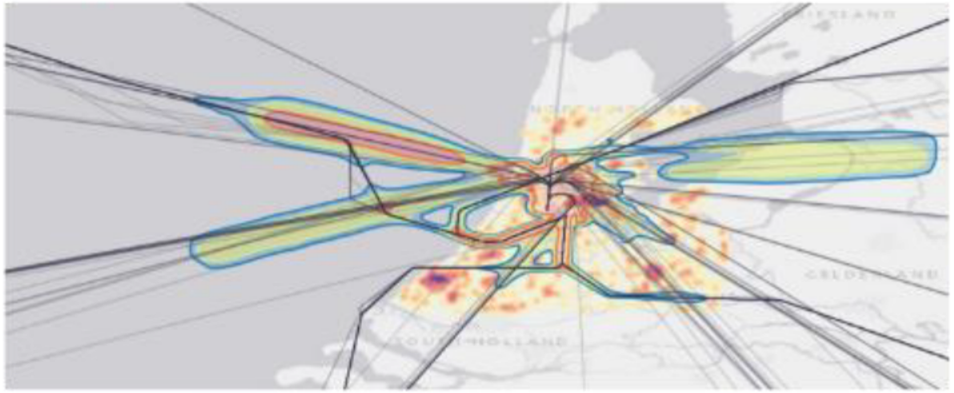
FULLTUBE



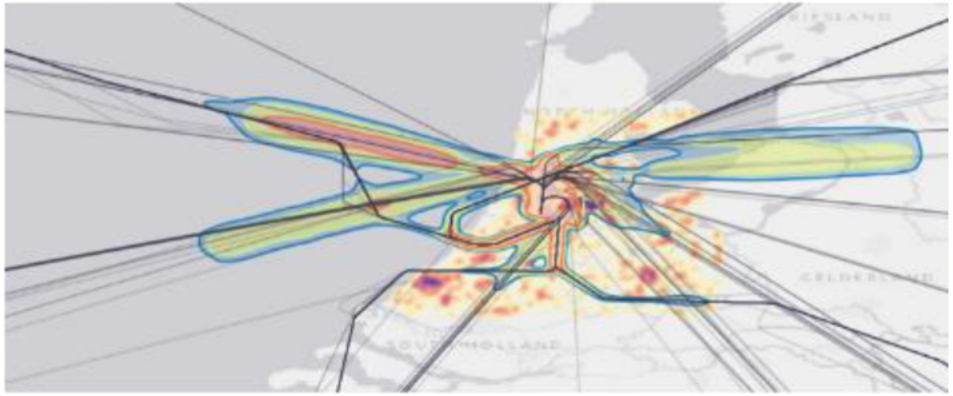
VIII.8.2.5 Tracking of tubes, 2025, Northerly, 2A & 1D

Scenario	Direction	Runway configuration	Tracking of tubes up to
2025	Northerly	2 arrival RWYs, 1 departure RWY	3,000ft – 6,000ft

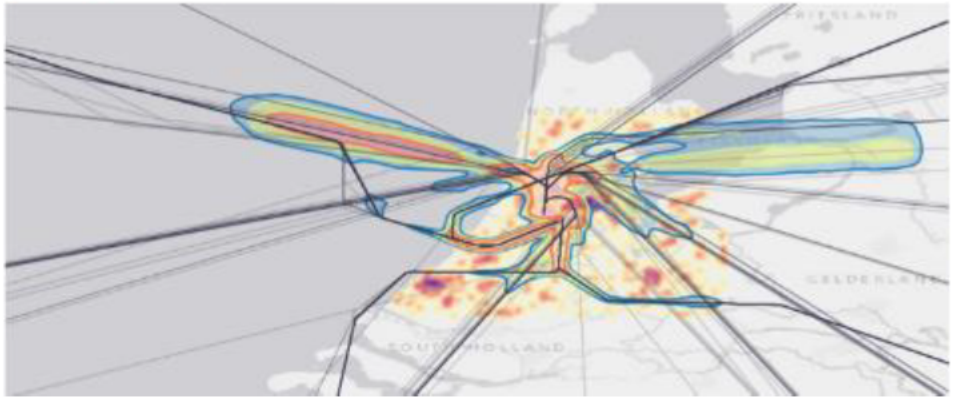
3000FT



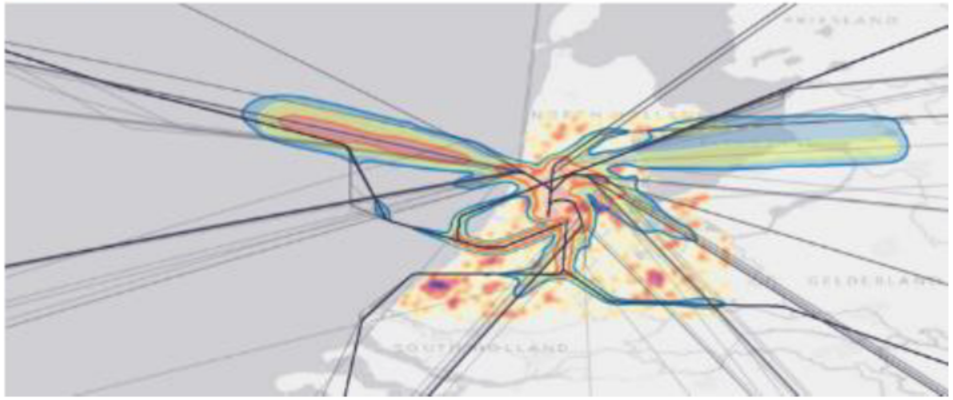
4000FT



5000FT

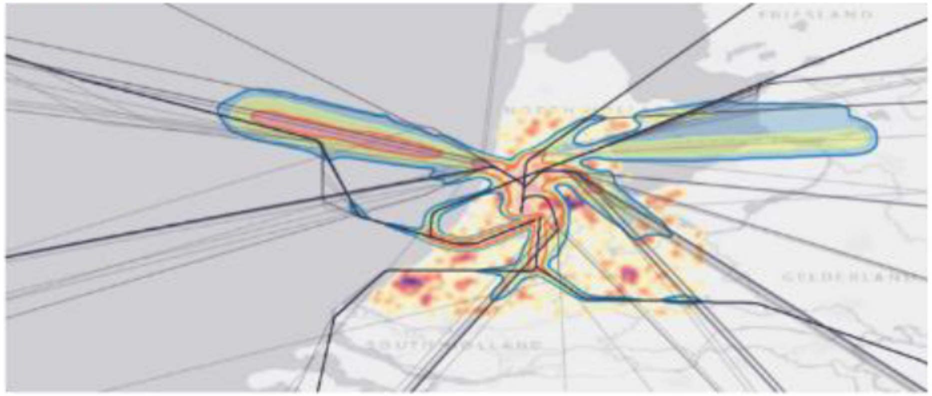


6000FT

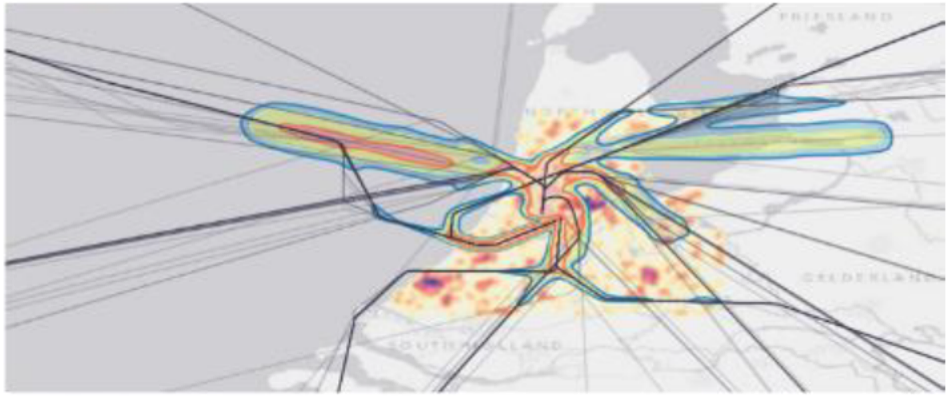


Scenario	Direction	Runway configuration	Tracking of tubes up to
2025	Northerly	2 arrival RWYs, 1 departure RWY	7,000ft – full tube followed

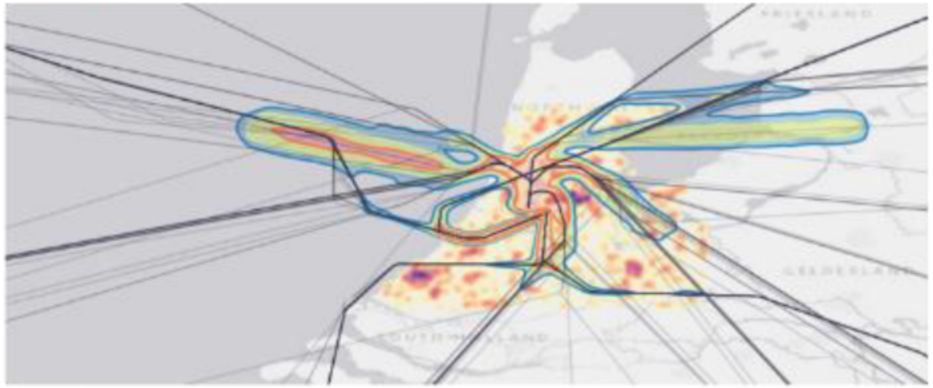
7000FT



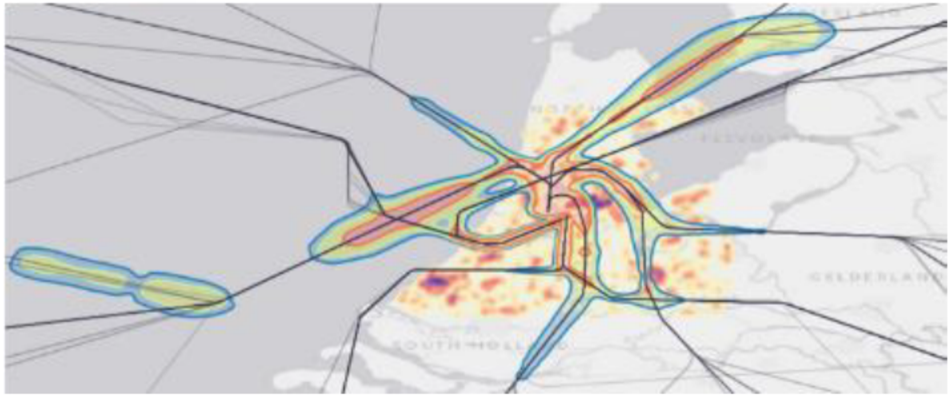
8000FT



9000FT



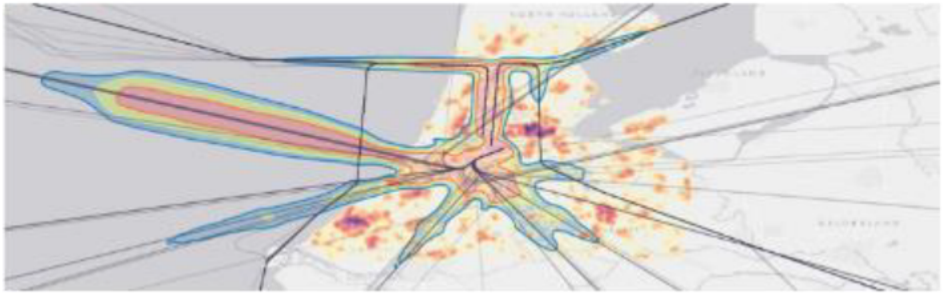
FULLTUBE



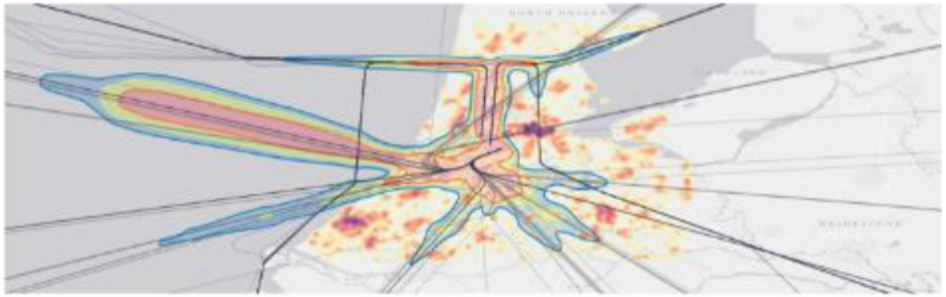
VIII.8.2.6 Tracking of tubes, 2025, Southerly, 2A & 1D

Scenario	Direction	Runway configuration	Tracking of tubes up to
2025	Southerly	2 arrival RWYs, 1 departure RWY	3,000ft – 6,000ft

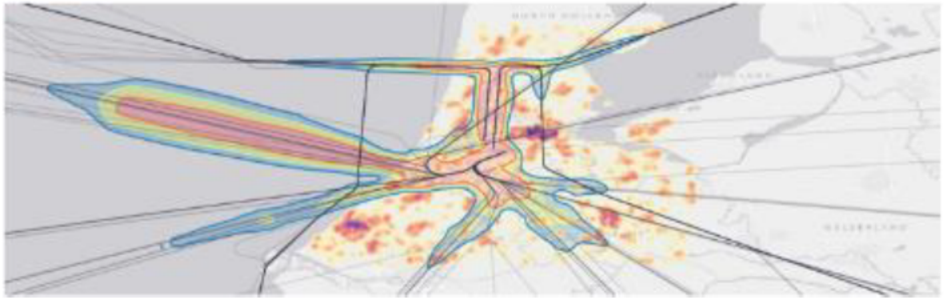
3000FT



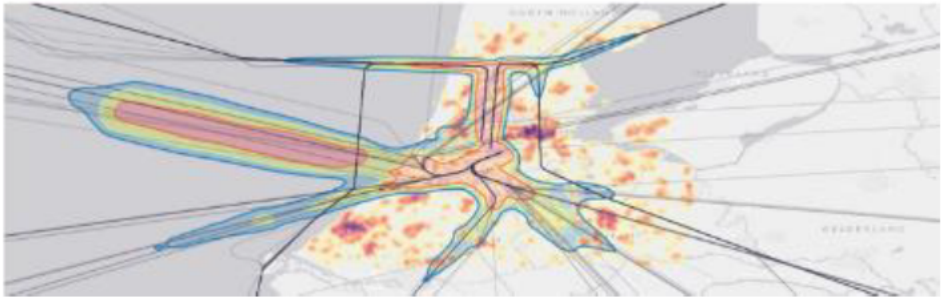
4000FT



5000FT

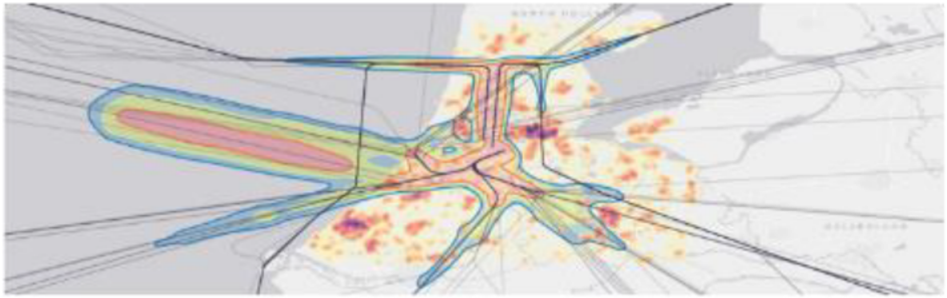


6000FT

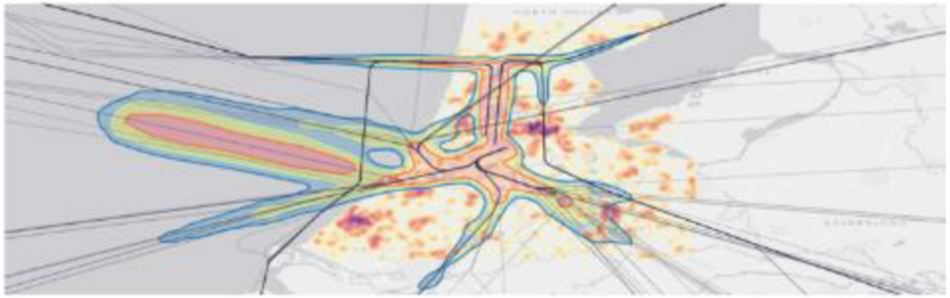


Scenario	Direction	Runway configuration	Tracking of tubes up to
2025	Southerly	2 arrival RWYs, 1 departure RWY	7,000ft - full tube followed

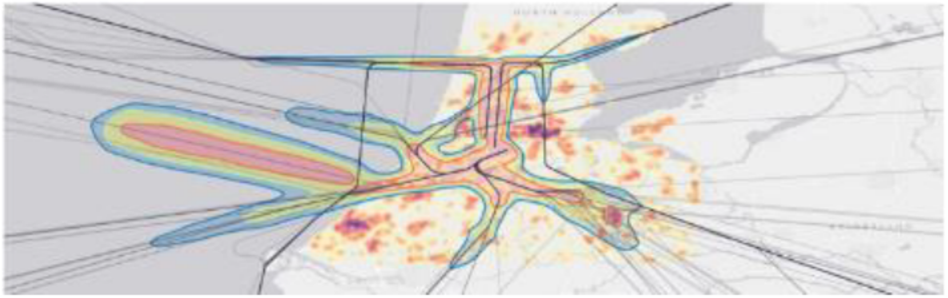
7000FT



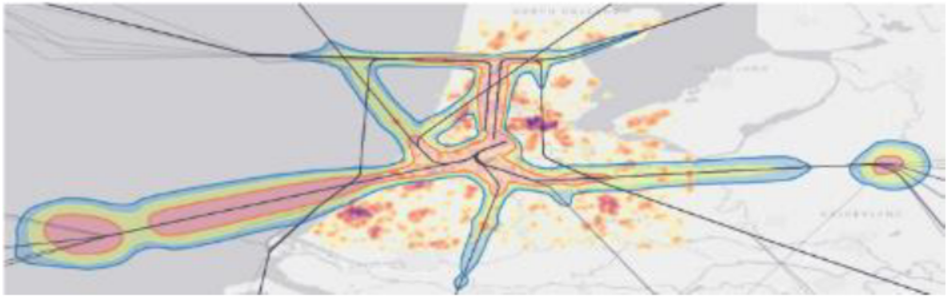
8000FT



9000FT



FULLTUBE

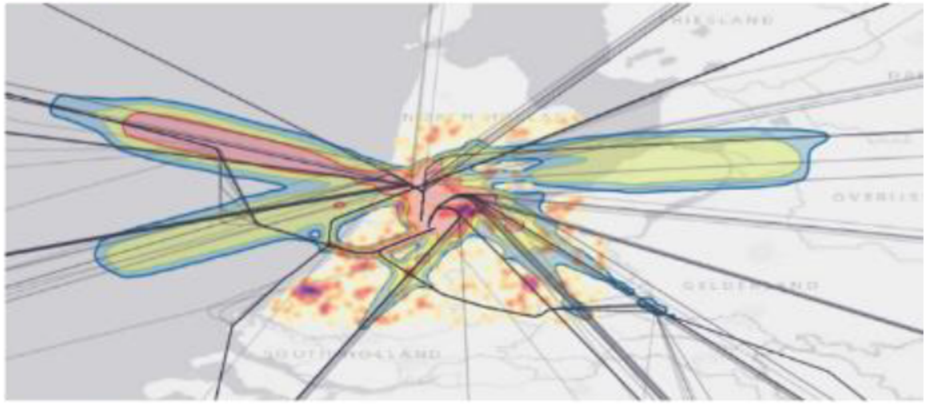


VIII.8.2.7 Tracking of tubes, 2025, Northerly, 1A & 2D

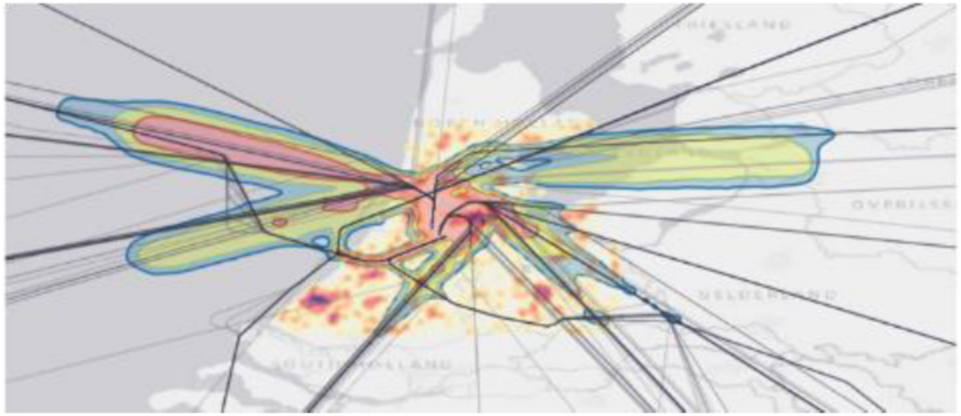
Scenario	Direction	Runway configuration	Tracking of tubes up to
2025	Northerly	1 arrival RWY, 2 departure RWYs	3,000ft – 6,000ft

3000FT

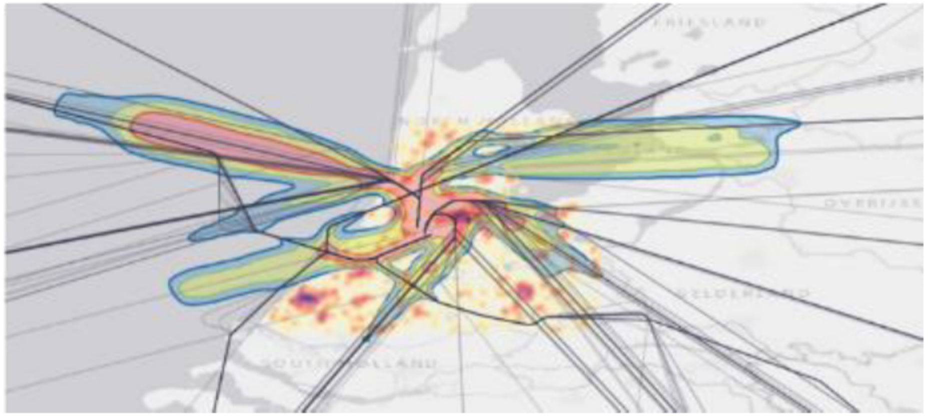
4000FT



5000FT

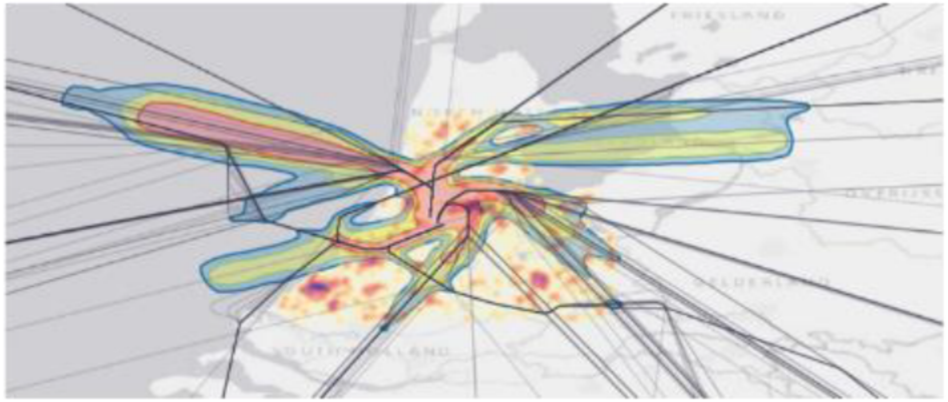


6000FT

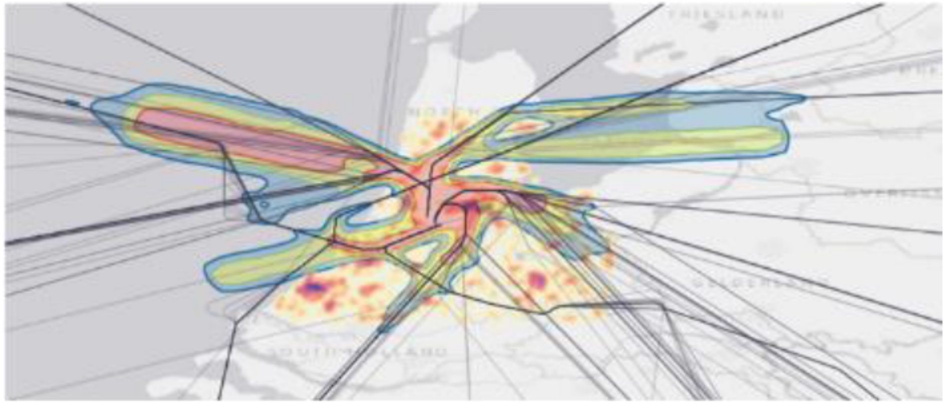


Scenario	Direction	Runway configuration	Tracking of tubes up to
2025	Northerly	1 arrival RWY, 2 departure RWYs	7,000ft - full tube followed

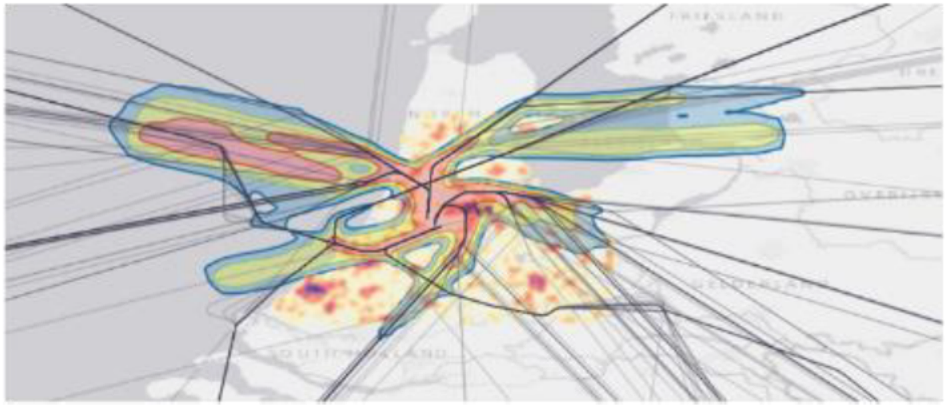
7000FT



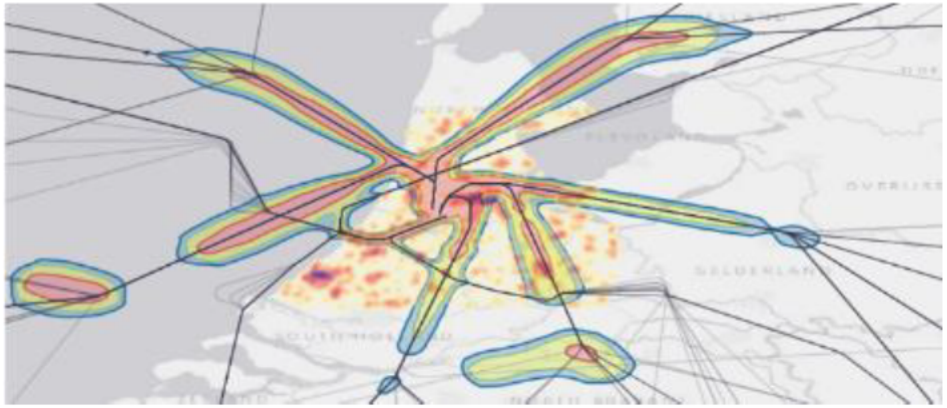
8000FT



9000FT



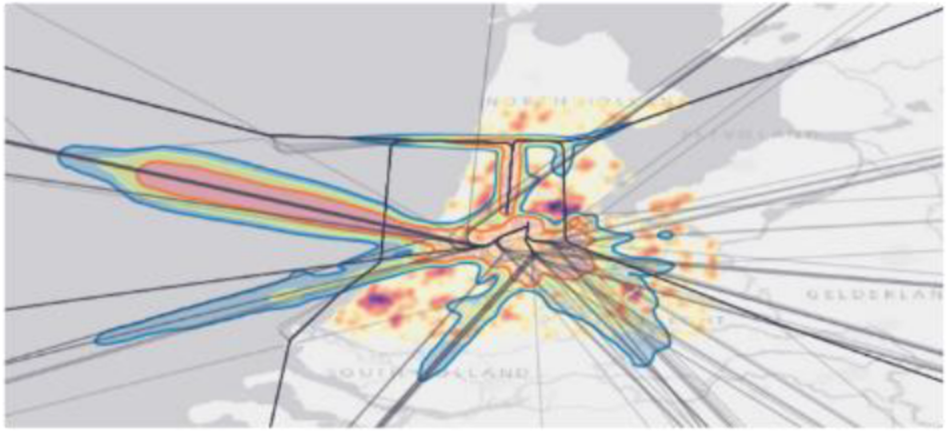
FULLTUBE



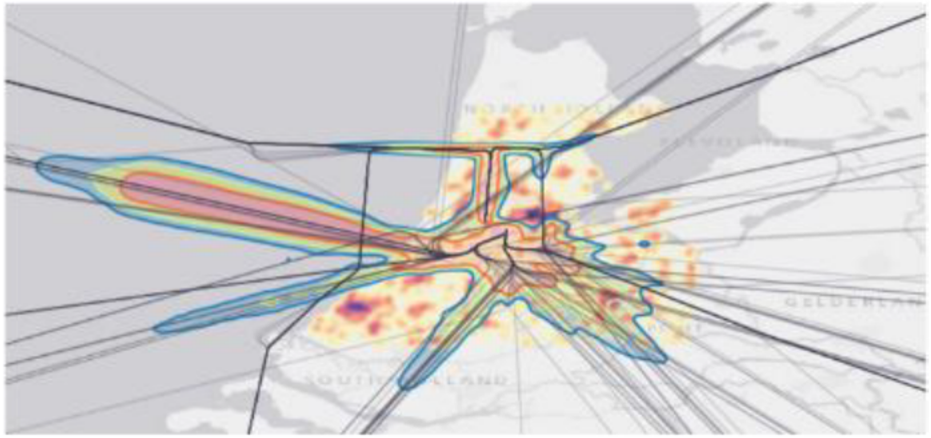
VIII.8.2.8 Tracking of tubes, 2025, Southerly, 1A & 2D

Scenario	Direction	Runway configuration	Tracking of tubes up to
2025	Southerly	1 arrival RWY, 2 departure RWYs	3,000ft – 6,000ft

3000FT



4000FT



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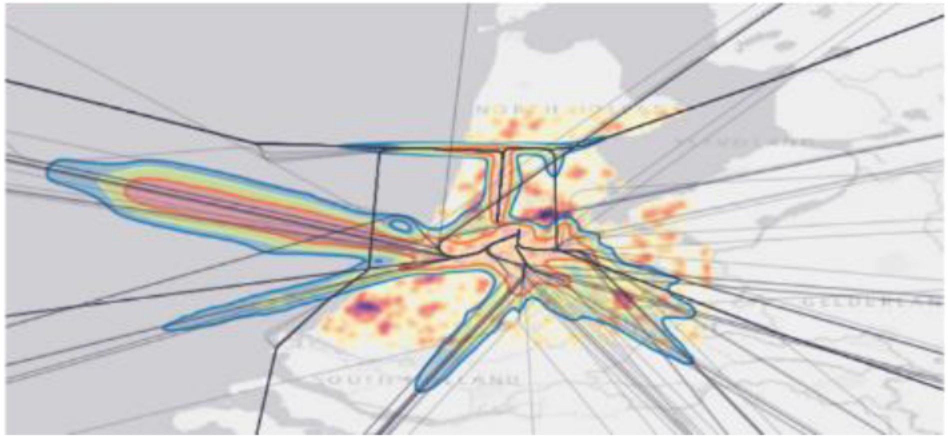
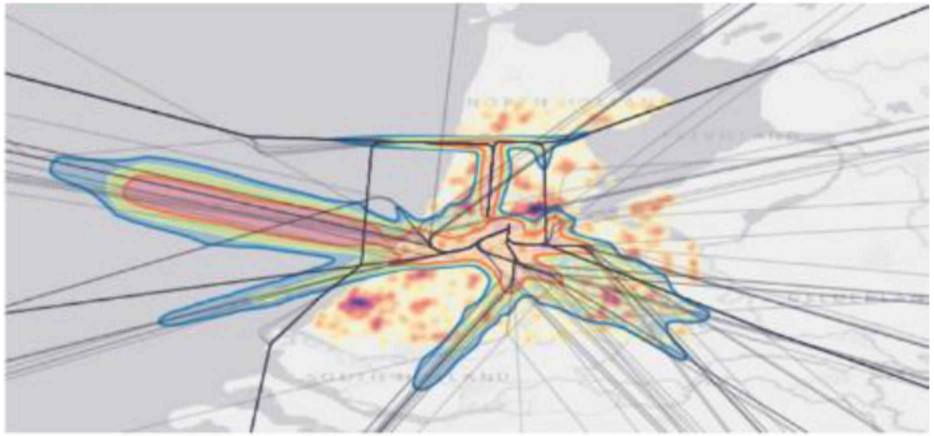
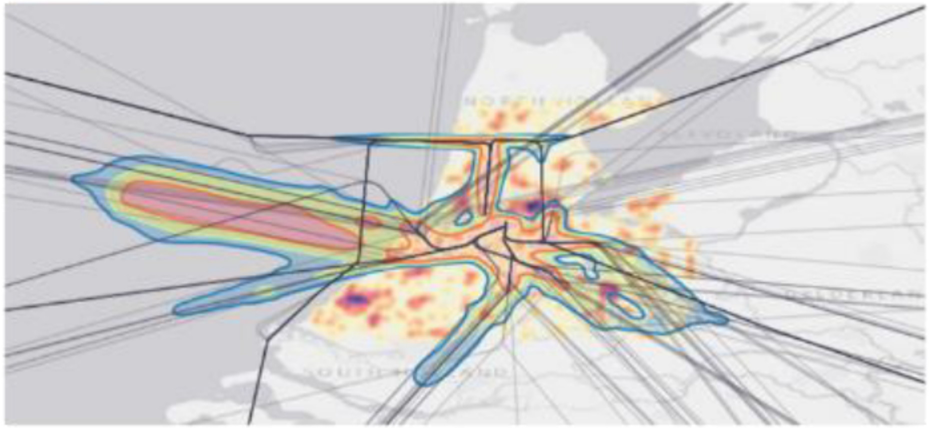


6000FT

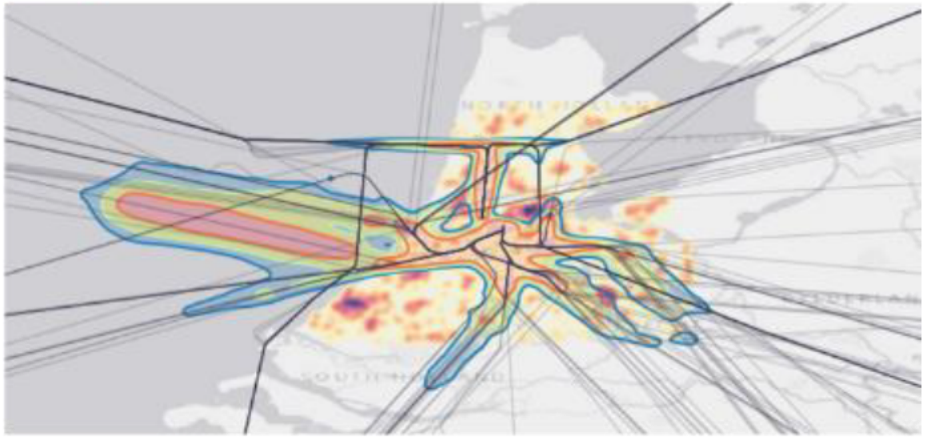


Scenario	Direction	Runway configuration	Tracking of tubes up to
2025	Southerly	1 arrival RWY, 2 departure RWYs	7,000ft – full tube followed

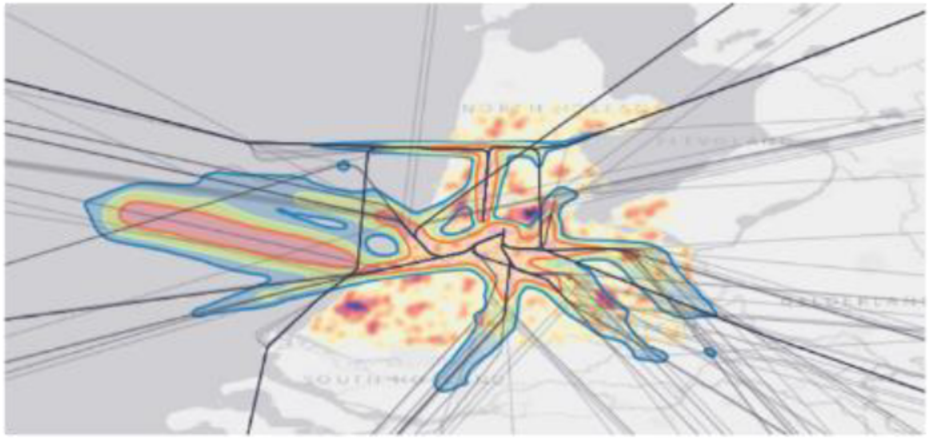
7000FT



8000FT



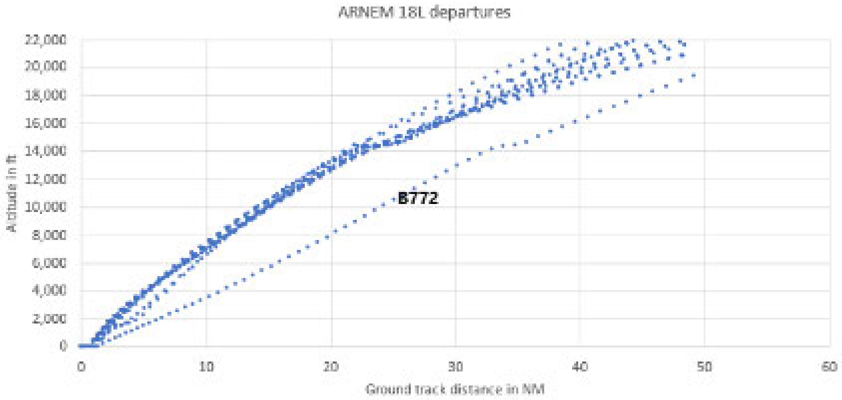
9000FT

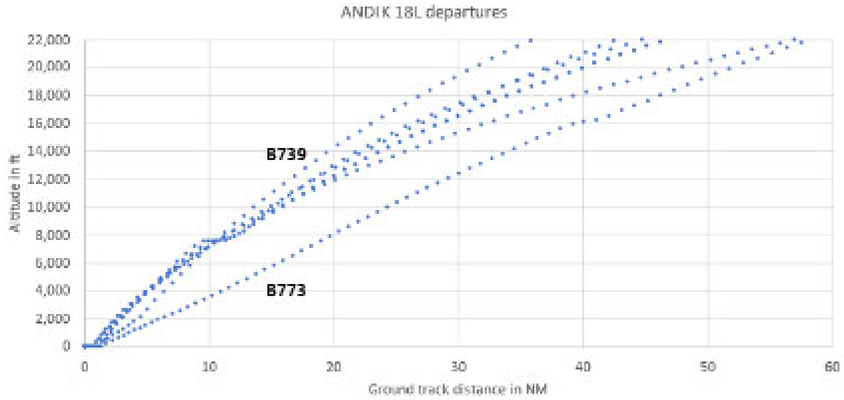


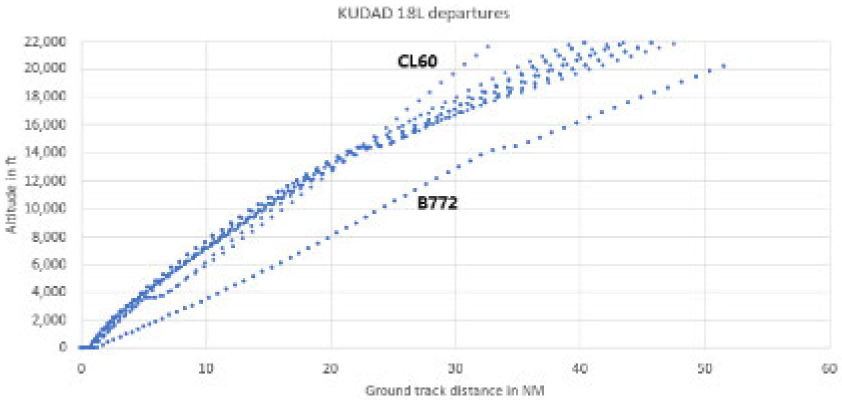
FULLTUBE

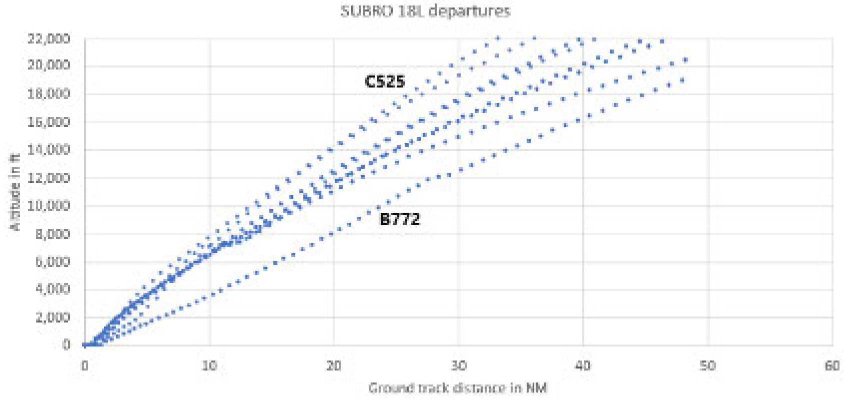
VIII.8.3 Climb and descent gradients (detailed results)

VIII.8.3.1 Climb profiles (10% initial climb to 10,000ft, then aiming for the minimum altitude restriction at the end of the tube)

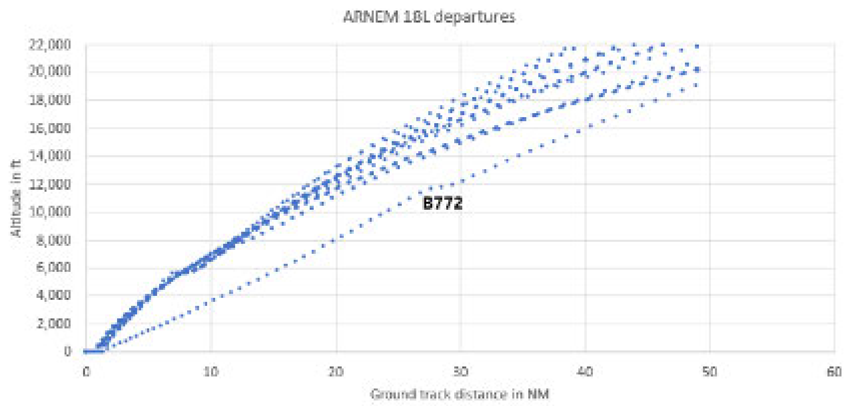


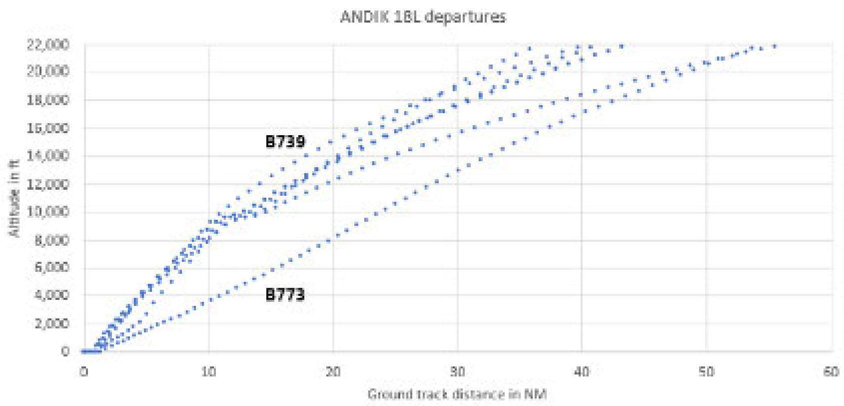


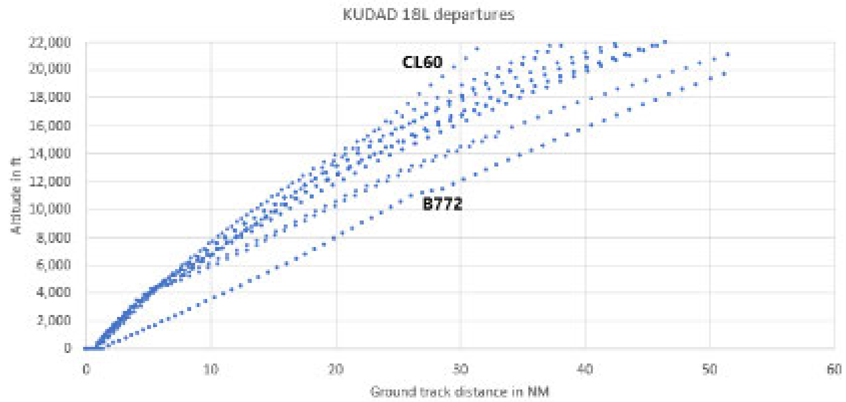




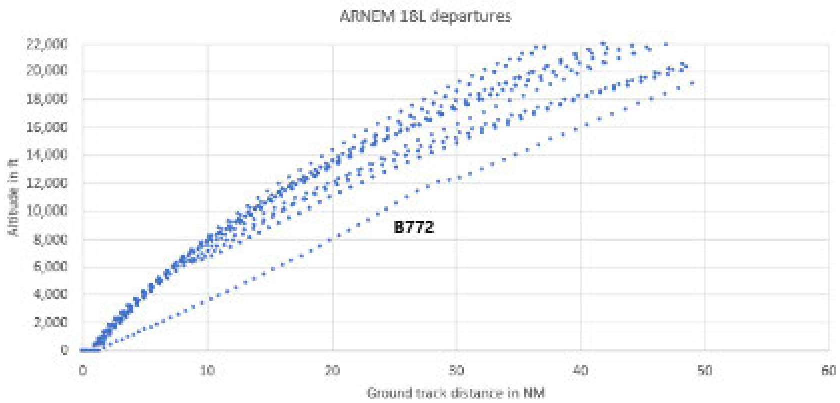
VIII.8.3.2 Climb profiles (13% initial climb to 10,000ft, then aiming for the minimum altitude restriction at the end of the tube)

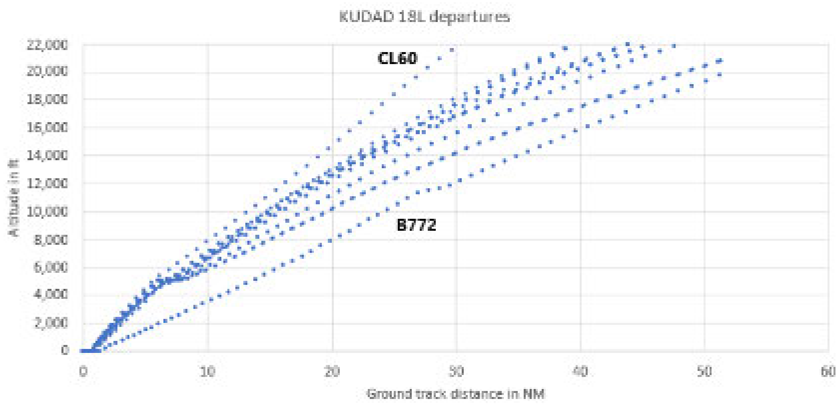


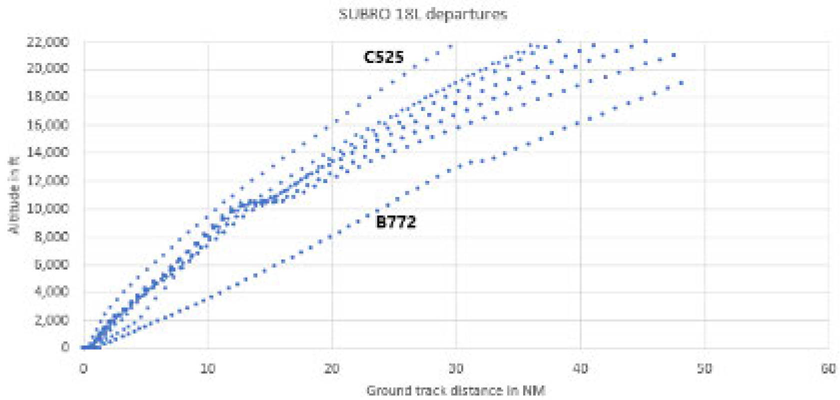




VIII.8.3.3 Climb profiles (15% initial climb to 10,000ft, then aiming for the minimum altitude restriction at the end of the tube)

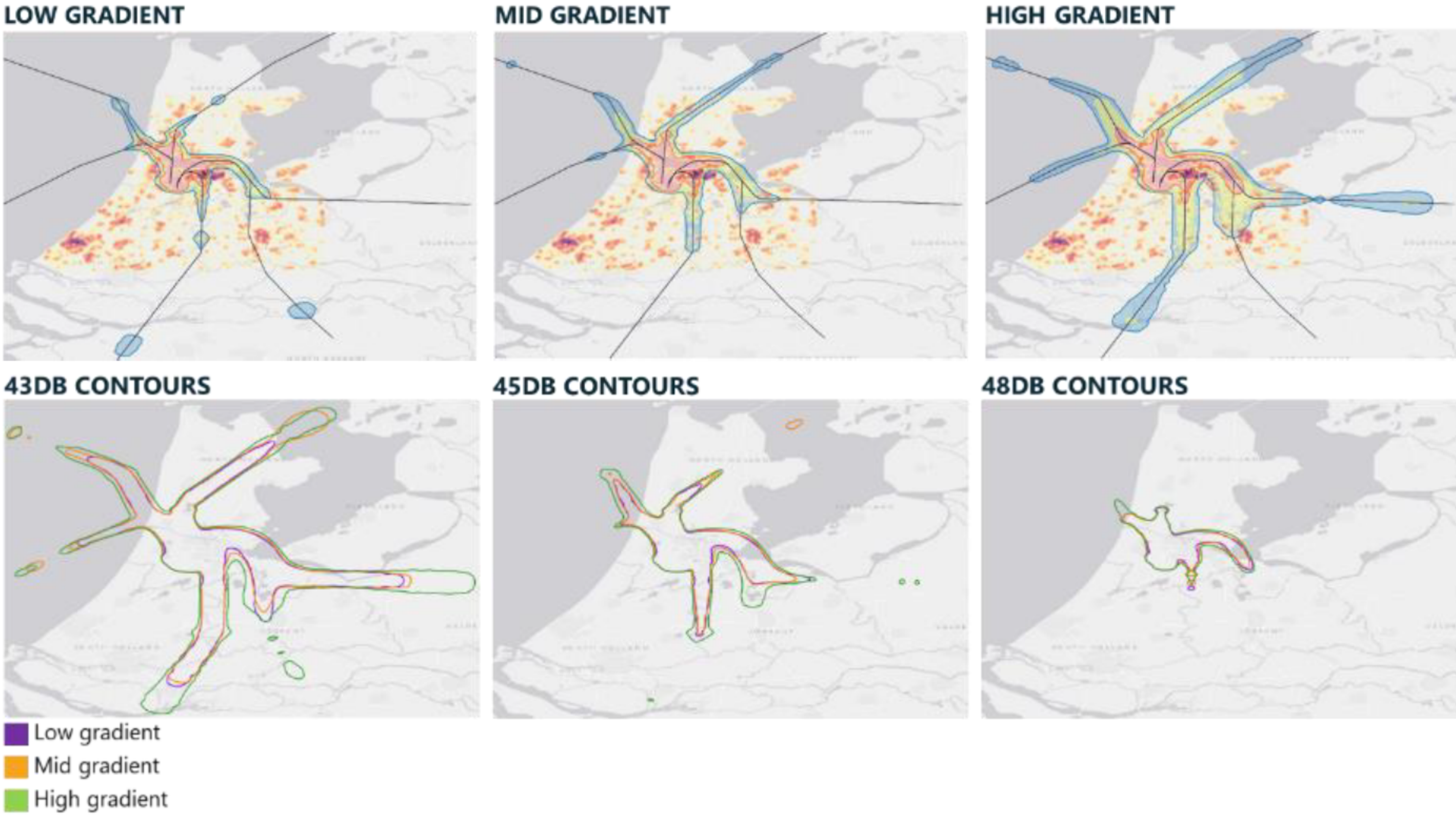






VIII.8.3.4 Climb gradient, 2025, Northerly, 2 runways, LVNL low/mid/high, restricted climb

Scenario	Direction	Runway configuration	Climb gradients
2025	Northerly	2 departure RWYs	LVNL low/mid/high edge of the tube. Restricted climb.



VIII.8.3.5 Climb gradient, 2025, Southerly, 2 runways, LVNL low/mid/high, restricted climb

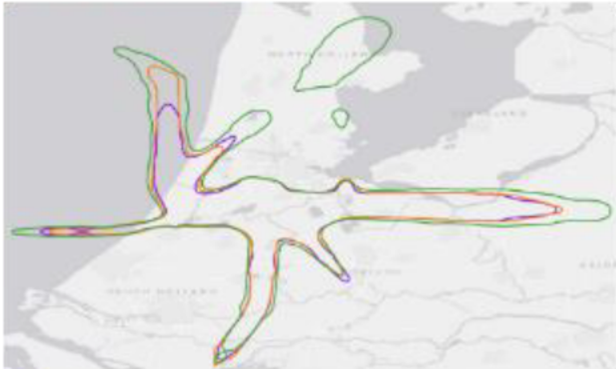
Scenario	Direction	Runway configuration	Climb gradients
2025	Southerly	2 departure RWYs	LVNL low/mid/high edge of the tube. Restricted climb.

LOW GRADIENT

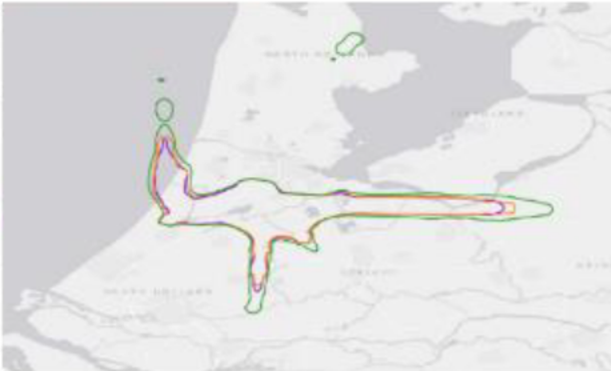
MID GRADIENT

HIGH GRADIENT

43DB CONTOURS



45DB CONTOURS



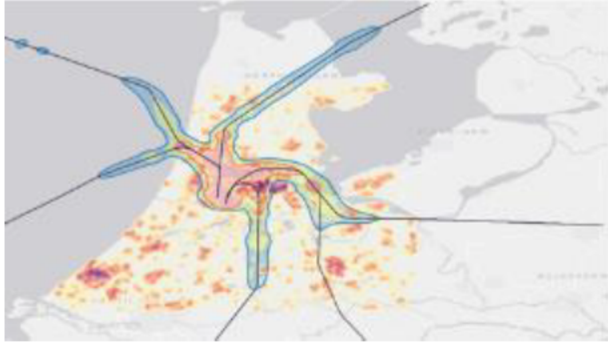
48DB CONTOURS

- Low gradient
- Mid gradient
- High gradient

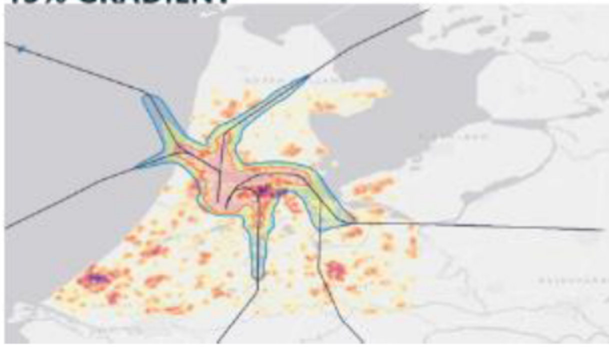
VIII.8.3.6 Climb gradient, 2025, Northerly, 2 runways, 10%, 13% and 15% initial climb, then mid end of the tube, restricted climb

Scenario	Direction	Runway configuration	Climb gradients
2025	Northerly	2 departure RWYs	10%, 13%, 15% initially to 10,000ft, then aiming for the mid end of the tube. Restricted climb

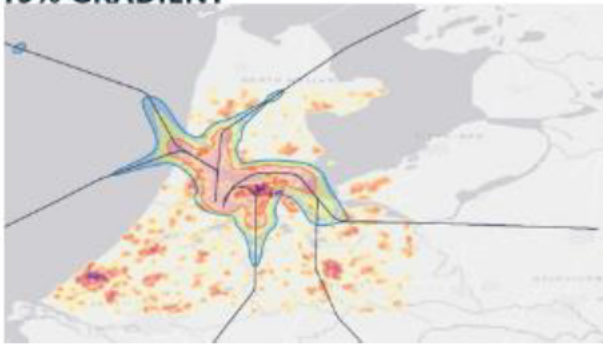
10% GRADIENT



13% GRADIENT



15% GRADIENT



43DB CONTOURS

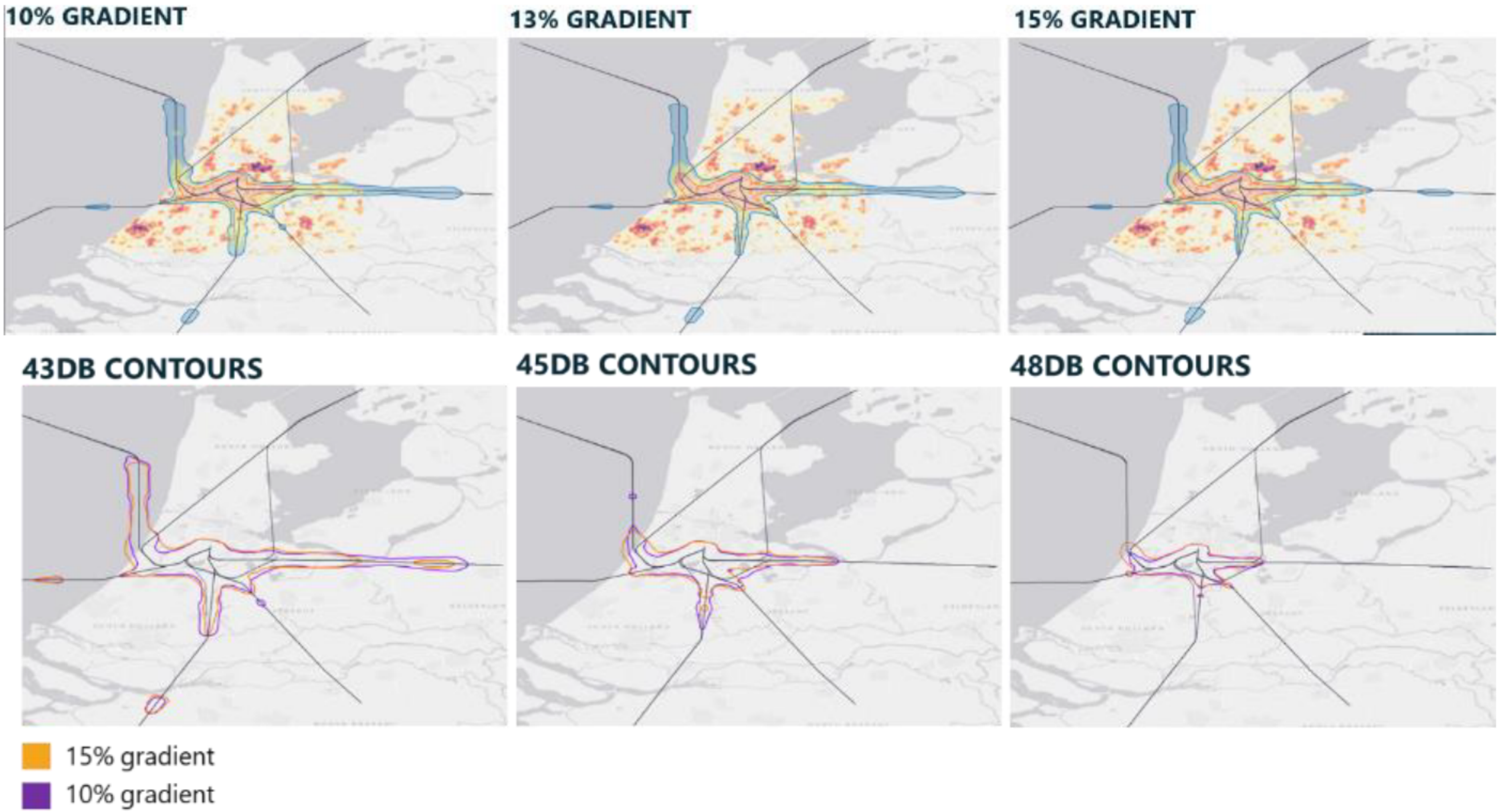
45DB CONTOURS

48DB CONTOURS

15% gradient
10% gradient

VIII.8.3.7 Climb gradient, 2025, Southerly, 2 runways, 10%, 13% and 15% initial climb, then mid end of the tube, restricted climb

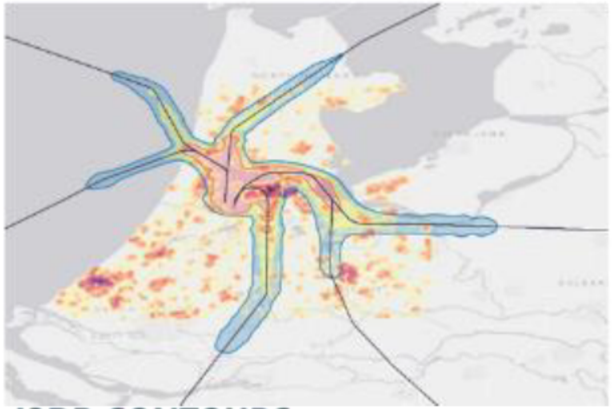
Scenario	Direction	Runway configuration	Climb gradients
2025	Northerly	2 departure RWYs	10%, 13%, 15% initially to 10,000ft, then aiming for the mid end of the tube. Restricted climb



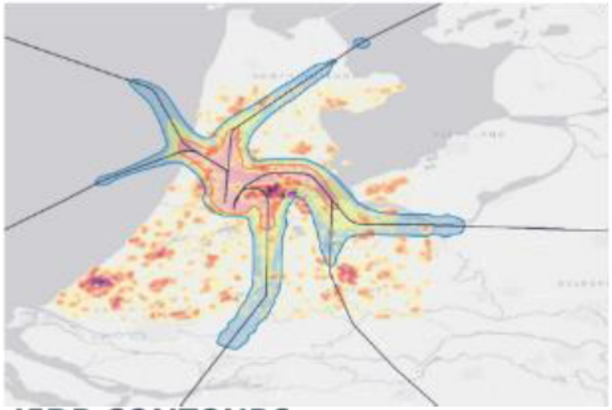
VIII.8.3.8 Climb gradient, 2025, Northerly, 2 runways, 10%, 13% and 15% initial climb, then low end of the tube, unrestricted climb

Scenario	Direction	Runway configuration	Climb gradients
2025	Northerly	2 departure RWYs	10%, 13%, 15% initially to 10,000ft, then aiming for the low end of the tube. Unrestricted climb

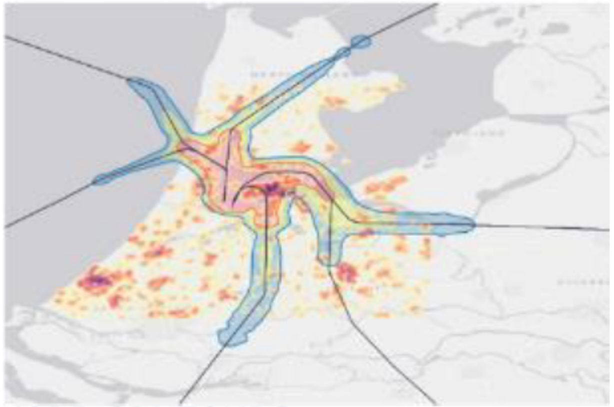
10% GRADIENT



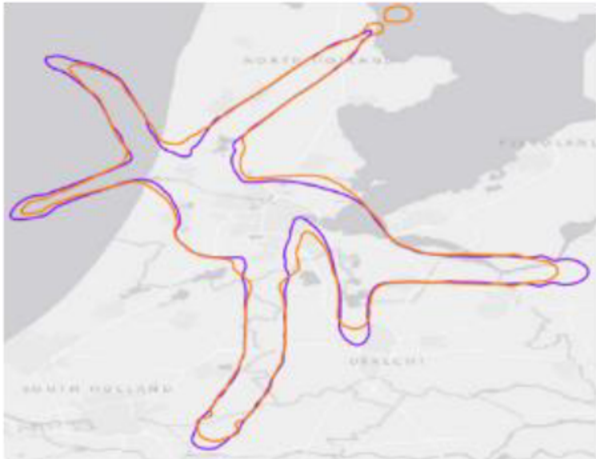
13% GRADIENT



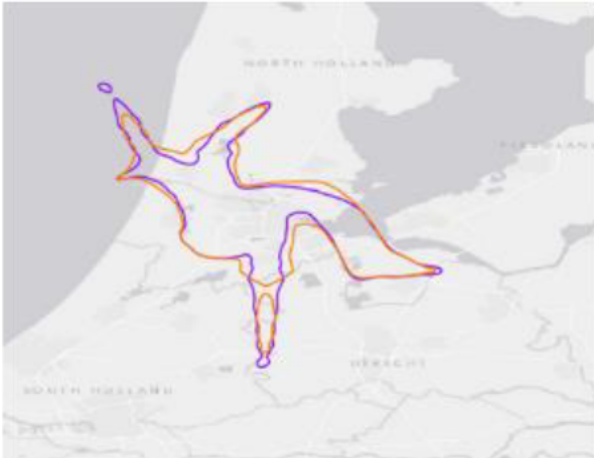
15% GRADIENT



43DB CONTOURS



45DB CONTOURS



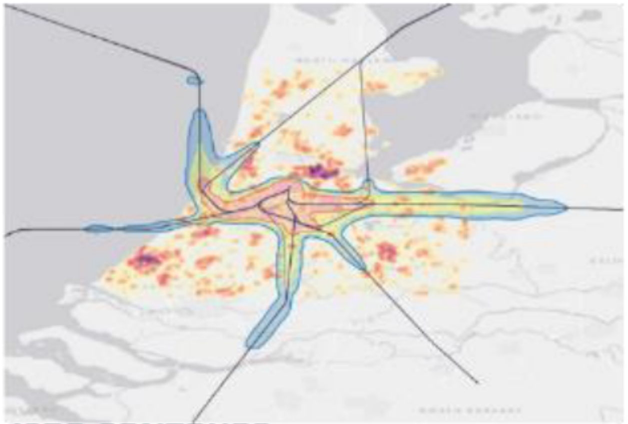
48DB CONTOURS

15% gradient
10% gradient

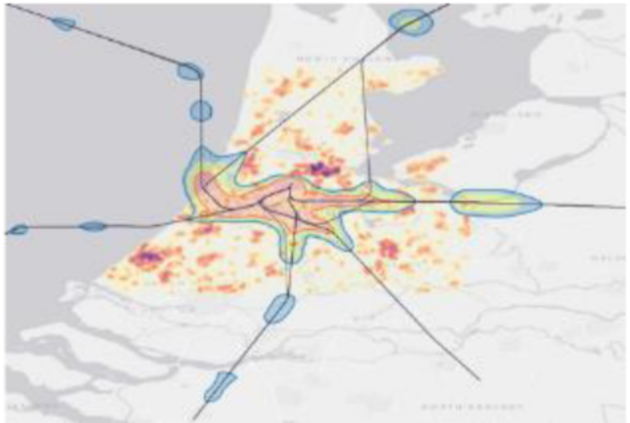
VIII.8.3.9 Climb gradient, 2025, Southerly, 2 runways, 10%, 13% and 15% initial climb, then low end of the tube, unrestricted climb

Scenario	Direction	Runway configuration	Climb gradients
2025	Southerly	2 departure RWYs	10%, 13%, 15% initially to 10,000ft, then aiming for the low end of the tube. Unrestricted climb

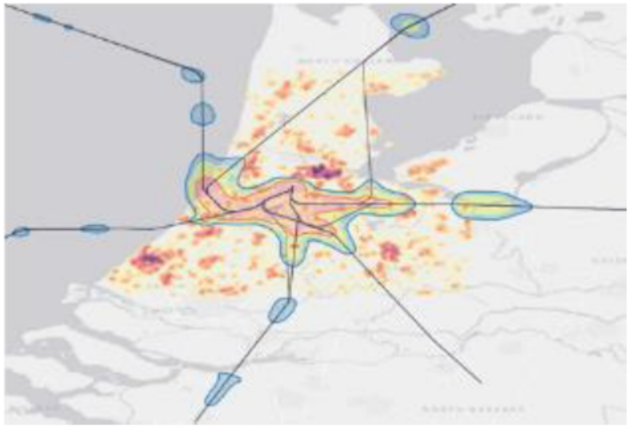
10% GRADIENT



13% GRADIENT

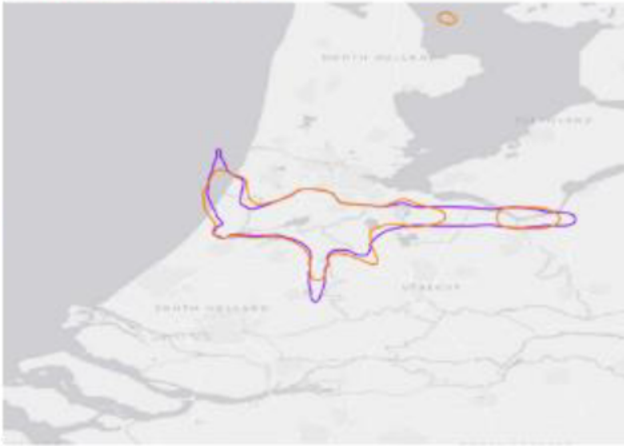


15% GRADIENT



43DB CONTOURS

45DB CONTOURS



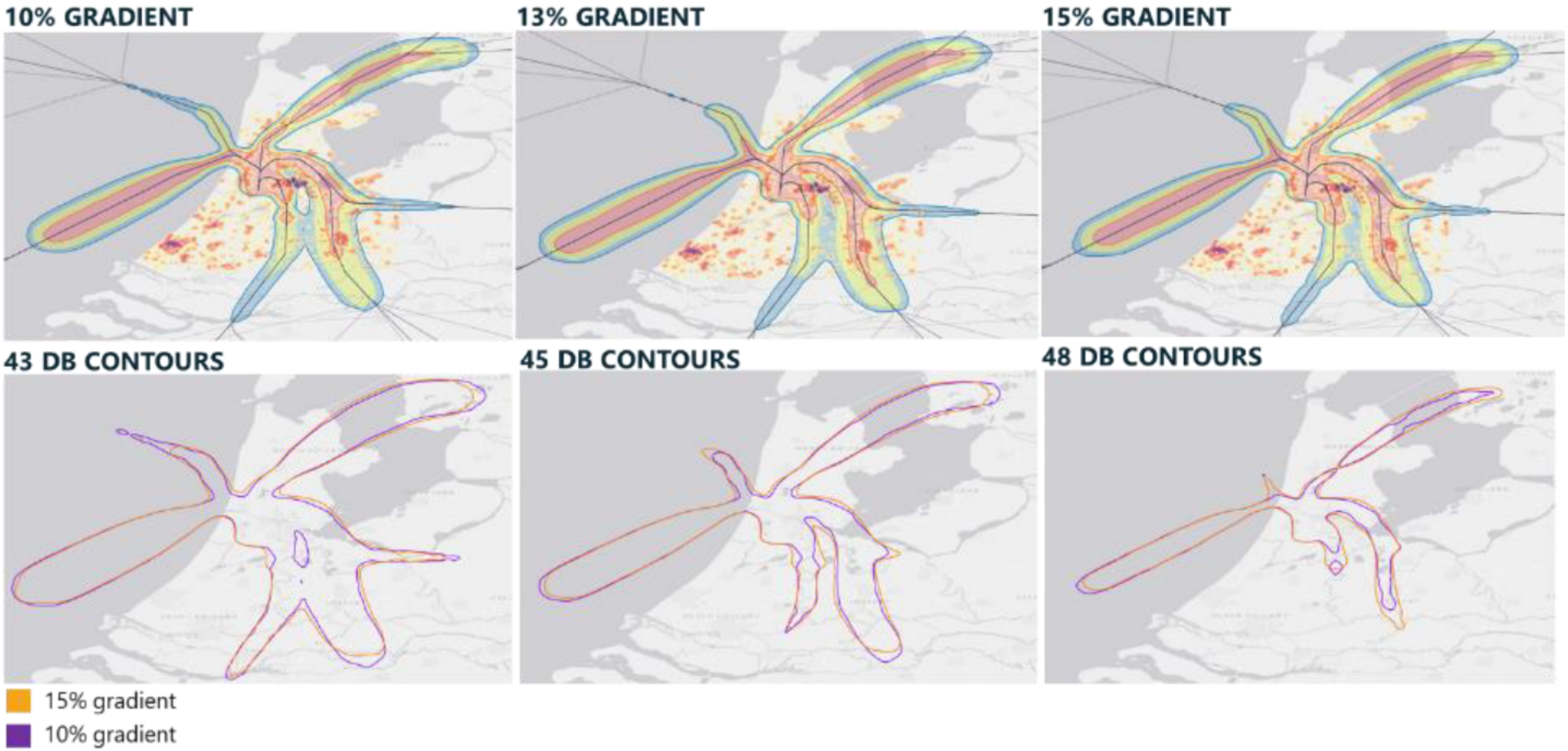
48DB CONTOURS

15% gradient

10% gradient

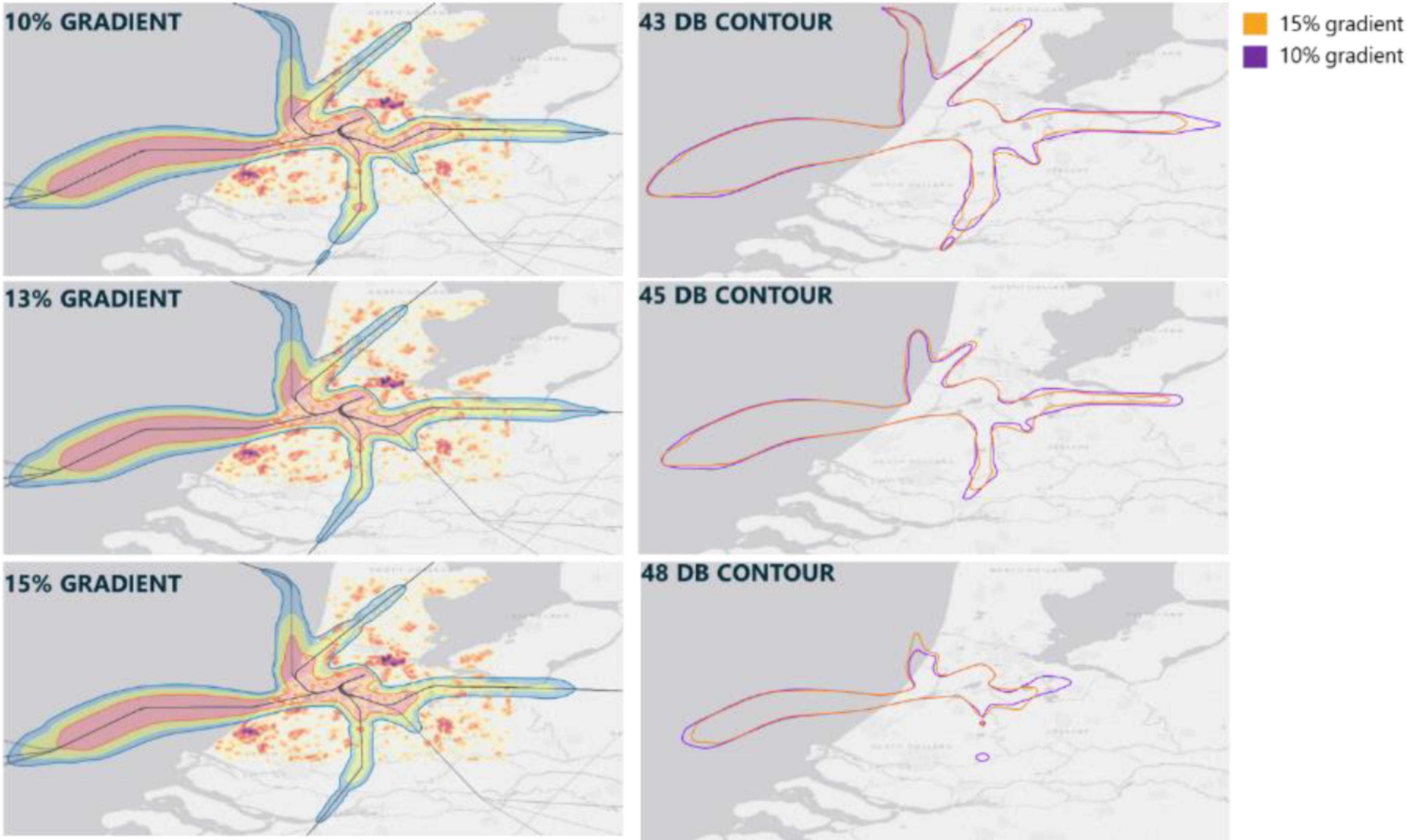
VIII.8.3.10 Climb gradient, 2025, Northerly, 1 runway, 10%, 13% and 15% initial climb, then low end of the tube, unrestricted climb

Scenario	Direction	Runway configuration	Climb gradients
2025	Northerly	1 departure RWY	10%, 13%, 15% initially to 10,000ft, then aiming for the low end of the tube. Unrestricted climb

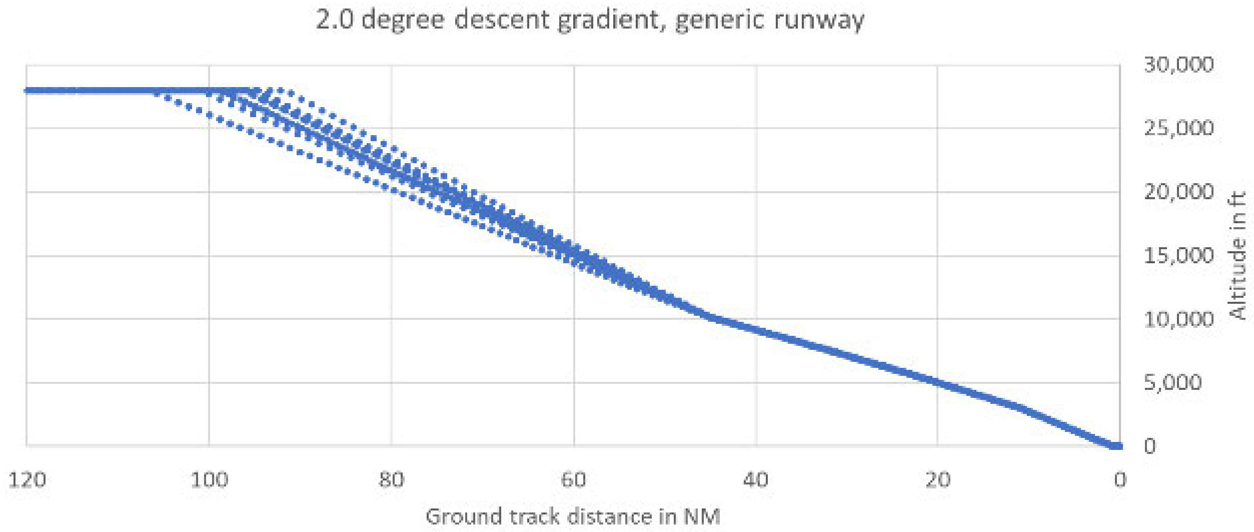


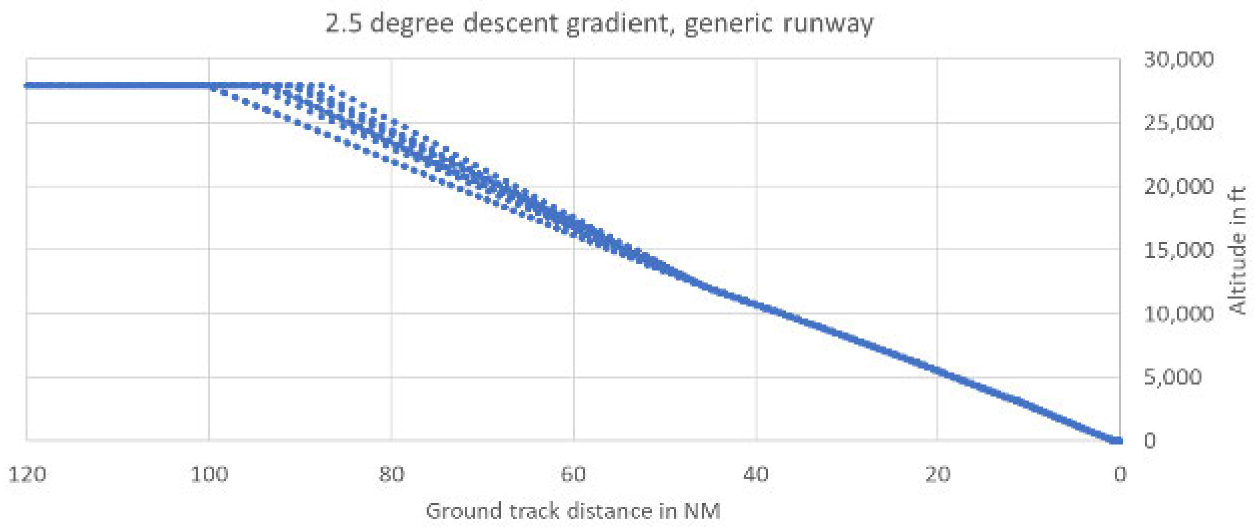
VIII.8.3.11 Climb gradient, 2025, Southerly, 1 runway, 10%, 13% and 15% initial climb, then low end of the tube, unrestricted climb

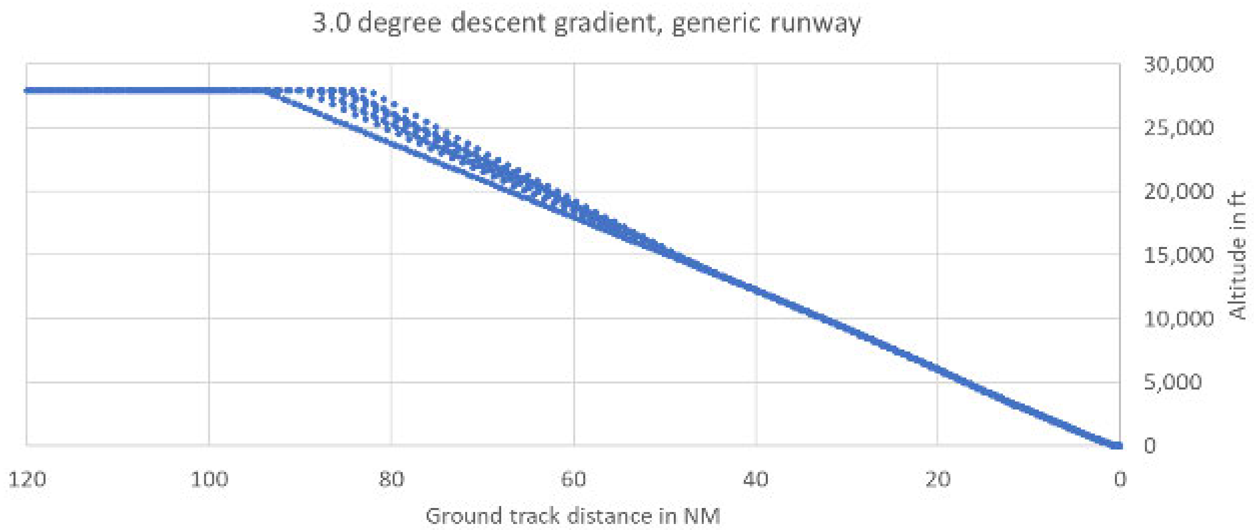
Scenario	Direction	Runway configuration	Climb gradients
2025	Southerly	1 departure RWY	10%, 13%, 15% initially to 10,000ft, then aiming for the low end of the tube. Unrestricted climb



VIII.8.3.12 Generic descent profiles



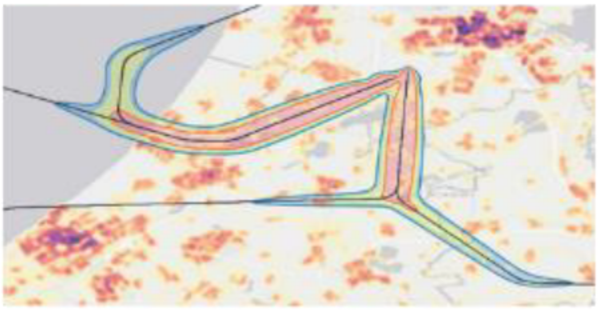




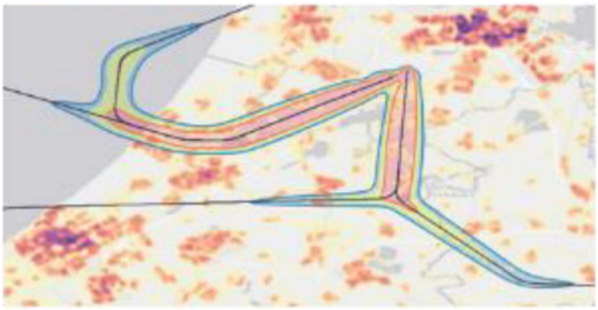
VIII.8.3.13 Descent gradient, 2025, Northerly, 2 runways, 2, 2.5 and 3 degree gradients

Scenario	Direction	Runway configuration	Descent gradients
2025	Northerly	2 arrival RWYs	2.0-3.0 degrees With/without level segment (LS)

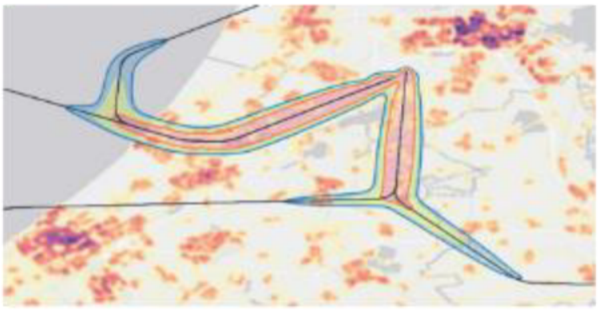
2.0 DEGREES GRADIENT



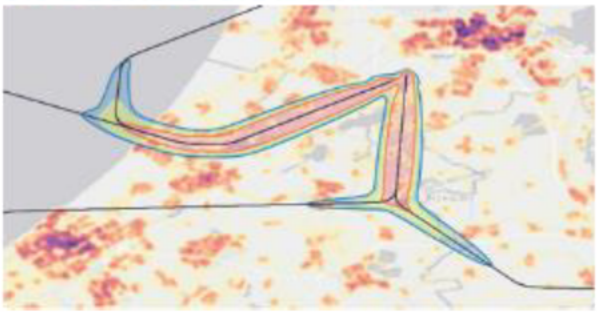
2.0 DEGREES GRADIENT, LS AT 10,000FT



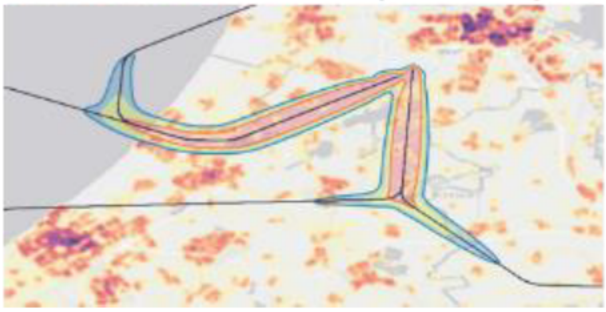
2.5 DEGREES GRADIENT



3.0 DEGREES GRADIENT



3.0 DEGREES GRADIENT, LS AT 10,000FT



Scenario	Direction	Runway configuration	Descent gradients
2025	Northerly	2 arrival RWYs	2.0-3.0 degrees without level segment

43 DB CONTOUR

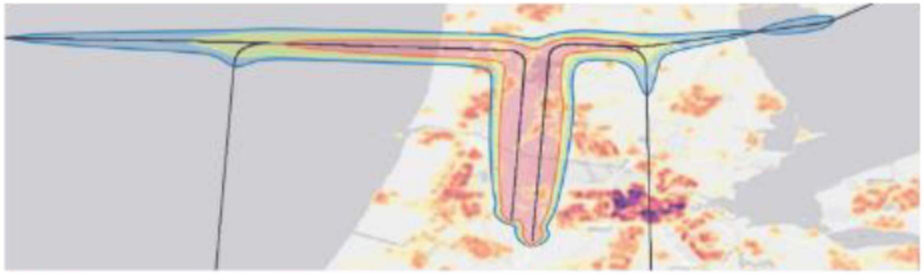
45 DB CONTOUR

48 DB CONTOUR

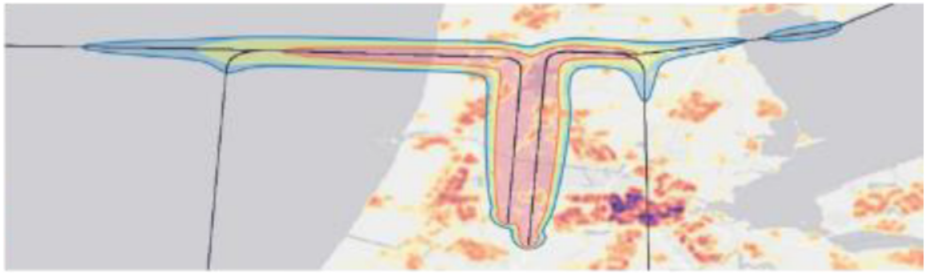
VIII.8.3.14 Descent gradient, 2025, Southerly, 2 runways, 2, 2.5 and 3 degree gradients

Scenario	Direction	Runway configuration	Descent gradients
2025	Southerly	2 arrival RWYs	2.0-3.0 degrees, With/without level segment (LS)

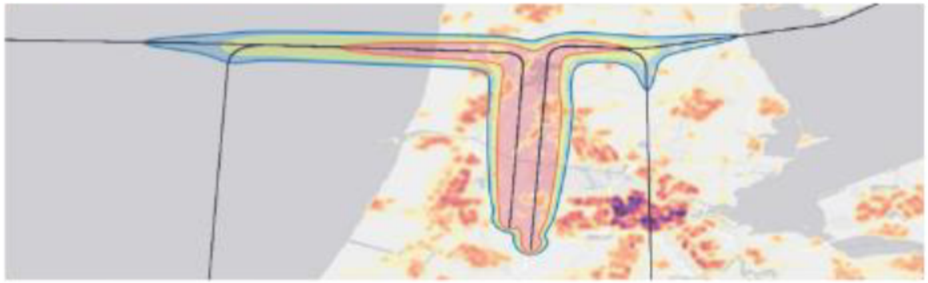
2.0 DEGREES GRADIENT



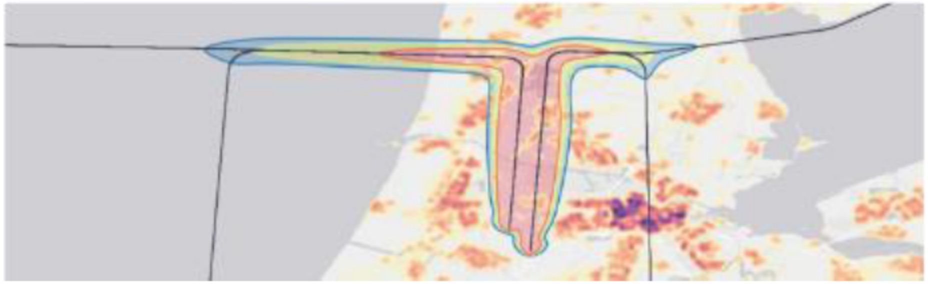
2.0 DEGREES GRADIENT, LS AT 10,000FT



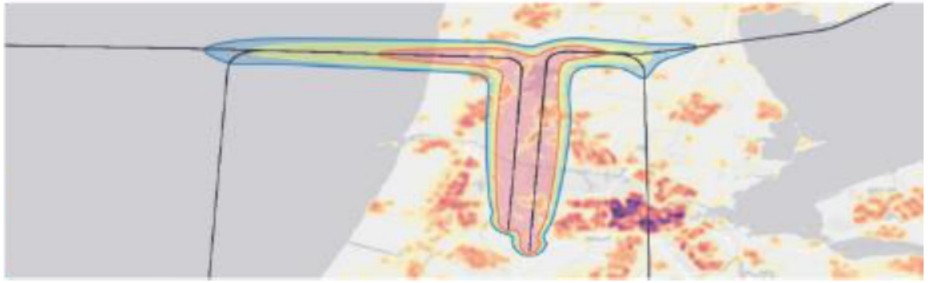
2.5 DEGREES GRADIENT



3.0 DEGREES GRADIENT



3.0 DEGREES GRADIENT, LS AT 10,000FT



Scenario	Direction	Runway configuration	Descent gradients
2025	Southerly	2 arrival RWYs	2.0-3.0 degrees, without level segment

43 DB CONTOUR

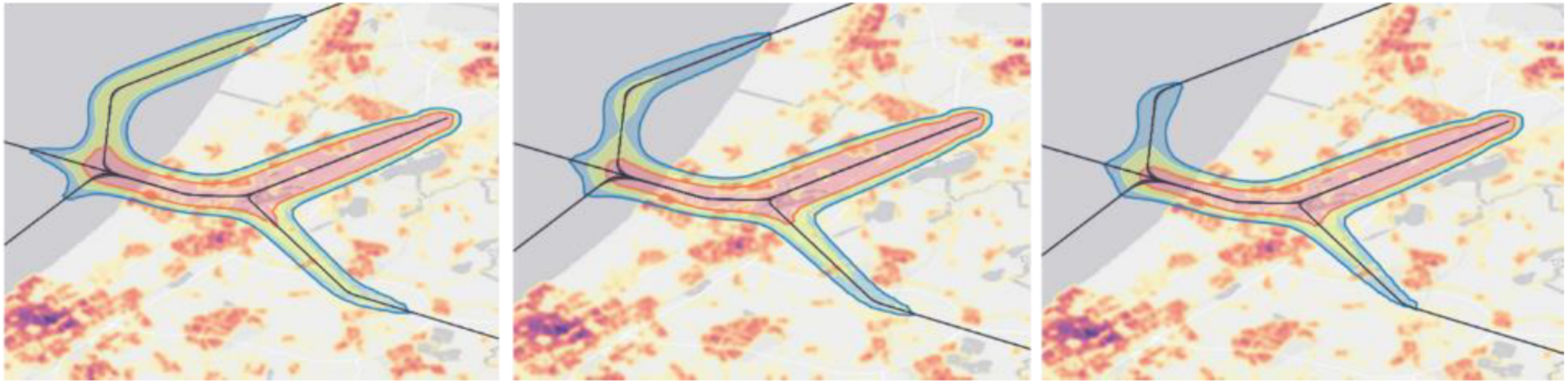
45 DB CONTOUR

48 DB CONTOUR

VIII.8.3.15 Descent gradient, 2025, Northerly, 1 runway, 2, 2.5 and 3 degree gradients

Scenario	Direction	Runway configuration	Descent gradients
2025	Northerly	1 arrival RWY	2.0-3.0 degrees

2.0 GRADIENT **2.5 GRADIENT** **3.0 GRADIENT**



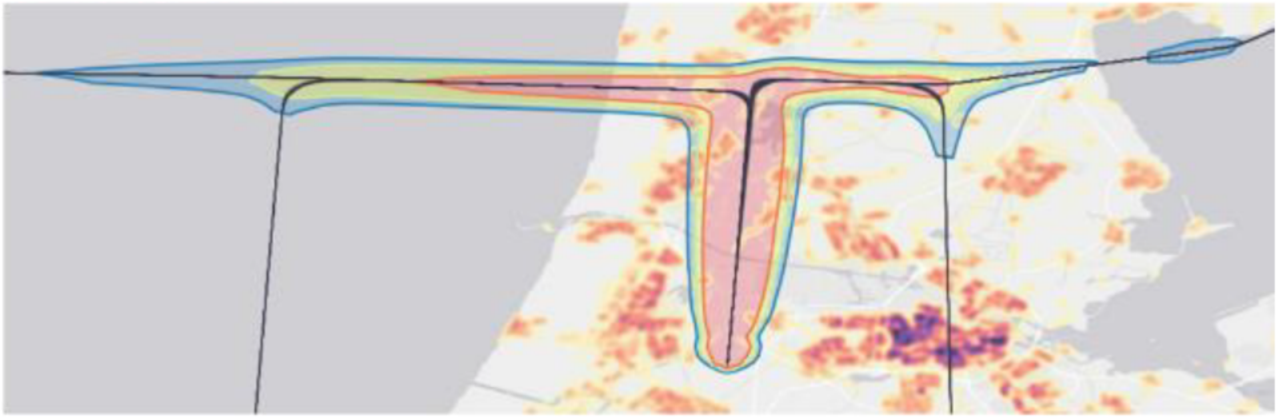
43 DB CONTOUR **45 DB CONTOUR** **48 DB CONTOUR**

2° gradient
2.5° gradient
3° gradient

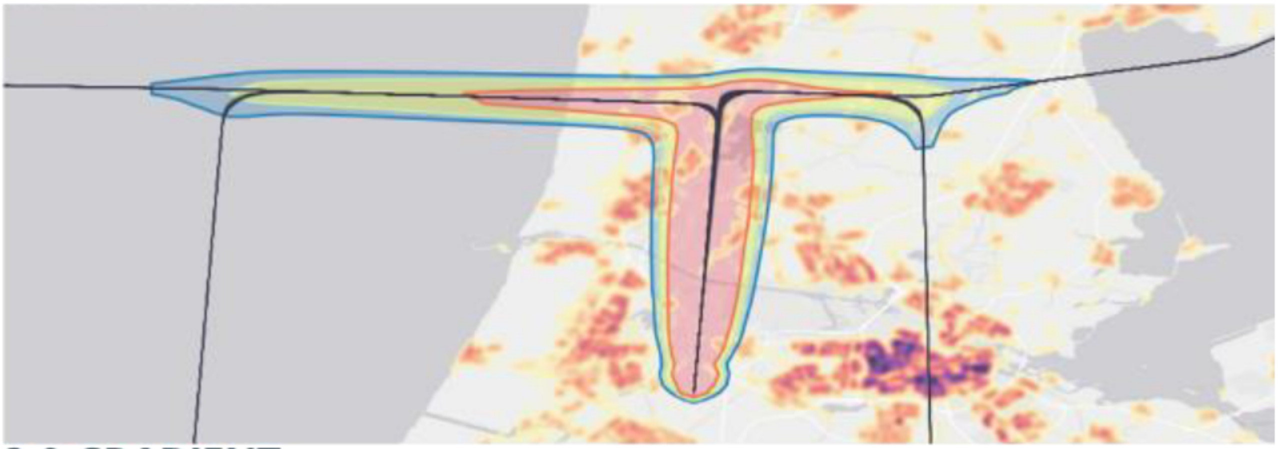
VIII.8.3.16 Descent gradient, 2025, Southerly, 1 runway, 2, 2.5 and 3 degree gradients

Scenario	Direction	Runway configuration	Descent gradients
2025	Southerly	1 arrival RWY	2.0-3.0 degrees

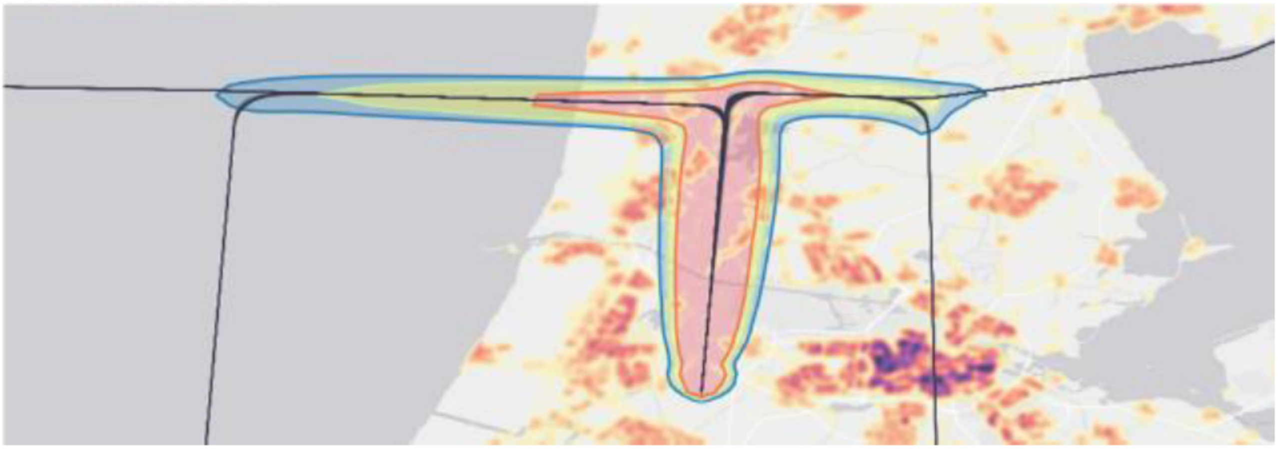
2.0 GRADIENT



2.5 GRADIENT

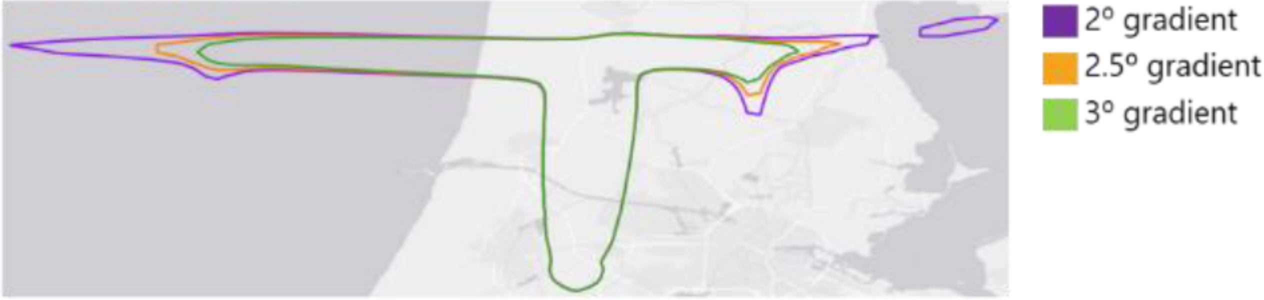


3.0 GRADIENT

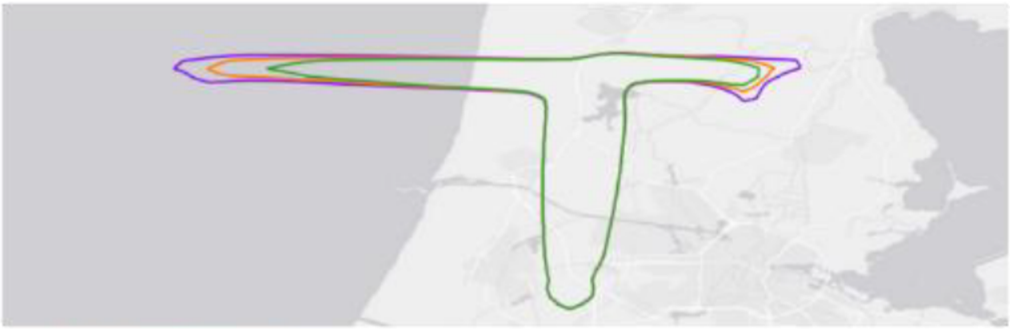


Scenario	Direction	Runway configuration	Descent gradients
2025	Southerly	1 arrival RWY	2.0-3.0 degrees

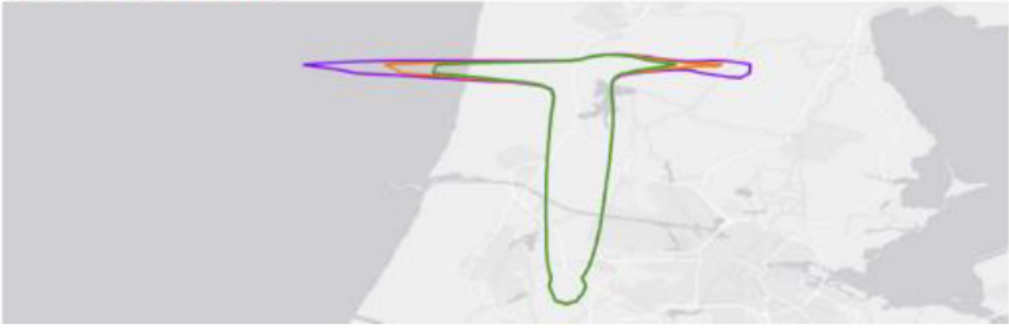
43 DB CONTOUR



45 DB CONTOUR



48 DB CONTOUR



VIII.9 Annex 9: List of sources reviewed during the desktop research

Source	ID	Document
RTCA	RTCA DO-236D	Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation
EUROCONTROL	PJ01	Enhanced arrivals and departures (multiple documents)
EUROCONTROL	PJ02	Increased airport throughput (multiple documents)
EUROCONTROL	PJ10	Advanced separation management (multiple documents)
EUROCONTROL	-	European PBN Route Spacing Handbook PBN HANDBOOK No. 3
UK CAA	CAP1711	UK Airspace Modernisation Strategy
EUROCONTROL/WG85	-	i4D Distance Reduction Analysis
UK CAA	CAP1385	Performance-based Navigation (PBN): Enhanced Route Spacing Guidance
SUSTAINABLE AVIATION	-	UK Decarbonisation Roadmap: A Path to Net Zero
MITRE	12-2356	4D Trajectory-Based Operations
UK CAA	CAP1691	Departure Noise Mitigation: Main Report
Shivanjli Sharma and John E. Robinson III		Methodology to Define Delivery Accuracy Under Current Day ATC Operations
John E. Robinson III and Jane Thipphavong	-	Enabling Performance-Based Navigation Arrivals: Development and Simulation Testing of the Terminal Sequencing and Spacing System
NATS	-	PBN Research Project
Egis projects	-	Review of The Dutch Airspace Redesign Project Track 2
Egis projects	-	Reduced Night Noise Trial Environmental Analysis

IX References

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