RECAT-EU FOR DEPARTURES AT SCHIPHOL

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Date 30 October 2020
Version V1.0
Document Nr FWY-2020-01
Executed by 1.Ferway & 2. MovingDot

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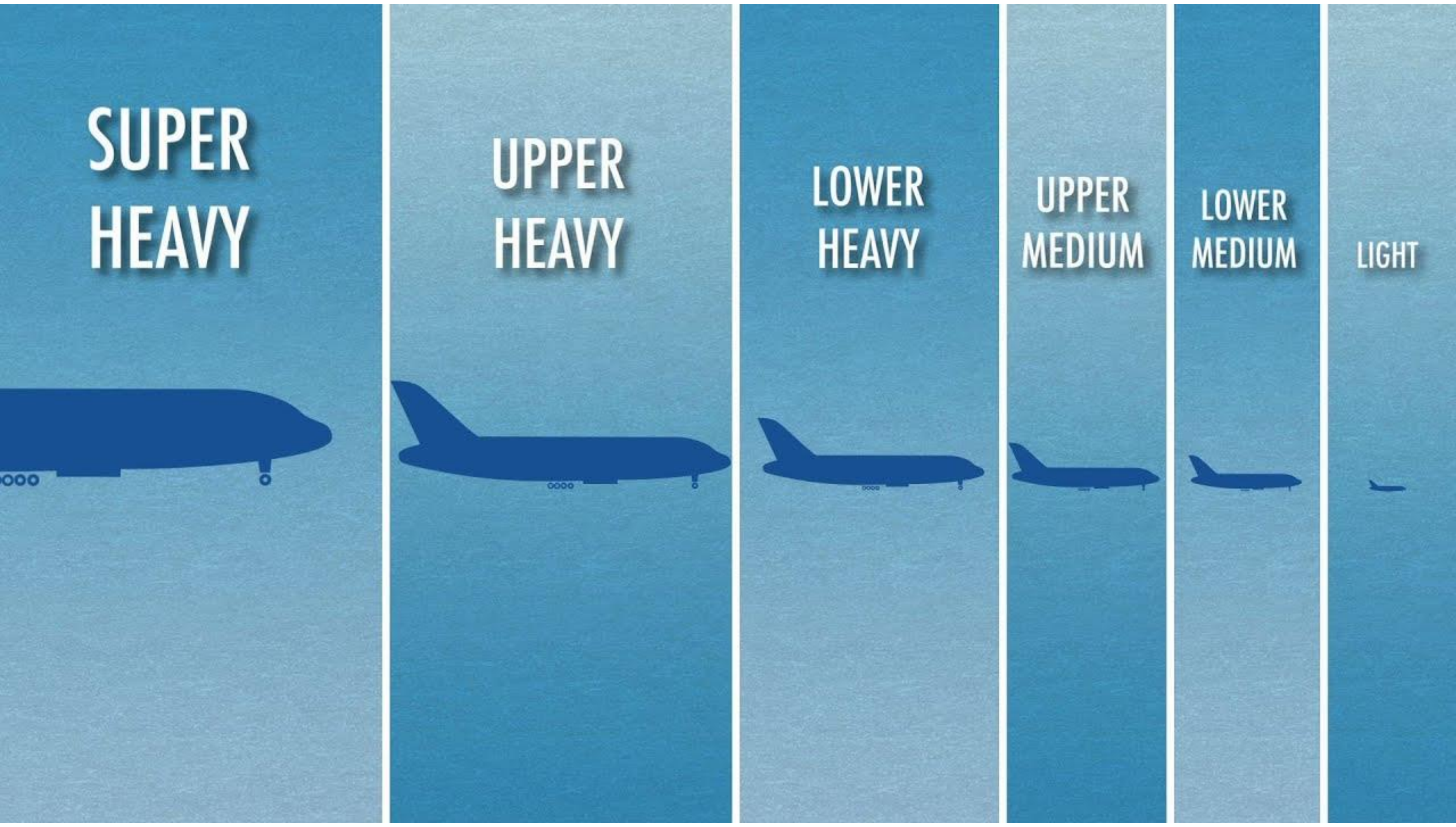

Date	30 October 2020
Report nr.	FWY-2020-01
Version	V1.0

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Report	FWY-2020-01
Version	V1.0
Status	Final
Date	30 October 2020
Title	RECAT-EU for departures at SCHIPHOL
Project number	KDC2020004
Client	Knowledge and Development Centre (KDC)
Executed by	Ferway & MovingDot
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Project team MovingDot	Nienke Jester Ander Okina
File name report	FWY-2020-01 RECAT-EU for departures v1.0
Classification	Internal

Report authorisation	Name	Date
Created by	Ander Okina (MovingDot), Ferdinand Dijkstra (FerWay)	30 March 2020
Reviewed by	Nienke Jester (MovingDot)	22 September 2020
	KDC-MT	28 October 2020

CONTENTS

SUMMARY

This study analyzed the factors that have a bearing on the departure capacity at Schiphol, in particular in relation to the potential introduction of RECAT-EU versus currently applied ICAO WTC separation criteria. The analysis revealed many factors that influence the start interval and the magnitude of this impact.

The results presented in this document provided an insight into real life operations at Schiphol where currently visual, time- and distance-based separation is provided, but now looking at it from only a time-perspective that is considered to be implemented with RECAT-EU. Unexpected behaviors in results could be attributed to the mix in separation concepts currently being applied and should thus be contextualized.

The most influential factor is the WTC or RECAT-EU category itself. The prevalent WTC categories in the traffic distribution have been studied and their average separation is given in Table 1. The current start intervals may range from 60 seconds to 140 seconds, depending on other parameters.

Table 1 - WTC-pair STIV summary – current operation

WTC-pair	Average STIV (sec)	Average STIV (NM)
Medium - Medium	78	3.4
Medium - Heavy	84	3.7
Heavy - Heavy	97	4.7
Heavy - Medium	138	7.2

The Start Interval (STIV) value for M-M pairs corresponds to the expected time separation of 80 seconds. For a M-H pair, some extra seconds are added to account for the faster speeds of heavy aircraft. Also, for H-H pairs the value of 97 is close to the nominal value of 100 seconds. Remarkably, the H-M pair show an average spacing of 140 seconds, which is 20 seconds more than the minimum required spacing of 120 seconds. It also produces a much larger distance spacing than expected: 7NM versus the required 5NM of WTC separation. This is inherent to the takeoff clearance process where the controllers, for the H-M pair only, apply 120 seconds between the takeoff roll and the next clearance.

The other elements of influence are tabulated in Table 2 to provide a quick overview and reference:

Table 2 - Summary of factors affecting the STIV

Impact item	Factor	STIV range	percentage of M-M pair
1	SID construction (Diverging)	20 seconds	25%
2	Runway dependencies	5 – 12 seconds	15%
3	Speed differences	10 seconds	13%
3	Weather (visibility)	4 – 7 (15 for H-H) seconds	9%
4	Airline Operating Practices	5 – 7 seconds	9%
5	Wind aloft	3 – 5 seconds	6%

Especially for the M-M WTC-pairs, all factors in Table 2 influence the departure timing. For other WTC-pairs, these factors have decreasing impact, whereas for H-H WTC-pairs there is no influence due to the large required WTC-separation.

For departures on diverging SIDs, about one third start below 3NM, after which spacing typically grows above this value after a minute.

Speed differences between a departure pair typically range from -30 to +30 KIAS for the first minute after departure. There is a clear correlation between the delta-speed and the STIV. This correlation is even stronger for departures on diverging SIDs.

The most promising beneficial RECAT pair (B-D) shows that typically more spacing is applied than required, especially for the non-diverging SID departure pairs. The gain is limited by the overall percentage of beneficial RECAT pairs in the Schiphol fleet-mix.

SID construction has a significant impact on departure timing and therefore on capacity. When designing SIDs, this should be taken into account where capacity and noise abatement may be competing arguments. However, when more non-diverging SIDs would be used, the reduction of separation for wake becomes more important, as more aircraft would have to adhere to wake separation at takeoff.

The percentage of RECAT-EU flight pairs in the Schiphol traffic mix with associated separation reduction is 14%. The most beneficial RECAT-EU pair (CD) forms only a very small part of the overall set of pairs with benefits, and only in the first three Schiphol traffic peaks. The busy fifth and last outbound peak has only a small set of BB and BD pairs. This distribution will significantly influence the RECAT-EU potential benefits for Schiphol.

This should be taken into account when calculating potential benefits. Moreover, while the RECAT-EU concept allows both time- or distance-based separations to be applied for both departure and arrivals, only the time-based implementation is being considered for Schiphol. This in contrast to current procedures where the TWR controller applies a mix of time, distance, and visual separation. For diverging SIDs, the TWR controller is applying aerodrome control under visual conditions, thus already making use of reduced spacing due to the nature of the routing after takeoff.

Based on the pilot responses received, operating departures under a RECAT-EU regime at Schiphol airport is not expected to have significant impacts on their operations at Schiphol airport.

An initial numerical assessment of the capacity impact indicates a possible gain from RECAT-EU for departures at Schiphol of 0.75 (afternoon peak) to 1.4 (morning peak) flights per hour per runway, depending traffic mix. The difference primarily stems from the number of heavies in a peak. Heavies are concentrated in the morning peak, hence, more benefits are achievable there.

This calculation applies to high demand situation. However, benefits may also be obtained under less demand situation for dependent and mixed-mode runway operations. It must also be noted that the total airport capacity is dependent on analysis measures a ‘gap in time’ in situati a departure sequence, the controller may have chosen to use this time for a runway crossing for an arrival for example. Therefore, when interpreting both the effects of factors affecting spacing and assessment of capacity gain, this should be considered as a source of error.

1 INTRODUCTION

1.1 Background

EUROCONTROL has developed a re-categorization of the wake turbulence categories as defined by ICAO. The initiative splits the "Heavy" and "Medium" categories into "upper" and "lower" categories. The [illegible] longitudinal separation minima for traffic. The new categories yield lower separation minima for certain traffic combinations. This can potentially benefit runway throughput, while still maintaining acceptable safety levels.

Implementing the new wake turbulence categories are expected to lower the separation minima for certain traffic combinations. It is expected that Schiphol airport will see a runway throughput increase, as the traffic combinations are expected to be positively affected by the new separation minima.

1.2 Objective

The objective of this study is to provide insight into:

- the expected capacity increase with the introduction of RECAT-EU for departures.
- the factors that influence or are relevant to the expected capacity increase.
- resources that could be deployed to promote the realization of expected capacity gains.
- safety aspects of the RECAT-EU operation for departures.

1.3 Scope

The scope of this study is limited to the time-based RECAT-EU for departures potential at Schiphol Airport.

1.4 Methodology

To obtain the necessary insights, a number of activities were carried out by FerWay and MovingDot. The activities carried out are briefly described below.

Analysis of departures under ICAO-WTC and RECAT-EU regime

This part of the work will explore the extent to which current departure capacity is limited by the application of the ICAO WTC regime. There are a multitude of factors involved in this relation, the most important ones comprise:

- Current ICAO separation rules applied in practice
- Visibility conditions
- Construction of Standard Instrument Departures (SID)
- Runway pressure: is there enough demand for the runway in order to measure capacity factors?

Other, less well-known factors include:

- Takeoff runway: are there differences between runways?
- Wind aloft: sometimes controllers take the wind after the aircraft is airborne into account for the departure timing.
- Airline Operating Practices: to which extent does pilot behavior with respect to WTC separation influence the departure capacity?
- Speed profiles of aircraft types operating at Schiphol

By means of a correlation analysis, other potential factors will be looked for that are perhaps not directly obvious from expert judgement.

The analysis will use traffic data from the years 2018 and 2019.
Analysis and corresponding findings of departures under ICAO-WTC and RECAT-EU regime at Schiphol airport are presented in chapter 2.

Examination of cockpit and ATC operating practices
In order to obtain insights into potential implications of the implementation of RECAT-EU regime on either cockpit or ATC operating practices, conversations were held with both active Schiphol TWR/APP controllers and pilots of a (limited) selection of airlines that have current operations at Schiphol airport. Examination of cockpit and ATC operating practices and corresponding findings of departures under a RECAT-EU regime at Schiphol airport are presented in chapter 3.

Impact analysis and possible collaboration with EUROCONTROL
It is expected that after delivery of this study, Eurocontrol will perform an impact analysis of the departure capacity at Schiphol for the introduction of RECAT-EU for departures. At the time of writing of this report, the target date for the results of this study is not known yet. When these results become available, they will be integrated into a second release of this report as an Annex with an update to relevant other sections as appropriate. This may also include recommendations with respect to safety monitoring.

Therefore, this study has focused primarily on the factors affecting the departure capacity by applying RECAT-EU criteria. The initial delivery of the document will however provide an indicative assessment of the impact on capacity based on the outcome of the analysis.

Analysis of safety impacts
Specific Schiphol dependencies, which could have an impact on the implementation of RECAT-EU were also considered. Analysis of safety impact analysis and corresponding findings of departures under a RECAT-EU regime at Schiphol airport are presented in chapter 5.

2 ANALYSIS OF DEPARTURES UNDER ICAO-WTC AND RECAT-EU REGIMES

In this chapter, departure separation under the current International Civil Aviation Organization (ICAO) Wake Turbulence Category (WTC) separation rules and RECAT-EU regime are analyzed in depth. Separation on departure is governed by many factors. The three regulatory rules defined by ICAO are:

- WTC separation
- Minimum radar separation (TMA + CTA)
- Visual separation

Details of the ICAO WTC and RECAT-EU categories are presented in Annex B.

Furthermore, there are many conditions and circumstances affecting the departure capacity, ranging from traffic demand, aircraft type, airline operating practices, to runway layout and meteorological conditions. This chapter starts by providing a short description of the method used to conduct the study followed by the analysis material.

Note: While the RECAT-EU concept allows both time - or distance-based separations to be applied for both departure and arrivals, only the time -based implementation is being considered for Schiphol departures. This is in contrast to current procedures where the TWR controller applies a mix of time, distance, and visual separation.

2.1 Departure separation analysis method

This study aims to analyze the effect of wake turbulence separation strategies on departure capacity thus providing insight into potential gains should Schiphol TWR apply time-based separation only. To this end, real-life data of departure operations at Amsterdam Airport Schiphol was collected for the years 2018 and 2019. Since airport capacity has not increased in the last years and the scope of this study does not include trend analysis, these two years are deemed sufficient to facilitate a statistically relevant analysis. There was however a six-week period in 2019 during which a new electronic flight strip system was installed in the TWR, with reduced arrival and departure rates being applied during this period.

Application of wake turbulence separation criteria may increase departure spacing and therefore reduce departure capacity. However, a reduced realized capacity may also be the consequence of lack of demand. Lack of demand in this context means insufficient traffic available for departure at the runway, even though a flight could have taken off, had it been waiting at or on the runway.

In order remove the cases where lack of demand existed, several techniques can be used. The technique used in this study is described in section *2.3 Runway Pressure*.

Given a method to classify whether a takeoff occurred, the timing of which was not influenced by departure demand, these takeoffs are initially explored by distribution over takeoff runways at Schiphol, wake categories and departure peak-periods. This information provides the context for subsequent analysis in this chapter.

Given the context of how traffic under demand pressure is distributed over runways and wake categories, different factor affecting the departure separation were analyzed. Factors well known to bear a relation with departure capacity was analyzed first, followed by an exploratory investigation of other possible elements of influence.

Finally, to gain insight into the effect of aircraft speeds on departure capacity, the separation between aircraft pairs in the TMA-phase of flight was studied.

Depending on the particular analysis topic, a perspective from ICAO-WTC and/or RECAT-EU wake categorization was used. Often, the RECAT-EU analysis itself provides insight into ICAO-WTC distributions as well since the RECAT-EU categories are more detailed sub-categories of the ICAO-WTC. However, both were addressed, as they are relevant to the topic under investigation.

2.2 Departure time definition (ATD, ATOT)

In this study, a detailed analysis of factors affecting departure timing is performed. It is therefore essential to define precisely the moments in time which are compared. A key time reference point in departure studies is obviously the actual moment of departure. Various definitions exist:

- **ATD (Actual Time of Departure)**: This term is used in LVNL systems and data analysis. The ATD is determined by the Schiphol TWR automation system and in principle, refers to the moment the aircraft has passed the mid-point of the runway. However, during validation of this information, it appeared that the method employed by the TWR system is based on a calculation, not the actual detection of passing of this point. Hence inaccuracies result.
- **ATOT (Actual Take Off Time)**: This term is defined by EUROCONTROL as 'The time that the aircraft takes off from the runway'. The definition is not specific as to the exact moment. For this study, Multi-Lateration (MLAT) data was processed to derive the exact moment the aircraft passes the mid-point of the runway, as is intended by the definition of ATD used within LVNL. To distinguish where necessary, the term ATOT is used in this study using this implementation.
- Another conceivable interpretation would be the moment the **aircraft rotates**. This moment is not chosen for this study for different reasons. First, it is not consistent with the LVNL definition of ATD. Secondly, it does not provide a fixed reference point to measure separation. Also, the derivation of this definition is not reliable due to insufficient accuracy of the MLAT altitude data.

Important to note that when the controller uses time to determine departure intervals, the reference point is when the preceding aircraft starts its takeoff roll.

2.3 Runway Pressure

In order to be able to distinguish whether separation between a pair of aircraft is determined by rules for separation or merely by demand on the departure runway, a method is needed to qualify aircraft pairs, preferably for each consecutive aircraft taking off, rather than for a period of time. When using a period of time, a choice is forced to "draw the line" at a cer
that period, in order for them to be considered as taking off under high-demand conditions. That is, a certain capacity threshold needs to be assumed for considering a time period as under high demand. Such a mechanism will, on the one hand, discard certain aircraft pairs while that happ
on the other hand it may include pairs where there happened to be a short period with lack of demand. Another method could be to filter on peak periods or use of two departure runways. These two methods suffer from the same inaccuracies.

In this study, a method was developed to determine if an aircraft has taken off under high-demand conditions, that is, its takeoff timing was not a result of demand but rather by rules of separation. This is achieved by using the following principle:

An aircraft is considered to have departed under runway pressure when the time between the ATOT of the preceding departure and the moment the aircraft has entered the runway is less than a nominal value.

Different nominal values have been used for Heavy/Super and Medium aircraft. The nominal values are established based on a statistical analysis of the line-up time distribution in high capacity periods. This method was verified to be a reliable indicator to determine whether the takeoff timing was driven mainly by demand or by separation rules. This was achieved by comparing high hourly capacity realisation with this runway pressure indicator

2.4 Departing traffic context

Before starting an in-depth analysis of the departure timing characteristics, some context is needed regarding traffic volumes, how they are concentrated over periods of the day and what they are composed of in terms of wake categories. This information is provided in the following sections.

2.4.1 Runway Loading

Due to the preferential runway systems, selection of a takeoff runway is not only based on demand and wind, leading to some departure runways being used for more traffic than others. In Figure 1, the distribution of departures over the available takeoff runways is given, further divided by if the departure occurred under runway pressure or not.

The figure indicates that the departures from 24+18L and 36C+36L, usually combined in this manner, are used most often. Runway 18C is used infrequently, but when used, it is used with runway pressure, the same holds even more so for runway 09. Traffic from runway 27 is negligible. Note that runway 06 has not been included as the number of departures from this runway was too low to be relevant.

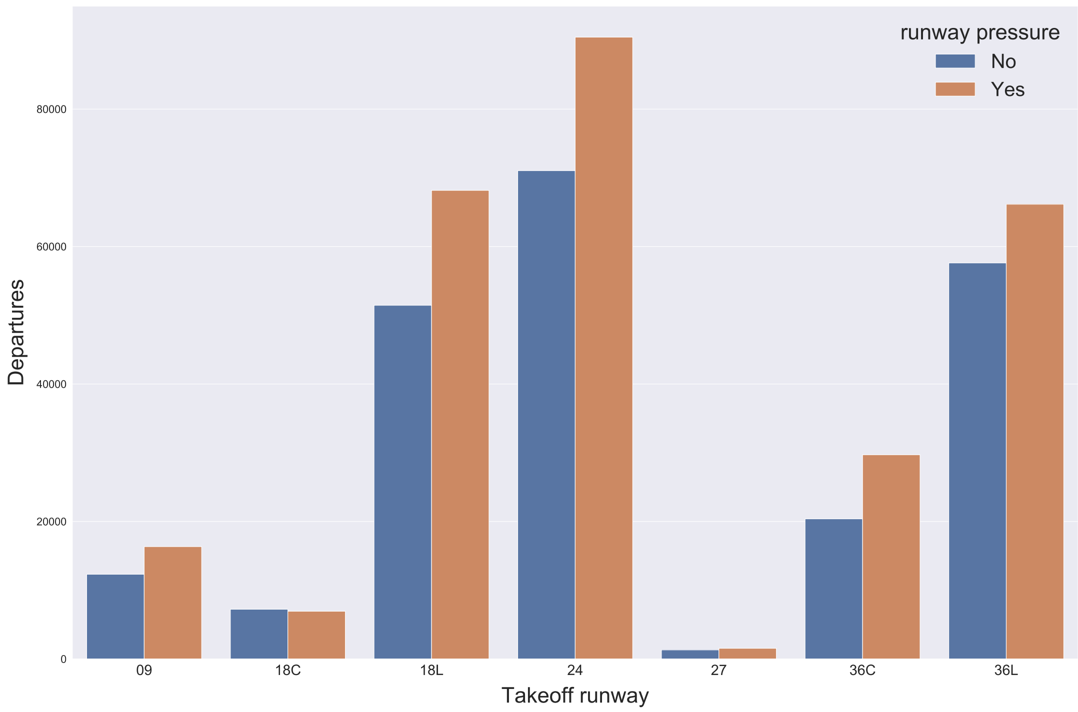

Figure 1 ǒRunway loading: distribution of departures over the available takeoff runways.

2.4.2 Distribution of wake category types

In order to better understand the analysis of wake separation effects, an overview is provided of the distribution of wake categories in departing traffic. For ICAO-WTC, this overview is given in Figure 2, whereas Figure 3 shows the distribution for RECAT-EU. Refer to Annex B for an overview of the ICAO WTC and RECAT-EU categories.

The ICAO WTC figure clearly shows that the vast majority of aircraft pairs involves the following pairs: HH, HM, MH, MM (in total 99%). Considering the very low frequency of the other pairs, only the pairs involving Medium [M] and Heavy [H] aircraft were further explored in this study especially since the potential impact on capacity of the pairs involving Light (L) and Super (J) will be negligible.

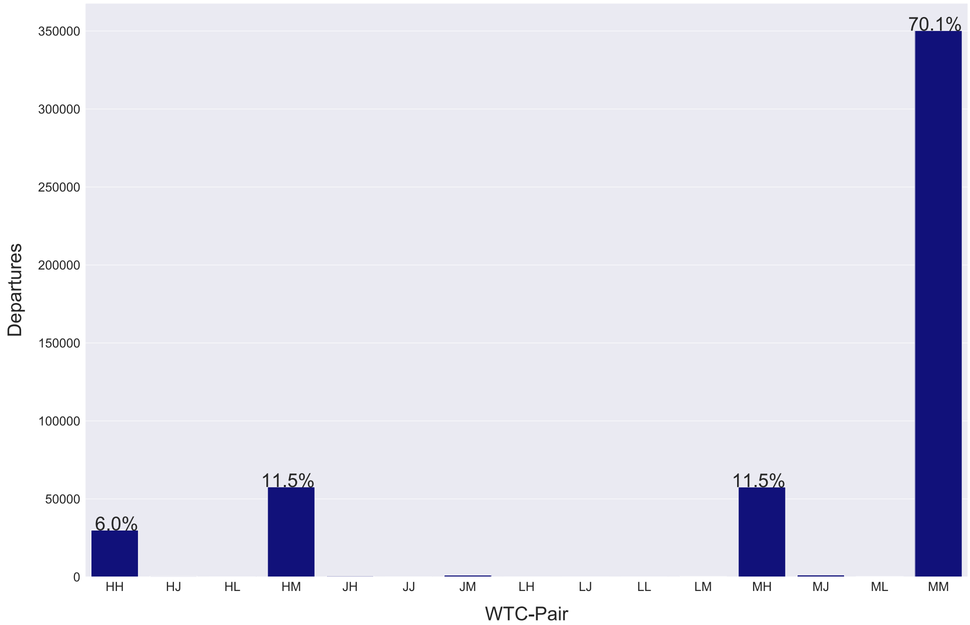

Figure 2 - Distribution of ICAOwake category pairs in departing traffic.

Obviously, similar patterns can be seen in the breakdown in RECAT-EU categories. For the same reason as for ICAO-WTC, this study focuses on pairs that have a noticeable presence in the sample. This excludes the pairs involving A and F. This allows the study to be more focused, as especially for RECAT-EU, many permutations are possible and make the results less compact.

Note that for the RECAT-EU scheme, there are six category pairs that have benefits in terms of reduced separation (refer also to Annex B for the RECAT-EU category specification):

- 20 seconds potential benefit: BB, CB, CC, BD and CE
- 40 seconds potential benefit: CD

In this study, these categories are defined as:

> *Beneficial RECAT-EU pairs are those departure pairs for which the RECAT -EU scheme defines reduced separation compared to ICAO-WTC.*

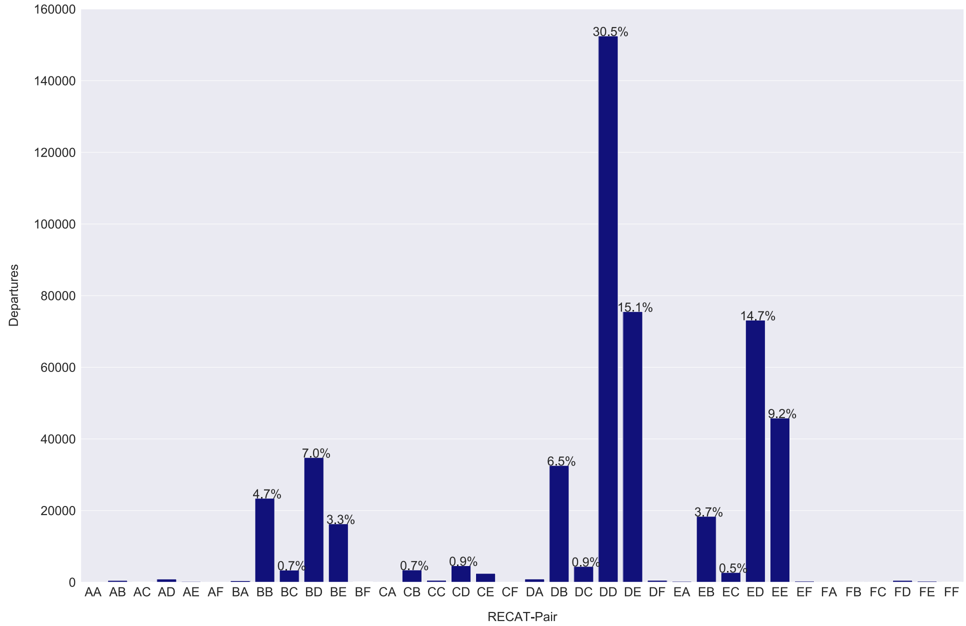

Figure 3 - Distribution of RECAT-EU wake category pairs in departing traffic

Finally, the relation of the beneficial RECAT-EU pairs to runway pressure is depicted in Figure 4. For most of the pairs, roughly 50% are take-offs under pressure. Consequently, from a point of view of single runway throughput, half of the beneficial pairs could contribute to potential benefits. There are however additional potential benefits that could be expected, these will be described as part of controller feedback in Chapter 3.

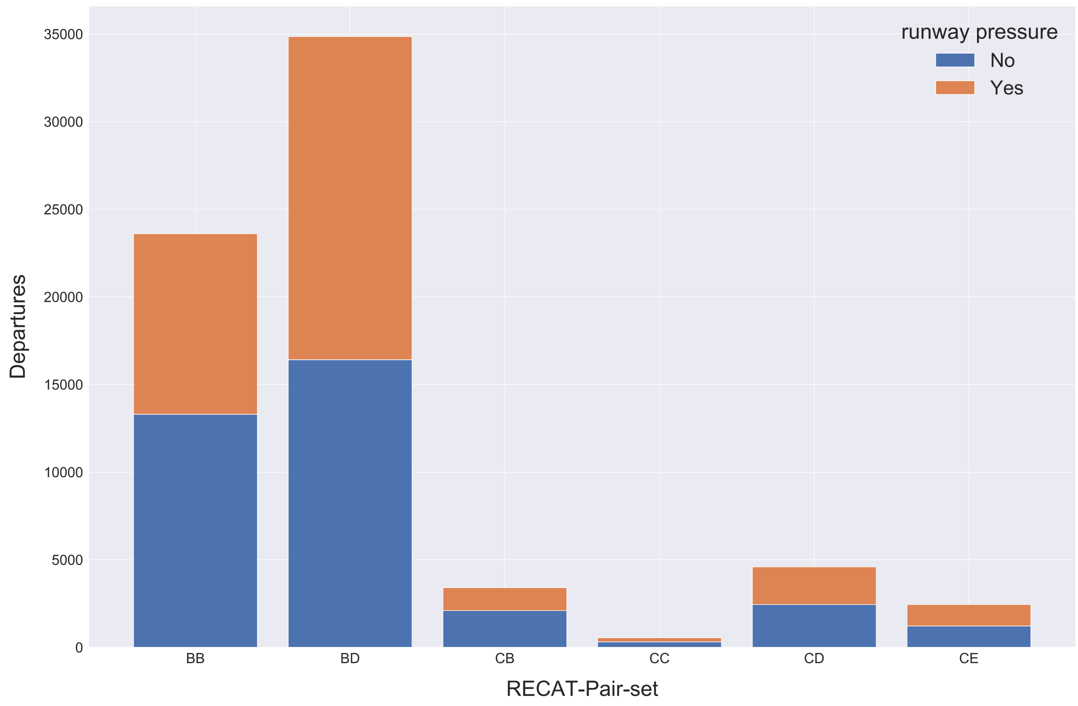

Figure 4 - Relation of beneficial RECAT-pairs and runway pressure

2.4.3 Distribution over outbound peaks

Traffic at Schiphol Airport arrives and departs primarily in peak-periods. During, for example, an outbound peak, two departure runways are used to manage the outbound demand. However, not all outbound peaks are created equally. Morning arrival peaks typically contain a higher concentration of heavy aircraft than the evening peak. Outbound peaks have different volumes of traffic. Normally, of the five peaks, the first and last peaks show higher demand than the other peaks. Figure 5 provides background information on the composition and volume of outbound peaks relevant to the potential benefits of RECAT-EU. This information will later be used to quantify potential benefits. The pairs comprising the beneficial RECAT-EU pairs are shown (BB, BD, CB, CC, CD and CC) as well as all the remaining pair
the quantitative relation between the two main groups.

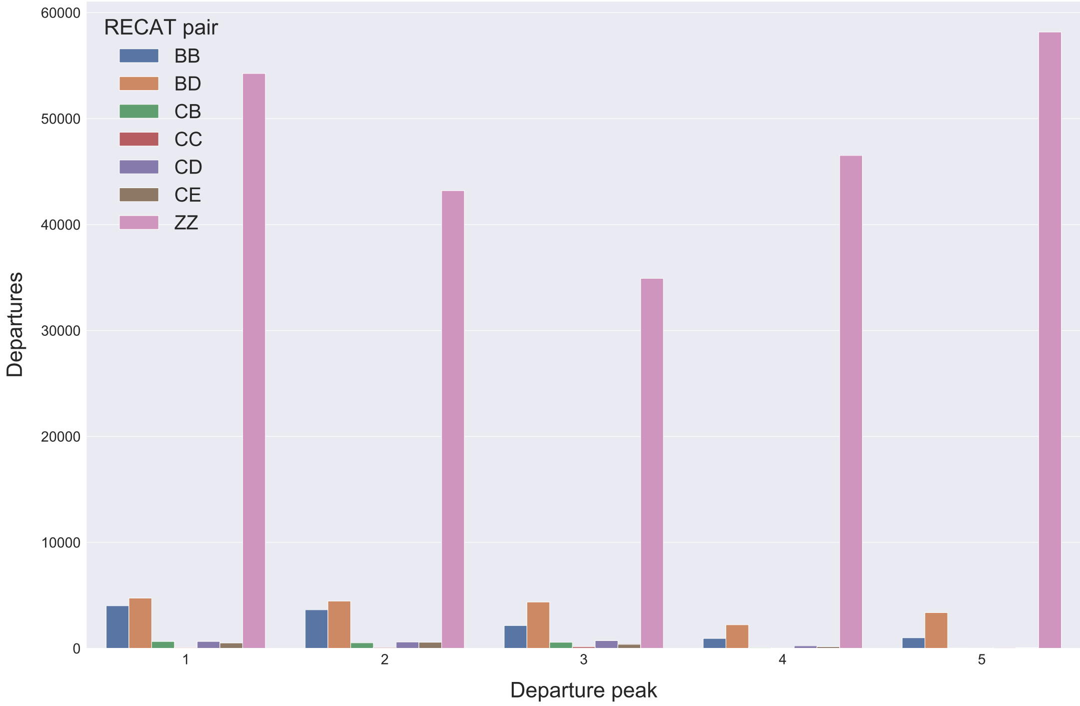

Figure 5 - Distribution of beneficial RECAT-EU pairs over outbound peaks

The figure shows that a relatively small portion of the traffic is subject to RECAT-EU benefits (14%). The most beneficial RECAT-EU pair (CD) forms only a very small part of the set of pairs with benefits, but only in the first 3 peaks. The busy fifth and last outbound peak has only a small set of BB and BD pairs. This distribution will significantly influence the RECAT-EU potential benefits for Schiphol.

2.5 Factors affecting initial departure separation

Given sufficient demand, that is, an aircraft is lined-up for departure before the preceding aircraft departing from the same runway is airborne (ref. section 2.6). However, there are many factors influencing the exact departure timing. An overview of the key items is provided below:

- Timing of takeoff clearance
- Pilot reaction time
- Aircraft acceleration till moment of ATOT
- Wake Turbulence separation
- Routing after takeoff (SID), like for example diverging routes right after takeoff.
- Aircraft speeds (horizontal, climbing)
- Visibility conditions
- Winds aloft
- Runway dependencies (converging runways, jet-blast)

The item 'Runway dependencies' entails many different factors which are beyond the scope of this study into the effects of wake separation on capacity. However, the influence of runway dependencies is taken into account in this study when analyzing the timing. The other factors listed are taken into account up to the ATOT of the second aircraft in an aircraft pair. The effects pertaining to the part where both flights are airborne is studied in the next section.

This report makes extensive use of boxplots - [illegible] to illustrate distributions. This method is chosen as it provides a powerful tool to clearly present median values, ranges and outliers. More details on how to read a boxplot can be found in Annex A.

2.5.1 ICAO WTC rules

For the specification of the ICAO WTC separation criteria refer to Annex B.

In Figure 6, the distribution of the measured departure separation distance at the moment of the second ATOT in a flight pair is given for each ICAO WTC-pair that will be studied. This figure gives a general impression of how WTC separation influences capacity. It expresses all the factors combined that are analysed in this section.

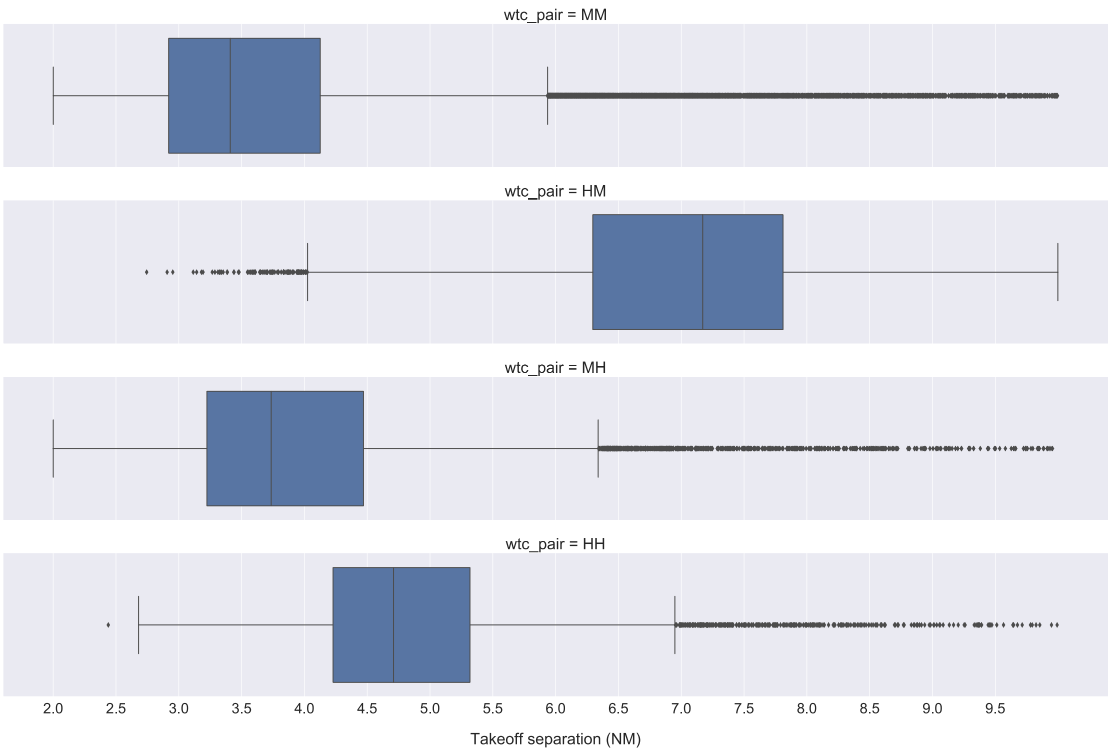

Figure 6 - measured ICAO WTC separationin distance

The medium-medium pairs have the smallest spacing, which is to be expected given the ICAO WTC specification. Note that for M-M pairs the ICAO WTC separation is equal to the MRS. Although the table suggests an equal separation between a heavy following a medium, the figure shows a slightly increased distance. This is attributed to the fact that the controller will wait a little longer with the takeoff clearance to account for the higher speeds of the heavy aircraft.

Another explanation could be that the controller uses similar timing methods, but if pilot reaction time or acceleration of the heavy aircraft takes longer, more departure separation would result. Analysis of the roll-time versus the ATOT has not demonstrated a noticeable difference between the WTC categories. The remaining cause is pilot reaction time. Controller expert judgement indicates about 10 seconds of difference between the takeoff of a medium versus a heavy aircraft, which could explain the time difference measured (ref. Figure 7). The relation with the actual takeoff clearance timing can only be confirmed by performing an analysis of timing measurements, which was not part of this study.

Just like for the previous two combinations (MM and MH), the HM and HH pairs show more separation than required by the ICAO WTC regime. This suggests that it is likely that more factors determine the eventual departure separation and a more detailed investigation is needed. This is done in subsequent sections.

Figure 7 shows the same measure ICAO WTC departure separation, but now given in time.

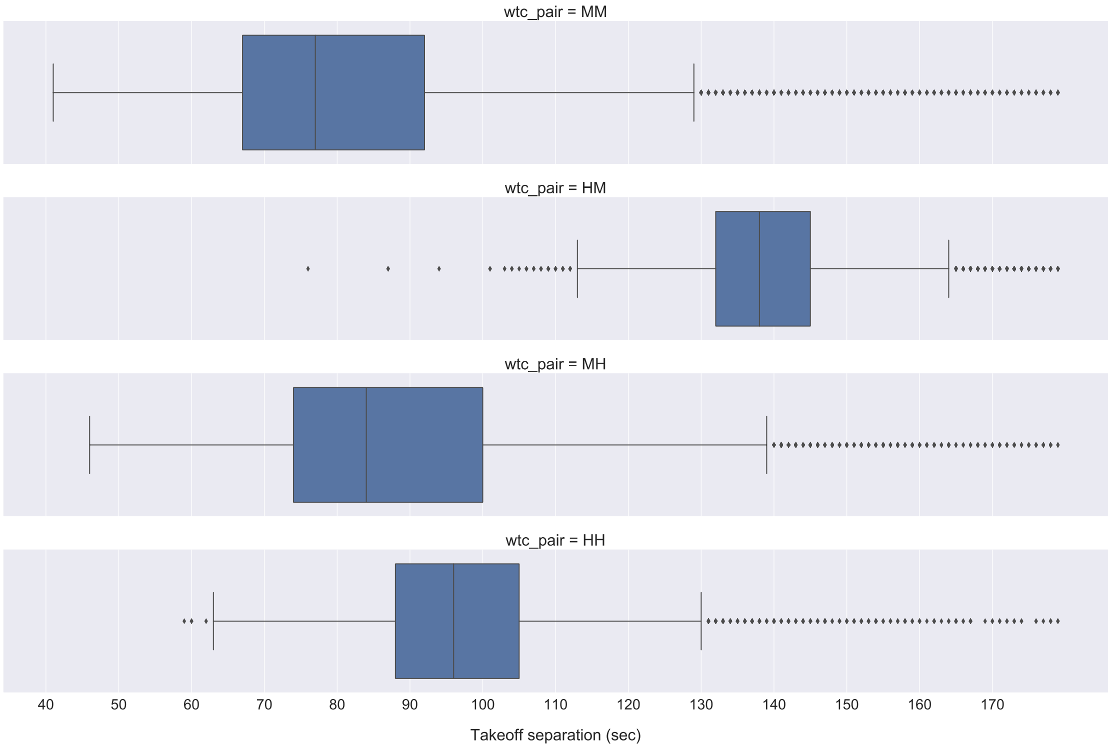

Figure 7 - measured ICAO WTC separation intime

Similar effects are noticed as for separation expressed in distance. Most notable is the difference in time for HM pairs. The ICAO criterion prescribes 120 seconds, while a mean of 140 seconds is measured. A reduction from 120 to 100 and 80 seconds as allowed under RECAT-EU, would first require an understanding of the current difference between the 140 seconds measured spacing and the norm of 120 seconds, see also the explanation for Figure 6 for HM pairs.

The effect of a heavy behind a medium was investigated further by analyzing the RECAT-EU categories to get a better understanding of this effect and a more accurate assessment of potential gains. This is shown in Figure 8. First, the figure shows that even though RECAT-EU spacing is not applied in the traffic set of this study, the RECAT-EU categories do mark a distinction in how heavy aircraft are spaced behind a medium: the larger the difference in weight class between B, C (Heavy) and D, E (Medium), the more spacing is recorded for the analyzed dataset. This holds for the B, C and C, D sub-groups amongst themselves and between the two groups. The figure does not show large differences for other pairs compared to their corresponding ICAO WTC categories.

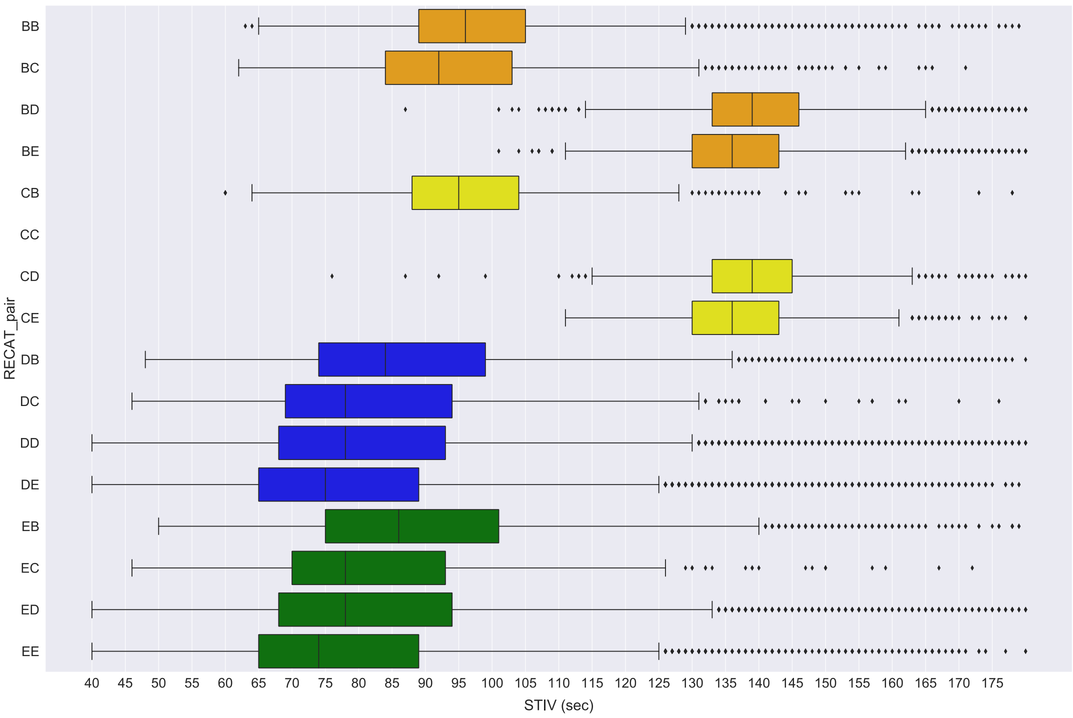

Figure 8 - measured spacing for RECAT-EU categories

2.5.2 Standard Instrument Departure (SID) routing

Based on controller input and expert judgement, it is a known fact that departure pairs using the same or similar SID, can have an influence on departure spacing. Based on conversations with TWR controllers, the analysis of the impact of SID-routing on departure is divided into two categories:

- **Divergent SID-pairs**: for the purpose of this study, a divergent SID-pair is defined as consisting of two SID's that will fan out within the first 4 track miles after departure.
- **Shared-path SID-pairs**: for the purpose of this study, shared-path SID-pairs includes all SID-pairs for which the aircraft pair SID's share at least the first 4 track miles after departure.

In other words, a SID is considered to diverge with the previous SID when it breaks away within the first 4 track miles of the lead aircraft. The reason for this criterion is that up to this point, under good visibility conditions, the TWR controller applies visual control before the aircraft is under control of APP which has to apply Minimum Radar Separation (MRS).

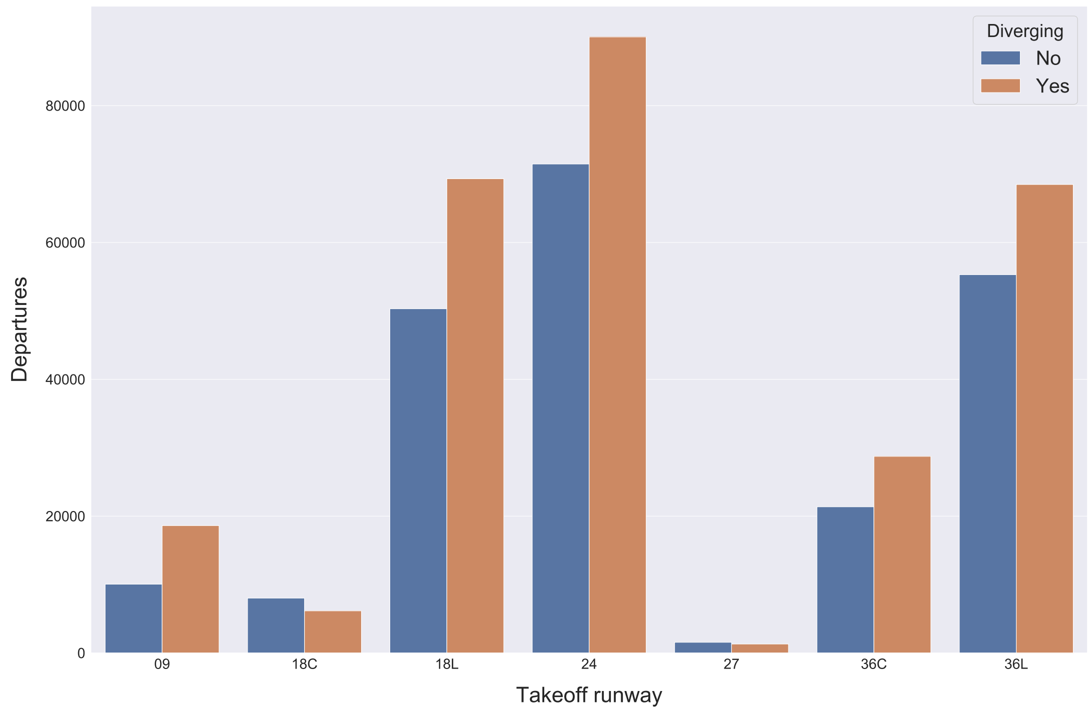

Figure 9 - SID divergence per runway

Figure 9 shows the distribution of departing traffic over runways per the defined criterion of divergent SID paths. Note that for most runways, the number of flights on diverging SID pairs are roughly 25% greater than for shared-path SID pair departures. Note that Figure 9 resembles Figure 1 (where runway loading under pressure is shown) to a large extent. This could suggest that there is a correlation between runway loading and the use of divergin g S.ll Ð ’ swe then look at the percentages of pressure, we find a distribution as presented in Table 3. For example, for all diverging SID-pairs, 59% occur under runway pressure, whereas for the not diverging SID-pairs this is only 48%.

Table 3 - SID Divergence in relation to runway pressure

Runway pressure	Not diverging SID-pairs	Diverging SID-pairs
No	52%	41%
Yes	48%	59%

Clearly, when there is pressure on the runway, more diverging SID pairs are seen. It is likely that this can be attributed to TWR optimizing the departure sequence with respect to the SID pairs.

For the detailed analysis of the factors impacting departure separation, the separation was measured in time only, as the RECAT-EU reduction at Schiphol will be applied in time, not distance. First, Medium-Medium pairs were analyzed in detail to identify dependencies with the takeoff runway. Subsequently, all WTC-pairs of this study were examined for their sensitivity to SID construction. In order to measure under high capacity only, 2 take-off runway operations are required and good visibility conditions. The effect of marginal or BZO conditions is analyzed at the end of this section.

Medium-Medium pairs:

Figure 9 shows the departure spacing in time for the two SID-pair categories defined above. To gain insight into any possible influence of a specific departure runway, a boxplot for every runway in each category was created.

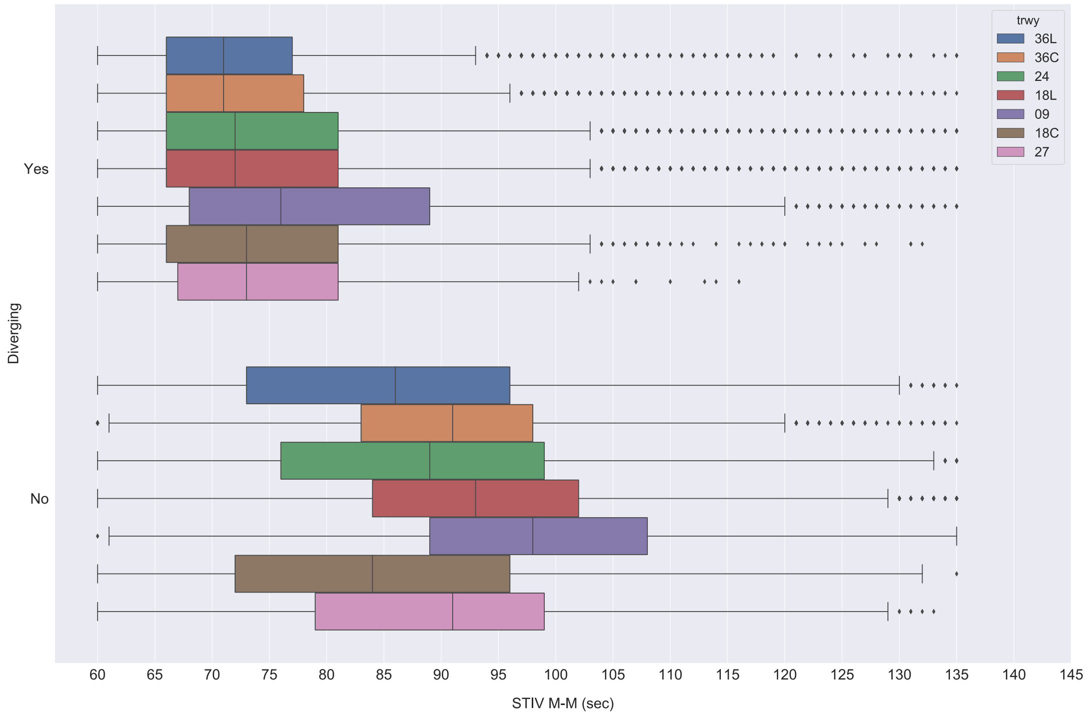

Figure 10 - Start interval per M -M WTGpair, takeoff runway and SID -type

The figure tells us that for a Shared-path SID-pair about 20 additional seconds for the departure interval are measured. The 20 second addition is to help ensure compliance with the required separation criteria during and possibly after the TMA phase. If separation criteria are reduced by RECAT-EU, the additional seconds would still be applied, but then to a reduced required separation value.

For diverging SIDs, very little variation is seen among the different runways, in particular for the median values. The only exception being runway 09, where more spread is observed. This is attributed to the dependency with landings on runway 06 or 36R. This was confirmed by eliminating departures from runway 09 whilst runway 06 was in use for landing. The shift that can be observed for runway 09 largely disappears for diverging SIDs.

For non-diverging SID-pairs similar patterns are seen, however, it is noticeable that departures from runway 18C have a slightly tighter departure timing, in the order of 5 seconds on average. This can be attributed to different causes:

- The TWR controller has an almost perpendicular view of the runway end for runway 18C departures (RWY-head 36C). Therefore, if the controller app separation timing tool, this is the most accurate for this runway.
- Runway 18C/36C is the shortest runway of the most frequently used runways for departure. If the “passing runway threshold” criterion is used, this is more than half of the difference in median value with runway 36L.

- Runway 18C is almost always used for parallel departures with one of the other 18 runways, for which a dedicated controller is used. This controller keeps the aircraft on his frequency until the departing aircraft has started turning, meaning that he is extra focused on the evolution of the traffic, and extra focused at providing the take-off clearance.

This warrants further investigation into whether adding automation to support the controller in the takeoff timing could result in the gain of a few seconds for each interval.

The slightly longer intervals seen for runways 24 and 18L are attributed to the impact of runway dependencies.

<u>**All WTC pairs:**</u>
Since the patterns per runway are similar for the other WTC-pairs in this study (M-H, H-H, H-M), they were collectively analyzed, including M-M for comparison, as shown in Figure 11. From this figure we learn that:

- For M-M pairs, the non-diverging SIDs reflect about 20 additional seconds to the start interval (as observed in Figure 10 too).
- For **M-H pair**, the same order of magnitude as for M-M is observed, although a slightly higher value would be expected because of the faster trailing Heavy aircraft. The sample does show however that the “fast side”, i.e. to the left of the medi -H pairs, is larger and therefore has more spread than for non-diverging pairs. This may be attributable to other factors like airline or speed profile as will be discussed in the next section.
- For **H-H pairs**, the increase compared to M-M pairs is also about 20 seconds for diverging SIDs and only 5 seconds for non-diverging SIDs. It can be concluded that for this pair, the wake separation is the dominant factor for departure timing.
- The **H-M pairs** have of course the largest wake separation (5NM) and therefore the longest interval time: about 140 seconds. There is no observed influence from the SID construction.

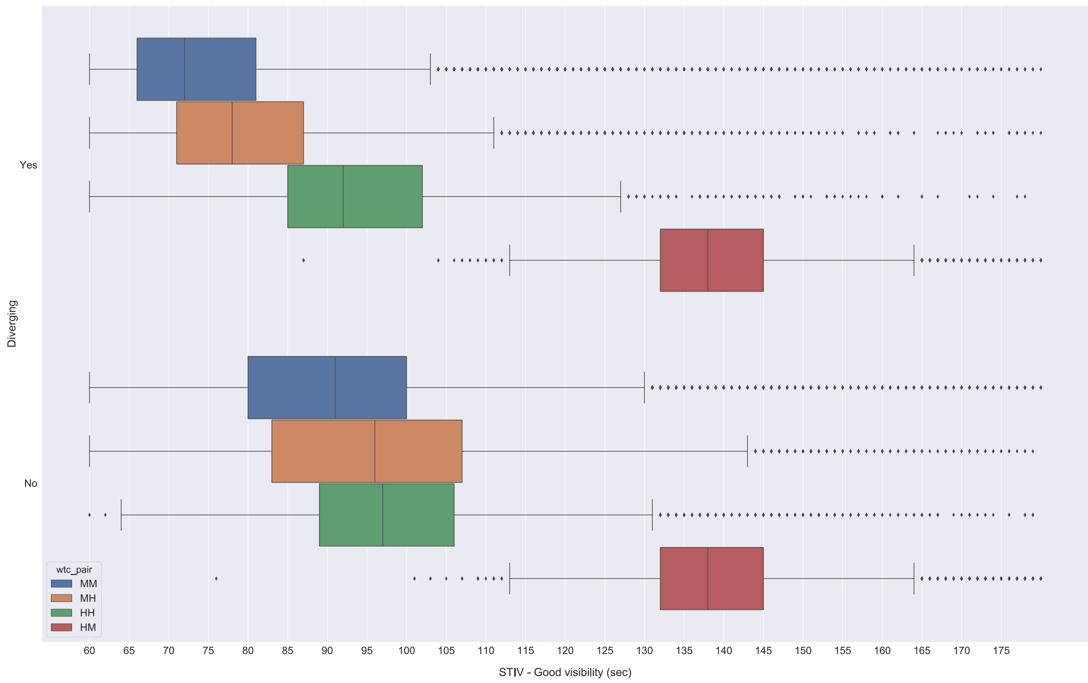

Figure 11 - Start interval per WTC -pair and SID-type, Good visibility conditions

In summary:

- SIDs that diverge within the first 4NM imply a significant contribution to takeoff capacity, in particular for the M-M and H-H pairs.
- Automation may potentially create additional capacity when SIDs do not diverge within 4NM. This should be investigated.
- For H-M pairs, SID construction has no influence on departure capacity.

2.5.3 Visibility Conditions

When airport visibility has deteriorated to limited visibility conditions (BZO), the TWR controller can no longer apply visual separation rules. This could have an impact in several areas:

- Irrespective of the SID-pair, MRS or WTC-separation must be established at takeoff.
- Runway dependency rules are stricter under limited visibility conditions and will therefore have an impact on departure intervals.
- Having to enforce spacing between arrivals and departures will cause loss of capacity.

In Figure 12Figure 7 the departure timing is shown during BZO conditions. Marginal conditions have not been included since it consists of many gradations that do not allow to distinguish a clear pattern in the effect on the start interval. It can be considered a “transiti Because between of the strong relationship with SID-routing, the impact of this criterion is included.

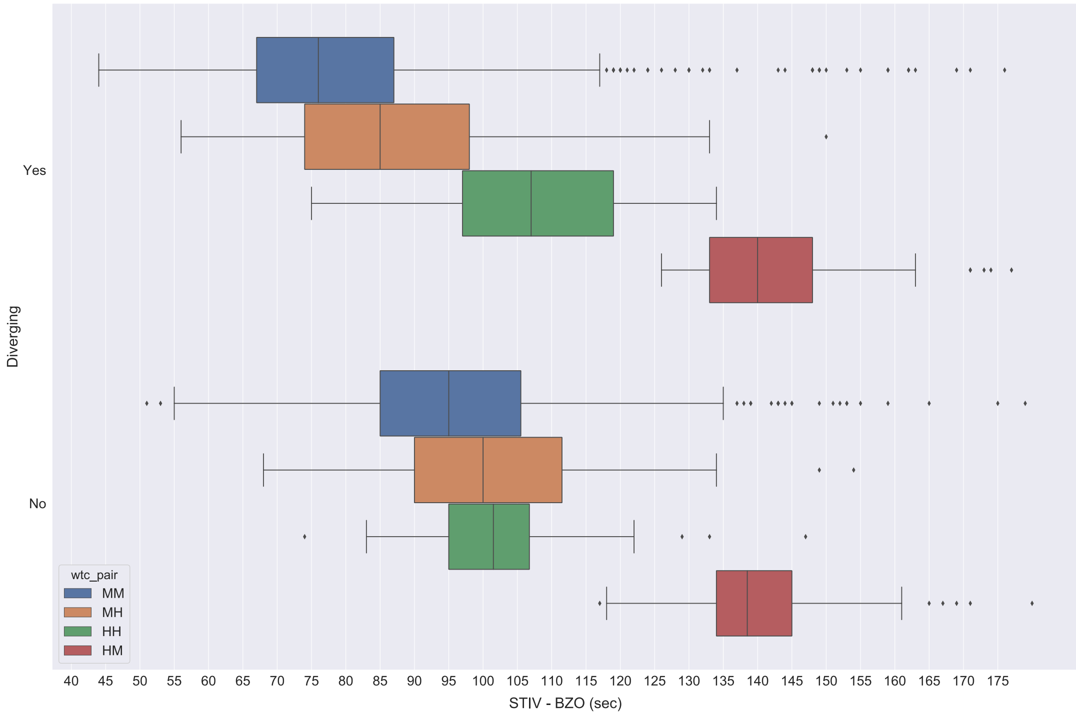

Figure 12 Start interval per WTC -pair and SID-type, BZO visibility conditions

The patterns observed during BZO are very similar to those for good visibility conditions with about 5 seconds of increase in Start Interval (STIV) for BZO.

In order to summarize the information presented in this section, the median values for all the assessed combinations are presented in Table 4.

Table 4 - Median start interval per WTC -pair and SID-type, BZO visibility conditions

WTC-pair	Diverging	Weather	Median
MM	Yes	Good	72
MH	Yes	Good	78
HH	Yes	Good	92
HM	Yes	Good	138
MM	No	Good	91
MH	No	Good	96
HH	No	Good	97
HM	No	Good	138
MM	Yes	BZO	76
MH	Yes	BZO	85
HH	Yes	BZO	107
HM	Yes	BZO	140
MM	No	BZO	95
MH	No	BZO	100
HH	No	BZO	102
HM	No	BZO	139

The table shows that:

- **M-M** and **M-H** pairs are affected most by SID-routing, rather than visibility
- **H-H** pairs are minimally affected by SID-routing or visibility
- **H-M** pairs are not affected by SID-routing, nor visibility

To conclude, the departure intervals, measured for the beneficial RECAT-EU pairs is given in Figure 13. The more detailed wake pairs of RECAT-EU for WTC-Heavy (B and C) as well as for WTC-Medium (D and E) do not show a significant variation between them compared to their corresponding WTC pairs.

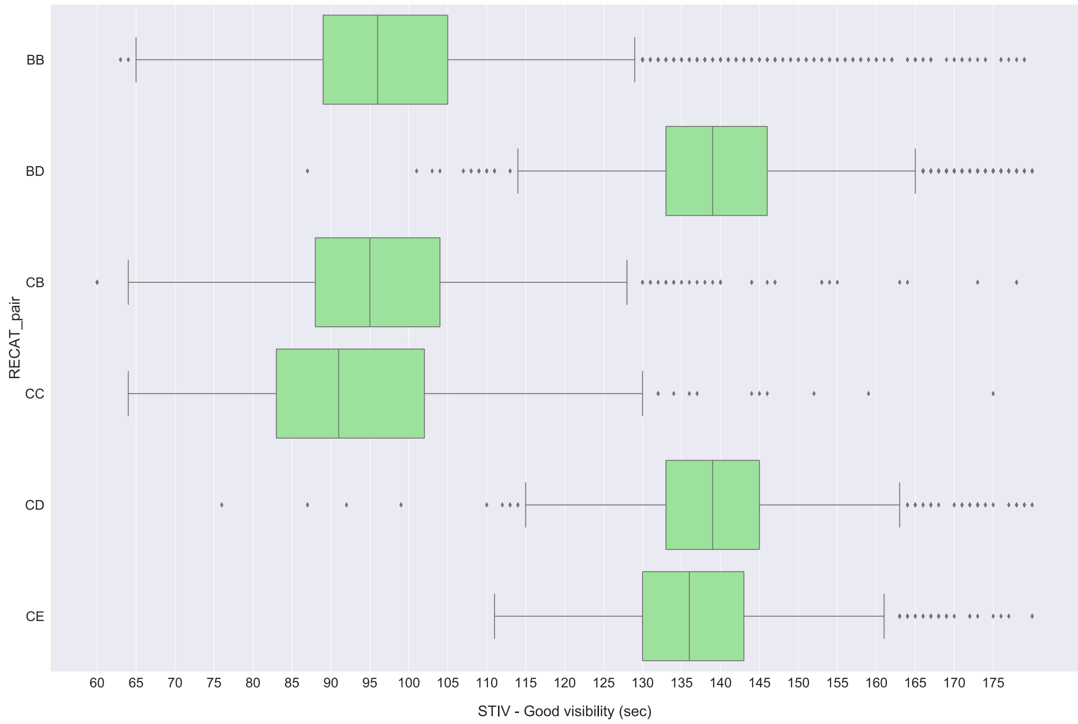

Figure 13 - Start interval per beneficial RECAT-EU pair, good visibility

2.5.4 Airline influence

Based on expert judgement, airlines from specific regions of the world employ different operating procedures with respect to departure timing. Moreover, there are even differences in operating procedures within a region. Of the analysed data, some airlines only operate at Schiphol with certain aircraft types. Noticeable differences for M-M pairs (5 seconds median difference), as well as for H-M pairs have been found in this study. This could be caused by detailed differences in cockpit procedures, but this would require further investigation.

2.5.5 Aircraft group in relation to STIV

Another factor that was mentioned by controllers is a general grouping of speed differences after takeoff by aircraft group. Specifically, Boeing aircraft are known to fly faster than Airbus. This was confirmed by data analysis. Figure 14 shows the impact of this aircraft grouping on the STIV. For reference, also another frequent aircraft type in the Schiphol fleet, the Embraer aircraft, were included in the group list. For the purpose of this analysis, departures on diverging SIDs were taken to remove the influence of the SID trajectory.

The figure shows that:

- The slower the lead aircraft, the larger the STIV becomes. This applies to most combinations.
- The slower the trailing aircraft, the smaller the STIV values.

The differences are not very large, but still noticeable. In section 2.6.1 the impact of speed differences will be explored further.

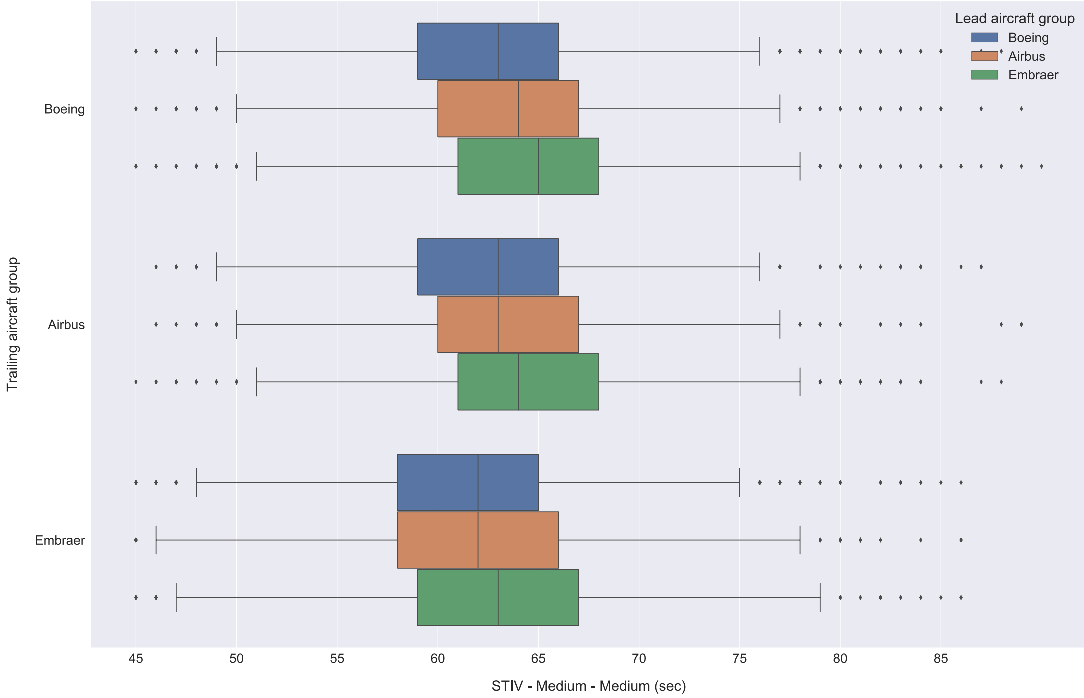

Figure 14 - STIV per Aircraft group

2.5.6 Wind effects

Conversations with controllers have revealed that sometimes the effects of wind in the departure area are taken into account. If the preceding aircraft would for example encounter a strong headwind during the initial climb out, additional separation might be applied.

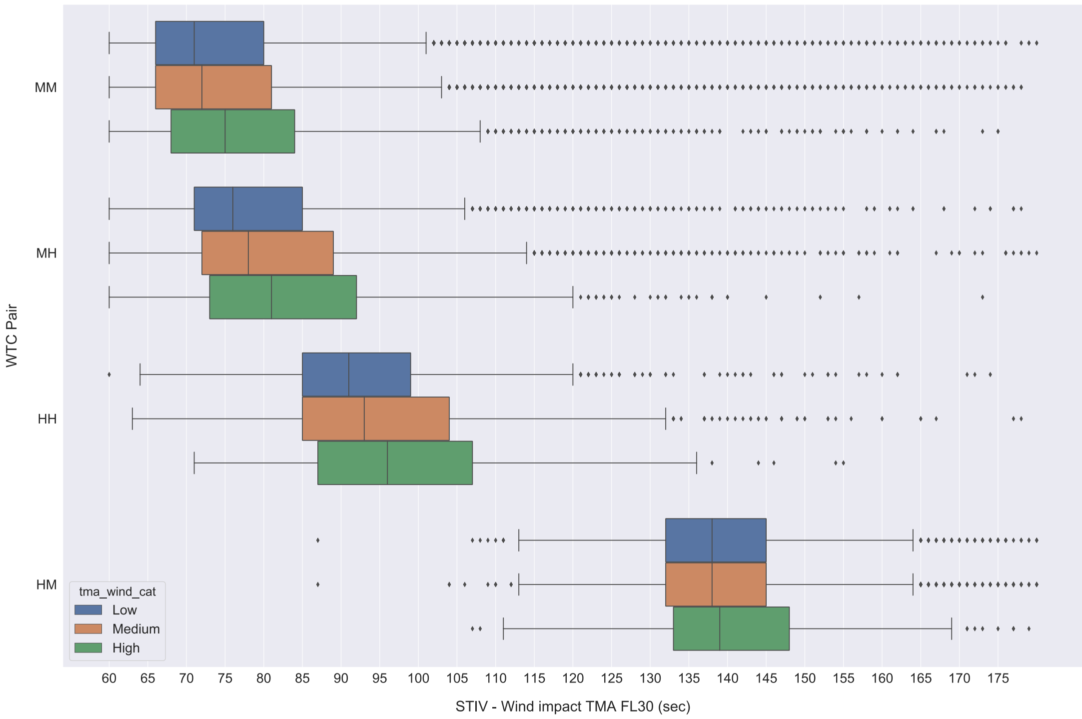

Figure 15 - STIV in relation to TMA wind

Figure 15 shows the impact of the wind in the Schiphol TMA at FL30, as reported by the KNMI. Three windspeed categories (tma_wind_cat) have been chosen to visualize the effect of wind:

- **Low**: calm winds up to 15 knots
- **Medium**: winds between 15 and 35 knots
- **High**: winds stronger than 35 knots

It is clear from the figure that TMA winds after takeoff have an impact on departure timing. This applies to all WTC pairs. Although for HM pairs with large STIV's due to wake separ the impact seems negligible.

For clarity, the figure only shows the STIV impact for diverging SID's. For non-diverging SID's, similar patterns are observed.

A similar analysis was performed for the effect of temperature, as during icing conditions, some more time is needed to spin-up the engines. The analysis showed however no significant change for temperatures around or below zero degrees Celsius.

2.5.7 Other factors

Apart from the factors studied in the preceding sections, a broad correlation of many different elements was performed using different correlation methods ('Ken did not reveal any new relationships that had not been covered up till now.

2.6 Departure spacing after takeoff

In this section the spacing from the moment of takeoff till exiting the TMA is studied. The TMA phase provides further insight into aircraft-pair separation following the takeoff of the second aircraft in each pair. This scope will cover the influence of aircraft speeds after takeoff. Since the aircraft pair is 'airborne', spacing is measured in distance in this section as opposed to time in the previous where there was a fixed reference point to measure from, i.e. the location of the ATOT, positioned at the mid-point of the runway.

In order to structure the analysis, aircraft pairs are grouped into three categories that cover their "WTC separation pattern" after takeoff. They are given a label for further reference in this section:

- **Above**: aircraft pairs that were separated by at least their wake separation or MRS as appropriate and continued to be appropriately spaced throughout the TMA phase.
- **Above-Under**: aircraft pairs that initially were appropriately separated, but at some point after takeoff lost required separation.
- **Under-Above**: aircraft pairs for which the initial separation after takeoff was below the wake separation or MRS as appropriate.

To get insight in the characteristics of the WTC separation pattern, the distribution of the three patterns over the WTC pairs of interest in this study is given in Figure 16 - WTC Separation patterns per WTC-pair**Error! Reference source not found.**. Clearly and also fortunately, the pattern where initial separation is lost after takeoff is a very small segment of all takeoffs. Another pattern of concern is the one where initial separation may not be sufficient but acquired after takeoff. This for example may happen when visual aerodrome control is applied in VMC conditions. The figure shows that only for medium-medium pairs a significant portion follows this pattern (about one third). The speed profile analysis will therefore focus on this WTC-pair.

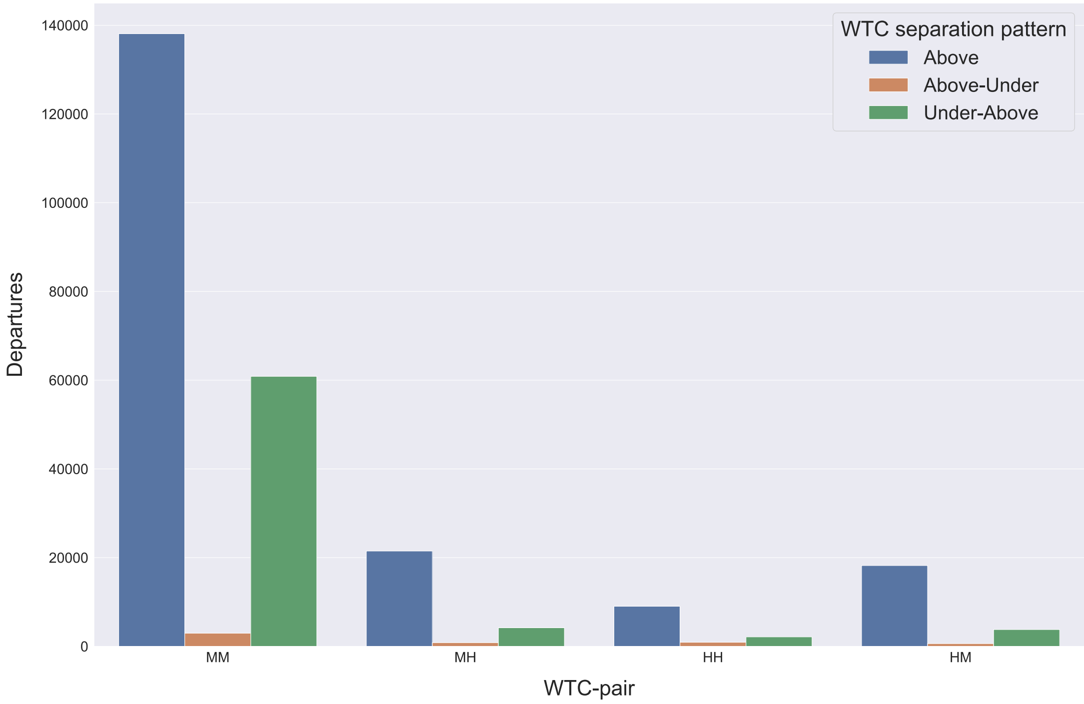

Figure 16 - WTC Separation patterns per WTC-pair

To provide some more context for the separation patterns, the distribution of the WTC separation patterns with respect to the SID construction is given in Figure 18. As could be expected, the Under-Above pattern is mostly observed for diverging SIDs where the controller knows that eventual separation will be achieved as the pair progresses along their SID trajectories.

For the beneficial RECAT-pairs the same analysis was performed, the results are shown in Figure 17. Logically, from Figure 16 it follows that the beneficial RECAT pairs show a much smaller percentage of flights exhibit the ‘Above-Under’ pattern. This suggests that for these pairs, more spacing is applied than for other the M-M WTC pairs.

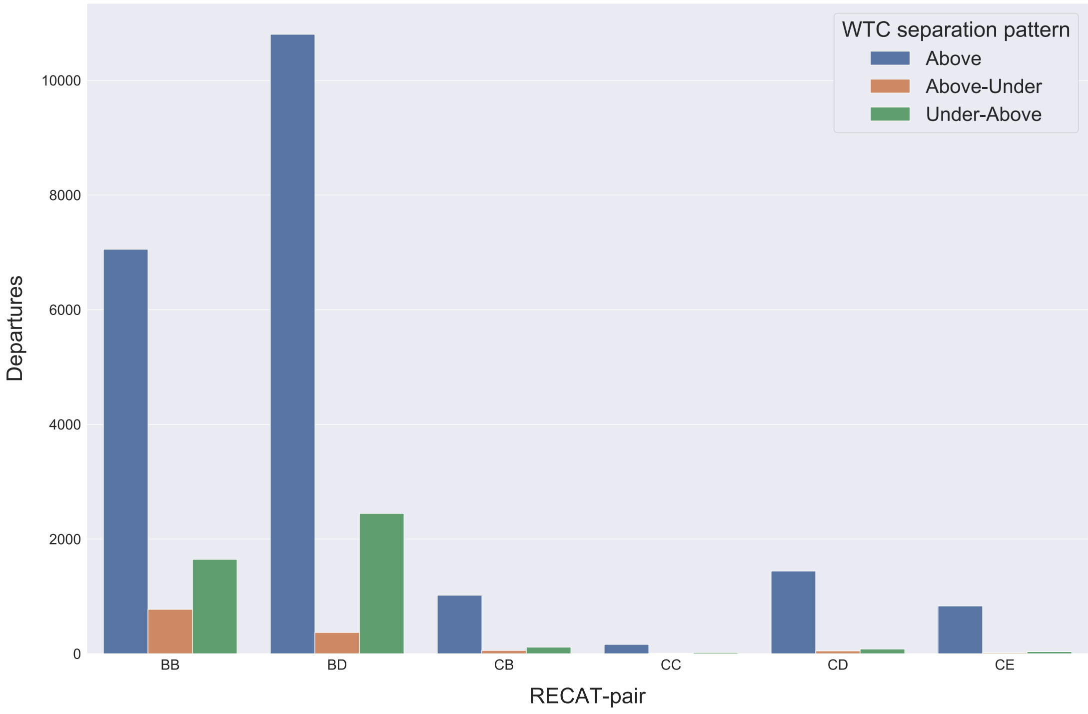

Figure 17 - WTC separation patterns for beneficial RECAT pairs

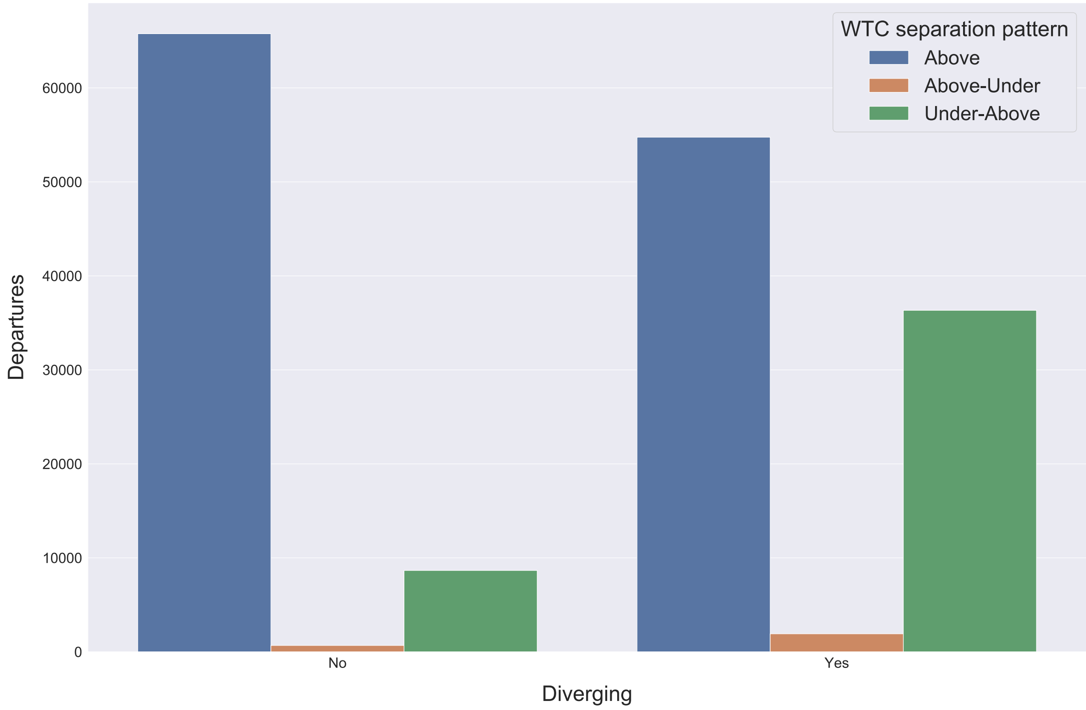

Figure 18 - WTC separation patterns in relation to SID construction

This analysis of the airborne part of the aircraft pair is divided into two sub-sections:

- **speed analysis**: of course, the relative speed of the aircraft pair is the driving factor in how the spacing-profile develops over time. Therefore, these relative speeds are studied first.
- **resulting spacing**: Subsequently the spacing resulting from the speed profiles will be analyzed as separation, which in the end is our operational criterion.

2.6.1 Speed analysis after takeoff

We first examine the M-M pairs and the relative speed for the pair. For this analysis, the actual speed profile was not taken but rather a ‘predicted speed af aircraft type and airline combinations, taking the average value of their reported indicated airspeeds during the first 2000 ft of their takeoffs in 2018 and 2019 (the reason to choose a 2000 ft height band will be explained later). By doing so, a value representing the average aircraft type + airline combination behavior was established, just as a controller will apply his/her expert judgement when timing takeoffs based on the aircraft types they are clearing for takeoff and the airlines executing them. This way, a predictive value becomes available that may show a better correlation with the timing of the controller than the actual speed behavior of a particular aircraft that a controller cannot predict.

In Figure 19 a distribution is given of this predicted speed difference for M-M WTC pairs under runway pressure. A negative delta speed means that the following aircraft is faster than the leading aircraft in the pair. As can be seen from the figure, the speed differences are fairly normally distributed, with a slightly greater presence of slower following aircraft. Speed differences larger than 40KIAS are rare.

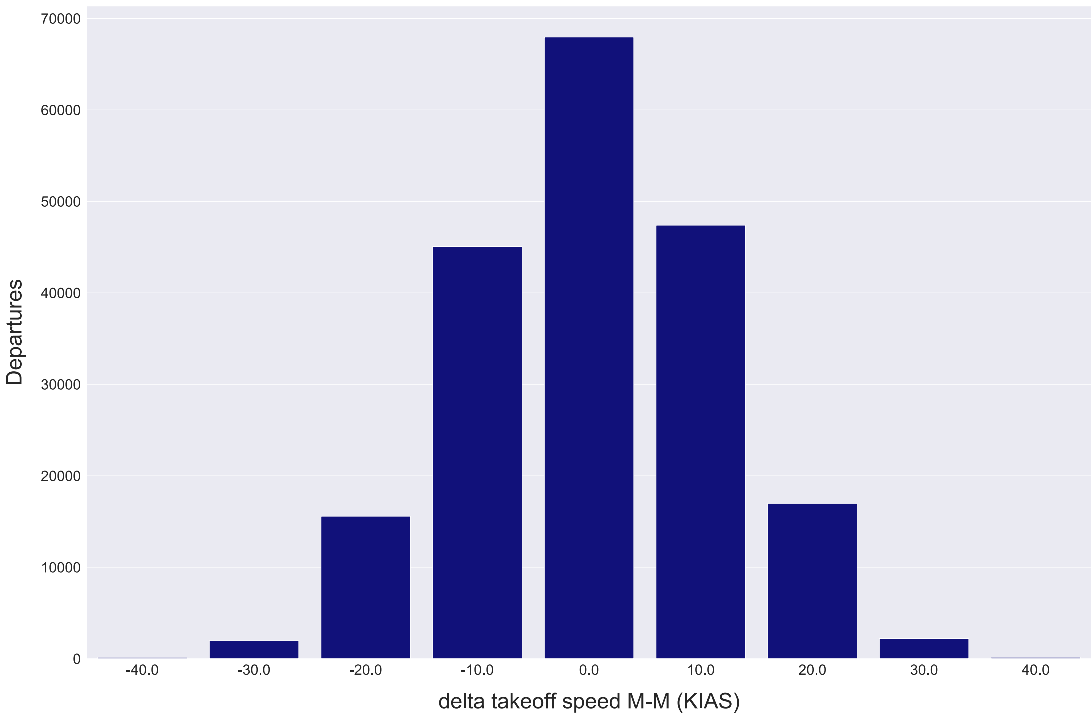

Figure 19 - delta takeoff speeds for medium -medium WTC pairs

First, we examine the impact of the delta speed on the most predominant separation pattern, labelled ‘Above’. This relat Figure 20 has a series of distributions of the STIV, one for each delta speed increment of 10 KIAS ranging from -30 KIAS to +30 KIAS. The figure tells us that there is a correlation between the predicted speed profile after takeoff and the departure timing. The difference between the peak of the -30 KIAS and the +30 KIAS distribution is almost 8 seconds.

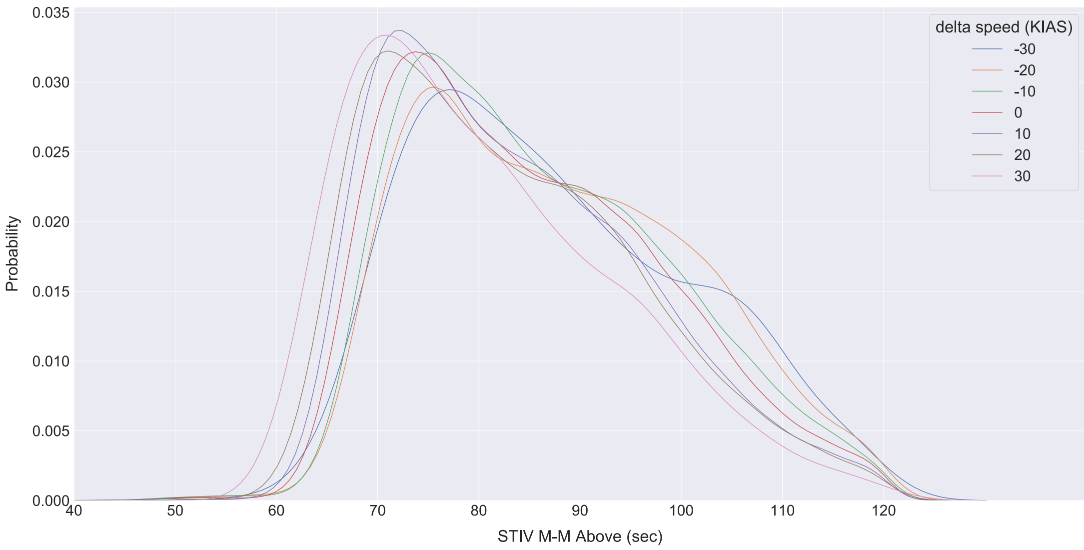

Figure 20 - distributions of STIV as a function of delta speed: Above separation pattern

Obviously, the separation pattern “Under-Above” is the most interesting, as t
to their separation, they form a large part of the population of aircraft pairs and they play a significant role in the runway throughput as the aircraft are spaced the closest of all pairs. Figure 21 shows a similar set of distributions as in the previous figures, but now f “Under-Above” pattern. The figure shows us an even more pronounced correlation between the predicted speed profile after takeoff and the departure timing. Notice also how the entire set of curves are shifted to the left with about 10 seconds, representative of the higher departure capacities for this separation pattern.

Although less pronounced, the pattern in these distributions are also seen for the beneficial RECAT-EU categories.

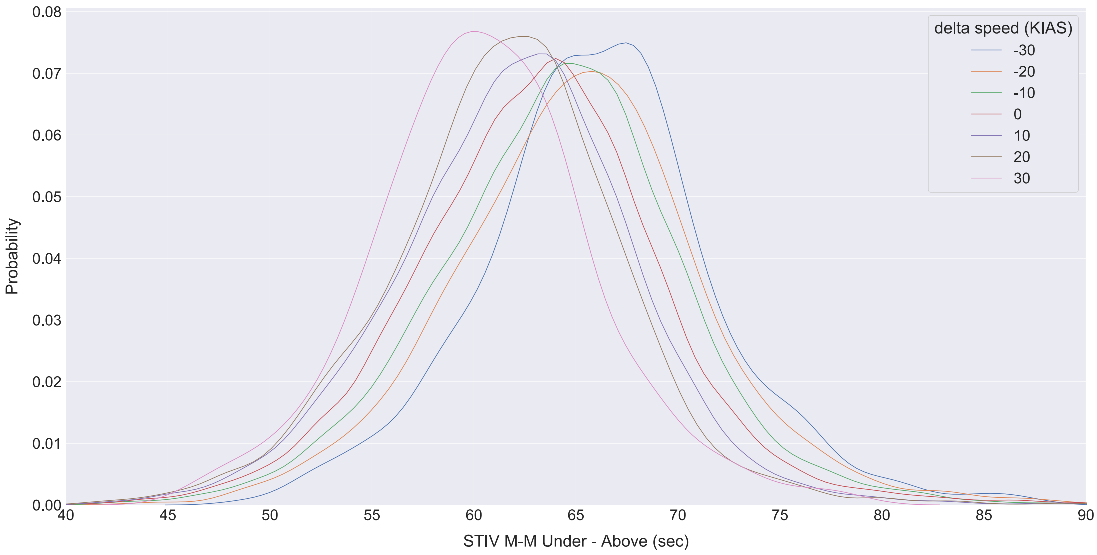

Figure 21 - distributions of STIV as a function of delta speed : Under-Above separation pattern

2.6.2 Distance analysis after takeoff

In the end, we want to know what effect the speed behavior - discussed in the previous section – will have on the eventual separation profile. These profiles will be explored in this section followed by a conclusion of the speed and distance profile analysis. From the speed profiles analysis, it became clear that the most interesting WTC separation profile is 'Under-Above'. In the following figures the distribution of separation distance versus time after takeoff are given. These are 2-dimensional probability distributions (Kernell Density Estimation).

In Figure 22, this distribution is given for the 'Under-Above' pair, non-diverging SIDs. The observations are:

- The hotspot is strongly centered around 3NM with a small area of about +/- 0.2NM.
- Already at 1 minute after takeoff, most cases below the 3NM have been resolved, whereas at 1.5 minutes, there are no more cases left.

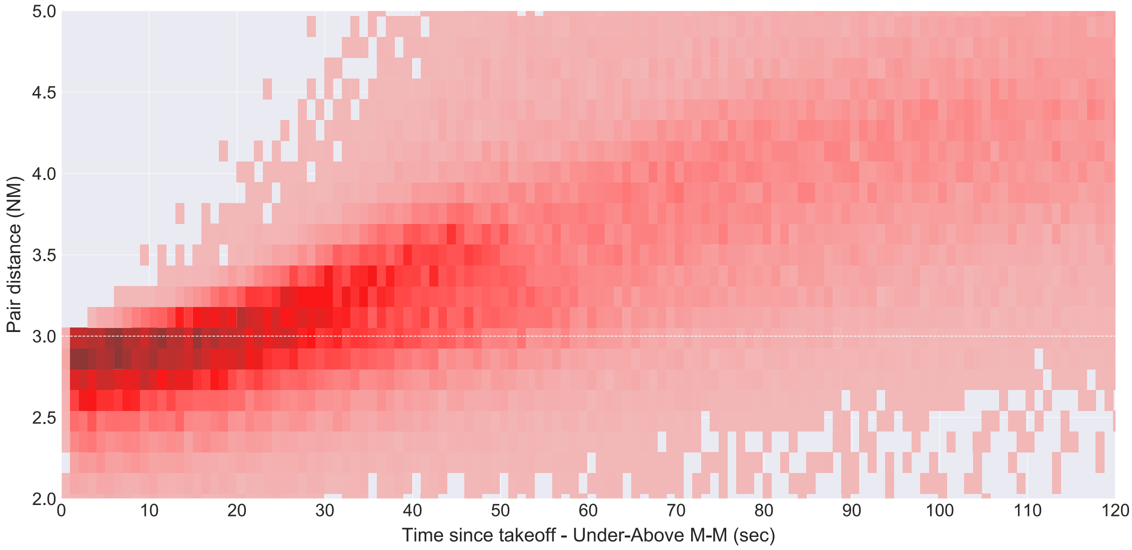

Figure 22 - Pairs distance versus time since takeoff for Under -Above, non-diverging SIDs

If we then look at the same figure, but then for diverging SIDs, we get Figure 23. When SIDs are diverging, much more separation reduction is accepted with values down to 2.5NM being no exception. The time period of separation below 3NM is slightly shorter for these departures as the diverging SID starts separating the pair.

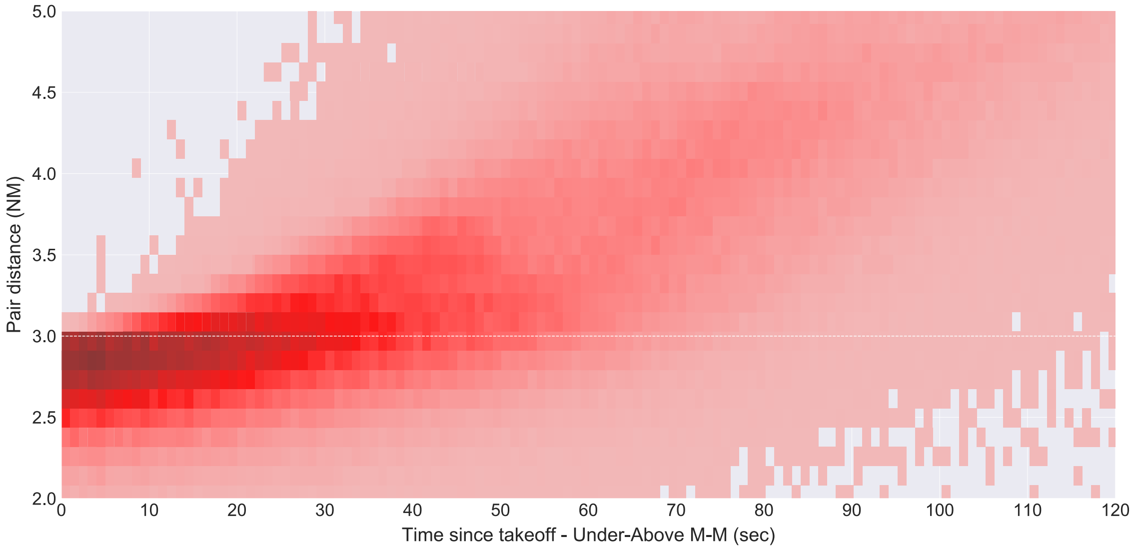

Figure 23 - Pairs distance versus time since takeoff for Under -Above, diverging SIDs

2.7 Summary and Conclusions data analysis

This chapter has presented many factors that have a bearing on the start interval. In this section, this information is summarized, and conclusions are drawn where possible.

The results presented in this section provided an insight into real life operations where visual, time and distance-based separation is provided, but now looking at it from only a time-perspective that is considered to be implemented with RECAT-EU. Unexpected behaviors in results could be attributed to this reason, and should thus be contextualized.

Of course, the most influential factor is the WTC category itself. Considering the traffic distribution, only the four WTC-pairs listed in Table 5 have been studied. The start intervals may range from 60 seconds to 140 seconds, depending other parameters. Table 5 provides the average values in units of time and distance.

Table 5 - WTC-pair STIV summary

WTC-pair	Average STIV (sec)	Average STIV (NM)
Medium - Medium	78	3.4
Medium - Heavy	84	3.7
Heavy - Heavy	97	4.7
Heavy - Medium	138	7.2

The STIV value for M–M pairs corresponds to the expected time separation of 80 seconds. For a Heavy following a Medium, some extra seconds are added to account for the faster speeds of heavy aircraft. Also for Heavy behind a Heavy the value of 97 is close to the nominal value of 100 seconds. The odd one out in this list are the Mediums behind Heavies. They show an average spacing of 140 seconds, which is 20 seconds more than the expected spacing of 120 seconds. It also produces a must larger distance spacing than expected: 7NM versus the required 5NM of WTC separation.
Feedback from TWR controllers indicated this is inherent to the takeoff clearance process: a timer is started once the aircraft commences its roll. Then after 120 seconds, the next takeoff clearance is issued. The radiotelephony time, readback and takeoff checks seem to amount to 20 seconds. Controllers sometimes anticipate on this extra delay but run the risk of not complying with the required time separation in case an aircraft reacts faster.

The other elements of influence are tabulated below to provide a quick overview and reference:

Table 6 - Summary of factors affecting the STIV

Impact item	Factor	STIV range	percentage of M-M pair
1	SID construction (Diverging)	20 seconds	25%
2	Runway dependencies	5 – 12 seconds	15%
3	Speed differences	10 seconds	13%
3	Weather (visibility)	4 – 7 (15 for H-H) seconds	9%
4	Airline Operating Practices	5 – 7 seconds	9%
5	Wind aloft	3 – 5 seconds	6%

Especially for the M-M WTC-pairs, all factors in Table 6 influence the departure timing. For other WTC-pairs, these factors have decreasing impact, where for H-H WTC-pairs there is no influence due to the large required WTC-separation.

For M-M WTC pairs, about one third of the departures the spacing starts below 3NM. Spacing typically grows above this value within 60 to 90 seconds. The majority of these departures are following diverging SIDs.

Of the beneficial RECAT-EU departures, not involving a WTC M-M pair, a much smaller portion start below their corresponding WTC-separation or MRS value.

Speed differences (delta-speed) between a departure pair typically range from -30 to +30 KIAS for the first 2000 ft which covers about the first minute after departure. There is a clear correlation between the delta-speed and the STIV. This correlation is even stronger for departures below WTC separation.

The most promising beneficial RECAT pair (B - D) shows that typically more spacing is applied than strictly required by WTC-separation criteria. This especially holds true for the non-diverging SID departure pairs. Therefore, for this pair, there seems potential for gain if this spacing could be reduced. We do however have to consider the overall percentage of beneficial RECAT pairs in the Schiphol fleet-mix, which limits the total capacity increase that could be obtained.

Conclusions

Departure spacing at Schiphol largely follows the ICAO WTC separation distances and times (for H-M). A remarkable exception is the separation of Medium aircraft behind Heavy aircraft which are separated by 20 seconds extra. This is inherent to the takeoff clearance process and could potentially benefit from supporting automation.

SID construction has a significant impact on departure timing and therefore on capacity. When designing SIDs, this should be taken into account where capacity and noise abatement may be competing arguments. However, when more non-diverging SIDs would be used, the reduction of separation for wake becomes more important, as more aircraft would have to adhere to wake separation at takeoff.

The percentage of RECAT-EU flight pairs with associated separation reduction is 14%. This percentage did not change from 2018 to 2019. This should be taken into account when calculating potential benefits. Moreover, while the RECAT-EU concept allows both time- or distance-based separations to be applied for both departure and arrivals, only the time-based implementation is being considered for Schiphol. This in contrast to current procedures where the TWR controller applies a mix of time, distance, and visual separation. For diverging SIDs, the TWR controller is applying aerodrome control under visual conditions, thus already making use of reduced spacing due to the nature of the routing after takeoff.

3 COCKPIT AND ATC PERSPECTIVES ON RECAT-EU

In order to obtain insights into potential implications of the implementation of RECAT-EU regime on either cockpit or ATC procedures, conversations were held with both active Schiphol TWR/APP controllers and pilots of a (limited) selection of airlines that have current operations at Schiphol airport.

3.1 Cockpit perspective

The introduction of RECAT-EU would not be transparent to the flight crew operating in and out of Schiphol airport (e.g. in some cases the term “HEAVY” will have to be included in the RT) and would therefore have to be informed of the change.

In order to get a more detailed insight into potential implementation or operational implications, the following the specific questions were posed to some pilots:

- Do you have experience with RECAT? If yes, at which of the following three airports: CDG/LHR/VIE[1]?
- RECAT is considered transparent to the flight crew. However, what is your perception/experience with RECAT with regards to:
    - Departure clearance
        - Time or distance - which is preferred and why?
        - Separation monitoring - are there any concern? If so, what are they?
        - Equipage issues - are there any? If so, what are they?
    - Initial climb phase
        - Time or distance - which is preferred and why?
        - Separation monitoring - are there any concern? If so, what are they?
        - Equipage issues - are there any? If so, what are they?
- Do you have any general concerns or comments about RECAT?
- Are the above answers the same irrespective a particular airport?

In total 3 pilots were consulted, representing 2 different airlines and a mix in aircraft types (i.e. B747-800, B777/B787 and B737).

One pilot (B747-400) has prior experience with RECAT at other airports than the three European airports that currently already has RECAT-EU implemented. Actual cockpit procedures were not deemed to be impacted with the introduction of RECAT. While it is agreed that RECAT is transparent to the flight crew, RECAT ‘distance’ is preferred as it is considered easier to observe. This preference applies to the departure clearance and initial climb phase. In all situations the TCAS display or an ADSB-IN display is deemed to be beneficial for situational awareness purposes. The pilot is of the opinion that during no wind days with stable air, extra care should be used as with no movement of the air the vortices will sit in place with a greater likelihood of hitting them, especially with RNAV departure tracking being so good. Additional concerns, though not considered to be applicable to Schiphol airport, pertain to parallel runway operations and terrain:

a) closely spaced parallel runways would also be a concern regarding either catching a vortex drifting over from an adjacent runway or the recovery from hitting a vortex and the recovery causing an offset towards a parallel runway departure track. SFO or PHL would be examples of this, maybe FRA too.
b) If there was terrain that could cause a lift in the air flowing across a hill that could lift a vortex back into the flight path it might not be suitable.

[1] The three European airports that currently already has RECAT-EU implemented: Paris Charles de Gaulle Airport (CDG), Vienna International Airport (VIE) and London Heathrow Airport (LHR).

Another pilot (B777/B787), stated that RECAT-EU was completely t[illegible]ent to [illegible] “*we get the ATC clearance and we go*”.

A B737 pilot had experience with RECAT-EU at London Heathrow where he said it was actively applied. For departure, his preference was time since it was “ea[illegible] do. For the initial climb phase, he does not actively monitor it, they rely on TCAS. Heavier aircraft ahead climb slower, so the B737 [illegible] above any wake that could be a hindrance. Other than that, they rely on ATC to ensure proper separation and he had no other concerns for RECAT-EU for departures specifically.

Upon examination of the provided pre-takeoff cockpit procedures of different aircraft models (B777, A330, B737), small differences were found in the steps to be followed. This could explain some of the small timing differences that were found between some airline (groups).

Based on the pilot responses received, operating departures under a RECAT-EU regime at Schiphol airport is not expected to have significant impacts on their operations at Schiphol airport.

3.2 ATC perspective

The introduction of RECAT-EU would not be transparent to the air traffic controllers providing air traffic services at Schiphol airport (e.g. in some cases the term “HEAVY” will have to be included in the RT) and would actually alter the separation principles being applied (i.e. time-base separation versus visual separation) and would therefore not only have to be informed of but also trained on the change. The overall responsibility of ensuring separation would remain unaffected with the introduction of RECAT-EU. The requirement of achieving MRS prior to handoff to APP would also remain unaffected.

Input from ATC controllers was used to shape the analysis in chapter 2, in particular items related to:

- the criteria consider a SID diverging for TWR
- other factors possible influencing the departure timing:
    - anticipated speeds after takeoff
    - airline and pilot reaction time
    - aircraft type groups, in particular Boeing versus Airbus
- evaluation of the analysis results

The data analysis primarily focused on measurable impact of factors on departure intervals. Controllers did point out however that the total airport capacity [illegible] data analysis measures a gap in time in a departure sequence, the controller may have chosen to use this time for a runway crossing for an arrival for example. Therefore, when interpreting both the effects of factors affecting spacing and assessment of capacity gain, this should be considered as a source of error.

The analysis in chapter 2 focused on the impact of RECAT-EU on a stream of traffic departing from a single runway. To this end, the notion of ‘runway pressure’ w[illegible] select departure pairs for analysis. Controllers did point out however that benefits can also be obtained under circumstances where no or less runway pressure is present. This occurs during dependent runway operations. The reduction in separation time can potentially allow for an extra departure to take place whereas this would otherwise not be possible under the ICAO WTC regime. Examples include the departure operation on runway 24 while landing on runway 18R (dependent operation) or departures from 24 and 18L where the latter are constrained due to jet-blast from aircraft taking off from runway 24.

When a medium takes off from an intersection after a departure of a Heavy, an additional minute, so three minutes in total is required. Controllers indicated that in general they work to avoid this circumstance by having a medium available for takeoff at the beginning of the runway, after a heavy has taken off.

This study did not investigate the effect of flights with ATFM delay, that is with a slot time from the Network Manager in Brussel assigned. This may affect departure timing sometimes or required WTC timing is used to resolve some of the delay.

Another area where RECAT-EU could bring benefit is during mixed-mode operations. These operations are rare at Schiphol, but in those cases the reduced RECAT-EU criteria could allow for some extra heavy departures in between landings.

4 RECAT-EU INTRODUCTION IMPACT ANALYSIS

This chapter provides an indicative assessment of the capacity impact of RECAT-EU for departures. A full simulation-based analysis will be performed by EUROCONTROL at a later stage. Therefore, this chapter takes the results from chapter 2 and presents provisional capacity impact figures based on a numerical approach.

As chapter 2 has shown, the actual departure capacity depends on a multitude of factors. One of the key drivers is of course the composition of the traffic fleet that is departing. A sequence including many heavy aircraft will obviously result in a lower departure rate than when exclusively medium aircraft depart. This in turn will affect the impact of reduced separation time as if less aircraft can depart in an hour, it will yield less room. To a lesser extent, this applies to all the variables identified in Table 6.

Any projection of capacity based on a change in departure timing will therefore be subject to a particular traffic mix. For that reason, the projections presented here are based on two traffic mixes in terms of heavy versus medium:

- An average of the first departure peak (15%)
- An average of the fifth arrival peak (7%)

These two peaks can be considered the extreme cases in terms of number of Heavies in the departure mix. Only the Heavies that belong to a beneficial RECAT pair are counted.

To calculate a projection, the following approach was taken:

- the default separation time for Medium aircraft is used: 80 seconds.
- for Heavy aircraft the default is 120 seconds, but measurements have shown that the median value is approximately 140 seconds, therefore the latter value is used.
- As a starting point, a capacity of 38 aircraft per hour is taken and the percentage of Heavies is used to find how many of them would be Heavies.
- This number of Heavies is multiplied by 140 seconds to yield the amount of time needed for H-M pairs, assuming they are not optimized for departure.
- For the remaining Mediums, they are multiplied by 80 seconds.
- The total time is then the amount of time necessary to handle 38 aircraft with a mix of 15% heavies.
- Of course, this amount is not precisely equal to one hour, so the actual hour rate corresponding to this mix is proportionally adjusted to find the approximate capacity for this mix.

These steps are then repeated, but with 20 seconds less spacing between the heavy and medium aircraft. Strictly speaking, for the C-D RECAT pairs, this should be 40 seconds, however these pairs comprise only 1% of the first departure peak and 0.1% of the last peak, so this is ignored to not overcomplicate the calculation without added accuracy.

This process then results in the following outcome:

- Potential gain for first departure peak: **1.4 aircraft per rwy/hour** (2.8/hour in a peak)
- Potential gain for first departure peak: **0.75 aircraft per rwy/hour** (1.5/hour in a peak)

It is very important to take into account that these numbers are only indicative for different reasons:

- As the analysis in chapter 2 has shown, there are many factors influencing the departure timing. These will all affect this projection since they will change the number of aircraft that take off in an hour and therefore the opportunity to apply the RECAT-EU reduction, but also the effect of the reduction itself. The interactions are many and complex, hence the need for a simulation and eventually measurements in real life.

- There is also the issue of the timing process for a Medium taking off after a Heavy. The time that elapses between the issuance of the takeoff clearance to a Medium, given 120 seconds after the start of the roll of a preceding Heavy, is added to this departure pair interval and has been measured to be in the order of 20 seconds on average. A further reduction would be possible if a timing mechanism/procedure could be developed to aid the controller to potentially reduce this time interval.
- Another potential benefit that cannot be quantified numerically, is the impact of reduced intervals in dependent runway operations. As described in section **Error! Reference source not found.**, the reduced intervals create opportunities for takeoff under dependent operations that would not have existed otherwise. This even applies to circumstances where there is less runway pressure.

In order to provide a qualitative assessment of the impact of RECAT-EU on the factors studied in the previous chapter, an indication is given in Table 7 per each of the factors explored, of the potential impact that RECAT-EU introduction may have on these aspects. Of course, the WTC itself will be impacted most by the recategorization. SID construction on the other hand, is expected to see little impact as controllers are applying visual separation, relying on the divergence of the SID rather than the category. Similarly, weather conditions resulting in increased required separation will also (largely) eliminate reduction gains brought about by RECAT-EU. Moreover, Airline Operating Practices relate more to procedural steps in the cockpit than specifically wake related delays. These procedures have been found to be transparent to the introduction to RECAT-EU. Other factors are likely to see some benefit as the reduced criteria may be applied in the context of these factors.

Table 7 - RECAT-EU impact on factors affecting STIV

Impact item	Factor	Impact
0	WTC	++
1	SID construction (Diverging)	o
2	Runway dependencies	+/++
3	Speed differences	+
3	Weather (visibility)	o
4	Airline Operating Practices	o
5	Wind aloft	+

++ - significant positive impact
+ - slight positive impact
o – positive nor negative impact

5 RECAT-EU SAFETY IMPACT ANALYSIS FOR SCHIPHOL

The objective of RECAT-EU was to develop a new categorization of aircraft for the traditional ICAO, whose aim was to safely increase arrival and/or departure capacity at airports by redefining wake turbulence categories and their associated separation minimum[2]. The safety case developed by EUROCONTROL and endorsed by EASA approving the separation minima modification, is provided as a basis for the implementation safety case for individual airports. The implementation safety case is to address operational and technical aspects of the airport, while validating assumptions made about the airport environment.

The safety impact analysis performed for the KDC is not an implementation safety case, but rather an evaluation of potential safety implications and/or constraints should time-based RECAT-EU for departures be considered for implementation at Schiphol airport. For this evaluation, the EUROCONTROL safety case for the modification of separation minima is considered a given, as it was approved by the EASA.

Schiphol has 6 runways, three of them parallel in a north-south direction (18R/36L, 18C/36C, 18L/36R), one runway perpendicular to these (09/27), and two more runways in an angled geometry with the rest of the runways (06/24, 04/22), as seen in Figure 24. Runway 04/22 is smaller than the rest of the runways and is usually used by business aviation flights or in non-nominal situations such as closure of other runways or atypical wind conditions.

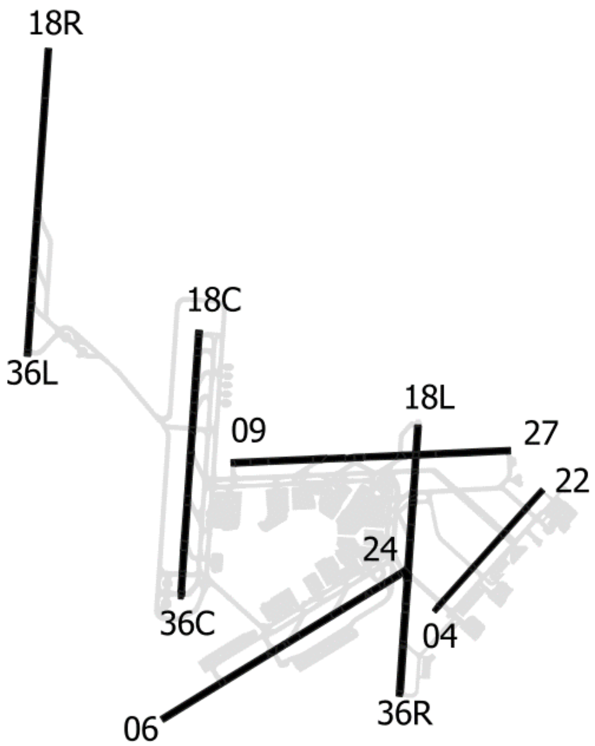

Figure 24 - Schiphol runway configuration [LVNL]

[2] RECAT-EU, European Wake Turbulence Categorisation and Separation Minima on Approach and Departure, Edition 1.1, 15/07/2015.

5.1 Time vs. distance option

As stated in the EUROCONTROL RECAT-EU safety case, provision of separation minima for departure is primarily time-based in the current ICAO Wake Categorisation context. However, the RECAT-EU concept allows both time and distance-based separations to be applied for both departure and arrivals.

Implementations of RECAT-EU for departures so far reflect application of both options: Vienna Schwechat (VIE) and Paris Charles de Gaulle (CDG) have applied distance-based separation on departure, with London Heathrow (LHR) applying time-based separation.

Specific considerations for RECAT-EU time-based departures[3] relevant to Schiphol:

- *Aircraft on departure are better able to withstand and respond to a WT encounter should one occur. This is because the departing aircraft is heavier, is at near full throttle, and configured and powered for climb, whereas an aircraft on approach is lighter, slower, and will need to be re-configured to perform a missed approach (this has been verified through pilot consultation during the EUROCONTROL/DSNA WIDAO project and recorded in the EUROCONTROL Guidance document* 'Principles and guidance for wake vortex encounter risk assessment' *[27])*.
  The guidance document does not consider Schiphol operations or specific runway configurations.
- *Due to large variability of departing trajectories and climbing performance, an aircraft will be in the correct geometrical relationship to an arrival only for a very short time for a WVE to occur, whereas an arriving aircraft flies low and for longer.*
  This is however not so for Schiphol, as not only is it dependent on the SID pair involved, but also more so on expected horizontal speed behaviour than climbing performance for SIDs to be considered. See section 2.5.2 for definitions of divergent and shared-path SID-pairs for Schiphol.

5.2 Scope differences from EUROCONTROL baseline

The concept proposed by EUROCONTROL for time-based departures states that, for the proposed separation minima, the same conditions as ICAO provisions [ICAO Doc. 4444] are applicable. They are the following[4]:

> 5.8.3.1 A minimum separation of 2 minutes shall be applied between a LIGHT or MEDIUM aircraft taking off behind a HEAVY aircraft or a LIGHT aircraft taking off behind a MEDIUM aircraft when the aircraft are using:
>
> a) *the same runway;*
>
> b) *parallel runways separa ted by less than 760 m (2 500 ft);*
>
> c) *crossing runways if the projected flight path of the second aircraft will cross the projected flight path of the first aircraft at the same altitude or less than 300 m (1 000 ft) below;*
>
> d) *parallel runways separated by 760 m (2 500 ft) or more, if the projected flight path of the second aircraft will cross the projected flight path of the first aircraft at the same altitude or less than 300 m (1 000 ft) below.*

NOTE: '*c)*' is of particular [illegible] Schiphol context with departures from runways 04 and 22 with respect to runways 09 and 18L & 24 respectively.

[3] RECAT-EU Safety Case report edition 1.3 issued by EUROCONTROL

[4] ICAO Doc 4444, §5.8.3 Departing aircraft

> 5.8.3.2 A separation minimum of 3 minutes shall be applied between a LIGHT or MEDIUM aircraft when taking off behind a HEAVY aircraft or a LIGHT aircraft when taking off behind a MEDIUM aircraft from:
>
> a) *an intermediate part of the same runway; or*
>
> b) *an intermediate part of a parallel runway separated by less than 760 m (2 500 ft).*

NOTE: *b)** is not relevant for Schiphol as parallel runways are separated by more than 760 m.

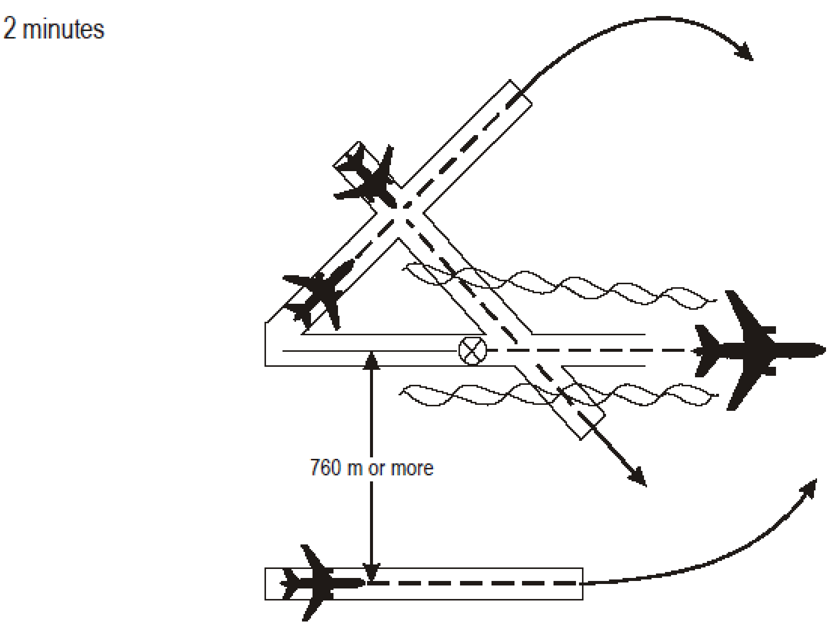

Figure 25 - Doc. 4444 illustration for section 5.8.3.1

Regarding mixed-mode operations, ICAO Doc. 4444 states the following[5]:

[5] ICAO Doc. 4444, §5.8.4 Displaced Landing Threshold

5.7.1.1 If an arriving aircraft is making a complete instrument approach, a departing aircraft may take off:

a) *in any direction until an arriving aircraft has started its procedure turn or base turn leading to final approach;*

b) *in a direction which is different by at least 45 degree s from the reciprocal of the direction of approach after the arriving aircraft has started procedure turn or base turn leading to final approach, provided that the take -off will be made at least 3 minutes before the arriving aircraft is estimated to be ove r the beginning of the instrument runway.*

5.7.1.2 If an arriving aircraft is making a straight-in approach, a departing aircraft may take off:

a) *in any direction until 5 minutes before the arriving aircraft is estimated to be over the instrument runway;*

b) *in a direction which is different by at least 45 degrees from the reciprocal of the direction of approach of the arriving aircraft:*

   1) *until 3 minutes before the arriving aircraft is estimated to be over the beginning of the instrument runway; or*

   2) *before the arriv ing aircraft crosses a designated fix on the approach track; the location of such fix to be determined by the appropriate ATS authority after consultation with the operators.*

5.7.1.3 If an arriving aircraft is following an RNAV or RNP instrument flight procedure, a departing aircraft may take off on a departure path that is clear of the arrival protection area for the arriving aircraft provided:

a) *vertical separation is applied until the arriving aircraft has reported passing the compulsory reporting waypoint on the instrument flight procedure, the location of such waypoint to be determined by the appropriate ATS authority;*

b) *the take -off takes place before the arriving aircraft crosses a designated waypoint on the instrument flight procedure, the location of su ch waypoint to be determined by the appropriate ATS authority; and*

c) *the departing aircraft remains clear of the arrival protection area until another form of separation is established.*

The concept of RECAT-EU does not explicitly address the mixed-mode use of runways, and thus the reduction of the separation minima for that case is not considered to change.

In the context of time-based separation, it is assumed that less stringent conditions than those stated above mean no (additional) separation needs to be applied between those departing aircraft. This however leaves the cases of:

- diverging runways and
- parallel runways separated more than 760 m, with the projected flight paths not crossing

unaddressed, and with no specific provision in ICAO Doc. 4444.

These conditions specifically pertain to runway usage. At Schiphol, departing runways can be used individually (e.g. inbound peak: two arriving runways and single departing runway) or in a combination of two (e.g. outbound peak: one arriving runway and two departing runways). Table 8 contains the runway combinations for outbound peaks, the condition between the two departing runways and relevant issues regarding the ICAO criteria presented above. The table is arranged by the amount of operations that happened for each combination in the last two years (a total of 500000 operations), where the number of operations can be seen of the left column.

Table 8 ðSchiphol departing runway combinations

Departing runway		Condition departing runways	Notes	Number of operations
24	18L	Diverging	Intersecting departing runways: An additional minute must be applied if a medium is operating from an intersection after a heavy, but does not apply to the S6 intersection. Airline operations manuals provide additional information on topic; but TWR controller has to apply extra time no matter what.	143264
36L	36C	Parallel	36L and 36C are considered independent departing runways from a (RE-CAT) wake turbulence perspective [ICAO Doc 4444, §5.8.3].	79650
36L	09	Diverging	Independent departure runways	26672
18L	18C	Parallel	18L and 18C are considered independent departing runways from a (RE-CAT) wake turbulence perspective [ICAO Doc 4444, §5.8.3]	22380
36L	24	Diverging	Independent departure runways	22296
24	27	Diverging	Independent runways	6196
24	09	Diverging	Independent runways	5144
18C	09	Diverging	Independent runways	5022
36C	09	Diverging	36C and 09 are considered independent departing runways from a (RE-CAT) wake turbulence perspective [ICAO Doc 4444, §5.8.3].	4505
36C	24	Diverging	Independent runways	1811
09	18L	Diverging	Intersecting departing runways, with 18L departures taking off from E5 (primarily) or E6 intersection, very few from E4. An additional minute must be applied if a medium is operating from an intersection after a heavy. Airline operations manuals provide additional information on topic; but TWR controller has to apply extra time no matter what. A controller can mitigate the need for applying extra time by having the following M aircraft make a full-length take-off rather than an intersection take-off.	1044
36C	06	Diverging	Independent	0
36C	18L	Opposite parallel	Independent	0
36L	06	Diverging	Mixed-mode landing & departing runway (06).	0

- **NOTE-1:** Arrival runway that might be used in combination with presented departing runway combinations is not presented.
- **NOTE-2**: The parallel runways at Schiphol are each separated from each other by more than 760 m.
- **NOTE-3**: When parallel runways are used for take-off, the eastern-most runway is used for SIDs turning east, and western-most runway for SIDs turning west. With this measure in place, it is ensured that departures from parallel runways will not have route crossings, at least in the initial segments of the departure.
- **NOTE-4**: Runways 24, 18L, 36C and 36L are regularly used with intersection departures

Consequently, looking at how the departure runway combinations at Schiphol relate to the ICAO Doc. 4444 criteria, it can be stated that the RECAT-EU minima remain applicable to these runway combinations, the same way ICAO WTC was applicable.

5.3 Assumptions and information from EUROCONTROL baseline

Key assumptions and information from EUROCONTROL RECAT-EU baseline are the following:

- EASA[6]
  - The RECAT-EU project was developed – on the basis of the ICAO PANS-ATM[7] provisions for wake turbulence separation – a revised aircraft categorization framework and the associated separation minima.
  - A dedicated task force composed by experts from Air Navigation Service Providers, Aviation Authorities, Aircraft Manufacturers and Research organisations supported the development of the safety approach and the analysis of operational benefits and constraints of the RECAT-EU proposal.
  - EASA performed the review of the safety assessment for the RECAT-EY scheme, covering the wake vortex data, the aircraft data and the determination of the safety risk indicators.
  - Following its review, EASA confirmed that the safety case report provides the assurance that the RECAT-EU wake turbulence separation scheme can be used by Member States as a basis to update current schemes.
  - In accordance with EU Regulations (EU) No. 1034/2011 and (EU) No. 1035/2011, the Air Navigation Service Providers from EU Member States considering to implement the RECAT-EU scheme, shall perform a risk assessment covering the changes to the ATM functional system and their lifecycle and shall obtain the approval of their competent authority.
- EUROCONTROL[8]
  - The European Organization for the Safety of Air Navigation (EUROCONTROL), in consultation with its Stakeholders, has developed a re-categorization of ICAO wake turbulence scheme and associated longitudinal separation mini-EmUa” ,ont oa ptphr eo a benefits of Airports and ATM Network Performance enhancement.
  - [Safety critical] Deployment requirements:
    - a system update, requiring updating local flight plan in the strip, adaptations to the Approach and Tower traffic surveillance display with new wake turbulence category designations, and publications of new applicable minima.
    - ATCO training on working with the six categories (*this can be conducted by use of ATC simulations*).
    - Flight Crew must be made aware and briefed on the local change.
    - Phraseology for ATC call, no change is needed sin RECAT-EU.
    - The RECAT-EU deployment will necessitate a collaborative approach involving all Stakeholders: Air Navigation Service Provider, Airport-based Airline(s), Airport Company and Authorities.
  - Data sources used:
    - The RECAT-EU safety validation is based on a relative and quantitative wake turbulence risk assessment, based on extensively measured wake datasets[9], aircraft geometry and final approach speed profiles characterized per aircraft types[10].

[6] EASA letter to Member States, 10 October 2014.

[7] International Civil Aviation Organisation (ICAO) Air Traffic Management – Procedures for Air Navigation Services (PANS-ATM), Doc 4444, Edition 15, 2007.

[8] RECAT-EU, European Wake Turbulence Categorisation and Separation Minima on Approach and Departure, Edition 1.1, 15/07/2015.

[9] RECAT-EU Safety Case - Appendix C - Wake Vortex Data (Document and Data Files, Covered by NDA)

[10] RECAT-EU Safety Case - Appendix D - Aircraft Types and Arrival Traffic Data (Document and Data Files, Covered by NDA)

- Wake data collected at London Heathrow and Frankfurt were made available for allowing reviewer (EASA) to re-run the analysis and confirm the results of the EUROCONTROL Safety Case[11].

  NOTE:

  - London Heathrow runways are two non -closely-spaced parallel runways;

  - Frankfurt has 4 runways, 3 of which are parallel, with one set closely -spaced. The 4th one intersects with the other 3, though impact(s) are runway use dependent.
- The final approach speed profiles have been established from Mode-S and RADAR measurements collected during 2 years respectively at London Heathrow and Paris Charles de Gaulle.

  NOTE:

  - Charles de Gaulle has two Closely Spaced Parallel Runway (CSPR) pairs. Typically, an external runway from each pair is used for landing and an internal runway for take-off. They operate in Independent Departure and Arrival Opera
- Aircraft wing geometries were extracted from r documentation.

The RECAT-EU concept was based on the data obtained from measurements in 8 different airports. Among those 8 are London Heathrow, Paris Charles de Gaulle and Frankfurt. It must be noted that the layout and operating conditions of those airports significantly differ from that of Schiphol, and thus it should be verified that the obtained data is still applicable to the case of Schiphol.

- RECAT-EU safety case documentation is essentially composed of the following:
  1) EUROCONTROL RECAT-EU Safety case report, ed 1.3
     Appendix A – Initial wake turbulence clustering and categorization
     Appendix B – Wake turbulence severity metric (*Restricted access under NDA*)
     Appendix C – Wake vortex data (Restricted access under NDA)
     Appendix D – Aircraft types and arrival traffic Data (*Restricted access under NDA*)
     Appendix E1 – Wake turbulence risk assessment complementary information (*Restricted access under NDA*)
     Appendix E2 – Wake turbulence risk assessment results for CAT-A / A380-800 (*Restricted access under NDA*)
     Appendix E3 – Wake turbulence risk assessment results for CAT-A / A380-800 –Additional evidence (*Restricted access under NDA*)
     Appendix E4 – Wake turbulence risk assessment for departure
     Appendix F – RECAT-EU WT Categories for all aircraft types
  2) EASA letter 2014(D) 54308 on RECAT-EU
  3) EUROCONTROL & AIRBUS A350 Wake Turbulence Categorisation Safety Case report

5.4 Safety considerations for Schiphol

As presented by EUROCONTOL, RECAT-EU criteria for when separation minima apply is the same as in ICAO Doc. 4444, meaning equivalent to the current situation with ICAO Wake Vortex Categorisation that is operational.

The ICAO and RECAT-EU separation standards are minimum values which should not be violated. A value lower than the standard equals a 'loss of safety' ...oration' e
With a lower separation minimum (i.e. RECAT-EU) there in essence is a 'shift i

The introduction of RECAT-EU would not be transparent to the flight crew operating in and out of Schiphol airport (e.g. in some cases the term "HEAVY" will have to be included in the RT) and would therefore have

[11] RECAT-EU Safety Case report edition 1.3 issued by EUROCONTROL

to be informed of the change. Moreover, the introduction of RECAT-EU would actually alter the separation principles being applied by the TWR controller (i.e. time-base separation versus visual separation) and would therefore not only have to be informed of but also trained on the change.

Schiphol TWR controllers operate visually when the visibility conditions allow, using the TAR and ASDE tools in the tower for increased situational awareness and for help in deconflicting traffic. Prior to handoff to APP then MRS is required.

It must be noted that the EUROCONTROL modeling was based on good visibility modelling analysis only and did not take converging runways into account. With limited visibility “numbers” will be
Moreover, during adverse weather traffic demand is different at which time traffic / capacity optimization might then not be the primary goal.
The RECAT-EU deployment will necessitate a collaborative approach involving all stakeholders: Air Navigation Service Provider, Airport-based Airline(s), Airport Company and Authorities.

Based on the changes proposed by the RECAT-EU concept, the following functional elements of the ATM system are impacted[12] when considering RECAT-EU for departures implementation at Schiphol:

- **FH1** - Change to local declared capacity and traffic level in peak hours;
- **FH2** - Change to local wake turbulence category (WTC) names and associated letter codes used in ATC traffic displays;
- **FH3** - Change to local Flight Plan Data Processing System (FDPS) for conversion of ICAO Flight Plan WTC information per aircraft types into the local WTC scheme based on RECAT-EU;
- **FH4** - Change to local ATC system for display of WTC code associated to an arrival or departure aircraft type;
- **FH5** - Change to local Arrival Management system to integrate changes to WT separation minima between aircraft types, and effects on traffic sequence optimization;
- **FH6** - Regarding the changes related to aircraft types assignment into WT categories
  - A few aircraft types (incl. B757) that are categorized as Mediums in the ICAO reference scheme are moved to (Lower) Heavy category in the RECAT-EU scheme, and may become subject to specific RT phraseology for announcing them as ‘Heavy’ on initial contact wi
  - The A124 is assigned CAT-A in the RECAT-EU scheme and becomes subject to specific RT phraseology for announcing as ‘Super’ on initial co
  - The B737 NG types and Classic types are assigned into 2 different categories, due to difference in wingspan.
    - *Note: This may cause confusion for the Controllers. However, based on the generalisation criteria and analysis developed in previous sections, if a B737 Classic is wrongly spaced as CAT-D as leader, it will be a weaker wake generator than other CAT -D, and as follower it will be wake resistant enough compared to other CAT -E. This mitigates the WT risk possibly induced by the mistake.*
- **FH7** - Change to the local number of applicable WTC and corresponding set of separation minima, and affecting ability of Approach and Tower Controllers to provide adequate and efficient WT separation.

Additionally, the local safety assessment will need to assess the requirements for training of TWR/APP controllers as currently the tower controllers apply visual separation, and arising issues of Human Factors (specifically pertaining to the choice of codes for the new wake categories).

While the RECAT-EU concept allows both time- or distance-based separations to be applied for both departure and arrivals, only the time-based implementation is being considered for Schiphol. This in

[12] RECAT-EU Safety Case report edition 1.3 issued by EUROCONTROL

contrast to current procedures where the TWR controller applies visual separation only and APP controller applies distance-based separation only.

Also, for diverging SIDs, often the controller is applying aerodrome control under visual conditions, already making use of reduced spacing due to the nature of the routing after takeof. so then ‘time’ rather t
‘visual’ would have to be applied as a default.

Additional items that must be considered as part of implementation steps:

- Changes to TWR operational documentation for new operations with reduced separation minima
- Changes that are made to the radar display, in part dependent on whether to incorporate an ATC Dynamic Departure Indicator (DDI) tool.
- Training of TWR air traffic controllers with changes to operating procedures and documentation

From the EUROCONTROL documentation regarding the implementation of RECAT-EU, some deployment requirements can be identified. These requirements are safety critical, and as such are included in the safety requirement table, Table 9. Safety requirements are grouped by topic, where the SR code DEPL means deployment related.

Table 9 - RECAT-EU Schiphol safety requirements

SR#	Safety Requirement	Hazard Reference	Responsible for Implementation	Note
DEPL1	ATCo system update	FH2, FH3, FH4, FH7	LVNL	Update local flight plan in the strip, adaptations to the Approach and Tower traffic surveillance display with new wake turbulence category designations, and publications of new applicable minima.
DEPL2	ATCo training	All FH	LVNL	ATCO training on working with the six categories (this can be conducted by use of ATC simulations).
DEPL3	Flight crew briefing	FH1, FH5, FH6	Airlines	Flight Crew must be made aware and briefed on the local change.
DEPL4	Phraseology update	FH6	LVNL and Airlines	Phraseology for ATC call, some aircraft might have to call as HEAVY.
DEPL5	Stakeholder involvement	FH1	LVNL	Involvement of all Stakeholders: Air Navigation Service Provider, Airport-based Airline(s), Airport Company and Authorities.

ABBREVATIONS

ATD	Actual Time of Departure
ATOT	Actual Take Off Time
BZO	limited visibility conditions (*'Beperkt Zicht Omstandigheden'*)
CDG	Paris Charles de Gaulle Airport
CTA	Control Area
EASA	European Union Aviation Safety Agency
EUROCONTROL	European Organisation for the Safety of Air Navigation
FL	Flight Level
ICAO	International Civil Aviation Organization
IQR	interquartile range
KDC	Knowledge and Development Centre
KIAS	knots indicated airspeed
KNMI	Koninklijk Nederlands Meteorologisch Instituut
LHR	London Heathrow Airport
LVNL	Luchtverkeersleiding Nederland
MLAT	Multi-Lateration
MRS	Minimum Radar Separation
RECAT-EU	European wake turbulence categories and separation minima on approach and departure,
SID	Standard Instrument Departure
STIV	Start interval
TCAS	Traffic Collision and Avoidance System
TMA	Terminal Maneuvering Area
TWR	Tower
VIE	Vienna International Airport
WTC	Wake Turbulence Category

REFERENCES

- EASA letter to Member States, 10 October 2014
- International Civil Aviation Organisation (ICAO) Air Traffic Management – Procedures for Air Navigation Services (PANS-ATM), Doc 4444, Edition 15, 2007
- RECAT-EU, European Wake Turbulence Categorisation and Separation Minima on Approach and Departure, Edition 1.1, 15/07/2015
- RECAT-EU Safety Case report edition 1.3 issued by EUROCONTROL
- RECAT-EU Safety Case - Appendix C - Wake Vortex Data (Document and Data Files, Covered by NDA)
- RECAT-EU Safety Case - Appendix D - Aircraft Types and Arrival Traffic Data (Document and Data Files, Covered by NDA)

ANNEX A BOX PLOT EXPLAINED

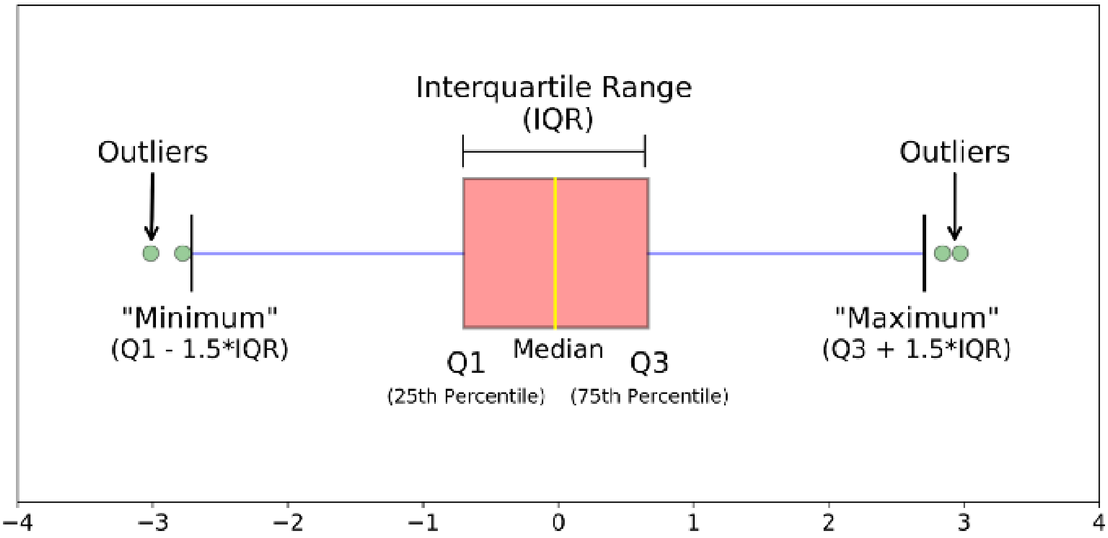

Figure 26 - Boxplot explained

Figure 26 shows the elements comprising a boxplot. The interquartile range (IQR) contains 50% of the sample. The bars connected to tihsek ebrosx”, raelpsroe sreenfte rtrheed mtior maximum, except for the outliers. Any value that exceeds the IQR by more than 50% is considered an outlier.

This graph type provides a quick few of the distribution of values in a set and if there a set of data is skewed.

ANNEX B ICAO WTC AND RECAT-EU SEPARATION TABLES

The current WTC separation criteria established by ICAO and implemented by LVNL is given in Table 10

Table 10 - ICAO WTC separation in NM / seconds

Lead \ Follower		Super Heavy	Heavy	Medium	Light
		J	H	M	L
Super Heavy	J	3 / 80	6 / 140	7 / 180	8 / 180
Heavy	H	3 / 80	4 / 100	5 / 120	6 / 120
Medium	M	3 / 80	3 / 80	3 / 80	5 / 120
Light	L	3 / 80	3 / 80	3 / 80	3 / 80

The new RECAT-EU wake separation rules are given in Table 11 where the pairs that imply a reduction compared to ICAO WTC have been marked in green.

Table 11 - RECAT- EU separation in NM / seconds

Lead \ Follower		Super Heavy	Upper Heavy	Lower Heavy	Upper Medium	Lower Medium	Light
		A	B	C	D	E	F
Super Heavy	A	3 / 80	6 / 100	6 / 120	7 / 140	7 / 160	8 / 180
Upper Heavy	B	3 / 80	3 / 80	3 / 80	4 / 100	5 / 120	6 / 140
Lower Heavy	C	3 / 80	3 / 80	3 / 80	3 / 80	4 / 100	6 / 120
Upper Medium	D	3 / 80	3 / 80	3 / 80	3 / 80	3 / 80	5 / 120
Lower Medium	E	3 / 80	3 / 80	3 / 80	3 / 80	3 / 80	4 / 100
Light	F	3 / 80	3 / 80	3 / 80	3 / 80	3 / 80	3 / 80

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