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Outbound traffic segregation at Schiphol Airport

A roadmap towards traffic segregation concepts

Aviation Consultants

to70

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Report

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1 Summary

1.1 Background

In the current Schiphol operation, during a departure peak (two runways in use for departures) departing traffic is segregated based on their departure sector and therefore destination. The primary departure runways operate traffic to sectors 1, 4 and 5 while secondary runways operate traffic to sectors 2 and 3. With sectors 2 and 3 being the busiest, the current East/West divide of departure routes leads to non-optimal usage of the primary runway in terms of capacity and noise. This research explores potential outbound traffic segregation concepts with improved performance on noise, capacity, and sustainability. The scope of the research is exploratory, focusing both on the performance case of concepts as on the operational feasibility. The goal of the research is to come to a roadmap with segregation concepts that are achievable in the short term and the steps which need to be taken for segregation concepts for the long term.

1.2 Conclusions

The roadmap lays out several steps which can be taken in the short term and the longer term. For the short-term focus should be on building out and structuring concepts which are already happening in the operation, such as coordinating the routing of destinations and enabling the more structural use of sector 1 and 2 from the secondary runway in southern mode.

In the longer term, Dual-SID or traffic merge concepts allows for a more optimal assignment of some sector traffic over the primary and secondary runway since gaps in the departure stream of the primary runway can be filled with departures from the secondary runway. Implementation of these concepts requires several (technical) enablers before these concepts are feasible. Deployment will also be limited to moments when there is only a marginal surplus of traffic, requiring a second departure runway. As part of the roadmap, further research into trajectory-based departure management is advised, as a first steppingstone towards traffic merging.

The negative outcomes of the feasibility study related to concepts which aim at facilitating alternative traffic (electric/hybrid or hydrogen aircraft) separate from main traffic flow indicate the potential issue for the future introduction of such aircraft. With the developments of these aircraft ongoing, further research and the development of a strategy on the introduction of alternative aircraft at Schiphol is advised as part of the roadmap.

1.3 Approach

This research is conducted in four phases. The first phase is an exploratory phase in which, through analysis of background material, operational expertise and brainstorms, initial ideas for traffic segregation concepts are defined and presented. The second phase focuses on the potential effects of traffic segregation on capacity and nuisance reduction. The initial concepts are further refined in phase 3. These more mature concepts are then in asses on feasibility, where (technical) enablers are identified for concepts that require them. Based on the outcomes of the feasibility study, a performance case is made for concepts. Together the outcomes of the third phase provide the input for the resulting roadmap which is drafted in phase 4.

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2 Introduction

2.1 Background

In the current Schiphol operation, during a departure peak (two runways in use for departures) departing traffic is segregated based on their departure sector and therefore destination. The primary departure runways (runway 36L and 24) operate traffic to sectors 1, 4 and 5 while secondary runways (runway 36C and 18L) operate traffic to sectors 2 and 3. This concept is visualised for the southern preferred runway mode of operation in the figure below. This current outbound traffic segregation concept basically places a wall within the TMA, creating an east/west divide.

Previous KDC research conducted by NLR (ref. NLR-CR-2021-157) showed, based on historical data from 2018/2019, that of the five departure sectors, sectors 2 and 3 are the busiest. With the current, East/West divide of departure routes this leads to non-optimal usage of the primary runway, with the capacity not being used optimally and for more hindrance to the population around the airport. Besides the non-optimal usage given the current operation at Schiphol, future developments, such as the introduction of electric, hybrid or hydrogen aircraft can have significant effects on the operational system.

Figure 1: Visualisation of current traffic segregation in southern operation

2.2 Research approach

This research explores potential outbound traffic segregation concepts with improved performance on noise, capacity, and sustainability. The scope of the research is exploratory, focusing both on the performance case of concepts as on the operational feasibility. Technical enablers, such as in the area of Trajectory Based Operations (TBO), can potentially act as enablers for the implementation of new traffic segregation concepts in the future. The goal of the research is to come to a roadmap that has two main focus points:

- Presenting segregation concepts that are achievable in the short term, with the limited use of (technical) enablers.

- Defining future-proof segregation concepts for the long term and the steps which need to be taken in the area of (technical) enablers on the development path towards the implementation of these concepts.

This research consists of four phases. The first phase is an exploratory phase in which, through analysis of background material, operational expertise and brainstorms, initial ideas for traffic segregation concepts are defined and presented. The second phase focuses on the potential effects on capacity and nuisance reduction, separately from the initial concepts defined in the previous phase. The initial concepts will be further refined based on the results of this phase. This further refinement is part of the third phase. These more mature concepts are then assessed on feasibility, where (technical) enablers are identified for concepts that require them. Based on the outcomes of the feasibility study, a performance case is made for concepts. Together the outcomes of this third phase provide the input for the resulting roadmap which is drafted in phase 4.

2.3 Context and assumptions

This research uses the operational concept of Schiphol as it was beginning of 2022 as a starting point. This includes flying according to the "Nieuwe Normen en Handhavingsstelsel (NNHS). The decision of the minister taken in the summer of 2022 to reduce the number of annual flights to/from Schiphol from 500.000 to 440.000 and stop the usage of the NNHS can have significant impact on the way Schiphol operates. It is however currently unclear under which specific rules Schiphol will have to operate in the upcoming years. This uncertainty can have a negative effect on innovation and implementation of new ideas. Changes in the airport schedule and the rules can therefore also have an impact on the concepts described in this report and on their implementation. It is however expected that the core ideas behind these concepts will remain relevant for further development of enablers and research.

2.4 Report structure

From chapter 3 onwards the structure of this report follows the four phases set out in the research approach. The resulting roadmap towards improved outbound traffic segregation is discussed in chapter 6. Final conclusions of the research are discussed in chapter 7.

3 Phase 1: Inventory of initial concepts

The goal of the first phase is to create an inventory of initial concepts which potentially can improve performance on departure capacity and noise. The focus of the concepts is on the two main runway modes of operation during the outbound peak, south (24+18L) and north (36L+36C).

Potential concepts were defined during two brainstorming sessions with the project team and to70 operational expert. The input used in the brainstorm consists of:

- The previous KDC study into traffic segregation concepts conducted by NLR.
- Internal analysis by RSG into sector swapping.
- Input from KDC work-session.
- Operational expertise of To70 with regard to the Schiphol operation, the ATM system and TBO.

Three types of concepts were considered during the brainstorm, these are shown in the figure below. The following paragraphs will present the inventory of initial concepts categorised by these three types. Concepts will be introduced on a high level. Introduction in this chapter explicitly does not mean that concepts are deemed (operationally) feasible. Phase three will go into more detail for every concept as part of the feasibility study. For several initial concepts, potential routes are drawn on a map to provide further explanation of how the concept could work. These drawn routes are for indicative purposes only and do not present an exact design of SIDs.

Table 1: Three types of segregation concepts considered

Redesign assignment and/or definition departure sectors	Operating one departure sector from two runways	Facilitating alternative traffic separate from main traffic flow
• Can be implemented as a static concept or partially • No changes to current SID design needed • No capability to "cherry pick" based on performance or noise • Most concepts feasible without SID conflicts	• Offers the capability to "cherry pick" based on performance or noise • Concepts may lead to route changes / new routes • Technical enablers supporting a feasible introduction of the concept	• Offers the capability to "cherry pick" based on performance or noise • Greater risk for SID conflicts • Leads to more usage of secondary runways instead of primary runways

3.1 Redesign assignment and/or definition departure sectors

In the current operational system, during outbound peaks departing traffic to departure sectors 1,4 and 5 is mainly operated from the primary runways while sectors 2 and 3 are operated from the secondary runways. Potential concepts in this section focus on operating specific destinations via a different sector or by operating different sectors from the primary runway.

Changing Sector 3/Sector 4 definition for South-west Europe (S34-DEF)

In the current operational concept aircraft departing via departure sector 3 during outbound peaks mainly depart from the secondary runways. Sector 3 traffic are flights with destinations located south/southwest of the Netherlands such as France, Spain, Portugal and parts of Africa. Actively allocating some of these destinations via sector 4 as well as sector 3 would create the possibility to move aircraft between the primary and secondary runway to optimize for noise/capacity. Primary runway usage can for example be increased by routing flights via sector 4, which is positive in terms of noise. Based on 2019, these flights make up roughly 7.500 departures a year. Potentially, destinations in Morocco (1.800 departures in 2019), Canal islands and Normandy (1.600 departures in 2019) can be added as well.

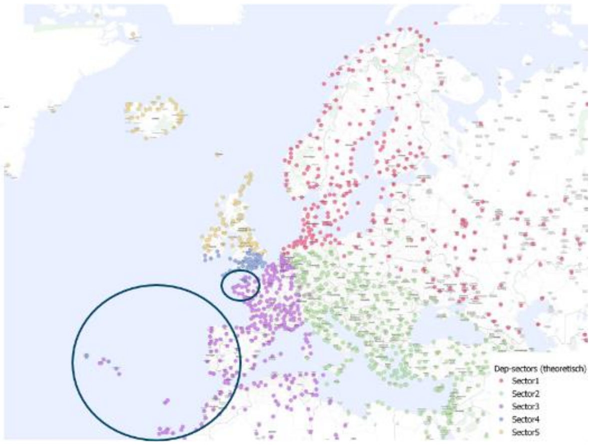


Figure 2: potential airports which are currently (dominantly) operated via sector 3 and can potentially be operated via sector 4

Changing Sector 2/Sector 1 definition for Eastern Europe (S12-DEF)

Besides departures to sector 3, the secondary runways mainly operate departures to sector 2 during outbound peaks. Several destinations can be operated via sector 1 as well as sector 2, this already happens on some occasions. Actively allocating some of these destinations via sector 1 as well as sector 2 would create the possibility to move aircraft between the primary and secondary runway to optimize for noise/capacity. Primary runway usage can for example be increased by routing flights via sector 1, which is positive in terms of noise. European destinations which have potential to be operated via both sectors 1 and 2 are destinations such as Berlin, Vilnius, Warsaw and Wroclaw, account for around 3.600 flights in 2019.

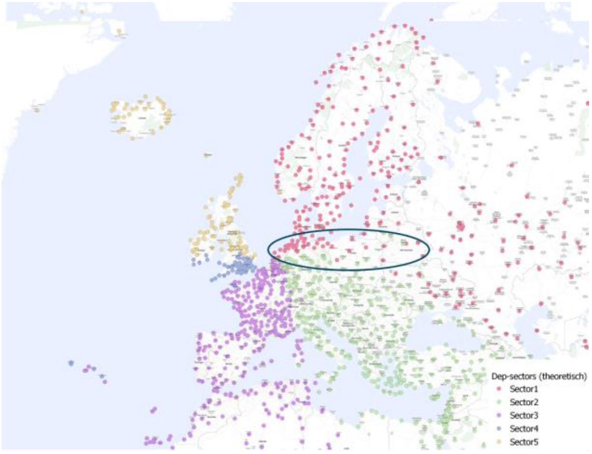


Figure 3: potential airports which are currently (dominantly) operated via sector 2 and can potentially be operated via sector 1

<u>Sector 1/2 from secondary runway instead of sector 2/3 – southern operation (S12-SOUTH)</u>

Instead of moving destinations from one departure sector to another, departure sectors can also be assigned differently to runways. In southern operation (departures from 24 and 18L) flights to sectors 1 and 2 (S12) can depart from the secondary runway instead of flights to sectors 2 and 3 (S23). Implementation can be achieved on different levels:

- Static: permanent change from S23 -> S12
- Dynamic per peak: based on traffic forecasts, usage of S12 or S23 is determined per peak.
- Dynamic within peaks: based on real time traffic developments, usage of S12 or S23 is determined in real time.

The concept could potentially lead to improvements in both capacity and noise. Research by RSG shows that S12 puts less traffic on the secondary runway compared to S23. In summer, the spread in runway occupancy of S12 is also smaller compared to S23, making the concept more robust. Noise reduction in the area South-east of Schiphol (especially Kudelstaart and Uithoorn-west) is expected due to a reduction in sector 3 traffic from 18L. West of Schiphol (Hoofddorp and Nieuw-Vennep) a noise reduction is expected due to a reduction in sector 1 traffic from 24.

Figure 4: Left: concept with sectors 1 and 2 from secondary runway (S12), Right: current operational system south (S23)

Sector 1/2 from secondary runway instead of sector 2/3 – northern operation (S12-NORTH)
Similar to the southern operation, in the northern operation (departures from 36L and 36C) flights to sectors 1 and 2 (S12) can depart from the secondary runway instead of flights to sectors 2 and 3 (S23). Implementation can be achieved on different levels as mentioned before, being static, dynamic per peak or dynamic within peaks.

To avoid SID crossings, a new 36L sector 3 SID needs to be designed. Being limited by sector 1 and 2 departures from 36C to the east of 36L, the new 36L sector 3 SID needs to turn west, before turning south above the sea towards sector 3. As mentioned in the southern mode concept, S12 puts less traffic on the secondary runway compared to S23. Furthermore, a noise reduction in Amsterdam-West is expected due to a reduction in sector 3 traffic from 36C.

Figure 5: Left: concept with sectors 1 and 2 from secondary runway (S12), exact location of new 36L sector 3 SID depends on fixed arrival routes DARP, therefore it is indicated by an area. Right: current operational system north (S23)

3.2 Operating one departure sector from two runways

Sector 1/2 from secondary runway, with dual SID usage sector 2– southern operation (S12-SOUTH-DUAL)
In the current operation, SIDs from runway 24 to sector 2 are usually not operated during outbound peaks since these SIDs cross sector 3 SIDs from 18L going to the south. With implementation of the previously mentioned S12-South concept however these 18L SIDs are not used, creating room to operate sector 2 from both the primary runway 24 as well as the secondary 18L runway. Besides the previously mentioned benefits of S12-South, dual-SID usage allows for the optimal assignment of sector 2 traffic over runway 24 and 18L since gaps in the departure stream of runway 24 can be filled with sector 2 departures from runway 18L. This optimal assignment can have benefits for both noise and capacity.

Introduction of a dual SID to sector 2 requires the 24 sector 2 SID to run parallel with the sector 2 SID of 18L. Currently this SID is not possible since it would go through TMA D, which is military airspace. As part of the Dutch Aerospace Redesign Program (DARP), TMA D is opened up for civil usage, making this an enabler for the S12-SOUTH-DUAL concept besides the S12-south concept. As shown in the figure on the next page, departures from runway 24 to sector 2 sometimes cross through TMA-D when it is available for civil usage. For this concept a permanent SID will have to be designed in this area.

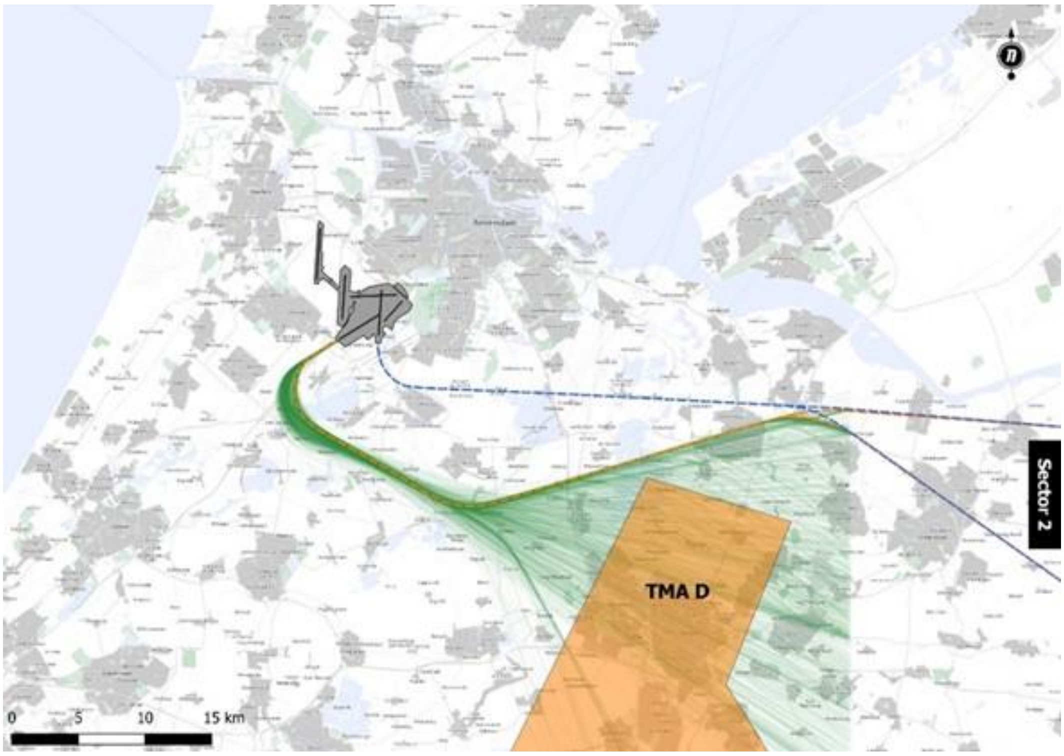


Figure 6: Dual SID concept sector 2 in southern operation

<u>Dual SID usage sector 2 – northern operation (S2-NORTH-DUAL)</u>

In the northern operation the current allocation of sectors (1,4,5 from 36L and 2,3 from 36C) potentially allows for sector 2 to be operated from both runways without SIDs crossing each other. Dual-SID usage to sector 2 allows for the optimal assignment of traffic over runway 36L and 36C since gaps in the departure stream of runway 36L can be filled with sector 2 departures from runway 36C. This optimal assignment can have benefits for both noise and capacity. This concept is not possible in combination with the S12-NORTH concept since sector 2 departures from 36L would then cross sector 1 departures from 36C. With the current SID design, this would create a merger of the two SIDs within the TMA. Several variants can be thought of which could mitigate this SID merger within the TMA.

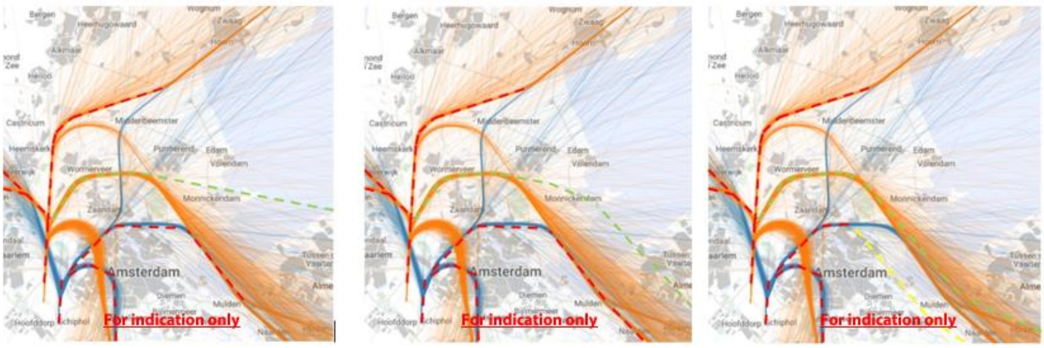


Figure 7: Dual SID concept sector 2 in northern operation, potential options

Dual SID usage sector 3 – southern operation - LOPIK (S3-DUAL-SOUTH-LOP)
In the current operation the LOPIK SID, going through military airspace, is often available in the weekends. When LOPIK is available, flights to sector 3, under specific circumstances, are occasionally operated via 24-KUDAD and 18L-LOPIK at the same time. When this is done, 24-KUDAD traffic is taken of the SID to fly separated from the LOPIK SID using radar vectoring. This is not a formal procedure; it is applied by controller's based on their operational assessment.

As part of the DARP, TMA D is opened up for civil usage, making the LOPIK SID permanently available and creating the option to operate sector 3 from runways 24 and 18L simultaneously. With dual-SID usage, the optimal assignment of sector 3 traffic over runway 24 and 18L can also have benefits for both noise and capacity. Since this concept requires sector 3 departures from 18L this concept can't be implemented in combination with concepts operating sector 1 and 2 from 18L.

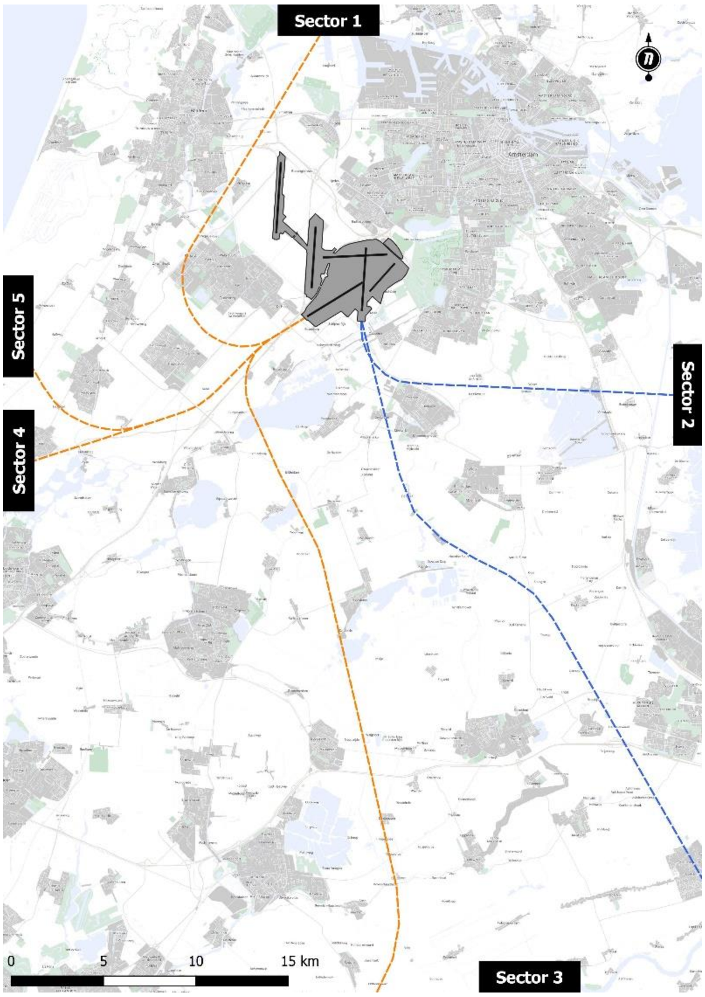


Figure 8: Dual SID concept sector 3 in southern operation, with current 24-Kudad and 18L-Lopik SIDs

Dual SID usage sector 3 – southern operation – KUDAD (S3-DUAL-SOUTH-KDD)

Currently, on occasions 24-KUDAD and 18L-KUDAD are operated at the same time. When this is done, 24-KUDAD traffic is taken off the SID to fly separated from the 18L-KUDAD SID using radar vectoring. This is not a formal procedure; it is applied by controller's based on their operational assessment of the situation. Adjusting the 24-KUDAD SID to the west would make the two KUDAD SIDs independent, allowing for dual SID usage to sector 3 and the optimal assignment of sector 3 traffic over runway 24 and 18L.

Adjusting the 24-KUDAD SID and not using the LOPIK SID makes the concept independent from the DARP. The adjusted 24-KUDAD SID, keeping separation from the 18L-KUDAD SID, would however cross over close by multiple highly populated areas. Adjusting the 24-KUDAD SID might cause local, and perhaps even overall, negative noise effects. This makes the S3-DUAL-SOUTH-LOP concept more desirable from a noise perspective compared to S3-DUAL-SOUTH-KDD.

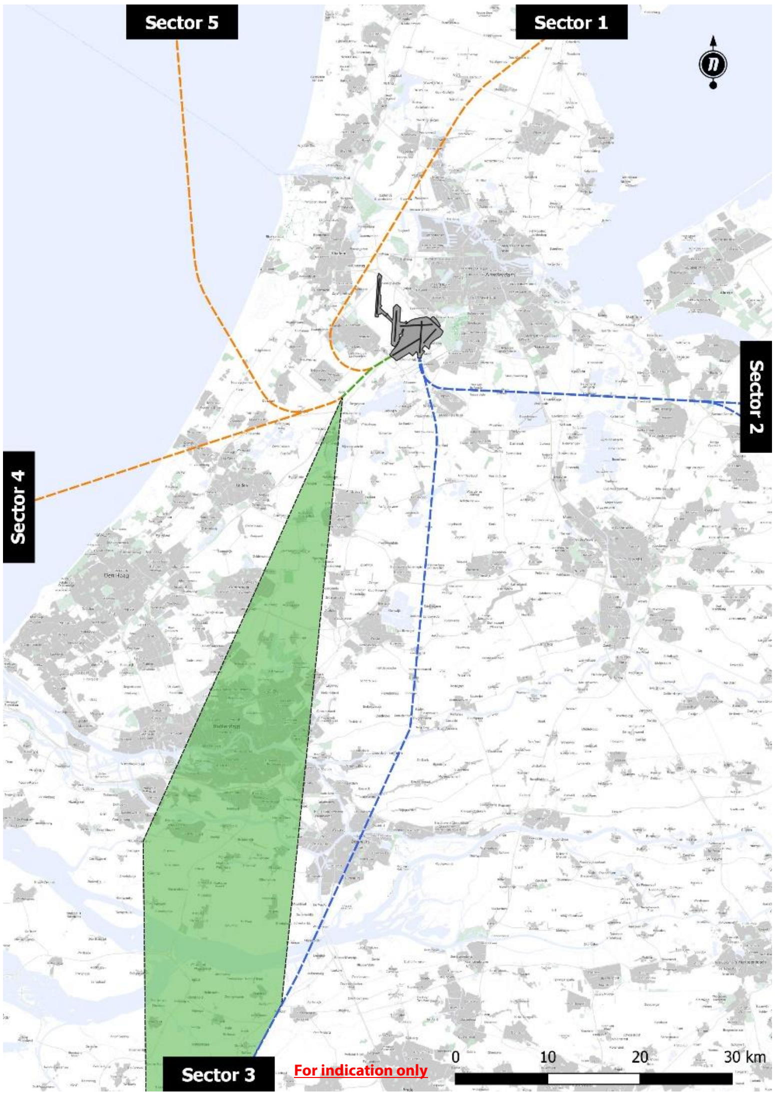


Figure 9: Dual SID concept sector 3 in southern operation, with location of adjusted 24-Kudad route located in green area

Dual SID usage sector 3 – northern operation (S3-DUAL-NORTH)

With the implementation of the S12-NORTH concept, a new western turning SID allows flights from 36L to depart for sector 3 separated from sector 3 departures on 36C. This allows for dual SID usage to sector 3, and the optimal assignment of sector 3 traffic over runway 36L and 36C. The concept however, just as the S12-NORTH concept, strongly depends on a conflict free 36L sector 3 SID to the west which needs to be designed and implemented.

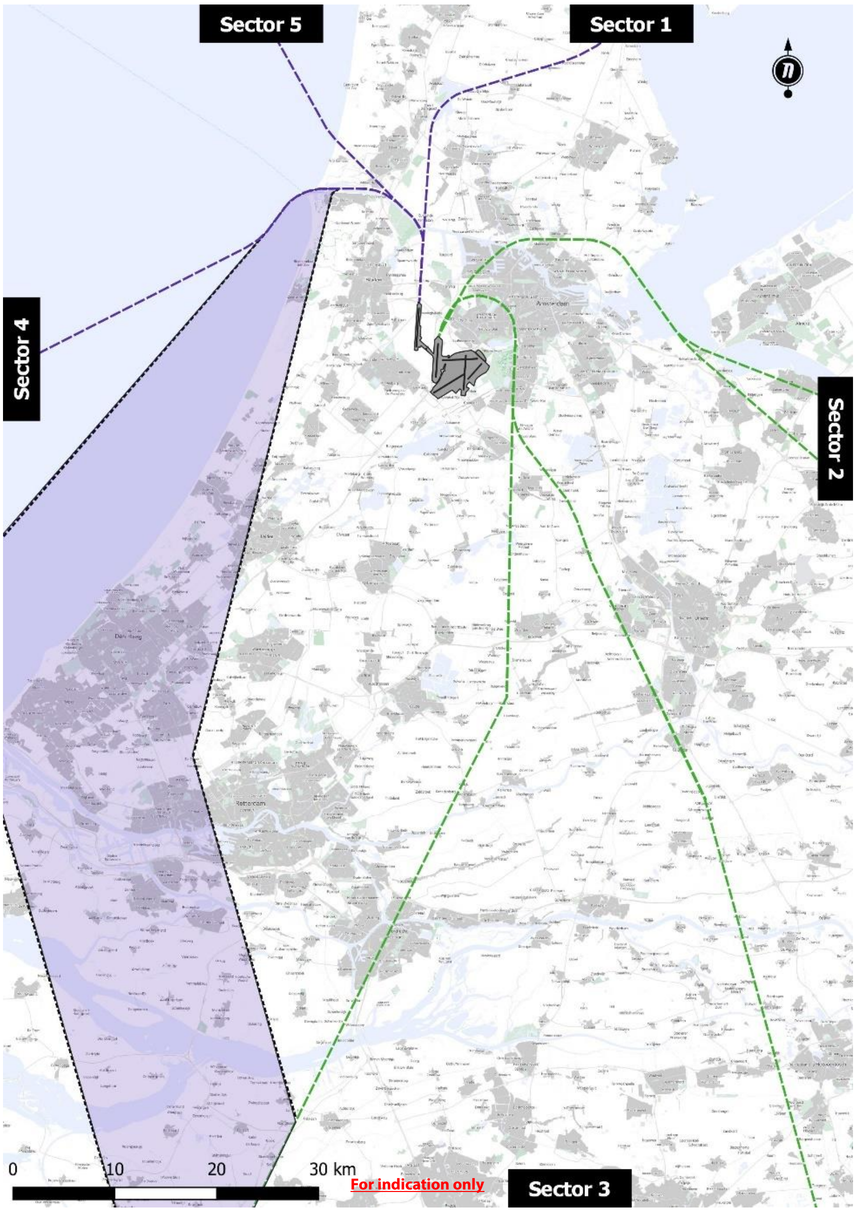


Figure 10: Dual SID concept sector 3 in northern operation, with (potential location) of new 36L sector 3 SID in purple, exact location of new 36L sector 3 SID depends on fixed arrival routes DARP.

Merging flights from two runways to the same exit point (TRAF-MERGE)
Current runway/sector combinations are operated in such a way that traffic on different SIDs does not merge or cross each other. In the current SID design, there are several SIDs which would merge if they were used at the same time: 24 and 18L traffic to sector 2, 24 and 18L traffic to sector 3, 36L and 36C traffic to sector 2 and 36L and 36C traffic to sector 1. With outbound traffic merging, spacing between aircraft is predicted and used to time aircraft take-off in order to merge aircraft from two SIDs within the TMA on to one common SID.

With the current sector assignment, outbound traffic merging would be an option for runway 24 and 18L traffic to sector 3 and runway 36L and 36C traffic to sector 2, without causing a conflict with other SIDs. When sectors 1 and 2 are operated from the secondary runways (S12), 24 and 18L traffic to sector 2, and 36L and 36C traffic to sector 1 can be operated without causing a conflict with other SIDs. This concept creates several bottlenecks in terms of separation, planning, safety and workload. These issues need to be considered. Therefore, the implementation of these concepts should be supported by technical enablers. Once implemented, the concept would allow for a more optimal assignment of traffic between the primary and secondary runways.

Figure 11: Traffic merging concept for southern (left) and northern (right) operation with current sector assignment

3.3 Facilitating alternative traffic separate from main traffic flow

Operating flights with different performance from an alternative runway (ALT-RWY)
Currently Schiphol operates in a 1+1, 1+2, 2+1 or 2+2 mode, depending on the traffic demand. This means that at maximum 2 departing runways are operated at a given moment. Occasional general aviation flights are handled from the 04-22 runway. These flights often require radar vectoring from ATC to guarantee separation from other traffic, which causes an increase in workload. With the majority of flights departing from the same one or two runways, differences in performance can cause large departure intervals to be applied between consecutive aircraft, which has a negative impact on capacity. Currently, aircraft with a different performance, mainly turboprops, are taken off the SID by ATCO's and given vectors to limit their impact on the capacity.

With the future introduction of electric/hybrid or hydrogen aircraft, the number of small/medium rotor aircraft used for passenger transport is expected to grow, maybe also at Schiphol. These aircraft's performance is expected to deviate from other (jet engine) aircraft, which might negatively impact capacity. Taking these aircraft off the SID and handling them separately is expected to cause a large increase in workload.

Using a secondary/tertiary runway separates these aircraft from other aircraft, mitigating the negative capacity impacts. In this concept, an alternative runway is used for flights with different performance. During off-peak moments, the secondary runway is used for departures with a different performance. During peak moments, a third runway is used for departures with a different performance besides the two main runways.

Operating flights with different performance from an alternative SID (ALT-SID)

Currently, departure traffic from Schiphol is handled on defined SIDs to five departure sectors. All traffic flies the same SIDs. As mentioned in the previous concept, with the majority of flights departing from the same one or two runways, differences in performance can cause large departure intervals to be applied between consecutive aircraft, which has a negative impact on capacity. Instead of placing these aircraft with different performance on an alternative runway or taking them of the SID, this concept segregates these flights procedurally by altitude. For each SID, a higher and lower variant is designed which allows small/medium rotor aircraft to level off and jet aircraft on the same SID to climb overhead.

3.4 Conclusions phase 1

This chapter, as a first phase of the research, has provided a high-level overview of initial concepts. Most concepts aim at structurally enabling some level of flexibility in the current strict segregation applied to outbound traffic. This flexibility would allow for a more optimal assignment of traffic between the primary and secondary runways. Optimal assignment based on noise or capacity can however lead to a different allocation of traffic. Phase 2 will go further into this potential of traffic segregation based on noise or capacity.

The concepts presented in this chapter are the result of several brainstorm sessions. Introduction in this chapter explicitly does not mean that concepts are deemed (operationally) feasible. However, with the introduction of the concepts, already several bottlenecks are identified in terms of separation, planning, safety and workload. In phase 3 concepts are further refined and will undergo a feasibility analysis.

The high-level overview of initial concepts already shows that several concepts depend on the implementation of other concepts, (elements of) the airspace redesign or on (a set of) technical enablers which need to be implemented before the concept can potentially be implemented. At the same time, there are several concepts which conflict with each other and cannot be implemented in combination. For concepts deemed feasible after phase 3, the roadmap in phase 4 will take these dependencies into account when describing the potential horizon and enablers which require development when working towards implementation.

4 Phase 2: Potential of traffic segregation

This second phase focuses on the potential of traffic segregation. The analysis in this phase is performed separately from the initial concepts presented in the previous phase. The analysis focus on the potential effects on capacity and nuisance reduction. The initial concepts will be further refined on the basis of the results of this phase.

4.1 Noise performance

The reasoning behind the current operation at Schiphol, using the preferential runway system, is that the two primary runways (Kaagbaan 24/06 and Polderbaan 36L/18R) are the best runways in terms of noise performance. However, given the demand at Schiphol, not all traffic can be handled on these primary runways. To get insight into the potential of traffic segregation on noise performance, an analysis of the difference in noise performance between the primary runways and the secondary runways for different aircraft types and departure sectors is conducted.

4.1.1 Approach

For this analysis, a noiseload database with SEL contours is used which has been constructed for a previous KDC study. This noiseload database is based on model routes for Schiphol and the noise data and flight profiles derived for Schiphol in 2017. The SEL levels are calculated with the ECAC Doc29 compliant model of Aerlabs.

The noiseload database contains SEL values per grid point for specific aircraft types, flying a specific route with a specific procedure. For each available combination (for departing traffic) the number of people living within specific SEL contours are determined, based on the housing situation used in the EIA Schiphol (housing situation on January 1st, 2018). From all these combinations, the average number of people within SEL contour per runway-aircraft type-sector combination is determined. Flights with specific aircraft types to the same sectors from the primary runways (24 or 36L) and the secondary runway (18L or 36C) are compared to determine which runway is more preferred from a noise viewpoint. The analysis focuses on the 70dB SEL contours.

4.1.2 Noise performance 18L vs 24

The graphs on the next page show a comparison in noise performance for an aircraft departing to a specific sector from either the primary or the secondary runway. The x-coordinate is determined by the average number of people within the 70 dB contour when departing from the secondary runway, while the y-coordinate is determined by the primary runway. This means that for aircraft to a specific sector (colour coded) which are located above the diagonal line there are less people within the 70dB contour when departing from the secondary runway 18L compared to when departing from the primary runway 24.

Runway 24 has two SIDs to sector 1, the SPY SID and the AND SID. The SPY SID is used when 24 and 18L are operated at the same time since the 24 AND SID would conflict with 18L SIDs. The AND SID is therefore used when runway 24 is the only departure runway. When considering outbound peaks (SPY SID used) all aircraft departing to sector 1 have a better noise performance from 18L compared to 24. During non-peak moments (when AND SID is used) most aircraft to sector 1 have a better noise performance from 24 compared to 18L. For some specific aircraft departing to sector 4 the secondary runway is preferred as well, due to the location of the 70 dB contour relative to housing. In terms of noise performance aircraft departing to the other sectors all have a better noise performance from the primary runway 24.

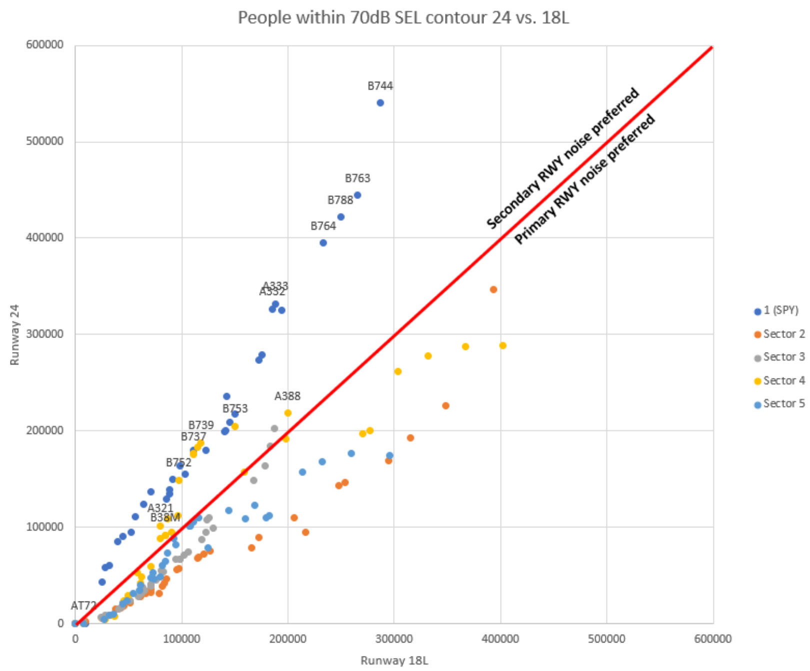


Figure 12: Comparison of noise performance for aircraft departing to a specific sector. With runway 24 sector 1 being flown via the SPY SID

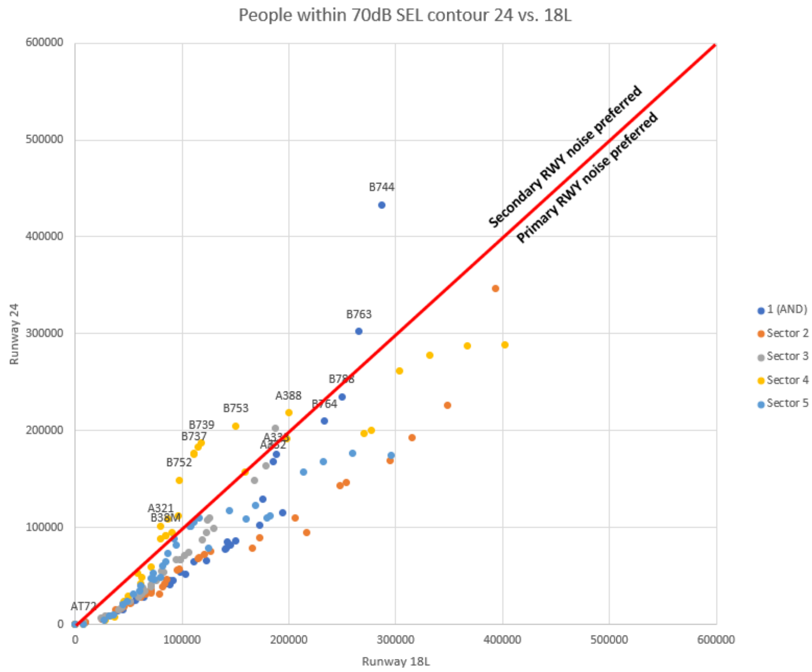


Figure 13: Comparison of noise performance for aircraft departing to a specific sector. With runway 24 sector 1 being flown via the AND SID

4.1.3 Noise performance 36C vs 36L

The figure underneath shows the same analysis when focusing on the northern operation. Since there are no official SIDs from runway 36C to sectors 4 and 5, the analysis for northern operation focuses on the remaining sectors 1,2 and 3. Additionally, since several concepts in phase one discuss a potential 36L sector 3 SID turning west, the figure also contains an indicative comparison between the sector 3 SID from 36C and this new 36L SID (named Kudad-left, KDL). For this indicative comparison, noise results of 36L sector 4 SIDs are used, since the new 36L SID is likely to follow the same path until it reaches the ocean and turns south.

The figure underneath shows that 36L has a better noise performance compared to 36C for all three sectors. When considering the potential 36L sector 3 SID turning west, this SID is more preferred then the current 36L and 36C SID, since it is located towards the western coast instead of Amsterdam in the east.

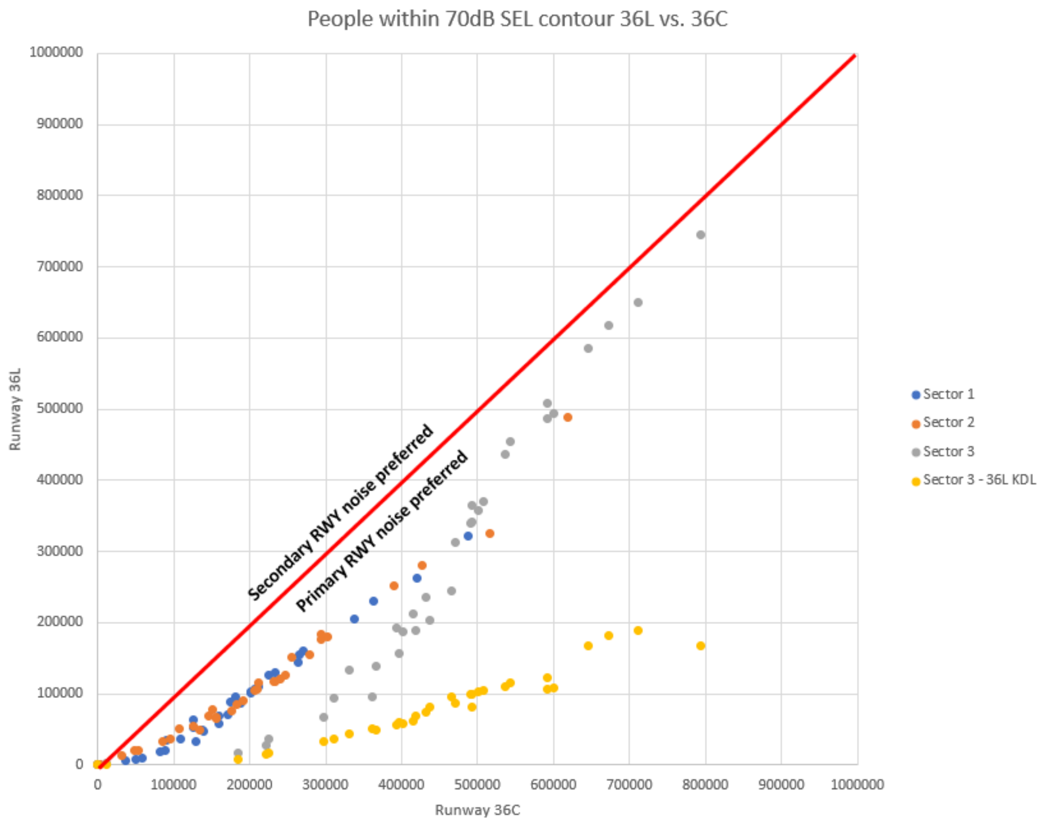


Figure 14: Comparison of noise performance for aircraft departing to a specific sector – northern operation

4.1.4 Conclusions

The analysis shows that for most aircraft and sector combinations noise performance of the primary runway is better compared to the secondary runway. The main exception are departures to sector 1 in southern operation, for which noise performance via the 24-SPY is worse than the noise performance of 18L-AND. For outbound traffic segregation this conclusion means two things from a noise perspective. Frist, traffic segregation concept should aim to maximise the throughput on the primary runway. And second, traffic segregation concept should aim to operate flights to sector 1 from runway 18L instead of runway 24

4.2 Capacity performance

From a noise perspective, where the reduction of noise hindrance is paramount, the use of the primary runway is preferential. However, from a capacity perspective the aim is to maximise aircraft throughput during departure peaks while minimising delays. To achieve this goal, aircraft departures during peaks should be divided among both operational runways to effectively exploit runway capacity. Runway capacity is influenced by a variety of factors, like weather, runway configuration, air traffic control separation standards, and fleet mix. A capacity model was developed to gain insight into these effects on runway capacity during outbound departure peaks.

4.2.1 Approach

Based on runway selection data from LVNL, a selection of outbound departure peaks with a minimum duration of 20 minutes was extracted from CDM-data of the year 2019. In total, 433 departure peaks were operated with the northern runway configuration (36L / 36C), while 818 departure peaks were operated with the southern runway configuration (24 / 18L).

Initially, the flights were assigned to the appropriate runway based on the concept of operation to be analysed. The baseline model (P145_S23), currently in use at Schiphol, operates flights to sector 1, 4 and 5 from the primary runway, while flights to sectors 2 and 3 depart from the secondary runway. Since both the gate and runway are in the CDM-dataset, the appropriate taxi-time could be defined and added to the Target Off-Block Time (TOBT) in order to determine the Target Take-Off Time (TTOT). The capacity model sequences the flights by their TTOT and computes the Actual Take-Off Time (ATOT) which is dependent on the original schedule times and the to be applied departure intervals. These intervals define the minimum required time between departures and is further elaborated on in the following section.

The capacity model returns an updated schedule of flights on both runways based on the concept of operation to be analysed. The following performance indicators are evaluated to analyse the performance of the operational concepts:

- Total sum of departure intervals representing the effective time the runway is in use
- Total delay (difference between TTOT and ATOT) at the runway
- Throughput on the primary runway

It should be noted that the developed capacity model does not optimise the schedules when evaluating different concepts. This means that schedule times (TOBT) are not adjusted when swapping flights from one runway to the other. Therefore, the computed delay is dependent on original schedule times.

4.2.2 Departure intervals

The actual traffic mix of aircraft types and destinations determines the real available runway capacity by defining the minimum interval between consecutive departures. To allow for the capacity benefits of Time-Based Separation (TBS) on departures, the interval between a pair follows from the required separation minimum of the two consecutive types and the distance until which this minimum applies. In time-based operations, the first is governed by the RECAT-EU standards (See Table 2). The latter is determined by the point at which the SIDs of both starts separate from each other and, therefore, destination.

This relation between capacity and consecutive starts implies that the maximum runway capacity will vary per:

- Time of day/peak (this affects destination and fleet mix)
- Runway (this affects the SID routes)
- Concept (this affects the SID routes and fleet mix)

Table 2: RECAT-EU Distance separation minima

Follower > **Leader V**	**A**	**B**	**C**	**D**	**E**	**F**
Super Heavy / A	3 NM	4 NM	5 NM	5 NM	6 NM	8 NM
Upper Heavy / B		3 NM	4 NM	4 NM	5 NM	7 NM
Lower Heavy / C			3 NM	3 NM	4 NM	6 NM
Upper Medium / D						5 NM
Lower Medium / E						4 NM
Light / F						3 NM

The empty cells require minimum radar separation, assumed as 3 NM

The intervals are determined for all RECAT-EU pairs and all possible lengths of the common path of the SID using a method comparable to that used in the KDC project "*CCO and High Altitude SIDs*". This method uses actual departure tracks as flown from Amsterdam Schiphol Airport to account for the variations in speed profiles between different aircraft types and even between flights and is described in Appendix A .

The analysis of departure profiles results a set of minimal intervals between consecutive departures (See Table 3). Note that the intervals do not necessarily increase with increasing required spacing (for example, all profiles with a Lower Heavy/C follower have a higher interval than with an Upper Medium/D follower). The variation relates to the variation in performance and operating speeds within a RECAT-EU class.

Table 3: Range of departure intervals

Follower > Leader V	A	B	C	D	E	F
Super Heavy / A	85 – 105	115 - 135	140 - 145	135 - 140	155 -155	190 - 195
Upper Heavy / B	70 - 80	75 - 110	100 - 115	95 - 110	115 - 115	150 - 155
Lower Heavy / C	65 - 75	70 - 100	80 - 110	75 - 100	95 - 100	130 - 135
Upper Medium / D	65 - 85	75 - 115	80 - 125	75 - 115	75 - 110	115 - 135
Lower Medium / E	65 - 85	75 - 120	80 - 130	75 - 120	75 - 115	100 - 140
Light / F	70 - 95	75 - 125	85 -135	80 - 135	75 - 120	85 - 135

The reported range of intervals (seconds) is between shortest common path of two SIDs (3.3 NM from start of take-off) and both aircraft following the same SID in to ACC.

4.2.3 Capacity analysis

As discussed, the departure intervals between sequenced departures are dependent on the aircraft RECAT-EU categories and the sectors consecutive aircraft depart to. A traffic mix which is more homogeneous would reduce intervals and thus provide the potential to further improve runway capacity. Table 4 below provides an overview of the distribution of aircraft RECAT-EU for each departure sector. It could be noticed that departures to sectors 2 and 3 are mostly Upper Medium aircraft, making the fleet mix to these sectors more homogeneous. Departures to sector 1 are more evenly distributed with Lower- and Upper Medium aircraft. Also, a slightly larger share of aircraft to sector 1 (compared to sector 2) are Upper Heavy aircraft, which significantly increase the required intervals (in case an Upper Heavy aircraft is followed by a lighter aircraft).

Table 4: Distribution of RECAT-EU aircraft types per departure sector

RECAT-EU	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5
Upper Medium	44%	59%	66%	44%	31%
Lower Medium	41%	27%	29%	34%	29%
Upper Heavy	15%	13%	4%	20%	31%
Lower Heavy	<1%	1%	1%	2%	9%
Super Heavy	<1%	1%	0%	0%	0%
Light	<1%	<1%	<1%	<1%	<1%

The required departure intervals could be reduced to specified RECAT-EU separation standards under the following circumstances:

- **VMC operation**: where aircraft could be separated visually. The required separation in visual conditions, based on expert judgement, would be 3000 ft / 8 km.
- **Immediate turns after take-off**: when the SIDs of two consecutive departures geometrically split in an early stage right after take-off (early split points)

These early split points (which can be seen in figure 1 in the introduction) are applicable to departures from 18L when the leading aircraft departs to sector 1 or 2 and the trailing aircraft departs to sector 3, 4 or 5. This also applies to aircraft departing from runway 24 to sector 1 (SPY SID) followed by aircraft departing to sector 2, 3, 4 or 5. In these cases intervals could be reduced from 75 seconds to 60 seconds. No split points are found in the northern runway configuration (36L / 36C).

The total sum of departure intervals over a sequence of flights is dependent on how departures are scheduled over a period of time during a departure peak. As explained, the capacity model used in this study was not developed to optimise this schedule by aiming to reduce delay and intervals between departures. In Chapter 5.3 the resulting schedules based on various concepts will be further analysed on runway capacity usage. Table 5 below summarises the results of the baseline model (P145_S23).

Table 5: Capacity figures for baseline model (P145_S23) for northern and southern operations in both VMC and non-VMC operations

Baseline model (P145_S23)	North (36L / 36C)	South (24 / 18L)	
	No VMC	No VMC	VMC
Number of departures [-]	35.325	68.699	68.699
Number of outbound peaks [-]	433	818	818
Average throughput [departures/hour]	46	41	41
Average required interval between departures [s]	93	93	87
Average delay per departure [s]	199	157	123

On average, departures have to be spaced at least 93 seconds, independent on the runway configuration. As mentioned, early split points after take-off allow for the reduction of departure intervals when operating in VMC. In the southern operation, average intervals between departures could be reduced to 87 seconds (-7%) under VMC. This positively affects the capacity usage as average delays per departure also decreased to 123 seconds (-22%). It could be observed that the average delay in the northern runway configuration is higher compared to the southern runway configuration, which is caused by the higher average throughput of departures in the northern operation.

4.2.4 Conclusions

The runway capacity is mostly impacted by the distribution of aircraft types sequenced on a runway, which defines the required amount of time that aircraft should be separated. A homogeneous fleet is more likely to have lower departure intervals. Besides, departure intervals could be reduced in VMC operations when aircraft could be separated visually. This lowers the average required timely spacing in between departures, providing the possibility of reducing delays.

4.3 Conclusions phase 2

The analysis shows that from a noise perspective, traffic segregation concepts should aim to maximise the throughput on the primary runway while specifically operating flights to sector 1 from runway 18L instead of runway 24. The analysis regarding capacity shows that traffic segregation concepts can impact capacity by the way they change the distribution of aircraft types sequenced on a runway. The analysis of capacity also showed that under VMC significant positive effects on capacity are achieved for segregation which contains early split points between sectors.

These conclusions are an example of the tension between noise and capacity optimal: from a noise perspective sector 1 from runway 24 is not optimal, while from a capacity perspective it is a preferred option. These tensions will emerge more and in different forms when the concepts are worked out and analysed further in the next phase.

5 Phase 3: Feasible and effective segregation-concepts

In this third phase, the initial concepts of phase one are combined with the insights from phase two to further mature the concepts, asses them on feasibility and identify potential (technical) enablers where needed. Based on the outcomes of the feasibility study, a performance case is made for concepts. Together the outcomes of this phase provide the input for the roadmap which is presented in phase 4.

5.1 Feasibility study

The feasibility study is the result of an iterative process. Together with To70 experts, the initial concepts presented in phase 1 have been developed further into more detailed concepts. After finishing this iterative process, the final concepts have been assessed on their feasibility. For the feasibility study, multiple sessions were held with To70 experts. The feasibility study focusses on the main aspects per concept which are of importance for its feasibility. The presented aspects in this report therefore are not an exhaustive list of aspects one has to consider when making a (detailed) design. The following paragraphs report per concept on highlighted aspects of the concept, the conclusions of the feasibility study, the expected implementation term and (if applicable) the conditions or enablers related to the concept. The results of the feasibility study are summarised in the table below.

Table 6: Conclusions of feasibility study

Concept	Feasibility	Implementation	Remark/conditions/enablers
S34-DEF S12-DEF	Feasible	Short term	- Arrangements need to be made with airlines, keeping in mind track miles and the workload in sectors involved.
S12-South	Feasible under conditions/enablers	Medium term	- Static or dynamic feasible under conditions: positive safety study 24-KDD, mitigating 24-LOP separation, manageable within runway capacity
S12-North	Feasible with enablers	Long term	- Static or dynamic feasible when traffic is separated using fixed arrival routes and departure tubes (DARP)
S12-South-Dual	Uncertain	Long term	- Dependent on DARP and S12-South concept - Potential limitations in traffic assignment, 4th IAF - Complex, further research needed
S2-North-Dual	Uncertain	Long term	- Potential limitations in traffic assignment, 4th IAF - Complex, further research needed
S3-Dual-South-LOP	Feasible under conditions	Long term	- Dependent on TMA D availability (DARP) - Separation between SIDs guaranteed - Moving mostly SW departures to primary runway
S3-Dual-North	Not feasible	-	- not feasible due to the capacity limitations in sector 3
S3-Dual-South-KDD	Not feasible	-	- not feasible due to the capacity limitations in sector 3 - Implementation unlikely from a community engagement perspective
Traf-Merge	Uncertain	Long term	- TBO provides several enablers - Unsure if the operation is predictable enough to adhere to required timing - Complex, further research needed
Alt-Rwy	Not feasible	-	- Alternative flights will not be able to operate separate from main flow conflict free
Alt-SID	Not feasible	-	- Limited effect on capacity while significant negative effects on noise - Merging alternative traffic with other traffic causes large increase in workload

5.1.1 Changing Sector 3/ Sector 4 definition for South-west Europe (S34-DEF) or changing Sector 2/ Sector 1 definition for Eastern Europe (S12-DEF)

Conclusion

The S34-DEF and S12-DEF concepts aim at operating some destinations via two sectors which can be operated from either the primary or secondary runway. Through the feasibility analysis, it is concluded that the concepts are feasible in the short term. The concepts don't require technical enablers to be implemented, they primarily rely on arrangements made with airlines. The scope of the concepts (number of flights moved) can be limited by economic aspects and/or workload in sectors and adjacent centers.

The conclusions above are based on a feasibility study focusing on the following aspects:

- Current sector usage
- Agreements with airlines on sectors

The main analysis per aspect is discussed in the following sections.

Current sector usage

The S34-DEF concept focuses on flights with destinations located south/southwest of the Netherlands. These destinations are located in France (destinations such as Nantes, Caen, Cherbourg, Le Havre), Spain (Canary Islands), Portugal and Morocco. The table underneath provides an overview of flights to the different destinations (based on 2019 traffic data), providing an overview of the departure sector used. The table shows that for destinations with a great circle which lies more westerly (Azores, Canary Islands, Channel Islands) sector 4 is already often used instead of sector 3. For destinations that are more direct south (France, Morocco, Portugal) sector 3 is dominant.

Table 7: Departures towards the southwest divided by departure sector

Airport	Departures via sector 4	Departures via sector 3	Movements total
Azores	**55**%	45%	55
Canary Islands	40%	60%	2226
Channel Islands	81%	19%	42
France	0%	100%	1548
Morocco	2%	98%	1837
Portugal	23%	77%	5331

The table on the next page shows the same overview as the table above for departures to destinations located to the northeast of the Netherlands. Based on 2019 traffic data, the table shows that already the usage of sector 1 or 2 to these destinations is mixed. Flights to Berlin are divided quite equally between sectors 1 and 2, for Warsaw most flights are operated via sector 2.

Table 8: Departures towards the northeast divided by departure sector

Airport	Departures via sector 1	Departures via sector 2	Movements total
Berlin (Tegel)	59%	41%	3723
Warsaw	18%	82%	2250
Vilnius	53%	47%	370
Wroclaw	34%	66%	182

The tables above show that, currently, most destinations are already being operated via multiple sectors. Currently, the decision to operate a flight via a specific departure sector is made by the airlines. These decisions can be driven by multiple company objectives, capacity being one of these decisions. 1-3 hours before departure, the tower and approach supervisors make the runway planning. Based on this planning, TSAT delay on the runways can be calculated. Flow coordinators from KLM can advise dispatchers to file certain flights via a different departure sector in order to reduce their start-up delay. The difference with this process and the proposed concepts is that the current practice is a voluntary change made by the airline to optimize their specific flight based on their own parameters, while the concepts are aimed at optimizing the system as a whole based on capacity or noise.

Agreements with airlines on sectors

The current operation shows that it is possible for airlines to change their departure sector in the hours before the flight. From a noise perspective, operating as many flights as possible from the primary runway is preferred. Primary runway usage would be increased by routing flights via sector 4 or 1 to fill the primary runway as much as possible. For these concepts to be implemented, arrangements should be made with airlines that by default a specific set of destinations are to be filed via the noise preferent sectors (1 or 4), and under specific capacity conditions via the secondary sectors (2 or 3). This can be done in a formal way, via a Route Availability Document, or more informal via bilateral agreements with large airlines. Economic aspects for airlines should be considered when making these bilateral agreements, which might result in not all destinations being flown via a sector linked to the preferred runway.

Changing the sectors of flights can cause sectors to overload when too many flights are being planned via a sector. Sector capacity will have to be considered during the planning phase and this might limit the number of flights which can change sector. Departures leaving the country via sector 4 are handed over to London ATC, which is currently already a busy sector. Adding additional flights to this sector might lead to workload issues at NATS. Workload in adjacent centres is therefore an important aspect which needs to be analysed and assessed before the concepts can be implemented. Based on this assessment the amount of additional traffic sent via sector 4 may be limited.

5.1.2 Sector 1/2 from secondary runway instead of sector 2/3 – southern operation (S12-SOUTH)

Conclusion

The S12-South concept aims for flights in southern operation (departures from 24 and 18L) to sectors 1 and 2 (S12) to depart from the secondary runway instead of sectors 2 and 3 (S23) in the current operation. Implementation can be achieved on different levels:

- Static: permanent change from S23 -> S12
- Dynamic per peak: based on traffic forecasts, usage of S12 or S23 is determined.
- Dynamic within peaks: based on real time traffic developments, usage of S12 or S23 is determined.

Through the feasibility analysis, it is concluded that static or dynamic per peak implementation of the S12-south concept is feasible in the medium to long term when several conditions are met:

- A positive safety study on the separation between 24-KDD and 18L-ARN/AND, acknowledging that 24-KDD and 18L-ARN/AND can be flown independently.
- The concept is only applied when the LOP-SID is not used (dynamic per peak), or a different mitigation for the separation issue between 24-LOP and 18L-ARN/AND is implemented.
- The selected departure sectors traffic is not unmanageably large on one of the two runways.

Based on the described conditions, it is expected that a dynamic per peak implementation has more potential of being implemented compared to a static implementation. Dynamic usage is currently already applied in some cases based on tactical decisions.

Even if technical support assists the controller in timing traffic, the dynamic usage of S12 or S23 within a peak is assessed as being the least feasible of the three concepts due to workload associated with the operational complexity of configuration changes.

The conclusions above are based on a feasibility study focusing on the following aspects:

- Separation between 24 KDD and 18L ARN
- Separation between 24 LOP and 18L ARN
- Runway capacity
- Dynamic usage within peaks

The main analysis per aspect is discussed in the following sections.

<u>Separation between 24 KDD and 18L ARN</u>

The figure on the next page shows model routes for the 24-KDD (sector 3) and the 18L-ARN (Sector 2) SIDs. For both SIDs, a buffer of 1,5 nautical mile is drawn in blue on both sides of the model route. As can be seen in the figure, the buffers of both SIDs do not overlap each other (except for the part close to/on the airport). This means that the 24-KDD and the 18L-ARN SIDs are theoretically separated from each other by means of 3 nautical miles. However, with the current SIDs being RNAV 1, an accuracy of 1 nautical mile needs to be considered. The doted lines indicate the buffers with an additional 1 nautical mile buffer. This shows that due to the accuracy of RNAV 1, aircraft could approach each other more closely.

In the current operation, S12 is sometimes applied for short timespans when the traffic mix under S23 is deemed to cause a to large imbalance between the two runways. Expert judgement and discussions with operational experts show that during the current usage of S12, a considerable part of air traffic controllers assess the situation with one aircraft on 24-KDD and one on 18L-ARN as being too close. This causes controllers to intervene (mostly by providing heading instructions to 24-KDD), which causes an increase in workload when S12 would be applied systematically.

A potential mitigation includes the improved accuracy of navigation (some RNP approaches are already 0.3Nm). This is however a long-term process which relies on the navigation capabilities of all aircraft visiting Schiphol. At the same time, it is also uncertain if this improved navigation will mitigate the human factors aspect that the controller perceives the aircraft to be too close to each other. A different mitigation would see an adjustment of the 24-KDD, making it divert more from the 18L SID. This would mean that the current radius fix at Leimuiden would have to be removed and be replaced by a heading of roughly 180. From a noise perspective this is not deemed feasible since this would direct traffic over Leimuiden, something the current radius fix is designed to avoid.

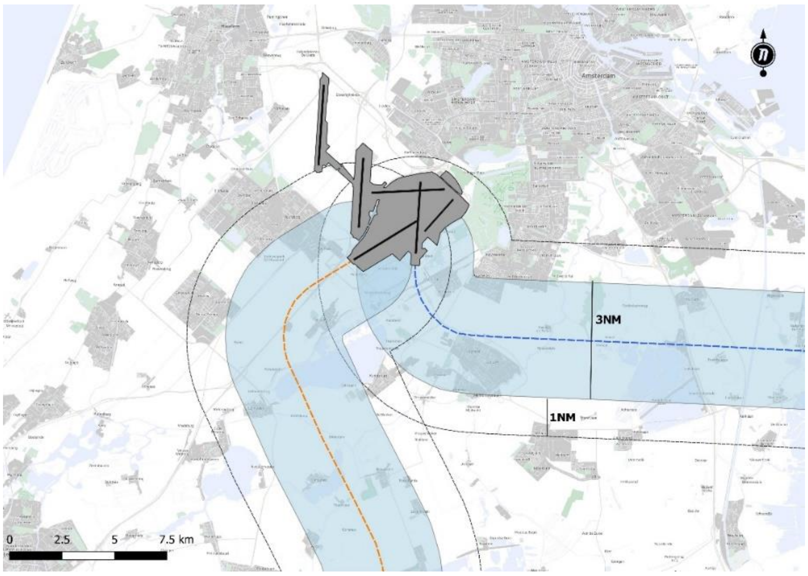


Figure 15: Comparison of 24-KDD and 18L-ARN SIDs including navigation uncertainty

A safety study should be carried out to further analyse these safety implications. Based on expert judgement it is expected that a positive safety case on this aspect will be complex but can be set up based on technical enablers and additional safety nets. This safety case would be based on the following elements:

- Certainty that a departure on 18L has selected a SID to sector 1 or 2 (SID confirmation). This could be achieved by downloading the selected SID from the FMS (See section 5.2).
- Additional safety nets through a No Transgression Zone (NTZ). NTZs are already applied for arrivals at Schiphol and can potentially also be applied for departures in this specific case.
- A warning in the AIP instructing 18L sectors 1 and 2 traffic to always turn before a defined point.

Separation between 24 LOP and 18L ARN

Besides the KDD SID, flights to sector 3 departing from runway 24 can also make use of the LOP SID. The figure underneath provides a comparison of the 24-LOP and 18L-ARN SIDs, similar to the previous figure. The overview of the SIDs including navigation uncertainty shows that the issue of separation is even more serious for 24-LOP and 18L-ARN compared to 24-KDD and 18L-ARN due to the 18L-LOP SIDs more south-eastern heading. Based on expert judgement and discussions with operational experts, it is assessed that no air traffic controllers, without further measures, would operate this combination as it is currently defined. The outlook for a safety study into this separation issue is therefore less positive compared to the safety case 24-KDD and 18L-ARN.

As a mitigating measure, the concept can be applied dynamic per peak. Currently, the usage of the LOP SID is limited due to the required availability of military airspace. Therefore, S12 could be applied in the peaks when the LOP SID is not used, and S23 when the LOP SID is used. This however limits the usage of the S12-South concept to weekdays between roughly 08:00 and 20:00. With the implementation of the DARP it is also expected that the LOP SID will be used more often, making the applicability of the S12 concept with this hybrid mitigation smaller.

As a mitigating measure, the 24-LOP SID can be adjusted, making it follow the 24-KDD SID longer, until there is no separation issue anymore, before turning south-east. This route change will cause local negative effects on the noise situation, making it a difficult mitigation in terms of acceptability/feasibility. This makes a final mitigation, dependent starts between 24-LOP and 18L traffic, more likely. This could however lead to some decrease in capacity.

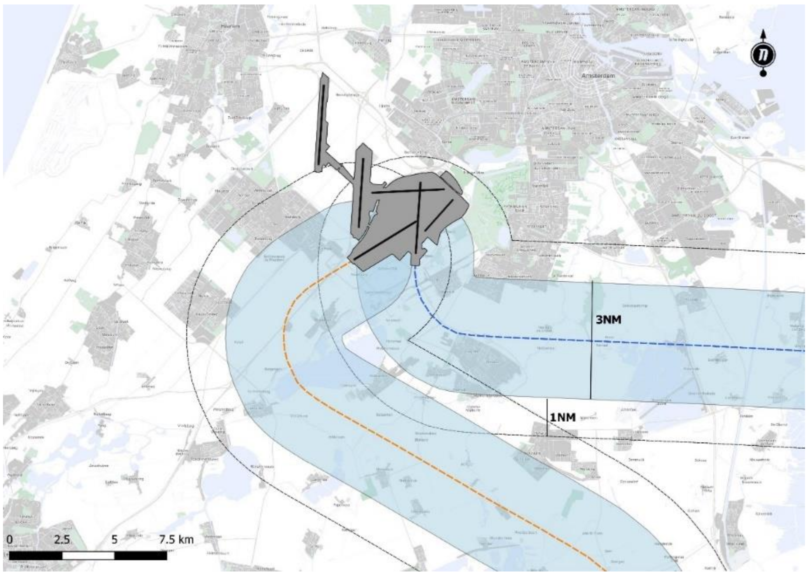


Figure 16: Comparison of 24-LOP and 18L-ARN SIDs including navigation uncertainty

Runway capacity

The S12-South concept aims to for flights in southern operation (departures from 24 and 18L) to sectors 1 and 2 (S12) to depart from the secondary runway instead of sectors 2 and 3 (S23) in the current operation. Traffic demand is not equally divided over the five departure sectors, making some busier than others.

This could cause the re-assignment of sectors to runways to result in a traffic demand which does not fit within the runways capacity.

To assess this potential issue, an analysis of rolling hour graphs has been conducted. For this analysis realised traffic of 2019 was used. Based on this data and the runway usage provided by LVNL, traffic within outbound peaks has been assigned to departure runways based on destination following either the current concept (sectors 1,4 and 5 on primary runway) or the S12-South concept (sectors 3,4 and 5 on primary runway). Based on the resulting traffic on the runways, rolling hour graphs are constructed per 10-minute bracket, considering the traffic in the past hour. Based on these graphs, per 10-minute block the number of days is counted in which the capacity of the runway exceeds 37 movements per hour. The resulting graphs are presented below for both runway 24 and runway 18L, comparing the current concept (in blue) with the S12-South concept (in orange). The analysis is a rough, indicative analysis since it does not consider changes in taxi time when changing sectors and it is based on the traffic of a single year.

The top graph, focusing on runway 24, shows that the S12-South concept causes the traffic demand for runway 24 to exceed the threshold of 37 movements per rolling hour during the morning outbound peak more often compared to the current concept. This is mainly due to the combination of sector 5 and 3 offering high traffic numbers in these hours. The current concept on the other hand causes the traffic demand for runway 24 to exceed the threshold of 37 movements per rolling hour more often in the evening compared to the S12-South concept. For runway 18L exceedances of the 37 movements mark occur mostly in the evening, with exceedances being quite similar between the concepts.

The graphs show exceedances of the threshold of 37 movements per rolling hour in both the current concept and the S12-South concept. The runway capacity is not a fixed but an average number, meaning that operating above 37 movements per hour can occur in the operation. The high number of days when runway 24 would operate above the 37 movements per hour during the S12-South concept however can indicate that from a runway capacity perspective the current concept is better fitted for this specific peak, while the S12-South concept is better suited for the other peaks. This would advocate for the dynamic usage of S12 or S23 per peak instead of a permanent change.

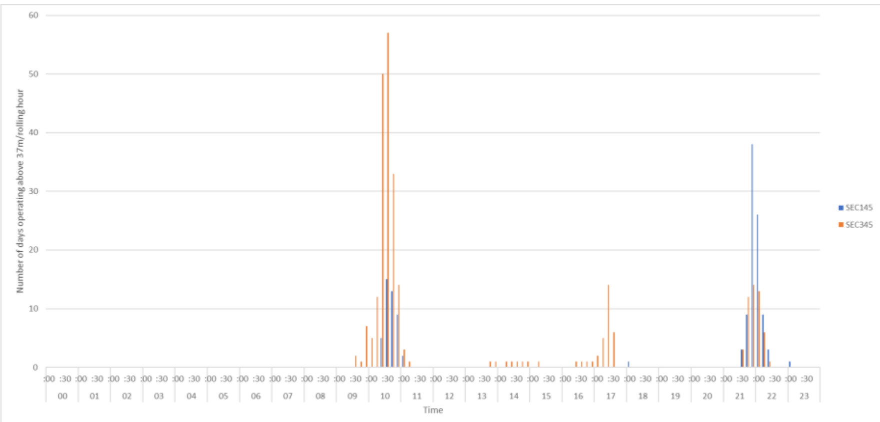


Figure 17: Number of days RWY 24 operates above 37 movements per rolling hour when operating sector 1, 4 and 5 compared to operating sectors 3, 4 and 5

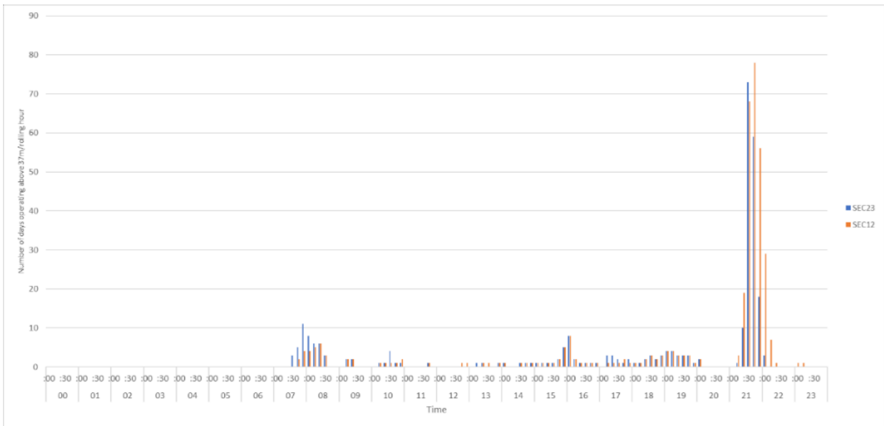


Figure 18: Number of days RWY 18L operates above 37 movements per rolling hour when operating sector 2 and 3 compared to operating sectors 1 and 2

<u>Dynamic usage within peaks</u>

As mentioned previously, S12 is in currently applied sometimes for short timespans when the traffic mix under S23 is deemed to cause a to large imbalance between the two runways. This is however done on a tactical basis, and not according to a clearly defined procedure. The dynamic usage of S12 or S23 per peak is not considered to be causing any additional feasibility issues compared to the static implementation. A procedure on choosing to apply S12 or S23 during an outbound peak in southern mode needs to be designed and implemented. This is comparable to current procedures on determining the runway combination for a peak period. Implementing such a procedure does mean that there is no global rule (S23 from secondary, rest from primary) for traffic segregation anymore which can be applied on all runway modes of operation.

Since SIDs to sector 1 and 3 from runways 24 and 18L lead to the same ATS-route, traffic can come into conflict with each other when the switch between S12 and S23 is made within a peak. This is only the case for the moment when the switch is made. For this moment, the first aircraft taking off to, for example, sector 3 from runway 24 will have to be timed against the last sector 3 aircraft taking off from runway 18L. The number of conflicts can therefore be limited, depending on the number of times a concept is changed within a peak. Even with a limited number of changes, the dynamic usage of S12 or S23 within a peak is expected to cause an increase in controller workload compared to the current concept. As a mitigation, technical support might assist the controller in timing traffic. This technical support is further discussed in paragraph 5.2. Due to its complexity, on top of the other issues already identified in this paragraph, the dynamic usage within a peak is considered less feasible compared to the static and dynamic between peaks approaches of the S12-south concept.

5.1.3 Sector 1/2 from secondary runway instead of sector 2/3 – northern operation (S12-NORTH)

Conclusion

The S12-North concept aims to operate flights in the northern operation (36L, 36C) to sectors 1 and 2 (S12) from the secondary runway instead of the current operation where departures to sectors 2 and 3 (S23) are operated from the secondary runway. Implementation can be achieved on different levels:

- Static: permanent change from S23 -> S12
- Dynamic per peak: based on traffic forecasts, usage of S12 or S23 is determined.
- Dynamic within peaks: based on real time traffic developments, usage of S12 or S23 is determined.

Through the feasibility analysis, it is concluded that static or dynamic per peak implementation of the S12-north concept is feasible when traffic is separated using fixed arrival routes and departure tubes. These enablers are part of the Dutch Airspace Redesign Project (DARP). Given this dependency the implementation horizon of the concept is assessed as long term. Just as is the case with the S12-South concept, the dynamic usage of S12 or S23 within a peak is assessed as being the least feasible of the three concepts due to workload associated with the operational complexity of configuration changes.

The conclusions above are based on a feasibility study focusing on the following aspects:

- Conflicts between departures and arrivals (south)west of Schiphol
- Fixed arrival routes and departure tubes
- Capacity primary runway
- Dynamic usage

The main analysis per aspect is discussed in the following sections.

<u>Conflicts between departures and arrivals (south)west of Schiphol</u>

As mentioned in the introduction of the concept, a new 36L sector 3 SID needs to be designed to enable to avoid SID crossings. Being limited by sector 1 and 2 departures from 36C to the east of 36L, the new 36L sector 3 SID needs to turn west, before turning south above the sea towards sector 3. The figure on the next page shows flightpaths from departing B772 on 36L to sector 4 (in blue) combined with flightpaths from arrivals to runway 06. In the current operation, these departures to sector 4 are a considerable workload for controllers due to the SUGOL arrivals to runway 06. Since arrivals are being vectored, they can occupy a large area at different altitudes.

The figure shows that the selected departures can fly over the arrivals when they are further (south-) west and therefore gained more altitude. For the new 36L sector 3 SID, the SID is expected to turn south/southwest towards sector 3. Based on expert judgement it is not expected that this new SID can be designed separated from the vectored arrival traffic. This would require additional instructions to both the arrivals and the departures, causing an unacceptable increase in workload.

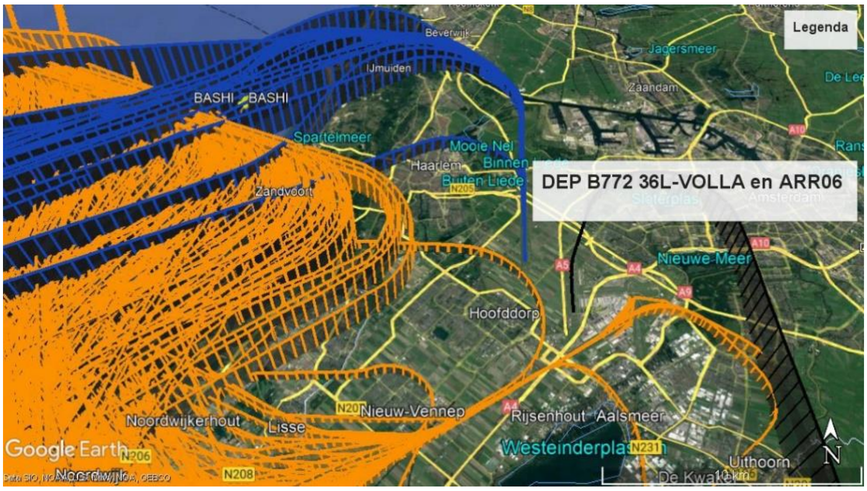


Figure 19: Example of aircraft departing west from runway 36L compared to arrivals to runway 06

Apart from conflicts with SUGOL arrivals, if the new 36L sector 3 SID follows the coastline further South-west it will come into conflict with the arrivals from RIVER. RIVER is located around the maasvlakte near Rotterdam. Since aircraft can hold at RIVER in a stack, a considerable area around the IAF should be avoided. This requires the 36L sector 3 SID to turn inland again after gaining altitude above the sea, avoiding RIVER, and flying a south-east course towards the current sector 3 SIDs. With this route the departures climb over arrivals to runway 06. When flights from RIVER are also vectored to runway 36R, this could potentially cause conflicts with departures on the new 36L sector 3 SID.

Fixed arrival routes and departure tubes

An enabler for this concept can be found in fixed arrival routes and departure tubes, which are some of the key features of the DARP. Fixed arrival routes for arrival aircraft from SUGOL (mainly to RWY 06), in combination with a 3D separated SIDs from 36L to sector 3, would keep aircraft separated from each other by design. Based on expert judgment it is expected that this combination of enablers would allow a conflict free flow of inbound and outbound flights west of Schiphol. This does make the concept dependent on the DARP. The design and implementation of fixed arrival routes and departure tubes are complex tasks, on which development is currently ongoing. The exact designs of the airspace redesign are unknown at the moment. It is also not expected that designs currently include a sector 3 SID west of the airport.

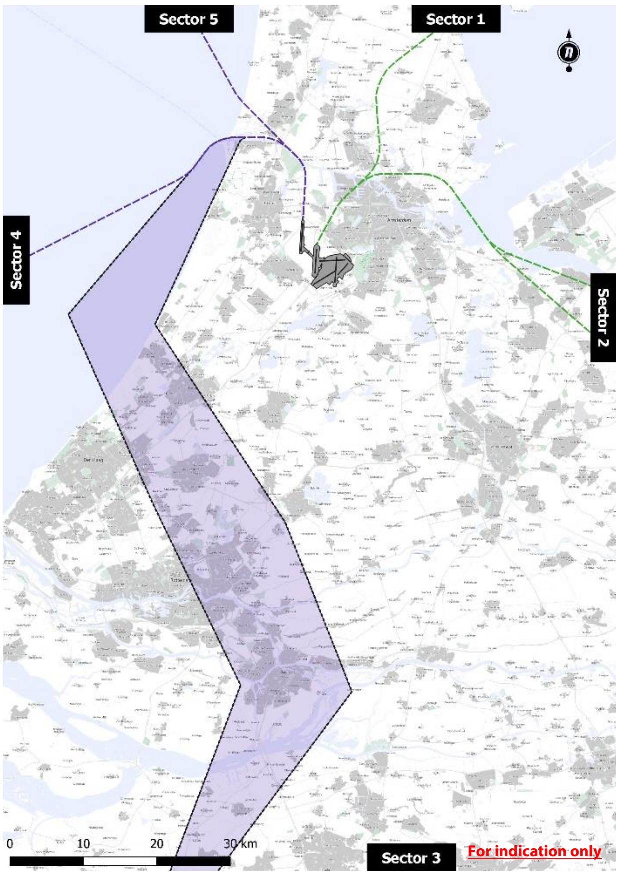


Figure 20: Adjusted indicative location for a new 36L SID, avoiding RIVER

<u>Capacity primary runway</u>

The S12-North concept aims to for flights in northern operation (departures from 36L and 36C) to sectors 1 and 2 (S12) to depart from the secondary runway instead of sectors 2 and 3 (S23) in the current operation. Traffic demand is not equally divided over the five departure sectors, making some busier than others. This could cause the re-assignment of sectors to runways to result in a traffic demand which does not fit within the runways capacity. Therefore, similar to the analysis for the S12-South concept, an analysis of rolling hour graphs has been conducted. The resulting graphs are presented below for both runway 36L and runway 36C, comparing the current concept (in blue) with the S12-North concept (in orange).

The graphs show exceedances of the threshold of 37 movements per rolling hour in both the current concept as the S12-South concept for both 36L and 36C. Overall, the graphs show a quite comparable number of days with the threshold of 37 movements per rolling hour being exceeded. A noticeable difference is the evening, where with the S12-North concept the number of exceedances on 36L decrease while they increase on 36C. This is due to the high volume of sector 1 traffic during this outbound peak.

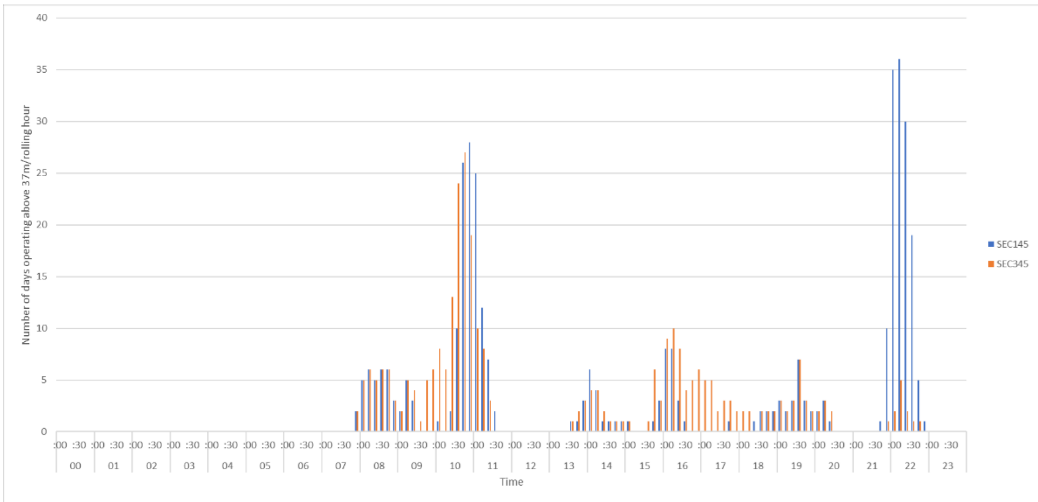


Figure 21: Number of days RWY 36L operates above 37 movements per rolling hour when operating sector 1,4 and 5 compared to operating sectors 3,4 and 5

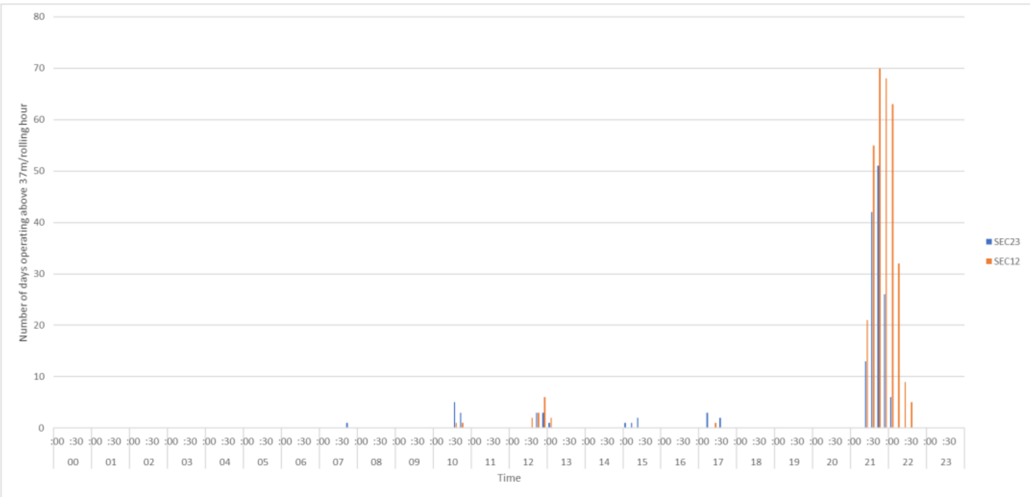


Figure 22: Number of days RWY 18L operates above 37 movements per rolling hour when operating sector 2 and 3 compared to operating sectors 1 and 2

<u>Dynamic usage within peaks</u>

Since the exceedance discussed in the previous section happen both in the current concept as well as the S12-North concept, this advocates more towards a static implementation. As mentioned before however, the analysis is a rough, indicative analysis since it is based on the traffic of a single year. With the analysis being a single year, the figures can change from year to year. As seen with the S12-South concept, dynamic per peak usage may be beneficial when traffic per sector results in a traffic demand which does not fit within the runways capacity.

Just as with the S12-south concept, the dynamic usage of S12 or S23 per peak in the S12-North concept is not considered to be causing any additional feasibility issues compared to the static implementation. A procedure on choosing to apply S12 or S23 during an outbound peak in northern mode needs to be designed and implemented. This is comparable to current procedures on determining the runway combination for a peak period. Implementing such a procedure does mean that there is no global rule (S23 from secondary, rest from primary) for traffic segregation anymore which can be applied on all runway modes of operation.

The dynamic usage of S12 or S23 within a peak is expected to cause an increase in controller workload compared to the current concept. This is mainly due to traffic to sector 1 which can cause a conflict when switching sectors. As a mitigation, technical support might assist the controller in timing traffic. This technical support is further discussed in paragraph 5.2. Due to its complexity, the dynamic usage within a peak is considered less feasible compared to the static and dynamic between peaks approaches of the S12-North concept.

5.1.4 Sector 1/2 from secondary runway, with dual SID usage sector 2– southern operation (S12-SOUTH-DUAL)

Conclusion

The S12-SOUTH-DUAL concept aims for dual-SID usage to sector 2, operating sector 2 from both the primary runway 24 as well as the secondary runway 18L. Through the feasibility analysis, it cannot be concluded if the S12-South-Dual concept is feasible. The concept depends on multiple other developments (S12-south concept and DARP), which are not all certain. At the same time there are limitations in the operation (a flight's handover point should be considered when assigning traffic to the runways) and future developments (4th IAF) might limit the feasibility of the concept. Besides these developments, the complexity of the concept requires further fast time simulation or real time simulation to study the flow of traffic and its effects on workload in more detail. Given its dependencies the implementation horizon of the concept, if it is deemed feasible after further research, is assessed as long term.

The conclusions above are based on a feasibility study focusing on the following aspects:

- New SID through TMA-D
- Dependency with S12-South
- Separation in ACC
- Fourth initial approach fix and changing exit points

The main analysis per aspect is discussed in the following sections.

<u>New SID through TMA-D</u>

Introduction of a dual SID to sector 2 requires the 24 sector 2 SID to run in parallel with the sector 2 SID of 18L. Moving the 24 SID to the south is favored above moving the 18L to the north due to the high number of dwellings located north of the 18L SID (Amsterdam region). Currently a permanent southern 24 SID to sector 2 is not possible since it would go through TMA D, which is military airspace. As shown in the figure on the next page, the current 24 sector 2 SID turns north-east to avoid the TMA D. When TMA D is available for commercial traffic however, sector two flights already fly straight through the TMA (indicated by the green tracks in the figure).

As part of the Dutch Aerospace Redesign Program (DARP), TMA D is opened for civil usage permanently. This allows for the design of the required SID from runway 24 to the east. This makes the DARP an enabler for the S12-SOUTH-DUAL concept. The figure on the next page provides an initial concept of such a SID, connecting runway 24 with the two main handover points in the east (SONEB and NAPRO). The location of the SID is indicative and will change due to design factors. These factors also include considering the location where handoffs usually happen. The new SID will have a local negative effect on the noise situation, this will be at locations further away from the airport.

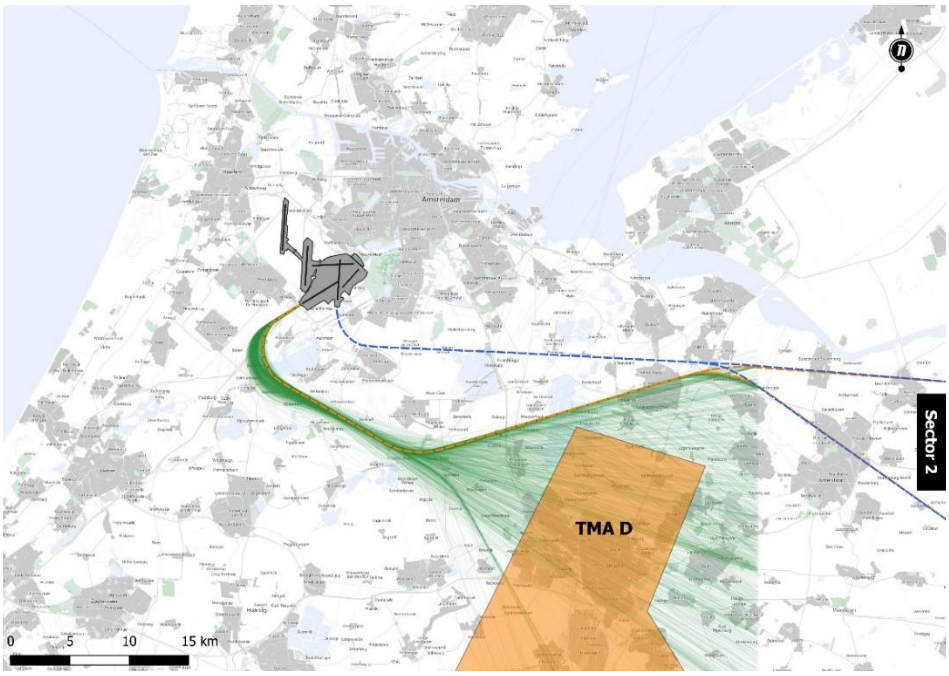


Figure 23: Current SIDs to sector 2 from runway 24 and 18L, avoiding TMA-D

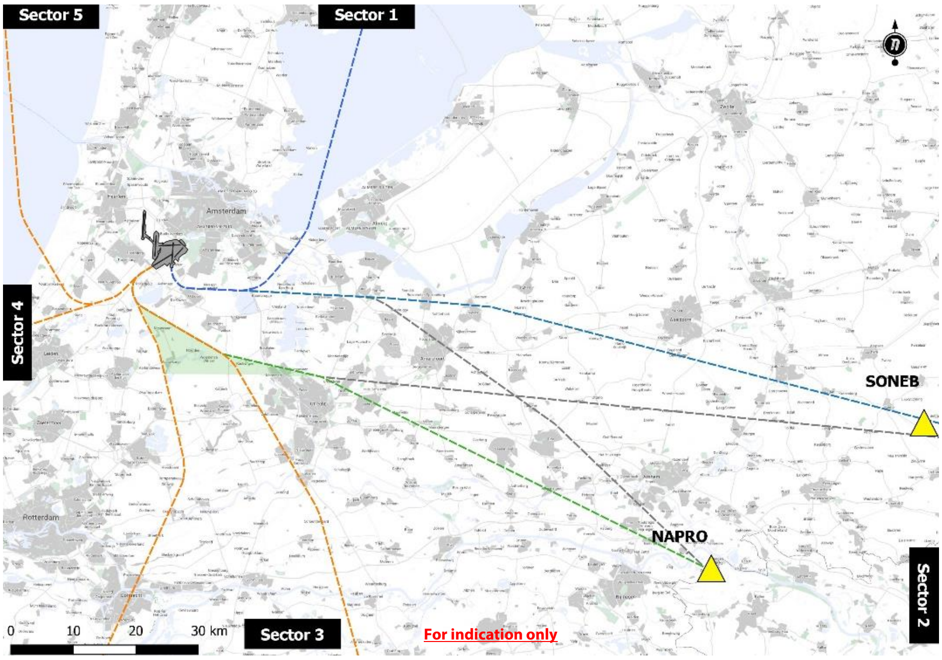


Figure 24: Dual SID sector 2 from runway 24 and 18L

Dependency with S12-South concept

As mentioned in the introduction of the concept, implementation depends on the S12-South concept. In the current operation, sector 3 is operated from 18L, which would conflict with sector 2 traffic being operated from runway 24. The S12-concept, operating sector 1 and 2 from 18L, creates room to operate sector 2 from both the primary runway 24 as well as the secondary 18L runway. This however means that the implementation the S12-South-Dual concept depends on a positive outcome of the safety study carried out for the S12-South concept and a mitigation of the 24-LOP separation issue. In the current figure the SID to sector 2 (in green) follows the 24-LOP SID (in orange), creating a separation issue with the 18L-ARN/AND SIDs as discussed in the S12-South concept. A potential mitigation, which would help the implementation of this concept, would be to adjust the SID to sector 2 and the 24-LOP SID towards the south, as indicated by the green area in the figure. Moving the SIDs would make the operation between runway 24 and 18L independent. When dependencies are kept in place, the effectiveness of the concept is expected to be considerably lower due to timing of departures.

Separation in ACC

To have the concept achieve the maximum positive effect on capacity and noise, flights from the secondary runway are moved to the primary runway whenever there is capacity available on the primary runway. Given that the separation issues mentioned above are mitigated, the flights from runway 24 and 18L to sector 2 are by SID design separated from each other when handed over to ACC. Sector two however consists of two exit points, being SONEB (ARN SID) and NAPRO (REN SID). ACC would guide aircraft to their required exit point.

This could however require aircraft from the two runways to sector 2 to be merged when going to the same exit point or to cross each other when going to opposite exit points. Aircraft would have to be separated by keeping them parallel, keeping them at different altitudes or by merging them behind each other. This practice is not uncommon in ACC, this for example also occurs with RTM departures towards the east. Within ACC there is also more flexibility due to the larger available airspace to handle these conflicts compared to within the TMA. With two sector 2 streams in sector 2, the available airspace however becomes more limited. This could limit the flexibility to handle these conflicts, while also leading to a lower capacity on non-nominal operations, since there is less airspace to manoeuvre in.

From a workload perspective of ACC however, traffic streams to the two exit points would be separated completely by segregating the traffic. This would mean that gaps in the capacity of the primary runway 24 would be filled with as many flights to exit point NAPRO as possible. At the same time, the secondary runway 18L would operate all SONEB traffic, and as minimal as possible NAPRO traffic which could not be placed on the primary runway. Apart from some merges between 18L NAPRO traffic and 24 NAPRO traffic, this would limit occurrences that require coordination. In the end, this could lead to splitting sector 2 into two separate sectors. This does however limit the moving of traffic to the primary runway to only a subsection of the sector 2 traffic. The performance case will go further into these numbers.

If this separation of Schiphol sector 2 is achieved, coordination with other traffic such as Rotterdam and Dusseldorf departures/arrival will remain. And, although the opening of Lelystad Airport is uncertain at the moment, opening of this airport could also lead to more traffic in sector 2.

Currently, having only one runway operating flights to sector 2 limits the flow of SPL traffic to sector 2 to the number of flights which can take off from one runway. When a second runway is used to operate flights to sector 2, more flights can take-off to sector 2 within a specific timeframe and delay is expected to decrease. This can however cause the number of flights within a specific timeframe to sector 2 to increase, with potential consequences for the workload. The number of flights in ACC is capped by a declared capacity to avoid workload issues. It is therefore expected that flights cannot move to the primary runway unrestricted whenever there is a gap in capacity at the airport, this will also depend on the resulting workload in sector 2.

Fourth initial approach fix and changing exit points
As part of the DARP, a fourth initial approach fix (IAF) will be established in the south-east of the Netherlands. Potentially, the introduction of the 4th IAF will not go together with the new runway 24 SID to sector 2 due to increases in workload or safety issues from new conflicting crossings between S2 outbounds and inbounds from the 4th IAF. Besides implementation of the 4th IAF, the DARP can also cause changes in the location and the number of exit points in sector 2. With the DARP still in process, it is currently unclear where what the final situation after implementation of the DARP will be in the south-east of the Netherlands. It is therefore also not possible to further assess the relationship between the concept and the DARP.

5.1.5 Dual SID usage sector 2 – northern operation (S2-DUAL-NORTH)

Conclusion

The S2-NORTH-DUAL concept aims for dual-SID usage to sector 2, operating sector 2 from both the primary runway 36L as well as the secondary runway 36C. The concept is therefore comparable to the S12-South-Dual concept. Similar to this concept, it cannot be concluded if the S2-NORTH-DUAL concept is in the end feasible. The concept is not dependent on the DARP, but its SID adjustments are more complex compared to the S12-South-Dual concept. There are also limitations in the operation (preferred separation of NAPRO and SONEB traffic) and future developments (4th IAF and exitpoints) which might limit the feasibility of the concept. The complexity of the concept requires further fast time simulation or real time simulation to study the flow of traffic and its effects on workload in more detail. Given the required further research and adjustments of SIDs the implementation horizon of the concept is assessed as long term.

The conclusions above are based on a feasibility study focusing on the following aspects:

- New Sector 2 SIDs from 36L
- Separation in ACC
- Fourth initial approach fix and changing exit points

The main analysis per aspect is discussed in the following sections.

<u>New Sector 2 SIDs from 36L</u>

During phase 1 multiple adjustments of sector 2 SIDs from runway 36L and 36C were proposed to enable dual SIDs to sector 2. Together with to70 experts these rough sketches have been worked out further. Based on the sketches and description of the options, keeping 36L parallel to 36C seems preferable since it avoids conflicts with ARTIP and does not force 36C SIDs over Amsterdam.

Further development of this concept, considering 3 nautical miles of separation, 1 nautical mile of navigation inaccuracy and the rules for independent parallel departures, leads to the concept shown in the figure on the next page. Keeping 36L parallel to 36C is not possible since it results in the SIDs converging at some locations. The 36L SID is therefore adjusted, following the sector 1 SID longer before turning east and south-east. Adjustments of this SID is expected to cause local negative effects on noise in locations further away from the airport. The longer common path of the sector 2 and the sector 1 SIDs from 36L can also have a negative effect on capacity.

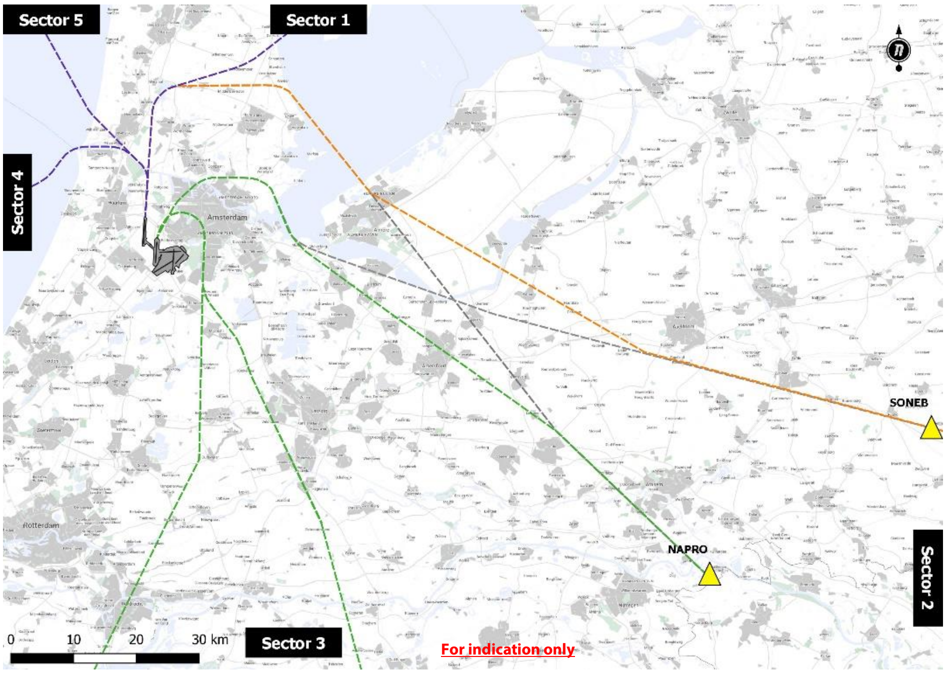


Figure 25: Dual SID sector 2 from runway 36L and 36C

The figure underneath compares the altitudes of departures to sector 2 from runway 36C with arrivals from ARTIP around Almere. The figure shows that within the selected data, close to all departures climb over the arrivals without conflicts. Since the new SID from 36L has more trackmiles, traffic is expected to be higher compared to the tracks in the figure. Specific slow climbers can cause a conflict and might require vectors. This is also the case in the current situation, but since in the DUAL SID concept the two SID's are parallel, the available space for providing vectors is more limited.

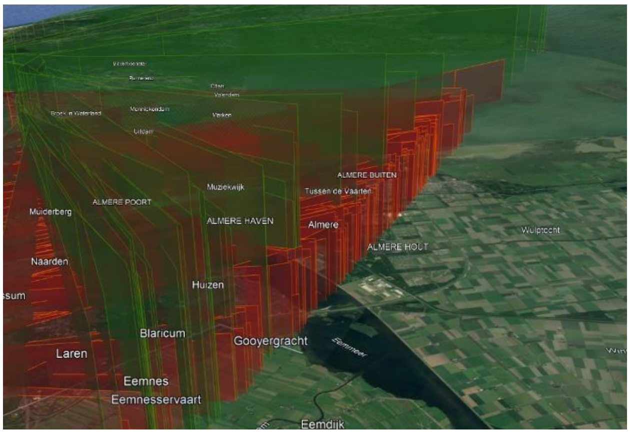


Figure 26: Comparison of altitude between sector 2 departures 36C and arrivals from ARTIP

The DUAL SID concept introduces two new SIDs from 36L to sector 2. Potentially, this could lead to there being 6 different 36L sector 2 SIDs: two form DUAL SID usage, two for when 36L is the only departure runway (current day SIDs) and two for the night (current night SIDs). To avoid SID blunders, the naming of the different SIDs requires specific attention. Using the same SIDs for DUAL SID as for nighttime can be further examined to keep the number of SIDs on the same level as the current concept.

Separation in ACC

The analysis regarding the separation in ACC is comparable for both dual SID concepts to sector 2. To have the concept achieve the maximum positive effect on capacity and noise, flights from the secondary runway are moved to the primary runway whenever there is capacity available on the primary runway. Sector 2 however consists of two exit points: SONEB and NAPRO. ACC would guide aircraft to their exit point depending on destination. This could require aircraft from the two runways to sector 2 to be merged when going to the same exit point or to cross each other when going to opposite exits. Aircraft would have to be separated by keeping them parallel, keeping them at different altitudes or by merging them behind each other. This practice is not uncommon in ACC, this for example also occurs with RTM departures towards the east. Within ACC there is also more flexibility to handle these conflicts due to the larger available airspace compared to within the TMA. With two sector 2 streams in sector 2, the available airspace however becomes more limited. This could limit the flexibility to handle these conflicts, while also leading to a lower capacity on non-nominal operations, since there is less airspace to manoeuvre in.

From a workload perspective of ACC however, traffic streams to the two exit points would be separated completely by segregating the traffic. This would mean that gaps in the capacity of the primary runway 36L would be filled with as many flights to exit point SONEB as possible. At the same time, the secondary runway 36C would operate all NAPRO traffic, and the SONEB traffic which cannot be placed on the primary runway. Apart from some merges between 36C SONEB traffic and 36L SONEB traffic, this would limit the amount of coordination needed. This does however limit the usage of the concept to only a subsection of the sector 2 traffic. The performance case will go further into these numbers. If this separation of Schiphol sector 2 is achieved, coordination with other traffic such as Rotterdam and Dusseldorf departures/arrival will remain. And, although the opening of Lelystad Airport is uncertain at the moment, opening of this airport could also lead to more traffic in sector 2 and above the Flevopolder.

Currently, having only one runway operating flights to sector 2 limits the flow of SPL traffic to sector 2 to the number of flights which can take off from one runway. When a second runway is used to operate flights to sector 2, more flights can potentially take-off to sector 2 within a specific timeframe and delay is expected to decrease. This can however cause the number of flights within a specific timeframe to sector 2 to increase, with potential consequences for the workload. The number of flights in ACC is capped by a declared capacity to avoid workload issues. It is therefore expected that flights cannot move to the primary runway unrestricted whenever there is a gap in capacity at the airport, this also depends on the current workload in sector 2. Simulations should provide further detailed insights on the number of flights which can take off towards sector 2 in a dual SID concept and its effects on workload.

Fourth initial approach fix and changing exit points

As part of the DARP, a fourth initial approach fix (IAF) will be established in the south-east of the Netherlands. Potentially, the introduction of the 4th IAF will not go together with the new runway 24 SID to sector 2 due to increases in workload or safety issues. Besides implementation of the 4th IAF, the DARP can also cause changes in the location and the number of exit points in sector 2. With the DARP still in process, it is currently unclear where what the final situation after implementation of the DARP will be in the south-east of the Netherlands. It is therefore also not possible to further assess the relationship between the concept and the DARP.

5.1.6 Dual SID usage sector 3 – southern operation - LOPIK (S3-DUAL-SOUTH-LOP)

Conclusion

The S3-Dual-South-LOP concept aims for flights to sector 3 to be handled from both the primary (runway 24 via the Kudad SID) and the secondary runway (runway 18L via the Lopik SID) when in southern mode. Through the feasibility analysis, it is concluded that the concept is feasible in the long term when several conditions are met:

- The Lopik SID becomes available permanently as part of the DARP.
- Separation between the two SIDs is guaranteed, either by adjustments to the SID or by improved accuracy of navigation.
- The concept is applied mostly for moving departures with a destination in the south-west to the primary runway.
- Other concepts which interfere with this concept (S12-South, S12-South-Dual) are not implemented

The conclusions above are based on a feasibility study focusing on the following aspects:

- Permanent usage of Lopik SID
- Separation 24-Kudad and 18L-Lopik
- Connection to ATS routes

The main analysis per aspect is discussed in the following sections.

<u>Permanent usage of Lopik SID</u>

In the current operation, the Lopik SID is only used during the weekends or evenings, when the TMA-D (military airspace) is available for civil usage. As part of the Dutch Aerospace Redesign Program (DARP), TMA D is opened up for civil usage permanently, allowing Lopik to be used permanently. This makes the DARP an enabler for the S3-Dual-South-LOP concept.

<u>Separation 24-Kudad and 18L-Lopik</u>

The figure on the next page shows model routes for the 24-KDD (sector 3) and the 18L-LOP (Sector 3) SIDs. For both SIDs, a buffer of 1.5 nautical mile is drawn in blue on both sides of the model route. As can be seen in the figure, the buffers of both SIDs touch each other near the town of Zevenhoven. This means that the SIDs are separated 3 nautical miles from each other at this point, meaning the SIDs are theoretically separated from each other by 3 nautical miles. However, with the current SIDs being RNAV 1, an accuracy of 1 nautical mile needs to be considered. The dotted lines indicate the buffers with an additional 1 nautical mile buffer. This shows that due to the accuracy of RNAV 1, aircraft could approach each other more closely causing a loss in separation. Besides this loss in separation, the two SIDs are also on a converging course which could trigger TCAS warnings.

A potential mitigation would see an adjustment of the SIDs to increase separation and adjust the courses in such a way that the SIDs do not converge. This would probably require both SIDs to be adjusted, with the Kudad SID moving west and the Lopik SID moving east. Adjusting the SIDs would move the SIDs towards more populated areas such as Alphen aan den Rijn and Mijdrecht (and Uithoorn if the Lopik SID needs to be adjusted earlier). Current and past route optimization project have shown that such route changes with local negative effects are difficult to realise.

Alternatively, a potential mitigation can be the improved accuracy of navigation (some RNP approaches are already 0.3Nm). This is a long-term process which relies on the navigation capabilities of all aircraft visiting Schiphol. At the same time, it is also uncertain if this improved navigation will mitigate the human factors aspect that the controller perceives the aircraft to be too close to each other. With improved navigation, the converging course could still trigger TCAS warnings. Further research should analyse the chance of a TCAS warning with improved navigation.

<u>Connection to ATS routes</u>

Although flights on the Lopik SID and the Kudad SID both depart towards sector 3 they have different exit points, being WOODY (Kudad SID) and LUTOM (Lopik SID). In terms of workload for ACC this is a positive aspect of this concept since flights don't have to be merged or separated before the exit point.

In the dual SID concept, sector 3 departures would by default depart from 18L (via the Lopik SID). Sector 3 flights are only moved to the primary runway (and the Kudad SID) when there is a gap in capacity on the primary runway. Due to the structure of ATS routes south of the Netherlands, a flight with a south-western destination (for example Spain) would be more efficient in terms of track miles exiting via WOODY compared to LUTOM, while LUTOM is more efficient for destinations in Switzerland/Italy. This could cause an increase in track miles when south-western destinations have to depart from the secondary runway. At the same time, it is not preferable for track miles to move destinations in Switzerland/Italy to the primary runway. Having two exit points therefore is preferred in terms of workload but puts limitations on the number of flights which can be moved to the primary runway. This is further discussed in the performance case.

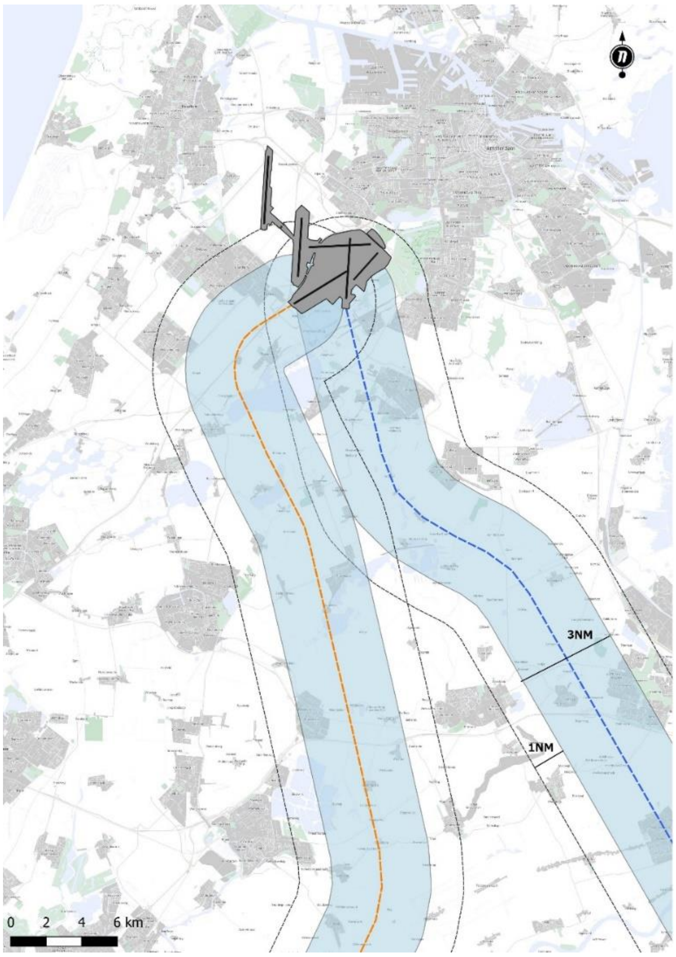


Figure 27: Comparison of 24-KDD and 18L-LOP SIDs including navigation uncertainty

5.1.7 Dual SID usage sector 3 – northern operation (S3-DUAL-NORTH)

Conclusion

The S3-Dual-North concept aims for flights to sector 3 to be handled from both the primary (runway 36L via a new Kudad SID) and the secondary runway (runway 36C via the Kudad SID) when in northern mode. Through the feasibility analysis, it is concluded that the S3-Dual North concept is not feasible due to the capacity limitations in sector 3 and the amount of traffic streams already presiding in sector 3.

The conclusions above are based on a feasibility study focusing on the following aspects:

- Dependency on fixed arrival routes and departure tubes
- Merging traffic at WOODY
- Sector 3

The main analysis per aspect is discussed in the following sections.

Dependency on fixed arrival routes and departure tubes

Just as the S12-North concept, the S3-Dual-North concept depends on a new 36L sector 3 SID. As discussed in the analysis of the S12-North concept, an enabler for this SID can be found in fixed arrival routes and departure tubes, which are some of the key features of the DARP. Fixed arrival routes for arrival aircraft from SUGOL (mainly to RWY 06), in combination with a 3D separated SIDs from 36L to sector 3, would keep aircraft separated from each other by design. Based on expert judgment it is expected that this combination of enablers would allow a conflict free flow of inbound and outbound flights west of Schiphol. This does make the concept dependent on the DARP. The design and implementation of fixed arrival routes and departure tubes are complex tasks, on which development is currently ongoing. The exact designs of the airspace redesign are unknown at the moment. It is also not expected that designs currently include a sector 3 SID west of the airport.

Merging traffic at WOODY

To have the concept achieve the maximum positive effect on capacity and noise, flights from the secondary runway are moved to the primary runway whenever there is capacity available on the primary runway. When the new Kudad SID from 36L is designed turning left, the flights from runway 36L and 36C to sector 3 are separated from each other when handed over to ACC. ACC would guide aircraft to their required exit point, which for sector 3 is only one point, being WOODY. Since there is only one exit point, aircraft from the two runways to sector 3 have to be coordinated by ACC to WOODY without causing conflicts. Aircraft would have to be separated by keeping them parallel, keeping them at different altitudes or by merging them behind each other. This practice is not uncommon in ACC, this for example also occurs with RTM and EIN departures. Within ACC there is also more flexibility to handle these conflicts due to the larger available airspace compared to within the TMA.

Sector 3

When discussing Dual SID usage towards sector 3 it is important to note that sector 3 is the busiest sector within the LVNL operation due to the different kinds of traffic taking place in the sector (traffic to/from Amsterdam, Rotterdam, Eindhoven, and Brussels). Airspace around WOODY is however more limited compared to S2. Arrivals to Brussels and Amsterdam in combination with military airspace makes keeping flights parallel to each other limited for example. In the past, discussions have been held to create an additional exit point in sector 3, which would provide more maneuvering space in sector 3. This additional exit point until now has not been realized due to airspace limitations in Belgium's airspace. In 2019 LVNL has adjusted operational systems[1] to better monitor traffic and make decisions on the deployment of personnel. After discussions with operational experts, it is however concluded that, with the current amount of traffic in sector 3, additional traffic flows such as this DUAL SID concept cannot be accommodated.

[1] https://www.lvnl.nl/over-lvnl/samen-luchtvaart-mogelijk-maken/verbeteringen-zuidelijke-sector

5.1.8 Dual SID usage sector 3 – southern operation – KUDAD (S3-DUAL-SOUTH-KDD)

Conclusion

The S3-Dual-South-KDD concept aims for flights to sector 3 to be handled from both the primary (runway 24 via a new to be designed Kudad SID) and the secondary runway (runway 18L via the current Kudad SID) when in southern mode. Through the feasibility analysis, it is concluded that the S3-DUAL-SOUTH-KDD concept is not feasible due to the capacity limitations in sector 3 and the amount of traffic streams already presiding in sector 3. Implementation is also unlikely due to the expected effects on noise.

The main analysis regarding merging traffic at WOODY and Sector 3 are the same for S3-Dual-South-KDD as for the S3-Dual-North concept, being:

- Since there is only one exit point, aircraft would have to be separated by keeping them parallel, keeping them at different altitudes or by merging them behind each other.
- Sector 3 is the busiest sector within the LVNL operation. After discussions with operational experts, it is however concluded that, with the current amount of traffic in sector 3, additional traffic flows such as this DUAL SID concept cannot be accommodated.

Additionally, the conclusions above are based on a feasibility study focusing on the negative effects on the noise situation.

Negative effects on noise situation

The concept requires a new Kudad SID to be designed. Phase 1 provided an indicative location for such a new Kudad SID, which would make the KUDAD SIDs from runway 24 and 18L independent. The figure underneath shows the current flightpaths (orange and blue) combined with the 48 dB contour of the EIA Schiphol 2020 and the proposed new Kudad SID. The figure shows that there are currently no SIDs in the area where the new Kudad SID is projected. Therefore, noise levels in this area are relatively low. With the new SID, noise levels at these locations will increase. Opposition to the new SID is therefore expected to be substantial, making its implementation from a community engagement perspective unlikely. In terms of noise, the S3-Dual-North concept performs better since a large part of the climb-out for sector 3 traffic from 36L is performed over the ocean before heading inland.

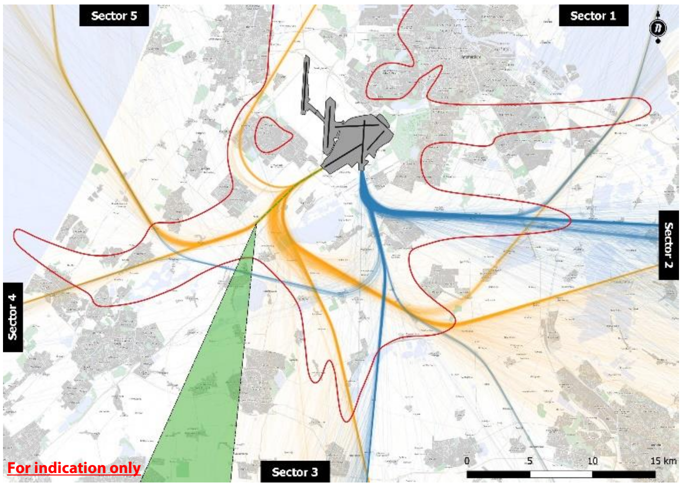


Figure 28: Overview of flight tracks, noise contour and new Kudad SID

5.1.9 Merging flights from two runways to the same exit point (TRAF-MERGE)

Conclusion
With outbound traffic merging, spacing between aircraft is predicted and used to time aircraft take-off in order to merge aircraft from two SIDs within the TMA on to one common SID. Through the feasibility analysis, it cannot be concluded if the concept is feasible. TBO provides several enablers which can support the timing of departures on mering SIDs. It is however unsure if the operation in its complexity is predictable enough to adhere to this required timing. The complexity of the concept requires further fast time simulation or real time simulation to study the timing of traffic and its effects on workload and capacity. Given the required further research and technical enablers the implementation horizon of the concept is assessed as long term.

The conclusions above are based on a feasibility study focusing on the following aspects:

- Merging within the TMA
- Supporting systems for merging traffic
- Complexity in the operation

The main analysis per aspect is discussed in the following sections.

Merging within the TMA
In the current SID design, there are several SIDs which would merge if they were used at the same time: 24 and 18L traffic to sector 2, 24 and 18L traffic to sector 3, 36L and 36C traffic to sector 2 and 36L and 36C traffic to sector 1. With the current sector assignment, outbound traffic merging would be an option for runway 24 and 18L traffic to sector 3 and runway 36L and 36C traffic to sector 2, without causing a conflict with other SIDs. When sectors 1 and 2 are operated from the secondary runways (S12), 24 and 18L traffic to sector 2, and 36L and 36C traffic to sector 1 can be operated without causing a conflict with other SIDs.

The map on the next page shows the merge locations for the current operation. In both northern and southern operation, the merging SIDs start converging a couple of kilometres after take-off and eventually merge. A key aspect in this concept is the timing of the merge. When timed correctly, the converging and eventual merging of the SIDs does not cause any conflicts between aircraft on the SID. The next section will go further into this timing.

The Dual SID concepts, discussed previously, merge traffic to the same sector, if needed, outside of the TMA. Inside the TMA, for Dual SID concepts traffic is separated by new to be designed SIDs. The traffic merge concept merges all traffic to the same sector within the TMA, using the current SID design. A large advantage of using the current SID design is that no new areas are exposed to noise, making implementation from a community engagement perspective more likely.

Currently, when a departure is clear of other traffic, it is handed over to ACC. With a merge occurring within the TMA, it is expected that controllers will not hand over a flight to ACC before they can confirm the merge has taken place and separation is maintained. This later handover can cause ACC to have less time to plan and manoeuvre flights.

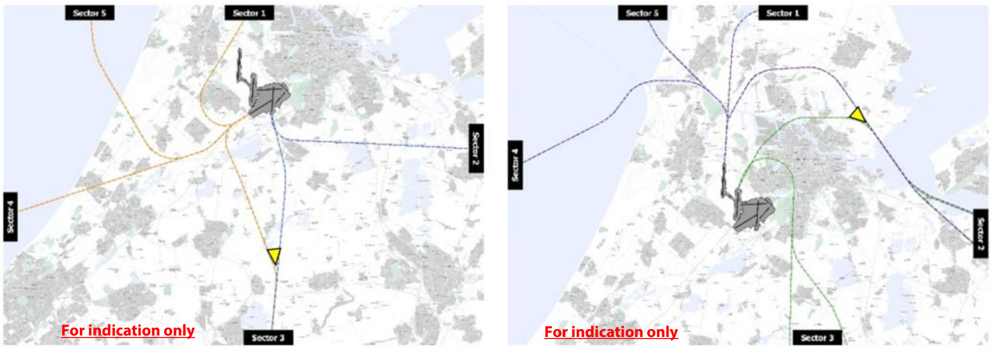


Figure 29: Merge points for northern and southern operation with current runway-sector assignment

Supporting systems for merging traffic

The effectiveness for this concept is dependent on the availability of flights to the right sector at the runway at the right time. An advanced outbound planner can support in making such an outbound planning. The outbound planner needs to identify aircraft in the initial sequence of departures which can be moved to gaps on the primary runway. An example of such a sequence is shown in the figure underneath.

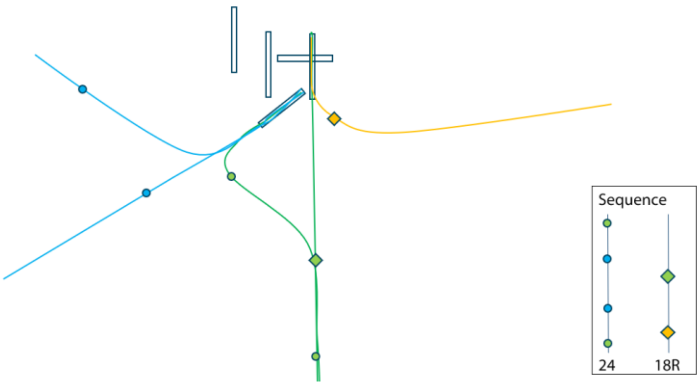


Figure 30: Example of an outbound sequence with merging traffic

Uncertainty in to the two aircraft's performance makes it difficult for controllers to time merges as foreseen in this concept. Without changes to the supporting systems, enabling a merge would require controllers to apply large buffer times between aircraft to the same sector in order to ensure a conflict-free merge within TMA. These large buffer times will have a negative impact on capacity. Decreasing the buffer times, and therefore the negative effects on capacity, can be achieved if the uncertainty is decreased. Two technical enablers, part of the Trajectory Based Operations concept, are required to provide this support (Section 5.2):

- Departure timing based on on-line trajectory prediction from stop bar.
- On-line monitoring of projected in-trail spacing using trajectory prediction.

These supporting tools can help in facilitating the work of TWR/APP controllers when it comes to timing and monitoring merging departures. The task for the TWR/APP controllers however becomes more extensive in this concept where conflicts are more time-based compared to the current concept in which the traffic on the SIDs is conflict-free based on spatial distance.

<u>Complexity of the operation</u>

The outbound planner, on-line trajectory prediction and on-line monitoring support determining which flights to which sector needs to be at the runway at which time. Realising such a planning and timing in reality will however be a large challenge within the infrastructure of the airport and the complex operational system.

The timing of departures can require flights to hold or overtake another flight at the runway. Due to the busy runway and taxiway system at Schiphol, departure streams are difficult to change. Sequence bays and intersection starts can be enablers for aircraft to either hold at the runway or let another aircraft go in front (sequence/intersection starts). Section 5.2 will go further into detail on this. Having traffic holding close at the runway can cause specific parts of the airport to become more crowded, increasing the chance for ground conflicts and congestion. This is specifically the case for the area around the head of runway 24 (S5-S6 and S7), where aircraft waiting for runway 24 can make it difficult for aircraft to 18L to pass by.

Besides the infrastructure needed to facilitate timing, the operation also needs to be able to deliver on this required accuracy in timing. The operation is however much more complex than only timing two departures which depend on each other since their SIDs converge. Examples of this complexity include:

- Departures from runway 24 for example need to be timed with arrivals on runway 18C due to the dependency with the missed approach of 18C. This timing could be further supported by a connection between the AMAN and DMAN.
- Departures from runway 18L which need to be timed with (some) departures from runway 24 due to the jet-blast over runway 18L.
- Flights have to adhere to the Calculated Take-Off Time (CTOT) if these are handed out by the network manager.

Finally for the ground part, it is unsure if pilots can deliver on the complexity of the concept. The advanced sequence planner could result in late runway changes, increasing the workload in the cockpit. The timing of departure also requires the pilots to be ready for departure directly after being given clearance. While not uncommon (e.g., Gatwick instructs pilots to be ready for immediate departure), especially pilots who are not very familiar with Schiphol may find it difficult to fit into such a strictly timed mechanism.

In the air, to keep the trajectory predictable, controllers should intervene as little as possible with the trajectory. The same goes for the pilots, for example in terms of speed (no speeding to make-up lost time). Ideally, in the future, information is not only received from the aircraft to make trajectory predictions and timing, but restrictions are also sent to the aircraft in terms of trajectory to ensure the aircraft will meet the required timing.

5.1.10 Operating flights with different performance from an alternative runway (ALT-RWY)

The conclusions above are based on a feasibility study focusing on the following aspects:

Conclusion

The ALT-RWY concept aims to facilitate alternative traffic segregated from the main traffic flow. During off-peak moments, the secondary runway is therefore used for departures with a different performance. During peak moments, a third runway is used for departures with a different performance.

Through the feasibility analysis, it is concluded that operating flights with different performance from an alternative runway is not feasible. It is assessed that flights with different performance would not be able to operate completely separate from the main flow on a second runway. Usage of a third departure runway besides the main modes is limited due to dependencies/conflicts between the runways. For the very few options available, designing SIDs to all five sectors is not deemed feasible.

- Runway usage rules
- Usage of a secondary runway
- Usage of a third runway

The main analysis per aspect is discussed in the following sections.

Runway usage rules

Schiphol operates under rules which envision the strict usage of preferred runways and to limit the usage of secondary runways as much as possible. Under these current rules, a concept as described in this paragraph is not deemed possible. The implementation of this concept therefore depends on the hypothesis that, in the future, exemptions are made for electric/hybrid or hydrogen aircraft in the legislation governing Schiphol, which is uncertain.

Usage of a secondary runway

Usage of a secondary runway to facilitate alternative traffic would be similar to how secondary runways are currently used during departure peaks. This means that a set of sectors can be flown from the primary runway and another set from the secondary runway. Designing conflict free SIDs from both the primary and the secondary runway to all five sectors is not deemed possible. Alternative traffic can therefore not fly to all sectors from the secondary runway. At the same time, operating the secondary runway would push conventional traffic from the primary to the secondary runway, since only specific sectors can be flown conflict free from either the primary or secondary runway (see phase 1). This conventional traffic then mixes with alternative traffic, which goes against the goal of the concept to keep alternative traffic separated.

Usage of a third runway

Usage of a third departure runway is limited due to dependencies/conflicts between the runways at Schiphol. When considering the two main runway combinations at Schiphol, the following dependencies are identified. Apart from dependencies in runways, there is a multitude of conflicts in the TMA when using a third runway, this is discussed in the table on the next page.

Table 9: Conflicts and dependencies for a third runway

Runway mode	Third take-off RWY	Identified dependencies directly surrounding the airport
24+18L/18R+18C	RWY 09	Crosses runway 18L. Also, with intersection starts 18L there is a dependency with heavies due to jet blast.
	RWY 27	Crosses runway 18L and 18C, also dependency with missed approach 18R. Also, with intersection starts 18L there is a dependency with heavies due to jet blast
	RWY 22	Traffic intersects with departures 18L which makes the combination fully dependent. Also, there is too little divergence with 24 departures making this combination also dependent.
	RWY 04	Could be possible from a runway perspective. Usage in combination with 24+18L/18R+18C is probably limited due to southern wind direction.
36L+36C/06+36R	RWY 09	Crosses runway 36R, causing a dependency with the missed approach on 36R. Also, a dependency exists with missed approaches on 06
	RWY 27	Crosses runway 36C and 36R, which makes the combination fully dependent
	RWY 22	Traffic intersects with 36R arrivals which makes the combination impossible. Also, there is too little divergence with 24 departures making this combination also dependent
	RWY 04	Dependency with missed approach 06

For all runways, with the exception of RWY 04 in combination with 24+18L/18R+18C, dependencies are identified. Usage of runways with large dependencies would cause an unacceptable level of controller workload. When such dependencies occur, capacity is decreased in order to manage the controller workload, which is counterproductive for handling more traffic. This makes structural usage of runways 09, 22 and 27 as a third runway unfeasible.

Off all available third runways, runway 04 offers the least conflicts with the primary and secondary runways. This runway however also has its limitations, being the unfavorable wind direction (in southern operation) and the dependency with the missed approach (in northern direction). When implemented, increased traffic on the runway 04-22 would also cause more runway crossings of 18L due to aircraft moving between the runway 04-22 and the terminal. Finally, with the current SID design, no conflict free SIDs can be designed laterally which can accommodate traffic from this third runway to any of the five exit points. Potential mitigations are to keep aircraft lower to separate SIDs by altitude (see ALT-SID concept).

5.1.11 Operating flights with different performance from an alternative SID (ALT-SID)

The conclusions above are based on a feasibility study focusing on the following aspects:

Conclusion

In the ALT-SID concept, for departures with a different performance a separate, conflict free, SID network is designed, connecting runways with the departure sectors while flying at a lower level compared to the current SIDs.

Through the feasibility analysis, it is concluded that operating flights with different performance on a network of lower level SIDs is not feasible. Leveling-off flights will partially alleviate the negative capacity effect of the introduction of departures with a different performance. The negative capacity effect will however remain considerable, while the levelling-off of flights will also have a negative impact on noise. After being levelled-off the airspace design will require low SIDs to eventually merge with the higher SIDs. Even with technical support it is not expected that such a task with high traffic numbers can be handled without a considerable increase in controller workload.

- Buffer times when levelling-off
- Noise
- Airspace design

The main analysis per aspect is discussed in the following sections.

<u>Buffer times when levelling-off</u>

The analysis in phase two have shown that the introduction of aircraft with different performance can have a negative impact on capacity. This is mainly due to the large departure intervals which need to be applied between these (propellor) aircraft and jets when flying on a common path. The idea behind the ALT-SID concept is to level these aircraft off, which allows jets to pass overhead, lowering intervals. As part of the feasibility analysis an indicative analysis was conducted to get insight into the effect of leveling off aircraft with alternative performance. The assumption under this analysis is that alternative aircraft will primarily be props or aircraft with similar performance to props. Also, an average climbing angle of 8 degrees for the Schiphol fleet is assumed (determined in KDC project "*High altitude SIDs*").

The table underneath provides an overview of a medium jet following a medium jet (baseline), a medium turboprop (leveling off at 5000ft) followed by a medium jet and a medium turboprop (leveling off at 2000ft) followed by a medium jet. Compared to a buffer of 70-80 for a M-jet/M-jet combination the introduction of a prop is always a deterioration in capacity. Leveling off a flight at 2000ft helps in keeping the effect smaller compared to not leveling off, but still an additional 30-second buffer is a large negative effect on capacity.

Table 10: Resulting intervals when levelling-off

Pair	Level-off	Interval
M-Jet, M-Jet	FL100+	70s-80s
M-Turbo, M-Jet	5000ft	120s
M-Turbo, M-Jet	2000ft	100s

Noise

Future aircraft (electric/hybrid/hydrogen) are expected to be quieter compared to their conventional counterparts. However, even the quietest aircraft will cause noise. Aircraft flying at a lower altitude will cause considerably more noise on the ground compared to aircraft flying at a higher altitude. Overall, a doubling in altitude reduces noise levels by 6 dB, not considering the additional reduction caused by atmospheric attenuation. Flying at lower altitude for a longer distance will therefore have negative effects on the noise situation around the airport.

Airspace design

The table on the next page gives an overview of the minimal altitude restrictions along SIDs from runways 24/18L to the five departure sectors. The table shows that for all SIDs the CTR boundary needs to be crossed at minimal of 2000ft to stay within controlled airspace, which corresponds with the calculation of leveling off aircraft at 2000ft. At 2000ft, aircraft can come into conflict with other aircraft in the case of a missed approach. In the case of a missed approach, departures are leveled-off at 2000ft to avoid conflicts with the missed approach. This can cause these aircraft to conflict with the low altitude SIDs.

Outside the CTR the airspace design within the Netherlands requires aircraft to climb to minimal altitudes to avoid Schiphol traffic entering military airspace, TMAs of other airports or come into conflict with SPL arrivals. This requires the aircraft at the lower SID to, at some point, climb towards the higher SID and merge with the traffic flying above.

To merge with traffic, the in-trail spacing requirements have to be considered, while also considering the performance difference between the aircraft. Merging traffic will cause a large increase in controller workload. Making this workload manageable might require an aircraft to be delayed on the runway to provide a gap for the alternative aircraft to climb, causing a drop in capacity. Technical support might assist the controller in merging traffic, this is further discussed in the section 5.2. Given the airspace design, alternative aircraft would have to be structurally merged with other traffic towards all different departure sectors. Even with technical support it is not expected that such a task can be handled without a considerable increase in controller workload.

Table 11: Minimal altitudes required for different departure sectors

SID	Minimal altitudes along flightpath ->		
18L ARN	Cross CTR boundary at minimal of 2000ft, otherwise uncontrolled airspace/obstacles	TMA boundary at minimal of FL070, otherwise aircraft enter TMA-D (military)	
18L LOP		TMA boundary at minimal of FL060, TMA-D delegated to ACC when LOP is used	
18L KDD		Part of Schiphol TMA has been delegated to RTM-APP (RAP), minimal transition level at this delegated area.	TMA boundary at minimal FL60, otherwise aircraft enter TMA-RTM
24 VAL		TMA boundary at minimal TL, otherwise aircraft enter TMA-RTM	CTA west, minimal FL060
24 BER		SPL TMA 2/6: minimal 4000ft	
24 SPY		Above Low flying arrivals between 0 – FL070	CTA east, minimal FL065 otherwise TMA B (military)

5.2 Potential of technical enablers / TBO

The table underneath presents some of the issues identified in the feasibility study which can potentially be mitigated with technical enablers related to Trajectory Based Operations (TBO).

Table 12: Identified issues which potentially can be mitigated with technical enablers

Concept	Issue	Potential technical enablers
S34-DEF	-	-
S12-DEF	-	-
S12-SOUTH (static or dynamic between peaks)	18L ARNEM has limited space for late turn to avoid 24 KUDAD or 24 LOPIK	Pre-departure SID confirmation using ADS-C EPP
		SID conformance monitoring
S12-NORTH (static or dynamic between peaks)	-	-
S12-SOUTH (dynamic within peaks)	Last aircraft to a sector can cause a conflict with the first aircraft to the same sector from a different runway.	Departure timing using MTCD
S12-NORTH (dynamic within peaks)		On-line monitoring of projected in-trail spacing using MTCD
S12-SOUTH-DUAL	Uncertainty in feasibility of merge in ACC	On-line monitoring of projected in-trail spacing using MTCD
	18L ARNEM has limited space for late turn to avoid 24 KUDAD or 24 LOPIK	Pre-departure SID confirmation using ADS-C EPP
		SID conformance monitoring
S2-NORTH-DUAL	Uncertainty in feasibility of merge in ACC	On-line monitoring of projected in-trail spacing using MTCD
S3-DUAL-SOUTH-LOP	KUDAD and LOPIK SIDS closely spaced	Pre-departure SID confirmation using ADS-C EPP
		SID conformance monitoring
S3-DUAL-NORTH	Uncertainty in feasibility of merge in ACC	On-line monitoring of projected in-trail spacing using MTCD
S3-DUAL-SOUTH-KDD	Uncertainty in feasibility of merge in ACC	On-line monitoring of projected in-trail spacing using MTCD
ALT-RWY	-	-
ALT-SID	Merging low-flying alternative aircraft with the stream of conventional aircraft above	On-line monitoring of projected in-trail spacing using MTCD
TRAF-MERGE	Large time buffer required due to in-trail spacing uncertainty on merge in TMA	Departure timing using MTCD
		On-line monitoring of projected in-trail spacing using MTCD
	Capacity dependent on availability of flights to the right sector at the runway	Sequence bay
		Intersection starts
		Advanced outbound planner

The uncertainty in future separation (laterally and longitudinally) limits the feasibility of most concepts. This uncertainty requires larger departure intervals and therefore negatively impact the capacity. Trajectory-based solutions provide the means to more accurately predict and monitor the uncertainty, reducing the impact on capacity.

This section describes three ways in which TBO may mitigate the issues caused by separation uncertainty:

- Conformance monitoring: Verifying that the intended separation provided by the design of the SIDs is indeed achieved by verifying correct executing of the SIDs
- Medium-Term Conflict Detection: Using predicted departure trajectories to evaluate and monitor separation at upstream merging points.
- Departure sequence management: Maximising the benefit of smaller departure intervals by ensuring that aircraft are ready to depart when an optimal slot is available on the optimal runway.

5.2.1 SID Conformance monitoring

Automatic Dependent Surveillance – Contract Extended Projected Profile (ADS-C EPP) allows downloading the trajectory predicted by the aircraft's FMS before departure. Comparing this trajectory with the selected SID allows immediate verification of the selected SID. This verification reduces the risk of SID blunder leading to a violation of the separation between nearby SIDs.

This concept is dependent on:

- The equipage of the aircraft with ADS-C EPP which is available on the newest aircraft
- The technical ability to request and receive ADS-C information
- Presentation of the comparison in the tower

5.2.2 Medium-Term Conflict Detection

4-Dimensional trajectories allow evaluation of future separation at downstream merging points. Such trajectories are already available in the iCAS system. Especially in departures, a lot of variation in speeds exist between different flights (including flights by the same aircraft type). For the proposed applications, accurate modelling of speeds will be required. The accuracy of the trajectories can be enhanced using concepts from the KDC study *Transition to Trajectory-Based Operations*, in particular FF-ICE (when provided with speed information) and ADS-C EPP.

<u>Monitoring spacing</u>

Using MTCD allows monitoring the future separation – in particular in-trail separation – of two merging departure routes. Through monitoring, adjustments may be applied that ensures separation and seamless merging. Such monitoring would be applicable when merging in the TMA and when merging in ACC.

<u>Timing Departures</u>

When the trajectory would be available before departure, the information can be used to time the departure based on the expected spacing at the merging point. The fact that the aircraft is on the ground provides much more flexibility in achieving the correct spacing. In such an operational concept the TWR controller would use an indicator of the predicted spacing to time the departure clearance of the trailing aircraft from one runway such that it would merge at the correct interval behind the aircraft from the other runway.

5.2.3 Departure sequence management

Using a concept of timed departures from different runways requires that those flights be ready to go when sufficient gap is guaranteed. If a primary aircraft would depart later, they would unnecessarily delay the next departure from their runway and could also delay the departure of the next trailing aircraft from the other runway. The concept therefore requires the ability to plan aircraft to both runways and ideally an ability to hold the aircraft at the runway to provide robustness.

<u>Advanced outbound planner</u>

The outbound merging concepts rely on flight to a single sector being planned from both runways. This requires a planning process that determines opportunities for merging departures from the primary runway. A more advanced outbound planner will be needed that determines when demand on the primary runway to the 'primary' sectors is low enough to allow departures to the 'secondary' sector.

<u>Sequence bays / Intersection starts</u>

The critical timing of the outbound merging concept is sensitive to disturbances at both runways. The merging flights cause a two-way interaction between the runways; if a flight is delayed on one runway, the flight on the other is also delayed. Having departures to the merging sector ready at a holding creates robustness and prevents cascading delays due to the introduced interaction of the runways. The current infrastructure provides such an option through intersection departures. However, these require an additional minute of separation which reduces capacity. Sequence bays would do the same without the separation penalty.

5.3 Performance case: noise, fuel and capacity

The performance case is conducted at two levels. For the feasible (either with or without conditions/enablers) concepts which aim at redesigning the assignment and/or definition of departure sectors, the performance on noise, fuel and capacity are calculated and presented in this paragraph. For the feasible concepts which aim at operating one departure sector from two runways the performance case goes into the applicability of these concepts. This alternative approach has been applied since these concepts are too complex to determine effects over the year at the detailed level of noise, fuel and capacity.

For the performance case on noise, fuel and capacity two datasets are used. For noise and fuel calculations, the GP2022 traffic is adjusted in conformity with the different concepts. Based on this adjusted traffic, effects on noise are determined using the SCM tool. For the noise calculation the noiseload database of the GP2022 is used. As indicator for noise, the number of highly annoyed people is used, based on the housing situation in 2018.

For the effects on fuel for both taxiing and in flight the Schiphol fuel model is used[2]. The capacity model was used to evaluate the delays and departure intervals of the departure sequences from the different concepts. The capacity results are based on historical CDM-data of 2019 (the last representative year with +/- 500.000 movements).

The table underneath provides an overview of the effects on noise, fuel and capacity for the selection of concepts. Results per concept are discussed underneath the table.

Table 13: Effects on noise, fuel and capacity for the selection of concepts compared to baseline model

Concept	Impacted flights[1]	Capacity (Relative change in average departure interval)	Capacity (Relative change in average delay)	EGH 48 dB	Fuel taxi phase (ton)	Fuel flight phase (ton)
S34-DEF	+/- 10.500	0%	-7%	-2.350	+122	+1.335
S12-DEF	+/- 4.000	0%	-2%	+350	+56	+258
S12-South[2] static	+/- 30.000	+1% / +7%	+1% / +30%	-5.600	-3	+104
S12-North	+/-15.000	+1%	+2%	-6.450	-150	+463

[1] Based on GP2022
[2] Capacity analyses of S12-concepts are based on departure intervals in non-VMC- and VMC operations (non-VMC / VMC)

[2] The fuel model of Schiphol calculates fuel usage for flights using the SID's as published in the AIP. This could create differences in calculated fuel usage in between scenario's which are a consequence of SID's in the AIP being defined until different exit points, creating different lengths.

5.3.1 S34-Def

The S34-Def concepts causes flights moved from sector 3 to sector 4 to depart from the primary runway instead of the secondary runway. The scope of the concepts (number of flights moved) can be limited by economic aspects and/or workload in adjacent centers. For this performance case (and the performance case of S12-Def) it is assumed that all flights to the selected destinations are moved to the primary sector, making the results the maximum result possible within the concept. As shown in phase 2, noise performance of flights to sector 4 is better from primary runways compared to secondary runways. In the performance case this leads to a decrease in the number of highly annoyed people within the 48 dB contour compared to the baseline.

Overall, the average delay per departure is reduced by 7%, which is caused by offloading the throughput on the secondary runway. This reduces the delays on the secondary runway, while only slight increases in the delays on the primary runway are noticed, causing the nett effect to be positive from a capacity-perspective. Mostly Upper/Lower Medium aircraft are swapped in this concept, which has a negligible effect on the average required intervals between departures on both runways.

Besides these positive effects, the concept also has negative consequences. In the northern operation, taxi distances from the terminal to 36L are considerably longer compared to 36C, causing an increase in fuel consumption during the taxi phase (the difference in taxidistance between runway 24 and 18L is minimal). Track miles within the TMA also increase, leading to an increase in fuel usage during the flight phase. The performance case for the S34-Def concept shows that for this concept a trade-off needs to be made between positive noise/capacity effects and negative effects on fuel.

5.3.2 S12-Def

The S12-Def concept has comparable effects in terms of fuel, caused by a longer taxi distance and more track miles. In terms of noise the performance case is however also negative. As shown in phase 2, noise performance of flights to sector 1 via the SPY SID from runway 24 is worse than the sector 1 SID from runway 18L. Increasing the number of flights on this SID will therefore lead to an increase in the number of highly annoyed people. The effects on capacity are comparable to the S34-DEF concepts. However, the effects are less noticeable since fewer flights are impacted. Due to the negative effects on fuel and noise the performance case for this concept is mostly negative.

Table 14: Performance of S12-Def and S34-Def concepts

Concept	Impacted flights[1]	Capacity (Relative change in average departure interval)	Capacity (Relative change in average delay)	EGH 48 dB	Fuel taxi phase (ton)	Fuel flight phase (ton)
S34-Def	+/- 10.500	0%	-7%	-2.350	+122	+1.335
S12-Def	+/- 4.000	0%	-2%	+350	+56	+258

5.3.3 S12-South

In S12-South, departures to sector 1 and 2 in the southern operation (departures from 24 and 18L) are operated from the secondary runway (18L), while in the current operation the secondary runway facilitates departures to sector 2 and 3 (S23). The feasibility study has analysed implementation of the concept on various levels:

- Static: permanent change from S23 -> S12
- Dynamic per peak: based on traffic forecasts, usage of S12 or S23 is determined.
- Dynamic within peaks: based on real time traffic developments, usage of S12 or S23 is determined.

The feasibility analysis concluded that static or dynamic per peak implementation of the S12-south concept is feasible in the medium to long term. Based on the conditions which have to be met it is expected that a dynamic per peak implementation has more potential of being implemented compared to a static implementation. For the performance case the effects of static or dynamic per peak implementation are calculated. For dynamic per peak, S12-South is applied in all peaks, except in the second morning peak where the feasibility study indicated that capacity on the primary runway might be too small for traffic to sector 3, 4 and 5. As a variant, dynamic per peak is applied in such a way that per peak the concept is applied (S12 or S23) that leads to the lowest delay.
Depending on the way the Lopik separation issue is mitigated, some negative effects can be expected on either noise (adjusting Lopik routes or applying S23 when using Lopik) or on capacity (timing Lopik departures). These effects are however not included in the performance case.

Concept	Impacted flights[1]	Capacity (Relative change in average departure interval)	Capacity (Relative change in average delay)	EGH 48 dB	Fuel taxi phase (ton)	Fuel flight phase (ton)
S12-South[2] static	+/- 30.000	+1% / +7%	+1% / +30%	-5.600	-3	+104
S12-South[2] dynamic per peak (morning peak)	+/- 23.000	+1% / +7%	+1% / +25%	-5.400	+7	+72
S12-South[2] dynamic per peak (capacity optimal)	+/- 16.000	0% / +2%	-14% / -7%	-4.600	+15	+ 46

[1] Based on GP2022
[2] Capacity analyses of S12-concepts are based on departure intervals in non-VMC- and VMC operations (non-VMC / VMC)

<u>S12-South static</u>

The S12-South concept has a strong positive effect on the number of highly annoyed people. This is primarily caused by the fact that the SPY SID from runway 24 is no longer used in this concept. This causes a large decrease in highly annoyed people in areas such as Hoofddorp and Nieuw-Vennep. Locally there are also some increases in highly annoyed people (such as Amstelveen), but the overall effect is strongly positive. In terms of taxiing, differences in taxi distance between 24 and 18L are minimal and therefore there is a minimal effect on fuel consumption during taxiing. There is a negative effect on the fuel usage during flight phase, compared to other concepts and the number of flights affected this effect is quite limited.

In this concept, sector 3 departures, mostly consisting out of upper medium aircraft, are moved from the secondary runway to the primary runway. This makes the fleet mix on the primary runway more diverse as sector 3 departures are merged with sector 5 departures, which mostly consists out of upper and lower heavy aircraft. Table 15 below shows that in S12-South the fleet mix slightly changes. For example, the departure sequences under S12-South consists of more upper heavy aircraft being followed up by an upper medium aircraft. These slight changes cause the overall average departure interval to increase by 1% in S12-South compared to the baseline model. On average, the delay also increases by 1%.

Table 15: Top 90% of leader - trailer combinations in departure sequences in baseline model (S23) compared to S12 concept in southern runway configuration

Leader - Trailer	S23-South	S12-South
Upper Medium-Upper Medium	29,23%	28,25%
Lower Medium-Upper Medium	15,94%	16,39%
Upper Medium-Lower Medium	15,72%	16,34%
Lower Medium-Lower Medium	11,29%	10,96%
Upper Medium-Upper Heavy	7,09%	7,39%
Upper Heavy-Upper Medium	6,70%	7,09%

In VMC operations, S12-South is clearly outperformed by the baseline model as, when visual separation could be applied, required departure intervals in the baseline model could be reduced due to the early split points of SIDs between sector 1 and 4/5 on the primary runway and between sector 2 and 3 on the secondary runway. This effect is not applicable to the S12-South concept. Hence, the average required departure interval is 7% higher compared to the baseline model, introducing an average increase in delay of 30%.

S12-South hybrid (morning peak)

In this S12-South hybrid concept, S12-South is applied to all peak moments, with the exception of the 2nd outbound peak in the morning, during which S23 is applied. Due to only one outbound peak not operating in S12, the effects on noise, fuel and capacity are lower compared to the full S12-South concept.

S12-South hybrid (capacity optimal)

The hybrid implementation of S12-South allows for the possibility to shift between operational modes per peak. In this concept, the operational mode (S12 or S23) is selected per peak by selecting the mode that results in the lowest delay. Table 16 shows the number of departure peaks operated in S12 and S23 in the S12-South Hybrid concept. As could be observed, in non-VMC operations, the outbound peaks are evenly distributed between concept S12 and concept S23. On the other hand, in VMC operations the S23-concept is often more preferable. The hybrid implementation of S12-South clearly has a positive effect from a capacity perspective as average delays decrease by 14% and 7% in non-VMC and VMC operations respectively. This increase in capacity however comes at the cost of some of the benefits made on noise which are lower in this variant compared to the static variant.

Table 16: Distribution of selected operational mode in S12-South Hybrid

S12-South Hybrid	South (24 / 18L)	
	Non VMC	VMC
Number of peaks where S12 is optimal	425 (52%)	263 (32%)
Number of peaks where S23 is optimal	393 (48%)	555 (68%)
Total	818 (100%)	818 (100%)

5.3.4 S12-North

The S12-North concept has a strong positive effect on the number of highly annoyed people. This is primarily caused by the new 36L sector 3 SID going over less populated areas and eventually the North Sea compared to the city of Amsterdam when departing from 36C in the baseline scenario. This new SID is however longer, causing more track miles to be flown and more fuel usage in flight phase. For fuel used during taxiing the effect is however positive compared to the baseline. This is due to the type of traffic which switches runways when the S12-North concept is implemented. Sector 1 contains more heavy traffic, which moves from 36L in the baseline to 36C in the S12-North concept. The other way around, sector 3 flights move from 36C to 36L. Sector 3 however contains fewer heavy aircraft, creating an overall effect that heavy aircraft have to taxi less in S12-North concept and medium aircraft more, which causes total fuel usage during taxiing to drop.

Concept	Impacted flights[1]	Capacity (Relative change in average departure interval)	Capacity (Relative change in average delay)	EGH 48 dB	Fuel taxi phase (ton)	Fuel flight phase (ton)
S12-North	+/-15.000	+1%	+2%	-6.450	-150	+463

From a capacity perspective, the results of S12-North are comparable to the results of the S12-South concept. Swapping flights departing to sector 3 from the secondary runway to the primary runway slightly adjusts the fleet mix on the primary runway. The same accounts for swapping flights departing to sector 1 to the secondary runway. These changes lead to different fleet mixes, causing the required departure intervals to change. On average, the required departure interval increases by 1% compared to the baseline model. The average delay increases by 2%. Table 17 shows the most frequently occurring leader-trailer combinations of aircraft types in the baseline model and the S12-North concept.

Table 17: Top 90% of leader - trailer combinations in departure sequences in baseline model (S23) compared to S12 concept in northern runway configuration

Leader - Trailer	S23-North	S12-North
Upper Medium-Upper Medium	29,73%	28,63%
Upper Medium-Lower Medium	16,16%	16,76%
Lower Medium-Upper Medium	16,04%	16,51%
Lower Medium-Lower Medium	11,81%	11,49%
Upper Medium-Upper Heavy	6,55%	6,92%
Upper Heavy-Upper Medium	6,38%	6,82%
Upper Heavy-Lower Medium	4,43%	4,23%

5.4 Performance case: applicability concepts

As mentioned in the introduction of the previous paragraph, for the feasible concepts which aim at operating one departure sector from two runways the performance case goes into the applicability of these concepts. The dual-SID concepts intend to operate one particular departure sector (sector 2 or sector 3) from both the primary and the secondary runway to optimise the usage on the primary runway. This section analyses the applicability of these concepts based on traffic data of 2019. The applicability is assessed by analysing:

- The capacity usage of the primary runway during departure peaks
- The throughput to the departure sector that would be operated from both runways
- The throughput to the departure sector via particular SIDs

Due to its complexity in timing and sequencing flights, the traffic merge concept is not included in this analysis of applicability. For the dual SID concept, this analysis provides some first indicative numbers on applicability, before more detailed research is conducted using fast time simulation or real time simulation. The complexity of the traffic merge concept only be analysed using FTS/RTS.

<u>The capacity usage of the primary runway during departure peaks</u>

The dual-SID concepts use space on the primary runway to transfer departing flights from the secondary runway to the primary runway, while complying to capacity constraints. The capacity usage of the primary runway is indicated by computing a rolling hour count of the number of departures from the primary runway. Technically, if the rolling hour count remains below the maximum capacity of 37 departures an hour, there is room to shift flights to the primary runway during an outbound peak. In the following sections, the percentage of outbound peaks where the number of hourly departures on the primary runway remained below certain limits (37, 30, 25, 20 departures per hour) were identified.

<u>The throughput to the departure sector that would be operated from both runways</u>

Operating one departure sector from both runways would require sufficient spacing between the departures to the particular sector in order to comply to minimum radar separation standard of 5 nm when traffic is handled by ACC to the exit points. The median spacing between departures to the dual-sector during the departure peaks was computed to assess the throughput and verify whether separation minima in ACC would not be violated when these departures would be operated from both runways. The minimum spatial separation of 5 nm in ACC was approximated to be equivalent to a time spacing of 1.25 minutes.

<u>The throughput to the departure sector via particular SIDs</u>

The throughput via particular SIDs was analysed to identify whether entire departure streams could be transferred from the secondary runway to the primary runway. Based on the feasibility study, for both sector 2 and sector 3, separate departure streams were identified based on SID usage:

- Sector 2: departure streams via SIDs to exit point NAPRO or SONEB
    - Southern operation: aim to operate all traffic to exit point NAPRO from runway 24
    - Northern operation: aim to operate all traffic to exit point SONEB from runway 36L
- Sector 3: departure streams via SIDs to westerly or easterly destinations
    - Southern operation: aim to operate all traffic to westerly destinations from runway 24

Table 18 below summarises the results of the evaluation of the applicability of various concepts where either sector 2 or sector 3 are operated from both runways during departure peaks. The results indicate that during 42% to 47% of the departure peaks at least five flights could be transferred to the primary runway in the southern operation. This holds for 32% of the departure peaks in the northern operation. During these peaks, the median time between departures to the dual-sector is approximately 2.5-3 minutes, which would be sufficient to operate this sector from both runways while complying to separation standards. However, results show that shifting entire departure streams to the primary runway is possible in only 20-30% of the departure peaks, making this specific condition in the concepts limitedly achievable. In the following sections the results per concept on applicability are discussed.

Table 18: Applicability of dual-SID concepts

	S12-SOUTH-DUAL	S2-NORTH-DUAL	S3-SOUTH-DUAL
Percentage of departure peaks where at least 5 departures could be shifted from the secondary to the primary runway (limited by 37 dep/hour)	42%	32%	47%
Median time between departures to the dual-sector	2,5 minutes	2,5 minutes	3 minutes
Percentage of departure peaks where a departure stream, via a SID to a dual sector (sector 2 or 3), could be shifted from the secondary to the primary runway*	20%	21%	33%

5.4.1 S12-SOUTH-DUAL

Table 19 summarises the results of the S12-SOUTH-DUAL concept. Each row evaluates a set of departure peaks where the hourly number of departures remains below a set limit. As the table shows, in 73% of the departures peaks there is a possibility to swap at least one sector 2 flight to the primary runway without violating the capacity limit of 37 movements. As the set limit drops to 30 departures an hour, only a quarter of the departure peaks remain below this limit. This indicates that the throughput of departures on the primary runway is relatively high. The median time between departures from runway 18L to the dual sector 2 is approximately 2.5 minutes. Aircraft departing every 2.5 minute to sector 2 results in an approximate separation of 10 nm, which complies to the minimum separation standard of 5 nm.

Table 19: Applicability of S12-SOUTH-DUAL

Number of hourly departures	Percentage of departure peaks	Average number of hourly departures to sector 2 from runway 18L	Median time between departures to sector 2 from runway 18L [mm:ss]
< 37	73%	17	02:31
< 30	25%	16	02:34
< 25	13%	15	02:34
< 20	7%	14	02:47

The table above shows that in some cases, gaps in the departure steam of runway 24 can be filled with sector 2 departures from runway 18L. The feasibility study showed that, from a workload perspective of ACC, traffic streams to the two exit points would be separated completely by segregating the traffic. This means that runway 24 should facilitate REN departures heading to exit point NAPRO, while 18L would facilitate ARN departures heading to exit point SONEB. The applicability of these parallel SIDs is evaluated by analysing the number of departure peaks where all departures to sector 2 using REN could potentially be shifted from runway 18L to 24.

Table 20 below takes a subset of departure peaks where the usage of the primary runway is such that at least 5 departures could be transferred to the primary runway. Next, the average number of departures that could potentially be shifted to the primary runway was computed together with the average number of departures to sector 2 via the REN SID from runway 18L. When the number of departures via REN is lower than the potential number of flights that could be shifted to runway 24, it is assumed that all REN departures could be moved to 24. This situation occurs in 160 departure peaks.

Table 20: Applicability of operating two parallel SIDs to Sector 2 in southern operation

Number of departure peaks where at least 5 departures could be transferred to runway 24 without exceeding capacity limit of 37 dep/hour	343 (42% of all departure peaks)
Average number of departures that could be shifted to runway 24 without exceeding capacity limit of 37 dep/hour	11
Average number of REN departures from runway 18L	12
Number of departure peaks where all REN departures could be transferred to runway 24 in order to operate two parallel SIDs to sector 2	160 (20% of all departure peaks)

5.4.2 S2-NORTH-DUAL

Table 21 below summarises the applicability results for S2-NORTH-DUAL. The same conclusions can be drawn as for the S12-SOUTH-DUAL concept. On average, the median time between flights to sector 2 is more than 2 minutes, which indicates that flights could be operated from both runways without violating separation standards. However, the number of departure peaks with room on the primary runway is rather limited.

Table 21: Applicability of S2-NORTH-DUAL

Number of hourly departures	Percentage of departure peaks	Average number of hourly departures to sector 2 from runway 36C	Median time between departures to sector 2 from runway 36C [mm:ss]
< 37	65%	18	02:22
< 30	14%	18	02:26
< 25	2%	19	02:12
< 20	0%	-	-

In peaks with sufficient space on the primary runway, the departure stream of runway 36L can be filled with sector 2 departures from runway 36C. This would require two parallel SIDs to sector 2. Currently, NYK and IVL are two SIDs used from runway 36C facilitating traffic to sector 2. In order to operate two parallel SIDs to sector 2, all NYK departures to sector 2 from runway 36C should be transferred to runway 36L.

Table 22 below summarises the number of departure peaks where it would be possible to shift these flights to the primary runway.

Table 22: Applicability of operating two parallel SIDs to Sector 2 in northern operation

Number of departure peaks where at least 5 departures could be transferred to runway 36L without exceeding capacity limit of 37 dep/hour	141 (32% of all departure peaks)
Average number of departures that could be shifted to runway 36L without exceeding capacity limit of 37 dep/hour	8
Average number of NYK departures from runway 36C	7
Number of departure peaks where all NYK departures could be transferred to runway 36L in order to operate two parallel SIDs to sector 2	90 (21 % of all departure peaks)

5.4.3 S3-SOUTH-DUAL

Based on Table 23 it can be observed that the throughput to sector 3 is generally lower compared to departures to sector 2 in the southern operation with a median time between departures ranging between 2.5 minutes to 3 minutes.

Table 23: Applicability of S3-SOUTH-DUAL

Number of hourly departures	Percentage of departure peaks	Average number of hourly departures to sector 3 from runway 18L	Median time between departures to sector 3 from runway 18L [mm:ss]
< 37	81%	13	03:10
< 30	27%	14	02:58
< 25	14%	15	02:41
< 20	11%	15	02:36

In this concept, westerly destinations to sector 3 would be operated from 24 rather than 18L. These destinations were identified by filtering on sector 3 departures that are not routed via LOP during the weekends.

Table 24: Applicability of operating two parallel SIDs to Sector 3 in southern operation

Number of departure peaks where at least 5 departures could be transferred to 24 without exceeding capacity limit of 37 dep/hour	388 (47% of all departure peaks)
Average number of departures that could be shifted to 24 without exceeding capacity limit of 37 dep/hour	12
Average number of departures to westerly destinations in sector 3	7
Number of departure peaks where all departures to westerly destinations in sector 3 could be transferred to 24 in order to operate two parallel SIDs to sector 3	273 (33% of all departure peaks)

5.6 Conclusions phase 3

The feasibility study has shown that the solution space for the short term is limited. Most concepts which are deemed feasible after analysis require further research, technical enablers or depend on other developments such as airspace becoming available after implementation of the DARP. Besides these needed developments, the feasibility study also set several conditions for concepts which might limit their application in practice.

Further research includes (safety) studies into identified issues for several concepts. For the concepts which aim at operating one departure sector from two runways the complexity of the concept requires further fast time simulation or real time simulation to study the flow of traffic and its effects on workload in more detail. Technical enablers can support in multiple concepts but require significant time to be developed. These trajectory-based solutions provide the means to more accurately predict and monitor the uncertainty, reducing the impact on capacity. Further research, technical enablers and the DARP cause the implementation horizon for most concepts to be long term. For alternative traffic the feasibility study did not find a way to segregate alternative traffic from the conventional flow of traffic, which highlights this as a future challenge.

For the feasible (either with or without conditions/enablers) concepts which aim at redesigning the assignment and/or definition of departure sectors, the performance case focuses on the performance on noise, fuel and capacity. The performance case for the S34-Def concept shows that for this concept a trade-off needs to be made between positive noise/capacity effects and negative effects on fuel. Based on the conditions which have to be met for implementation of the S12-South concept it is expected that a dynamic per peak implementation has more potential of being implemented compared to a static implementation. This means that not the full positive effect of the concept is achieved, but on the other side does limit negative effects on capacity. With the S12-South concept a large decrease in the number of highly annoyed people can be achieved against limited negative effects on capacity and fuel.

The dual-SID concepts intend to operate one departure sector (sector 2 or sector 3) from both the primary and the secondary runway to optimise the usage on the primary runway. The analysis on applicability has shown that there is room on the primary runways to shift secondary traffic from the secondary to the primary runway. However, with potential limitations which might be applied on moving traffic to the primary to keep traffic streams to the same sector more separated, the applicability of the concepts is further reduced to only 20-30% of the departure peaks.

This phase contains several large steps in the research. Concepts are further worked out, assessed on feasibility, and further analyzed on either noise, fuel and capacity or applicability. Through these steps, almost all concepts changed in a sense that either additional conditions must be met/ technical enablers have to be implemented before a concept can be implemented or a concept has to be scaled down in order to limit negative side effects. This shows the complexity of the operational system and the difficulty of designing a new concept of operations. A fixed form concept can’t be created and pushed directly into the operation, instead it must be sculpted over time further and further before it might fit into the operation well enough and help improve it. The roadmap in the next phase will go deeper into how this translates into steps to be taken in the future.

6 Phase 4: Roadmap towards improved outbound traffic segregation

This final phase uses the results of the previous three phases to create a roadmap. The roadmap presents segregation concepts that are achievable in the short term. For segregation concepts which might be feasible in the future, the steps which need to be taken in the area of research and (technical) enablers on the development path towards the implementation of these concepts are described.

6.1 Overview

Table 25 provides an overview of the necessary actions to perform in order to further develop and potentially implement the analysed concepts for improved outbound traffic segregation.

Table 25: Roadmap: timeline and required actions

Term	Action
Short term	Decision-making on S34-Def concept
	(Safety) study S12-South
	Defining directions for further research into operating one departure sector from two runways
	Coordinating concepts with DARP
	Researching the potential introduction of alternative aircraft at Schiphol
Medium term	Stakeholder engagement, procedural design and implementation S12-South (depending on outcome safety study)
	Further development on CONOPS S12-North (depending on DARP)
	Decision-making on concepts for operating one departure sector from two runways
	Implementation strategy alternative aircraft
Long term	Implementation of concept(s) for operating one departure sector from two runways
	Implementation S12-North
	Introduction alternative aircraft at Schiphol

6.2 Short term

The analysis conducted in the previous phase has shown that the solution space for short term improvements is limited. In the short term, focus should therefore lie on the S34-Def concept and on preparations for the further development of other concepts. Steps on the roadmap for the short term are:

- Decision-making on S34-Def concept
- (Safety) study S12-South
- Defining directions for further research into operating one departure sector from two runways
- Coordinating concepts with DARP
- Researching the potential introduction of alternative aircraft at Schiphol

Decision-making on S34-Def concept

The performance case for the S34-Def concept shows that for this concept a trade-off needs to be made between positive noise/capacity effects and negative effects on fuel. Both aspects are of importance for a sustainable operation. If the trade-off results in the continuation of the concept, implementation can be achieved in the short term. Before implementation, airlines which serve potential destinations should be consulted. Since the concept adds additional flights to sector 4, it is also recommended to consult the adjacent centre(s) on this concept.

After consultation, formal or informal agreement on the usage of sectors can be made to improve usage of the primary runway. Economic aspects for airlines or workload restrictions in adjacent centers should be considered when making these bilateral agreements, which might result in not all destinations being flown via a sector linked to the preferred runway.

(Safety) study S12-South

The performance case of the S12-South concept shows a strong positive effect on the number of highly annoyed people. This strong positive effect on noise and the potential for implementation in the medium term make this a concept to further develop in the short term. The feasibility study identified several conditions which must be met for the S12-South concept to be implemented. A primary condition is the positive safety study on the separation between 24 KDD and 18L ARN. In the short-term focus should be on conducting the safety study, since without a positive safety study a structural deployment of the concept is not feasible.

Parallel to the safety study, further research/development of the concept should be conducted on the other conditions and aspects related to the concept. These topics include:

- Mitigating the 24-LOP separation issue: the identified separation issue will need to be mitigated for example by applying the concept dynamic per peak, adjusting the SID, or by making starts on the 24-LOP SID dependent.
- Preferred application of the concept. The static use of the S12-South concept reaches the maximum reduction in the number of highly annoyed people but also has a considerable negative effect on capacity (under VMC conditions). Dynamic usage can result in a better performance on capacity, but this makes the positive effect on noise smaller. Based on the research conducted in this report and additional research a decision has to be made on the preferred way to deploy the concept when considering all the different aspects. Together, the

outcomes of the safety study and the further research/development of the concept result in a CONOPS which is feasible or not feasible.

Defining directions for further research into operating one departure sector from two runways

This research has explored multiple concepts which are aimed at operating one departure sector from two runways. Being able to operate one departure sector from two runways allows for a more optimal usage distribution of traffic to the sector over the two runways compared. Two different variants of concepts have been explored, either focusing on merging traffic within the TMA (TRAF-MERGE) or outside the TMA (dual-SID concepts). Both concept variants have pros and cons, and their implementation is dependent on technical enablers or changes in the airspace. At the same time, the complexity of the concept requires further fast-time simulation or real-time simulation to study the flow of traffic and its effects on workload in more detail. Questions that these RTS/FTS studies should aim at answering are, amongst others:

- Traffic-merge: is a merge within the TMA plannable given a different kind of uncertainty in the operation including on the ground?
- Dual-SID: how will the number of Schiphol departures within a sector change when this sector is operated by two runways? And what effect does this have on the workload?

Quickscan/orientation DARP

During the feasibility study of multiple concepts, developments that are part of the DARP were identified as either enablers or potential issues for the analysed concepts. These developments are fixed arrival routes and departure tubes, the civil usage of TMA-D and the fourth initial approach fix. The redesign of airspace is a complex task, on which development is currently ongoing and the exact results are currently unknown. For the concepts which depend on the DARP, a first quickscan/orientational discussion with the DARP would be a short-term action.

Further research into the potential introduction of alternative aircraft at Schiphol

The negative outcomes of the feasibility study related to concepts which aim at facilitating alternative traffic (electric/hybrid or hydrogen aircraft) separate from main traffic flow indicate the potential issue for the future introduction of such aircraft. With de developments of these aircraft ongoing, further research should focus on the potential introduction of such aircraft at Schiphol. Questions which the research should aim at answering are, for example:

- What initiatives for alternative aircraft are there and how could these change the traffic mix (size, performance, noise, traffic volume) at Schiphol in the future?
- Which small volumes of alternative traffic can Schiphol facilitate without significant effects on capacity?
- Are there volumes of alternative aircraft at which these aircraft are dominant enough for the traffic mix to become more homogenous and negative effects on capacity will ease?

6.3 Medium term

Steps on the roadmap in the medium term are dependent on decisions made in the short term and on the results of further research. Steps on the roadmap for the medium to long term are:

- Stakeholder engagement, procedural design and implementation S12-South (depending on outcome safety study)
- Further development on CONOPS S12-North (depending on DARP)
- Decision-making on concepts for operating one departure sector from two runways
- Implementation strategy alternative aircraft

Stakeholder engagement, procedural design and implementation S12-South

Further steps regarding the S12-South concept in the short-term result in a CONOPS which is feasible or not feasible. When the CONOPS is deemed feasible, follow-up steps can be taken towards implementation of the concept. Part of the follow-up steps include:

- Informing and discussing the proposed concept with involved stakeholders such as communities around the airport, airlines, and the ministry (former ORS).
- Design/adjusting the relevant LVNL procedures in preparation of implementation.

Depending on the outcomes of the discussions with stakeholders and the final procedural changes, the S12-South concept can be implemented.

Further development on CONOPS S12-North

This study concluded that the S12-North concept is only feasible when traffic over the North Sea is separated using fixed arrival routes and departure tubes. These enablers are part of the Dutch Airspace Redesign Project (DARP). A first Quickscan/orientational discussion with the DARP is a short-term action. Based on the results of this Quickscan/orientational discussion, an initial decision can be made whether to pursue further development on the S12-North concept. Further development of the concept primarily focuses on the design of the sector 3 departure route over the ocean, this would ideally be done in close collaboration with the DARP.

Decision-making on concepts for operating one departure sector from two runways

Based on the outcomes of further research into operating one departure sector from two runways and on the Quickscan/orientational discussion with the DARP decisions-making should take place to further focus on the implementation of a specific concept or multiple (cooperating) concepts. The primary choice is to focus development further on a concept in which traffic is merged within the TMA or outside of the TMA.

In the decision making, dependencies between different concepts have to be kept in mind. The S12-South concept is for example an enabler for the S12-South-Dual concept, but all other dual SID concepts in southern operation (such as S3-DUAL-South LOPIK) and the Traf-Merge concept cannot be implemented in combination with S12-South since they require sector 3 traffic from the secondary runway.

Based on the decision made, focus shifts to the implementation of technical enablers to support concept implementation. The primary focus should lie on development of the Medium-Term Conflict Detection (MTCD) which supports merging traffic both within and outside of the TMA. For MTCD, 4-Dimensional trajectories are already available in the iCAS system. MTCD should also be applied before take-off when merging departures within the TMA (TRAF-MERGE).

Development of implementation strategy alternative aircraft

Based on the outcomes of research into the potential introduction of alternative aircraft at Schiphol, a sector wide implementation strategy can be developed. Besides airports, airlines and LVNL, other parties such as the building industry and the national government can also have a role in the development of this strategy. The implementation strategy should describe the sectors view on how, where, when and under which conditions these new innovations can be introduced into an operational environment. Having this strategy allows for individual stakeholders to take further actions to accommodate this alternative traffic in an efficient way in the future.

6.4 Long term

Where the analysis conducted in the previous phase has shown that the solution space for short term improvements is limited, the solution space for the long term is potentially large. This solution space is however strongly dependent on the realisation of technical enablers, external developments, and decision-making along the way. Depending on these aspects, the following concepts could be implemented on the long term:

- Implementation of concept(s) for operating one departure sector from two runways
- Implementation S12-North
- Introduction alternative aircraft at Schiphol

Implementation of concept(s) for operating one departure sector from two runways

When all technical enablers and other conditions (for example DARP) are met, follow-up steps can be taken towards implementation of the concept(s). Parts of these follow-up steps can also be conducted in parallel. Follow-up steps include:

- Informing and discussing the proposed concept with involved stakeholders such as communities around the airport, airlines, and the ministry (former ORS).
- Developing the relevant LVNL procedures in preparation of implementation.
- Development of an implementation plan

Given the complexity of some of the proposed concepts, an implementation plan should be developed which lays out how the concept will be introduced in the operation. Based on the earlier conducted research, conditions can be set for when the new concept is applied. This can for example be during outbound peaks with relatively low traffic volumes and limited other activities in different sectors. Over time these conditions can be adjusted based on evaluations of the concept. When evaluations are positive, using the concept more often can be considered.

Implementation S12-North

If further development of the concept results in a feasible CONOPS including a sector 3 departure route over the ocean, follow-up steps can be taken toward implementation of the concept. Part of the follow-up steps include:

- Informing and discussing the proposed concept with involved stakeholders such as communities around the airport, airlines, and the ministry (former ORS).
- Design/adjust the relevant LVNL procedures in preparation for implementation.

Depending on the outcomes of the discussions with stakeholders and the final procedural changes, the S12-North concept can be implemented.

Introduction alternative aircraft at Schiphol

Based on the developed implementation strategy alternative aircraft preparations are made for accommodating alternative aircraft at Schiphol. Depending on the progress of these developments, alternative aircraft might be accommodated at Schiphol under specific conditions. These conditions can for example entail the maximum number of movements (related to the available hourly capacity), or on certain times of the day, outside of peak hours. The exact moment when electric, hybrid or hydrogen aircraft enter the market, and a commercial airline wants to operate these at Schiphol, can however remain uncertain for a long time.

7 Conclusions

This research explored potential outbound traffic segregation concepts with improved performance on noise, capacity, and sustainability. Through four phases, segregation concepts were defined, analysed and assessed on feasibility to come to a roadmap with segregation concepts that are achievable in the short term and the steps which need to be taken for segregation concepts for the long term.

Trough the different steps, more and more insights were gathered to further sharpen different concepts. First, clear tensions between noise and capacity where observed, with for example sector 1 from runway 24 not being optimal from a noise perspective, while from a capacity perspective it is a preferred option. Later, the feasibility study, clearly demonstrated the dependencies in the current concept and the challenges that come with adjusting such a complex system. Through these steps, almost all concepts identified in the first phase changed in a sense that either additional conditions must be met, or technical enablers have to be implemented before a concept can be implemented or a concept has to be scaled down in order to limit negative side effects. This shows the complexity of the operational system and the difficulty of designing a new concept of operations.

The roadmap lays out several steps which can be taken in the short term and the longer term. For the short-term focus should be on building out and structuring concepts which are already happening in the operation, such as coordinating the routing of destinations and the structural usage of S12 in southern mode. In the longer term, Dual SID and/or traffic merge concepts enable the option to operate one departure sector from two runways. Dual-SID or traffic merge concepts allows for a more optimal assignment of some sector traffic over the primary and secondary runway since gaps in the departure stream of the primary runway can be filled with departures from the secondary runway. Implementation of these concepts requires several (technical) enablers and deployment during real peak moments is not excepted. There are however plenty of moments when there is only a marginal surplus of traffic, requiring a second departure runway. It is in these "low density peak moments" that the potential for dual-SID or traffic merge concepts lies initially.

The future introduction of alternative traffic (electric/hybrid or hydrogen aircraft) at Schiphol has been a component in this research due to its relationship with traffic segregation. The negative outcomes of the feasibility study related to concepts which aim at facilitating alternative traffic (electric/hybrid or hydrogen aircraft) separate from main traffic flow indicate the potential issue for the future introduction of such aircraft. With de developments of these aircraft ongoing, further research in this area is required. The issue is currently not pressing, but with the ongoing developments it is only wise to use the available time to prepare for the future introduction of such aircraft.

The roadmap contains several actions which can be taken on the short term. Some of these actions are specifically related to the domain of a single stakeholder or to the sector as a whole but outside of the scope of the KDC. For the KDC specifically, further research which is recommended to be included on the KDC research agenda is:

- Further research into the potential introduction of alternative aircraft at Schiphol
- Further research into Trajectory based departure management, as a first steppingstone towards traffic merging.

A Analysis of minimum departure intervals

A 1 Objective

The minimum departure interval between consecutive departures depends on several factors:

- Required wake-turbulence separation between aircraft; setting a minimum that always applies and depends on the RECAT-EU class of both aircraft
- Required radar separation in TMA; setting a minimum in TMA
- Required radar separation in ACC; setting a minimum that has to have been achieved before handover to ACC
- The speed profiles of both aircraft; while initially the leading aircraft will always be faster, the trailing aircraft may catch up at some point.
- The distance until the aircraft are laterally separated by flying in different directions; this determines whether the aircraft reach ACC airspace and how long the trailing aircraft has to 'catch up' with the leading aircraft by flying faster.

To ensure a comparison that is robust for future application of RECAT-TBS on departure, the analysis calculates the minimum required interval from start of take-off roll that ensures that minimum separation is achieved everywhere on the common path. By using historic tracks, the variation in speed profiles is considered.

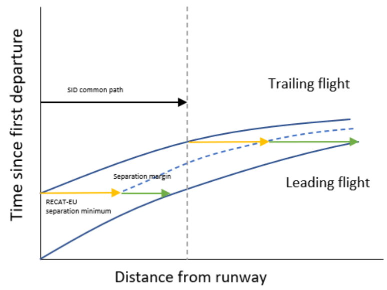
A 2 Process

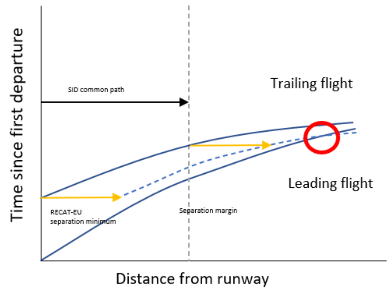
The analysis uses recorded ADS-B tracks from departures at Amsterdam to provide an accurate representation of the diversity in aircraft and operational speed profiles. The process steps are as follows:

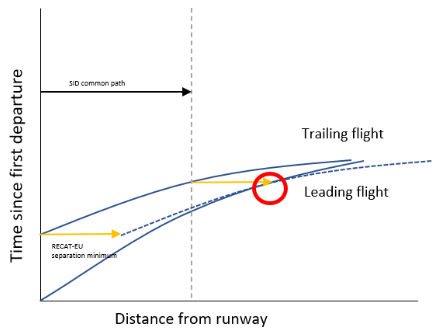
1. Selection of ADS-B tracks. The used tracks had the following properties:
    a. In the period between January 2020 and December 2021 to ensure representative behaviour
    b. From Schiphol
    c. Having reached at least 20000 feet to ensure sufficient information on speed profile
    d. For which a runway entry could be determined to provide the time since start of take-off roll
    e. For which Mode-S ES derived airspeed data is available and of sufficient quality
    f. With at least a datapoint every 0.5 NM
2. Derivation of groundspeed in ISA and zero-wind using METAR data. This ensures that all tracks can be compared irrespective of date or flight direction.
3. Calculation of a 1-D distance-time profile. This representation allows comparison on any theoretical SID regardless of wind speed and direction.
4. Analysis of minimum profile per group:
    a. Selection of group; selecting all tracks for the leader RECAT-EU class and all tracks for the trailer RECAT-EU class
    b. Determination of the separation requirements based on the length of the common path and the RECAT-EU class
    c. Calculation of all minimum separations and determination of the 90th percentile

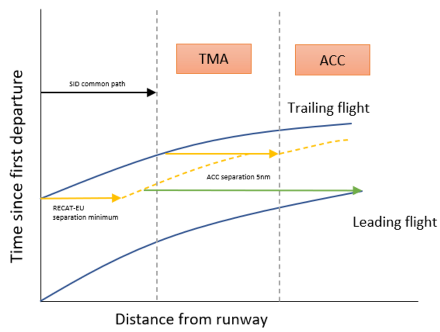
A 3 Determination of minimum interval between two tracks

The minimum departure interval between two tracks is determined by comparing the time-distance curves of these tracks:

<table>
<tr>
<td>1. Two tracks are place behind each other and the required separation interval is calculated as an offset (the yellow arrows) of the profile of the trailing aircraft (the dashed line).
2. The x-distance between the offset and the profile of the leading aircraft is the separation margin (separation more than required)</td>
<td>


</td>
</tr>
<tr>
<td>If the offset and the profile of the leading aircraft intersect after the end of the common path, the profiles are sufficiently separated.</td>
<td>


</td>
</tr>
<tr>
<td>If the offset and the profile of the leading aircraft intersect before the end of the common path, the trailing aircraft is delayed (the departure interval is increased) until the separation requirement is exactly met.</td>
<td>


</td>
</tr>
<tr>
<td>If the two tracks reach ACC on the same route, minimum separation for ACC (5NM) is included in the offset from 10NM after departure. This represents the need for APP to have achieved ACC separation before handover.</td>
<td>


</td>
</tr>
</table>

A 4 Source data

The source data contained 23911 ADS-B tracks from Amsterdam in the period between January 2020 and December 2021. Table 26 provides the number of tracks per RECAT-EU class.

Table 26: Number of tracks per RECAT-EU class

RECAT-EU Class	Number of tracks
Light	248
Lower Medium	4484
Upper Medium	9350
Lower Heavy	455
Upper Heavy	9260
Super Heavy	114
Total	**23911**