Appendix O Demonstration Exercise EXE-VLD-09-002 (Frankfurt Early Morning Arrival Stream Optimization) Report

The “Frankfurt Early Morning Arrival Stream Optimiziation” (EMAS) trial is targeting to improve the arrival situation in the first morning hour after the night curfew at Frankfurt Main Airport (EDDF) in terms of environmental impact, cost and flight efficiency aspects. The rationale behind this trial was the observation that in the first morning hour flights arrived too early on average and therefore caused inefficient flight profiles in or around the TMA. In order to improve this situation the EMAS target time procedure has been developed and was trialed the first time in a large scale demonstration exercise.

O.1 Summary of the Demonstration Exercise EXE-VLD-09-002 Plan

O.1.1 Exercise description and scope

Introduction

The xStream project aims at validating and assessing new arrival management tools in order to reduce the use of operational measures to absorb delays at low levels in TMA and improve flight efficiency. The project focused on four main areas:

- Extended AMAN between 200 to 350 NM.
- Handling of multiple inbound flows to multiple airports in the sectors of upstream ACCs.
- Improvement of Arrival Planning
- Airspace Users flexibility

The Demonstration exercise EXE-VLD-09-002 “Frankfurt Early Morning Arrival Stream Optimization” belongs to the exercises which were aiming to *Improve the Arrival Planning* by assigning target times to flights arriving at Frankfurt Main Airport already at an early stage of the flight or even before departure.

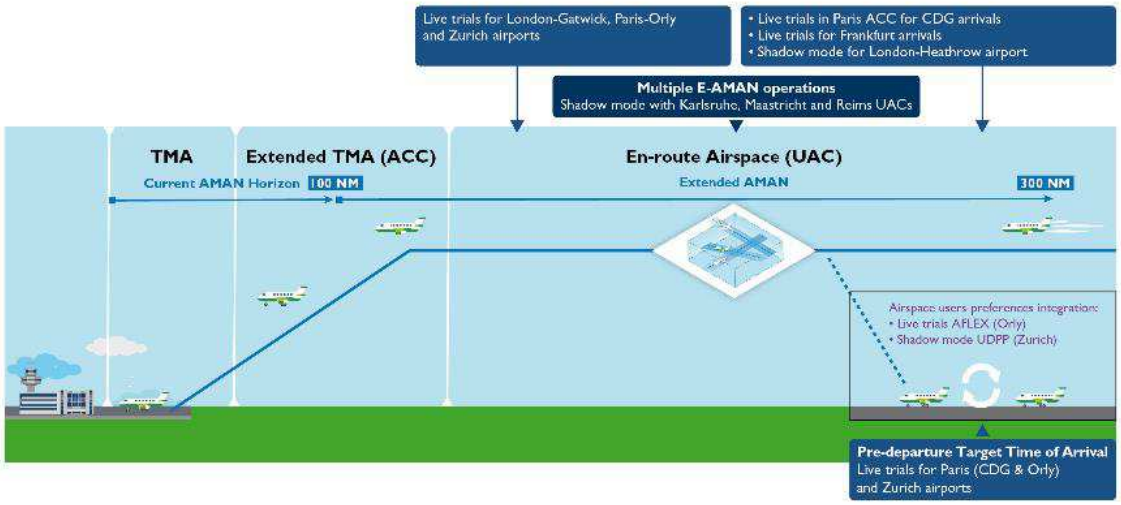

Figure 1: E-AMAN Concept summary

One of the reasons for this trial was the observation that quite some aircraft were too early in the vicinity of Frankfurt Main Airport before they could land after the night curfew which lasts until 0500 local time. This led to multiple holdings and extensive vectoring which could be avoided with a better arrival planning coordinated between Airlines and ATC.

Objective

Early morning arrival stream (EMAS) is a process of sequencing the inbound flights to Frankfurt Main Airport (EDDF) before entering the Frankfurt Terminal Airspace. It concerns all IFR arrivals in the first operation hour after the night curfew landing between 0500 LCL and 0600 LCL.

The aim is to optimize Frankfurt Arrivals through application of target times over designated points (Metering Fixes, COPs) in order to

- Avoid long transitions for delay absorption
- Reduce low level vectoring for delay absorption
- Enhance flight efficiency
- Reduce fuel burn
- Reduce / mitigate environmental effects, e.g. fly-over noise.

Concept

The concept of Target Times of Arrival (TTA) has been applied in the EMAS process as described in the following.

Planning Phase: The Planning Phase encompasses the period -24h to -6h before landing. In this phase the final flight plans are filed and the long haul flights are already taking off.

Coordination Phase: The Coordination Phase encompasses the period -6h to -5h before landing. In this phase the target times will be coordinated between ATC and Airlines and the planned optimized landing sequence will be calculated and communicated to all participants.

Execution Phase: The Execution Phase encompasses the period between -5h before landing until landing. During this time the flight crew tries to achieve its target time as closely as possible. ATC aims for an efficient arrival procedure based on the planned continuous arrival flow.

Evaluation Phase: Offline phase to evaluate the efficiency of the procedures and the KPAs in order to improve the EMAS procedure.

The Coordination Points (COPs) or Metering Fixes for which the target times (s. Figures below) are assigned have been chosen close to the border of FIR Langen with neighbouring FIRs rather than at the Initial Approach Fixes. In this way the Air Traffic Controllers within FIR Langen have the possibility to assign more direct routings to the Initial Approach Fixes – if traffic permits – to improve the arrival efficiency.

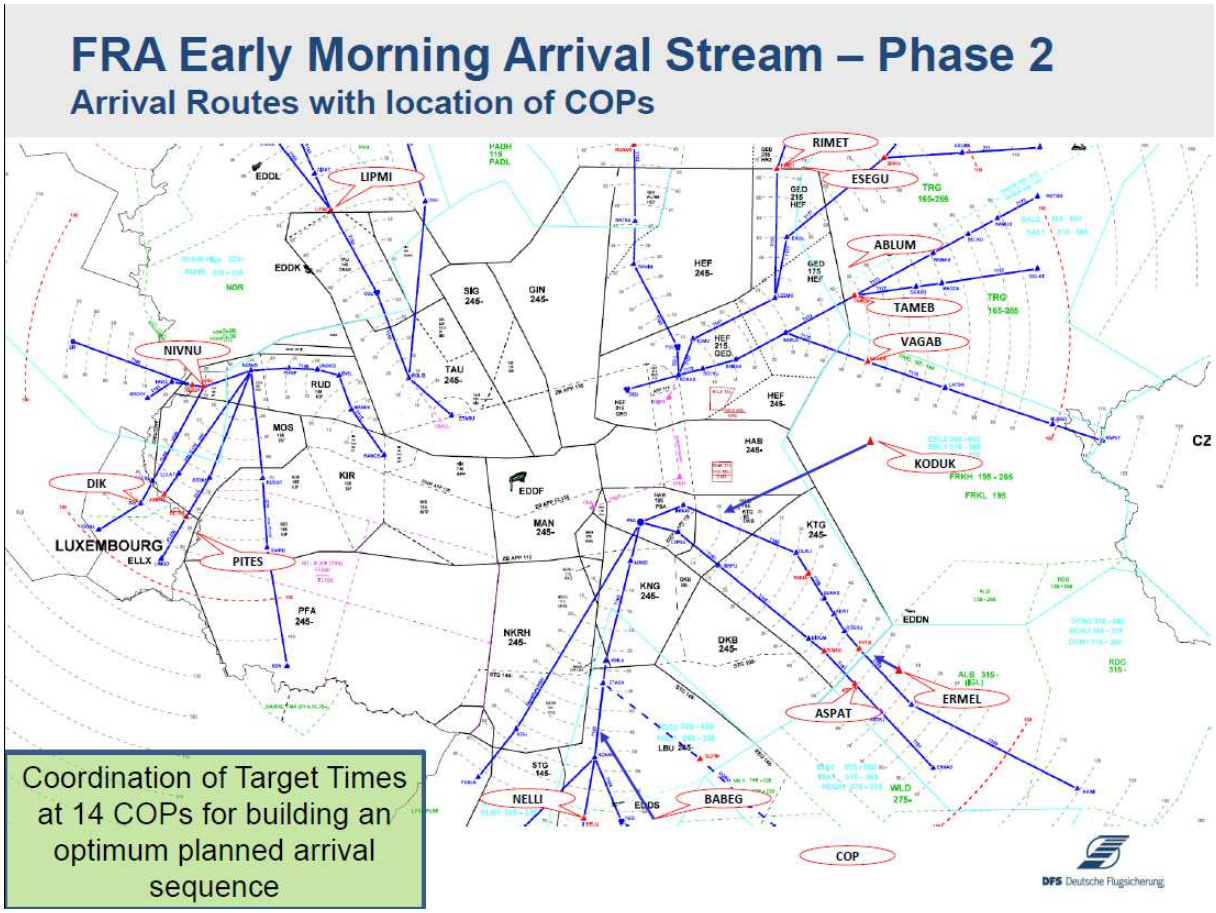

Figure 2: Location of Coordination Points (COPs) at the boundary of FIR Langen.

The Target Times are based on different inputs:

- For long haul flights: Estimated Time Over (ETO) over the relevant COP from aircraft FMS
- For medium and short haul flights: ETO over the relevant COP from latest filed Flight Plan
- Assumed flight times between COP and runway threshold. These flight times have been calculated based on a more direct routing in order to avoid too early arrivals

The individual Target Times for each aircraft are then calculated from an overall optimised arrival sequence under best consideration of the inputs listed above.

In order to automate the target time calculation as much as possible a web-based tool was developed which catered for the automated input process of ETO data and the calculation of the optimised arrival sequence. In addition, it provides the individual target times to the OCC of the related airline.

A generic presentation of the tool chain and the data flows is shown in the figure below:

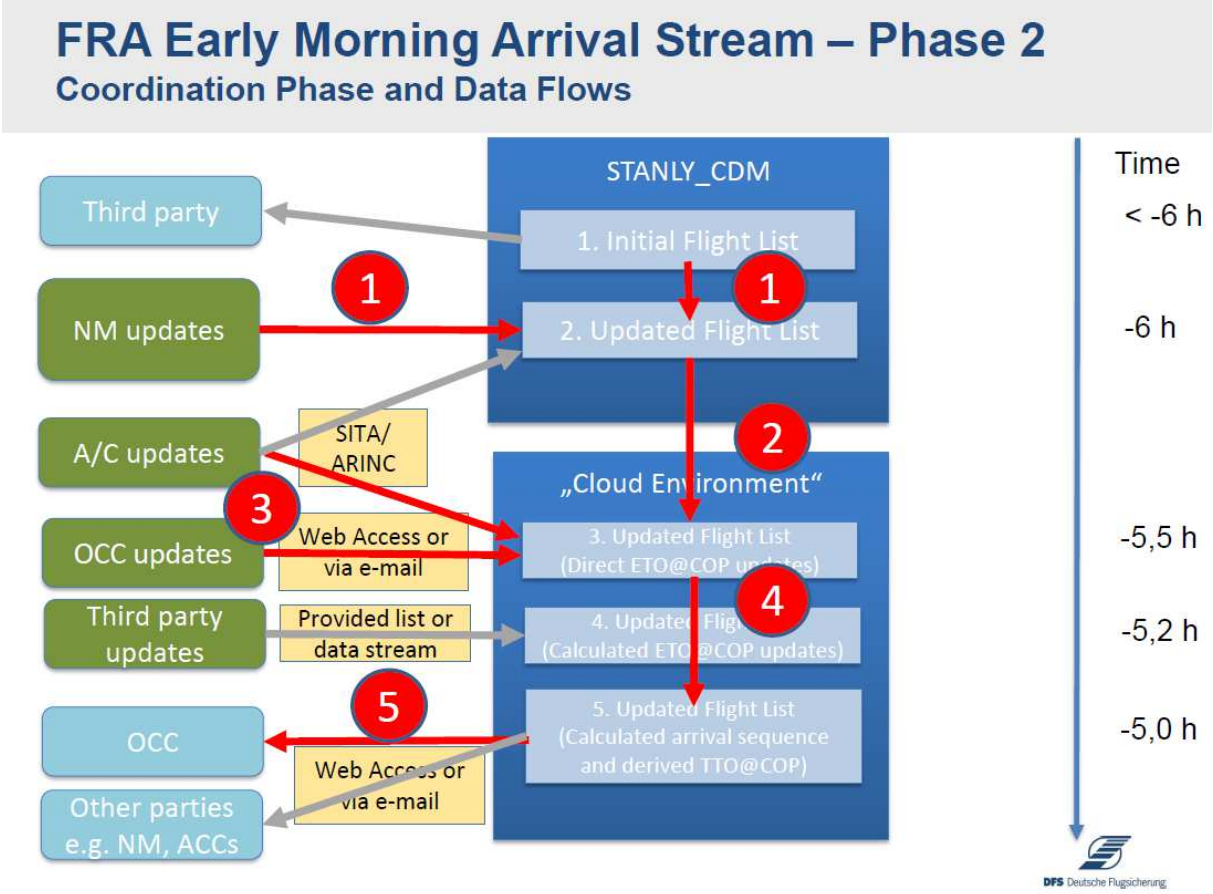

Figure 3: Tools and Data Flows for EMAS (Only the red arrow data flows have been implemented)

The coordination of target times follows a process with 5 major steps (s. Fig. 3):

- Step 1 constitutes the collection of flight plans and flight plan updates from the Network Manager in the flight data base provided by the STANLY_CDM system at DFS, Langen.
- In Step 2 the most current flight list is exported to the web-based EMAS Tool (“Cloud Environment”), which provides for the further processing of the flight data and which is accessible for various users with access rights.
- During Step 3 the estimate data (FMS ETO at COP) are provided by the individual aircraft via the SITA/ARINC Network and eventually via e-mail into the EMAS Tool. In addition Airline Operations Centres (OCC) can update ETO information manually, if required.
- In Step 4 the arrival sequence calculation is performed resulting in individual target times at the related COPs for all arriving aircraft.
- Step 5 is the dissemination of the target times to the Airline Operations Centres which in turn provide the individual target time via ACARS to their aircraft

Only the red arrow data flows are currently in use. In principle other actors and users can be integrated in the process which could potentially lead better quality of the data and the prediction and better adherence to the EMAS process.

O.1.2 Summary of Demonstration Exercise EXE-VLD-09-002 Demonstration Objectives and success criteria

The objectives and success criteria for EXE-VLD-09-002 are provided in the xStream DEMOR main document in chapter 3.4 "Summary of the xStream Demonstration Plan".

O.1.3 Summary of Demonstration Exercise EXE-VLD-09-002 Demonstration scenarios

Exercise Participation

All airlines planning flights to Frankfurt expected to arrive between 0300 UTC and 0400 UTC were requested to participate about the EMAS flight trials via the AIP AIC Germany 09/19.

The following airlines confirmed their participation:

Aerologic, China Southern Airlines, Condor, Deutsche Lufthansa, European Air Transport (DHL), Lufthansa Cargo, Sun Express, Thai Airways, TUIFly, United Airlines, Vietnam Airlines.

The participating airlines accounted for an average 79% (75% to 85%) of all flights arriving during the respective flight trial days.

The following ACCs contributed to the trial: ACC Langen, ACC Munich, UAC Karlsruhe, UAC Maastricht, UAC Reims. Neighbouring ATC units were informed about the trial.

Exercise Preparation:

AIP AIC Germany 09/19 requested Airline Operators to anticipate curfew hours when filing flight plans, thus that landing times according to the flight plan should be planned after 0300 UTC.

Briefing Material on the EMAS Process was prepared and distributed to all relevant units and actors:

- Airline OCCs: OCCs have a role in coordinating the target times and in disseminating the calculated target times to the flight crews.
- Flight Crews: Flight crews have to send the FMS ETO at the COP via ACARS datalink to the EMAS tool and – after reception of their target time – have to achieve the target time as closely as possible.
- ACC Langen: Supervisor triggers the target time calculation with the provided tools and records all limitations and deviations in the overall operations. En-route and approach controllers aim to provide efficient arrival routes.
- Neighbouring ATC Units: En-route controllers let aircraft "fly as filed" and avoid direct routings in order not to undermine the target time process.

Exercise Execution

Daily conduct of the trial:

1. At 2100 UTC of the previous day, DFS generated an approach sequence for all flights expected to arrive between 0300 UTC and 0400 UTC based on the available Flight Plan data. This sequence was transformed into estimated time over (ETO) the respective COPs for each individual flight, under consideration of the a.m. pre-defined flight times.
2. Until 22000UTC, participating, airborne aircraft provided updated - FMS-calculated - ETOs for the EMAS metering fixes via E-Mail, which constantly modified the arrival sequence.
3. At 2200UTC, processing of ETO messages ceased and the web application automatically adjusted landing times within certain, limited time parameters in order to avoid simultaneous landings and bunching and to achieve a constant and continuous arrival stream without jeopardizing economic efficiency of the flight.
4. Shortly after 2200UTC, the new Target Times over COPs for the individual flights were forwarded to the concerned airlines. The OCCs disseminated the times to Flight crews who should adjust the aircraft speed early enough in an economical reasonable way to arrive over the metering fix at the given time.

Special Considerations:

- Medium-haul flights (Northern Europe, North Africa and Middle East) not airborne by the time of ETO calculation were planned into the arrival sequence based on the FPL data or scheduled In-Block-Times (if FPL data was not available at this early stage).

- Short-haul flights (Airmail from Leipzig) were (manually) integrated into the arrival stream via the issuance of Target take off times (TTOT), based on their scheduled In-Block-Time and the average flight time based on the expected runway configurations. The TTOTs were transmitted to Tower Leipzig (EDDP) for consideration in their departure sequence. In this way the departures from Leipzig (EDDP) could be steered and an additional measure to avoid/reduce bunching of arrivals for Frankfurt arrivals could be implemented.

The EMAS trial took place on 14 consecutive days from September 9th to September 22nd. A reference period with almost the same conditions concerning traffic load and other conditions (e.g. weather, runway directions) was identified from August 22nd to September 8th.The following tables show the main parameters during the EMAS trial period and the reference period:

Date	Anticipated Runway	Runway Flown	No. of Flights (05:00-06:00LT)	
09.09.	25	25	27	Trial period
10.09.	25	25	33	
11.09.	25	25	32	
12.09.	25	25	33	
13.09.	25	25	33	
14.09.	07	07	30	
15.09.	25	07	30	
16.09.	25	25	25	
17.09.	07	25	30	
18.09.	07	25	30	
19.09.	07	07	30	
20.09.	07	07	32	
21.09.	07	07	31	
22.09.	07	07	29	

Table 1: List of Trial days

Date	Runway flown	No. of Flights (05:00-06:00LT)	
22.08.	07	30	Baseline / Reference period
23.08.	07	33	
24.08.	07	33	
25.08.	07	33	
26.08.	07	24	
27.08.	07	29	
28.08.	25	28	
29.08.	25	29	
30.08.	07	33	
31.08.	07	33	
01.09.	25	32	
02.09.	25	29	
03.09.	25	32	
04.09.	25	36	
05.09.	25	32	
06.09.	07	37	
07.09.	25	31	
08.09.	25	32	

Table 2: List of Reference days

Within the EMAS trial period and the selected reference period an equal number of days for both runway directions (07 and 25) have been recorded. In this way an evaluation of the trial for both runway directions is possible.

In Table 1 the column “anticipated runway” indicates the runway direction which has been assumed - based on the weather forecast and other operational conditions - when calculating the planned arrival sequence about 5 hours in advance. The column “Runway flown” indicates the runway in use when the flights arrived at EDDF. During three trial days the runway direction had been changed on short term based on operational consideration. The data of these days have been excluded from the further analysis.

O.1.4 Summary of Demonstration Exercise EXE-VLD-09-002 Demonstration Assumptions

The assumptions concerning EXE-VLD-09-002 are provided in the xStream DEMOR main document, in chapter 3.4 "Summary of the xStream Demonstration Plan".

O.2 Deviation from the planned activities

For three days of the EMAS trial period the data have not been included in the data analysis/assessment because of the following reasons:

On 15/09/2019, arriving flights were planned for runway 25 (as forecasted) and the respective pre-defined flight times (from COP to landing threshold) were applied in calculating the arrival sequence. However in the morning the active runway was changed to direction 07, which invalidated the arrival sequence planning (flight times differ up to 10 Min depending on runway direction).

On 17/09/2019 and 18/09/2019, arriving flights were planned for runway 07 (as forecasted) and the respective pre-defined flight times (from COP to landing threshold) were applied. However, in the morning the active runway was changed to direction 25, which invalidated the arrival sequence planning (flight times differ up to 10 Min depending on runway direction).

O.3 Demonstration Exercise EXE-VLD-09-002 Results

O.3.1 Summary of Demonstration Exercise EXE-VLD-09-002 Demonstration Results

The EMAS trial was executed during 2 weeks of September 2019 as planned. A reference period in August/September 2019 was identified with similar operational conditions.

Participating stakeholders engaged in the EMAS coordination process and procedure in a positive way. The developed EMAS tool helped to automate the process considerably and allowed to reduce the workload for most actors. Feedback of the actors indicated that automation of the EMAS process still should be improved and completed to be ready for a regular application in arrival management.

Related to the KPA Safety a very important and positive conclusion can be drawn: There were no safety related issues reported. Additional workload of pilots was rated not safety relevant. Air traffic controllers feedback was neutral or positive concerning the handling of the arrival traffic in the TMA.

The comparison of the other KPAs (Environment, Cost Efficiency, Capacity) for the trial phase and the reference phase did not reveal significant improvements, which came a little bit as a surprise as pre-trials had shown more positive effects.

There were only small effects observed for distance and time spent in the TMA. However, these were different for the two runway directions 07 and 25 and also for different arrival flows. The reason for this needs to be analysed further. For runway direction 07 an overall small positive effect could be achieved. For runway direction 25 only the arrival flows directly targeting at the runway direction could be slightly improved, but specifically arrival flows with long downwinds seemed to be penalized. So improvements could be generated in certain areas (e.g. related to noise), but not significantly on average.

1. Results per KPA

In the following the results of the exercise are summarized and interpreted.

a. KPA Safety

Within the scope of a Master's Thesis dealing with EMAS and Target Time procedures, a voluntary online survey has been issued to Pilots, Air Traffic Controllers and Dispatchers working for different companies. A total of 106 participants filed their opinions on EMAS until Oct-19th-2019.

i. Quantitative Assessment

The participants which responded to the question

"On a scale from 1 (not at all practicable) to 7 (extremely practicable), please rate how practicable EMAS is to you.",

gave the following opinion:

74.46 % (35 out of 47) of the responders answered with 5, 6 or 7, indicating a high level of confidence into the EMAS procedures.

Even if this question is not specifically targeting on safety, the safety oriented professional auditorium would generate lower numbers if they would have felt that safety would be generally in doubt.

Number of Incident Reports

During the EMAS trial period no incidents were caused and/or reported due to the EMAS implementation, neither from Airlines nor from ATC.

ii. Qualitative Assessment

In the survey mentioned above the following qualitative statements have been given by individuals:

Pilots with concerns on safety through EMAS:

- "Deviation from standard procedures" (2 times)

Pilots with no concerns on safety through EMAS:

- "Less congestion in airspace = higher flight safety" (1 times)
- "Controller has better preparation on expected traffic" (2 times)
- "Shorter and easier arrival routings after long night-flights have a positive effect on flight safety" (1 times) *

**For reasons of simplicity, the marked statements have been edited, anyhow falsification of the reported view has been avoided*

In addition to the before mentioned answers, the interviewed persons from all groups (total number of 19 persons) declared an increased workload through EMAS. The statement of increased workload was not given in respect of a question on "safety" itself but on a question of "negative side effects".

Feedback from Air Traffic Controllers at ACC Langen was neutral or positive. Some approach controllers which were on duty during the EMAS trials remarked that the arrival situation was more relaxed for them than during normal operations due to a more continuous inbound traffic flow.

b. KPA Predictability and Punctuality

This KPA has been assessed by comparing planned and actual times which are relevant in the EMAS process, .e.g. Times at COP or Metering Fix, Landing Times and In-Block Times.

i. Quantitative Assessment

Comparison of Planned and Actual Landing times

The EMAS process plans a landing time for each aircraft according to the optimised arrival sequence calculated about 5 hours before the first possible landing (at 0500 local time). This planned landing time (or target time of arrival, TTA) can be compared to the Actual Landing Time, ALDT. The difference between both is a measure of predictability.

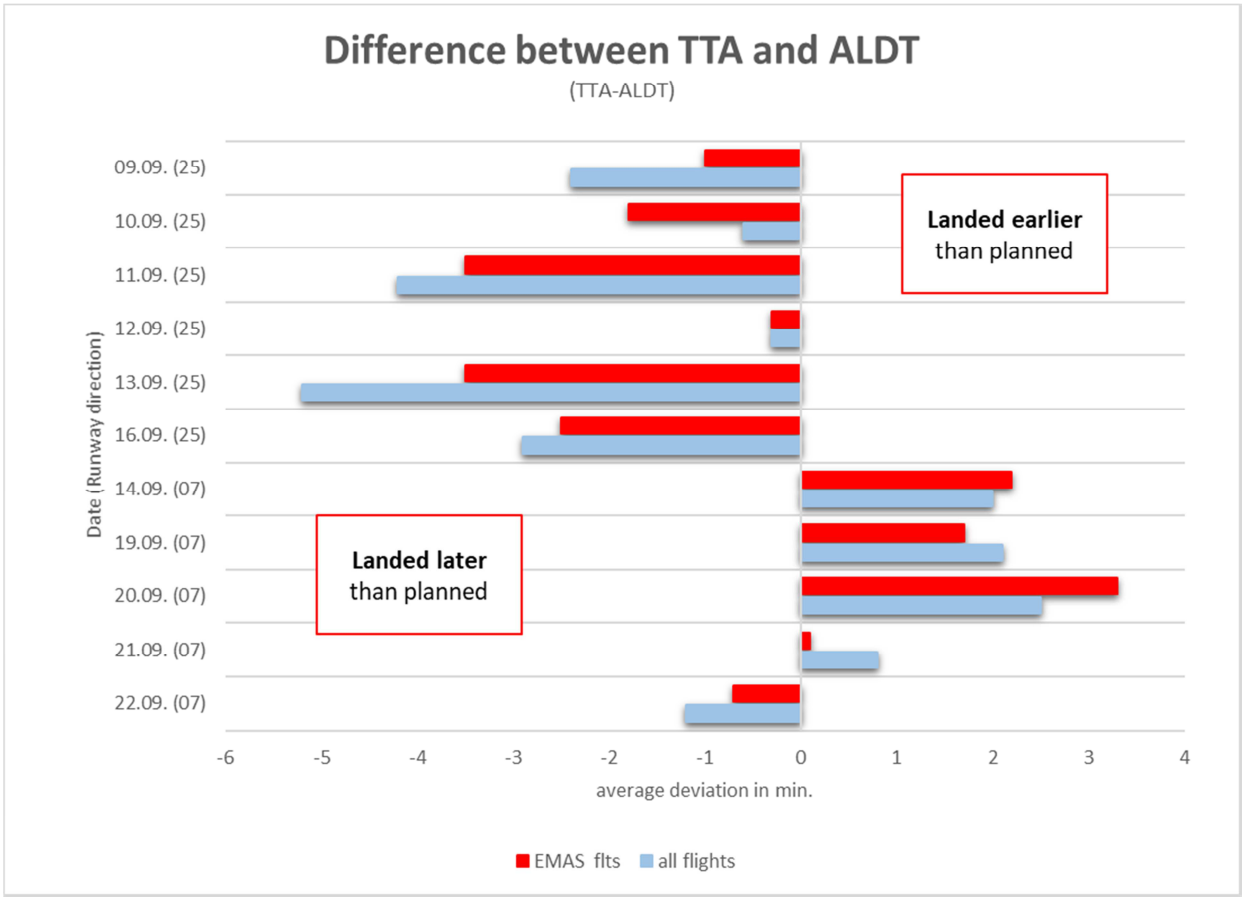

Figure 4: Difference between TTA and ALDT

Shown is the average difference between the TTA and the ALDT per day and – for a given day – separately for the EMAS participants and for all flights, i.e. including flights/airlines which were not participating to the EMAS procedure.

The average difference between TTA and ALDT differs from day to day, but is mainly contained within an envelope of +- 2 minutes. This points to a satisfactory predictability. On the majority of the trial days the difference is towards “later as planned”, specifically for runway direction 25. This points to the fact that the assumed flight times between COP and landing threshold are a little bit too short and should be adjusted.

The following figure provides additional information about the TTA adherence (=average difference between TTA and ALDT) per airline.

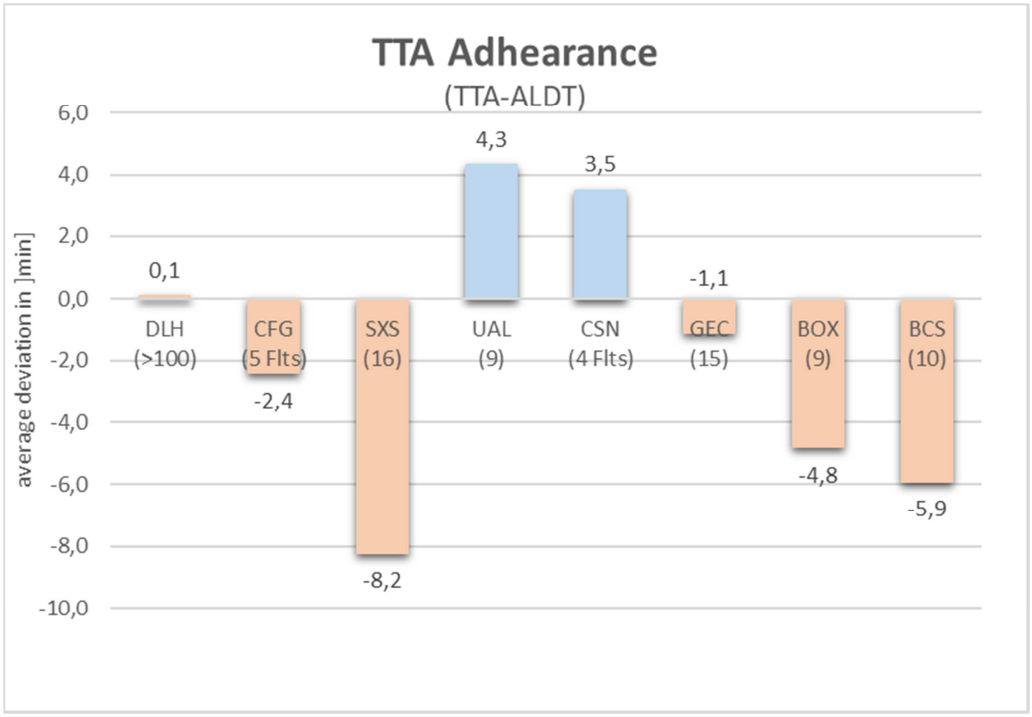

Figure 5: Average TTA Adherence per Airline

The figure shows that the Airlines with the most flights (DLH, GEC) achieved - on average - the best adherence to the predicted times. Also here the tendency can be seen towards a later arrival time.

A comparison with reference days cannot be made here as no TTA has been allocated.

Comparison of Scheduled and actual In-Block-Times

For most of the arrival flights an actual-in-block time (AIBT) was recorded at Frankfurt Airport, which has been used for the following analysis. For the remaining arrival flights, an AIBT has been derived from the actual landing time (ALDT) by adding the average taxi time to it.

Airlines satisfaction can be measured related to achievement of (or not later than) scheduled in-block time, SIBT. The success of the EMAS procedure would be related to achievement of (or not much earlier than) SIBT, because too early flights in the first hour of landings in the morning will most likely cause a bunching of arriving flights. Results of this comparison are visible in the figures below.

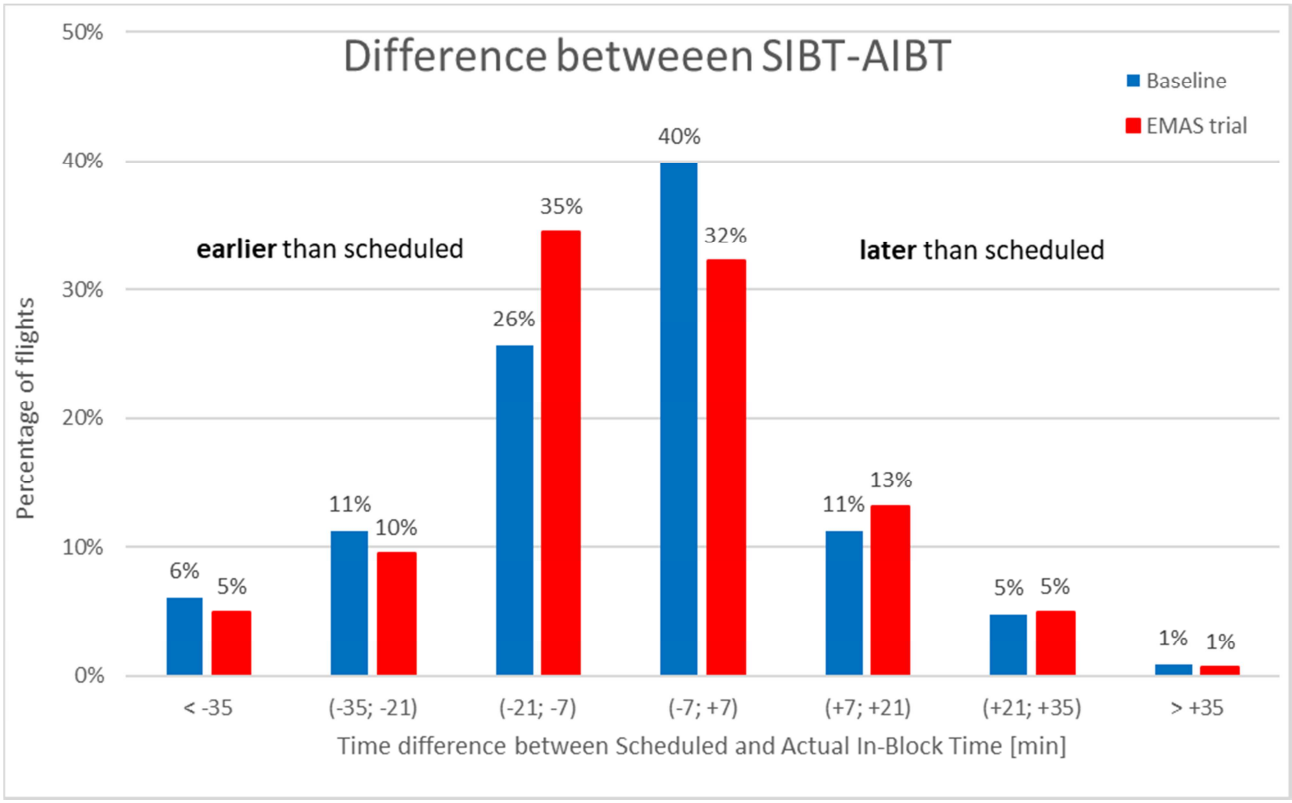

Figure 6: Difference SIBT-AIBT for all flights

Figure 7 below shows the same comparison but only for the long-haul flights that provided ETO information.

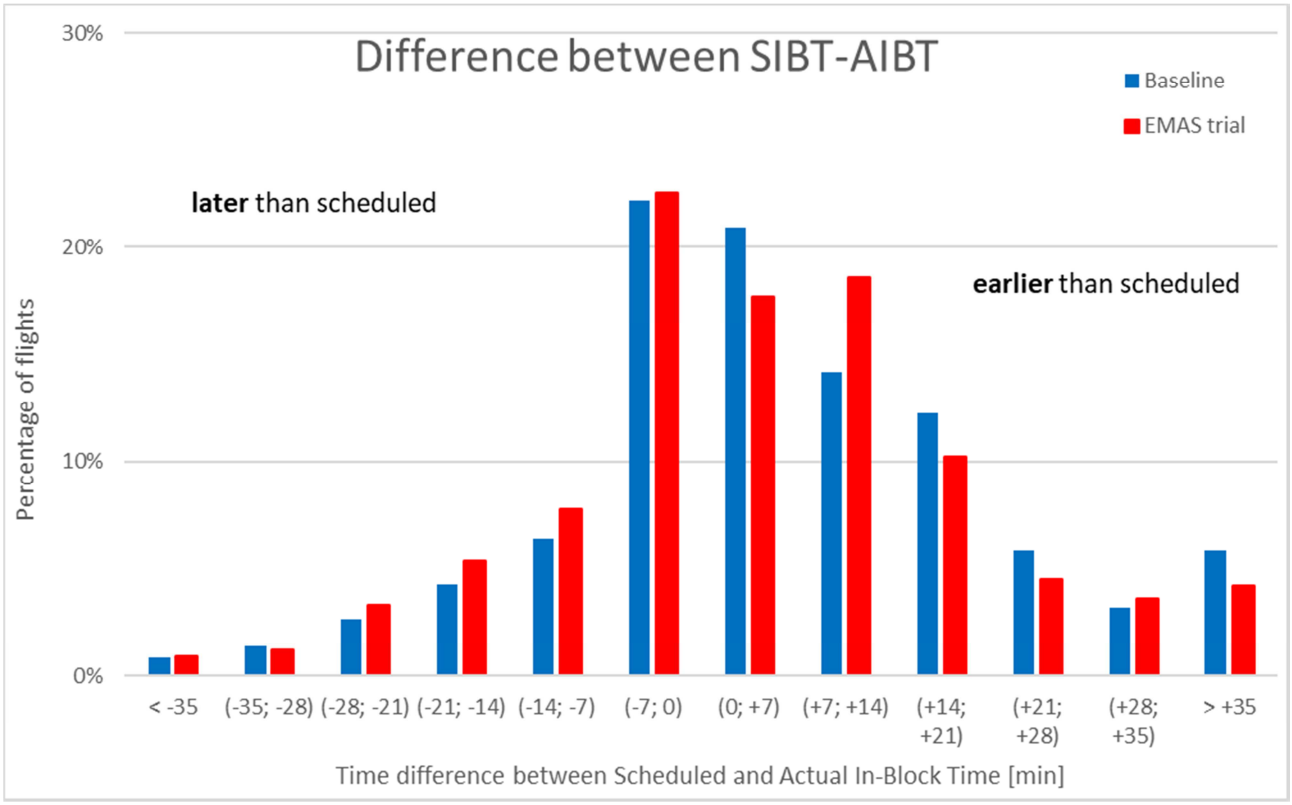

Figure 7: Difference SIBT-AIBT for long-haul flights that provided ETO information

Shown in both figures is the difference between SIBT and AIBT for all flights during the EMAS trial (red bars) and for all flights during the reference period (blue bars). There is no clear difference visible between the EMAS period and the reference period. This seems to be reasonable and can be explained because the EMAS process is not primarily trying to improve SIBT adherence in the best way, but about regulating the overall flow into the TMA. Nevertheless, the EMAS procedure should also lead to a slight reduction of too early flights.

Deviation between Target Time over COP and Actual Time over COP

The comparison between Target Time over COP and Actual Time over COP is a direct measure of the predictability of the aircraft's trajectory about 5 hours before passing the COP, i.e. it is a long term predictability measure for achieving a target time. However, the interpretation differs for long haul flights, which have provided an ETO value for the COP and medium to short haul flights, which are still about to depart.

Results are visible in the figure below:

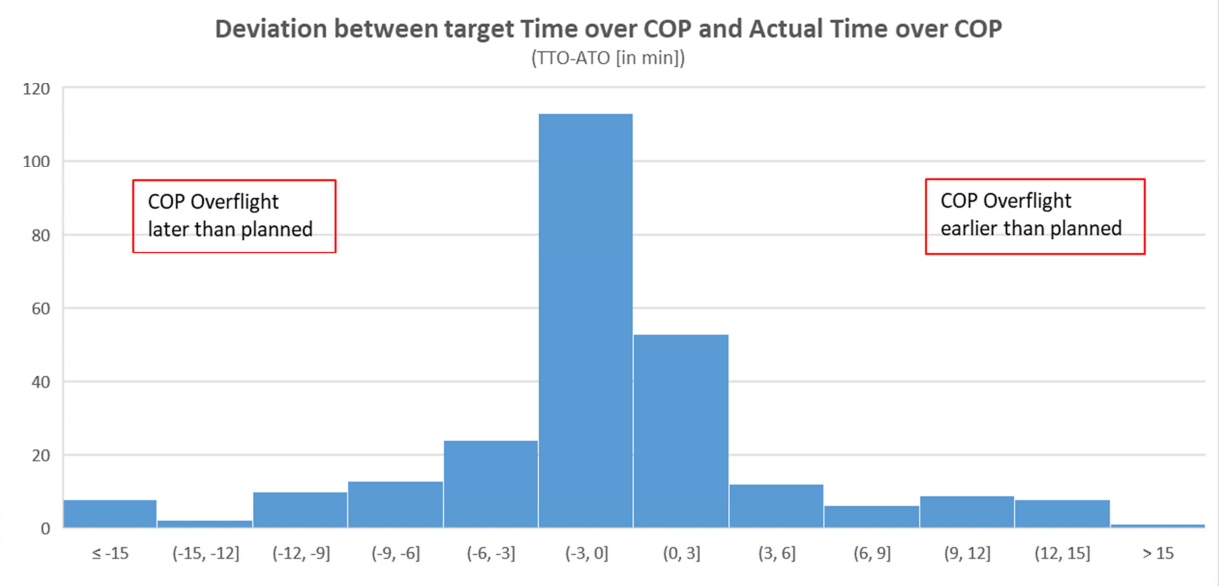

Figure 8: Time difference between ETO and ATO at COP

Figure 8 shows the adherence of the aircraft to the target time at the COP for the long-haul flights which provided an FMS-based ETO. More than 70% of the aircraft achieve their target time within 3 Minutes. However, there are still some outliers which are not able to comply with their target time. For the objectives of EMAS the flights which cross their COP too early are potentially more harmful than the ones crossing their COP later than their allocated target time.

The figure also indicates that, by receiving and using airborne FMS estimated times over certain COPs for the arrival sequence calculation and the target time allocation, the predictability of times at Metering Fixes and at the arrival threshold strongly increases. Since these estimates are also the basis for a meaningful target time procedure which maintains an economic en-route flight/speed profile, the necessity of obtaining these estimates is important for any long distance arrival flow management like EMAS.

Comparison between Pre-defined and Actual Flight Time from COP to THR

This comparison describes the quality and precision of the assumed flight time between COP and runway threshold and constitutes a parameter check of the EMAS trial. The EMAS planning procedure assumes a certain flight time between each COP and the runway threshold, which is taken from the flight time distribution of a long reference period. This flight time is the assumed target flight time which could be achieved with fully efficient EMAS procedures and which is used for the backward calculation from the planned arrival time to the target time at the COP

Results of this comparison are shown in the figure below for each COP separately.

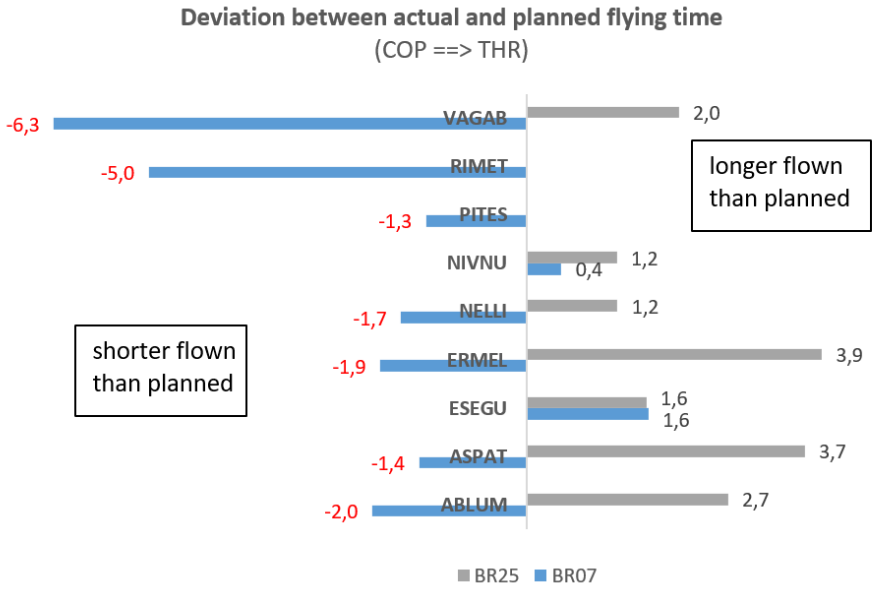

Figure 9: Time difference between planned and actual flying time from COP to Runway threshold (EMAS participants)

From Figure 9 it is evident, that the average flying time from a specific COP has been overestimated on average by about 2 minutes for runway direction 07 (BR07) compared to the planning values and underestimated on average by about 2 minutes for runway direction 25 (BR25). (Note, that the planning values differ for both runway directions). This points to a more efficient arrival routing for runway direction 07 than for runway direction 25 during the trial, and/or to a systematic deviation of real arrival routings from filed flight plan routings, which could be overall beneficial.

ii. Qualitative Assessment

Not foreseen.

c. KPA Environment

In principle there are various measures for the KPA Environment. Related to this exercise we take the KPI Time per Level flight in the TMA to determine whether the TTA allocation leads to a reduction of delay absorbing measures (holdings, delay vectors) and time spent in low altitudes and, directly related to that, less noise at ground level as well as less time in less economic flight phases. Other KPIs which are also relevant for the environment are discussed in the chapter on KPA Cost efficiency, like “Air Transport Time Efficiency” of “Air Transport Distance Efficiency”. These KPIs would – in principle - translate to the KPI “Fuel Efficiency”, but due to lack of accurate FDM fuel burn data, this translation could not be performed.

i. Quantitative Assessment

Time per Level

The KPI Time per Level flight during descent provides a measure on how much time is spent at a certain flight level in the descent phase of the aircraft. Environmentally ideal would be a continuous descent, but in reality there are always some level flight segments. How much time is spent in level flight segments in EMAS compared to the reference period is an indication of the environmental benefit of EMAS. In this analysis only level flight segments below 8000 ft are considered, since this is the relevant level range for e.g. noise.

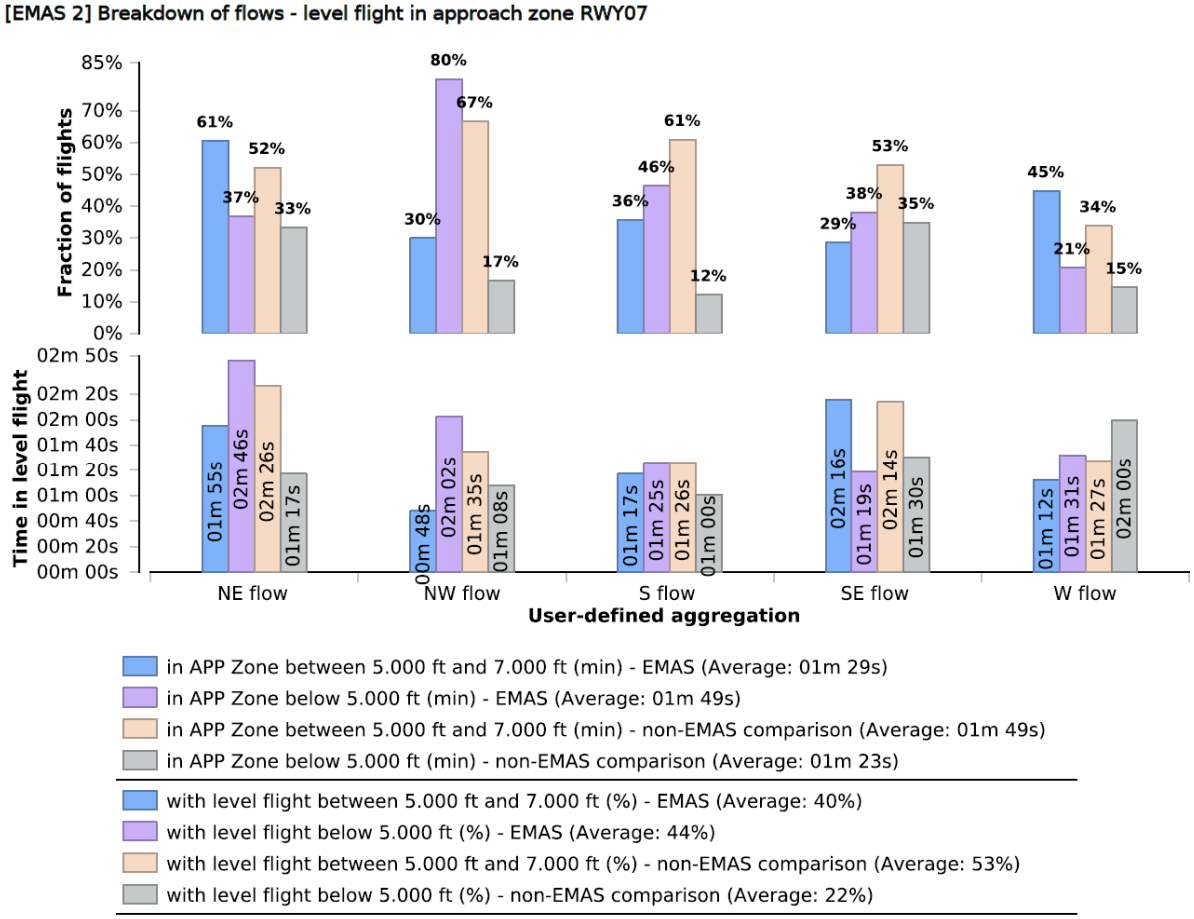

Figure 10: Time spent in level flight for all flights for the 5 different arrival flows and for 2 different altitude segments for runway direction 07.

For runway direction 07 and the altitude segment between 7000 ft and 5000 ft the time spent in level flight for the EMAS trial was about 20% below the value for the reference period. However, the situation was about reversed in the altitude segment below 5000 ft. So overall no positive environmental effect could be recorded.

If one differentiates this analysis by arrival flows it is evident that some flows (i.e. W, SE) have a better environmental effect than others (NE, NW). This points to a dependence between runway direction and flow direction related to this KPI.

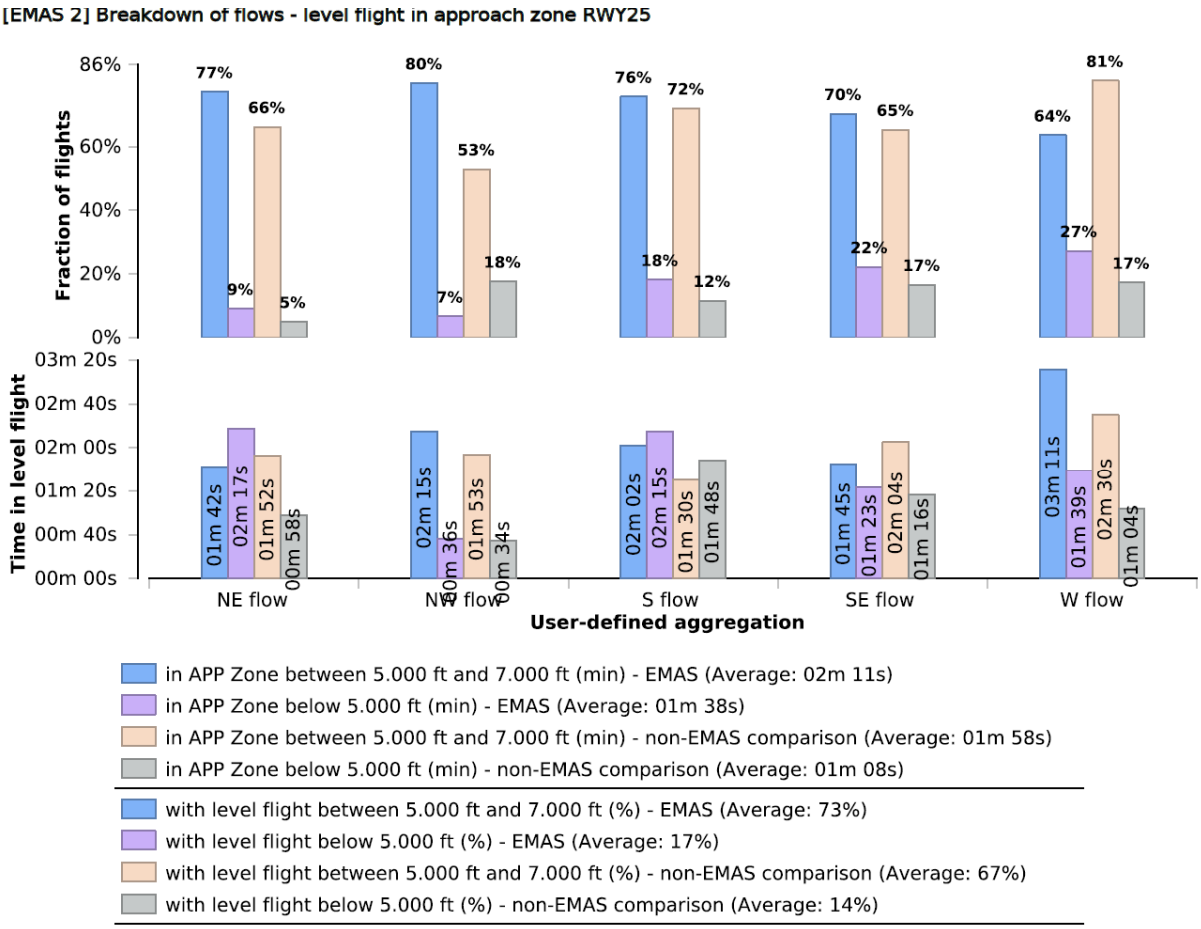

Figure 11: Time spent in level flight for all flights for the 5 different arrival flows and for 2 different altitude segments for runway direction 25.

For runway direction 25 and the altitude segment between 7000 ft and 5000 ft the time spent in level flight for the EMAS trial was slightly higher than the value for the reference period. Also for the altitude segment below 5000 ft this was the case. Positive was that for runway direction 25 only a small fraction of flights (< 20%) had some level flight segment. But overall no positive environmental effect could be recorded with EMAS related to this KPI.

If one differentiates this analysis by arrival flows no conclusive pattern arises.

d. KPA Cost Efficiency

Cost Efficiency can be measured in various ways. Related to this exercise the “Air Transport Time Efficiency” and the “Air Transport Distance Efficiency” were chosen as the main indicators, since these are closely related to fuel costs on one hand; and on the other hand short travelling times are in general one factor determining the number of flights which can be performed on one day with the same aircraft. . Also “Time/Distance in level flight” in the extended TMA is a measure of fuel efficiency.

i. Quantitative Assessment

Air Transport Time/Distance Efficiency has been measured by evaluating the real flown trajectories of all flights in the EMAS trial period and the reference period. The tool used for this analysis –

Honeywell GoDirect Flight Efficiency Software (GDFE) – provided an analysis within a 200 NM circle around Frankfurt Main Airport and within a circle of 30 NM approximating the TMA.

All results shown below follow the same presentation: The results are differentiated between 5 arrival flows into Frankfurt Main Airport, coming from the North East (NE flow), the North West (NW flow), South (S flow), South East (SE flow) and West (W flow). For these 5 arrival flows the average measure for time/distance for EMAS trial period and reference period is shown by the coloured bars (for both, the 200 NM circle and the 30 NM circle). On top of the graph, indicated by the lines and the numbers, the related number of flights is shown.

Air Transport Time Efficiency

The evaluation of times spent in the 200NM and within the 30NM circle around Frankfurt airport, differentiated by runway direction and arrival flow, result - for **all aircraft** arriving in the reference and/or trial period - in the following breakdown:

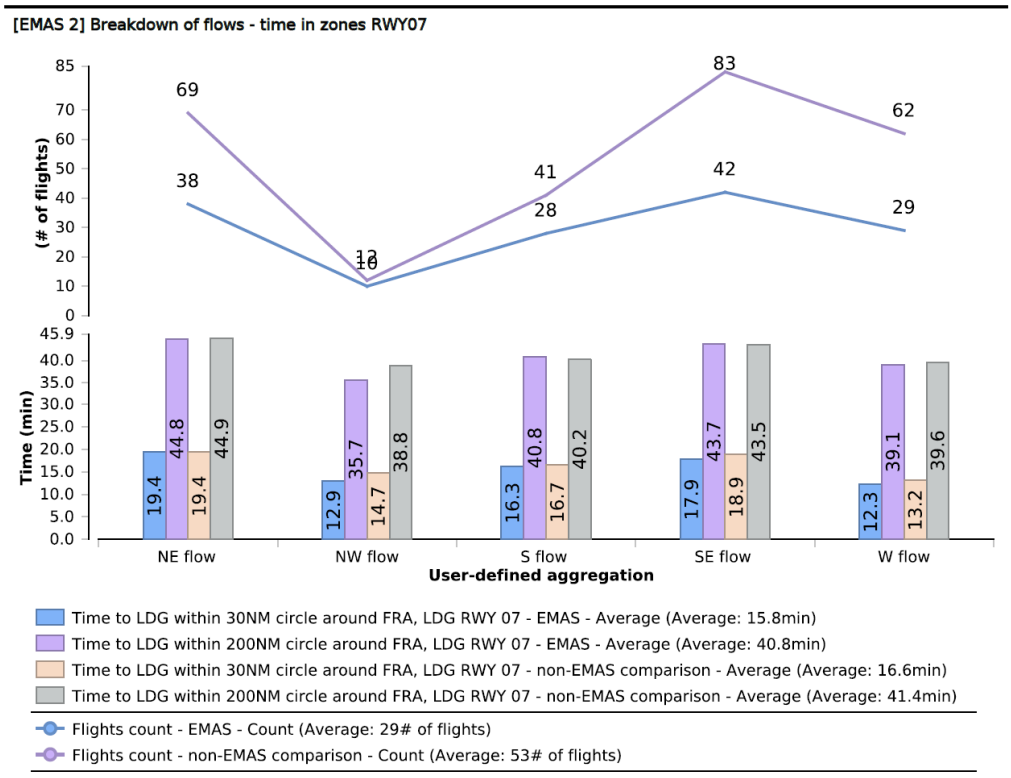

Figure 12: Time flown for all flights within a 200 NM and a 30 NM circle for 5 different arrival flows for runway direction 07.

For runway direction 07 a small positive effect (~ 5%) of the EMAS procedure can be seen in the TMA area for all flights compared to the reference period.

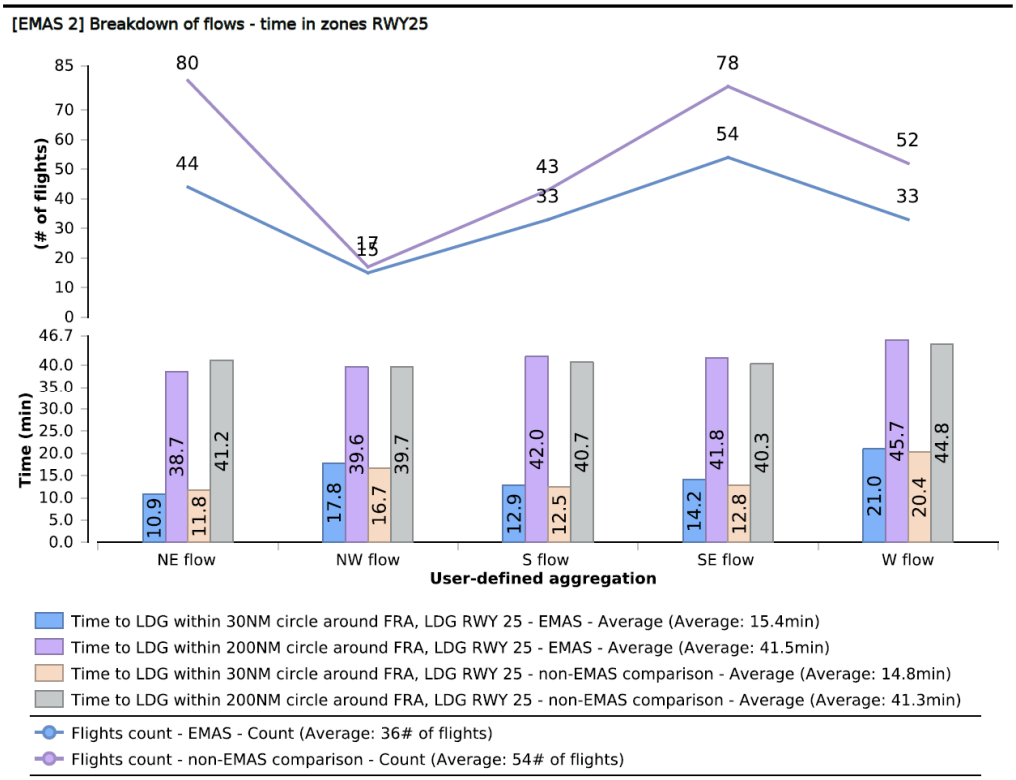

Figure 13: Time flown for all flights within a 200 NM and a 30 NM circle for 5 different arrival flows for runway direction 07.

For runway direction 25 a small negative effect (~ 4%) of the EMAS procedure can be seen in the TMA area for all flights compared to the reference period.

For **aircraft participating in the EMAS trial**, the evaluation of times spent in the 200NM and within the 30NM circle around Frankfurt airport, differentiated by runway direction and arrival flow, result in the following breakdown:

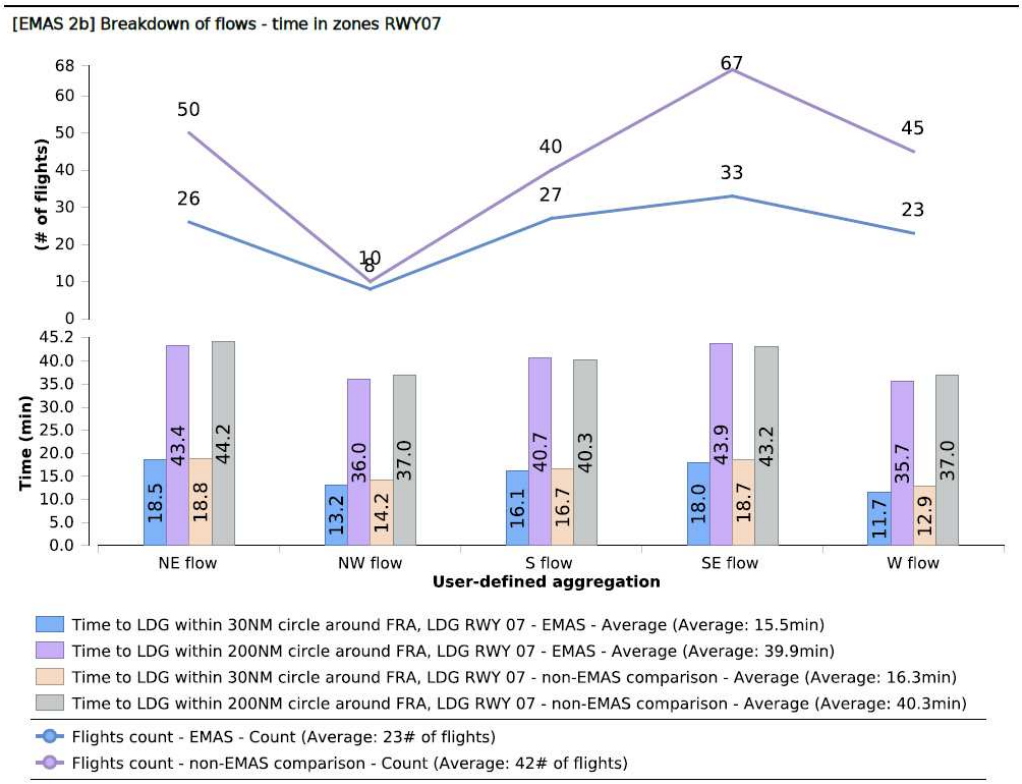

Figure 14: Time flown for EMAS flights only within a 200 NM and a 30 NM circle for 5 different arrival flows for runway direction 07.

For runway direction 07 a small positive effect (~ 5%) of the EMAS procedure can be seen in the TMA area for flights participating to the EMAS procedure compared to the reference period (also only taking into account the flights which were participating to the EMAS procedure during the EMAS trial period).

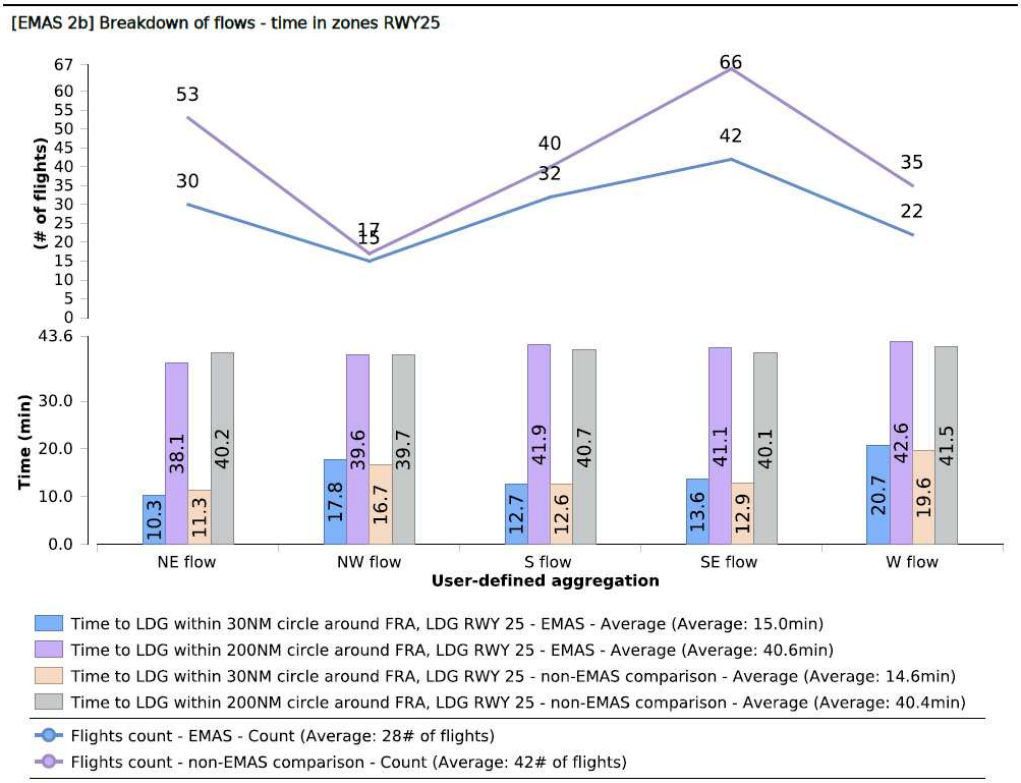

Figure 15: Time flown for EMAS flights only within a 200 NM and a 30 NM circle for 5 different arrival flows for runway direction 25.

For runway direction 25 a small negative effect (~ 3%) of the EMAS procedure can be seen in the TMA area for flights participating to the EMAS procedure compared to the reference period (also only taking into account the flights which were participating to the EMAS procedure during the EMAS trial period).

Air Transport Distance Efficiency

The evaluation of distances flown in the 200NM and within the 30NM circle around Frankfurt airport, differentiated by runway direction and arrival flow, result - for **all aircraft** arriving in the reference and/or trial period - in the following breakdown:

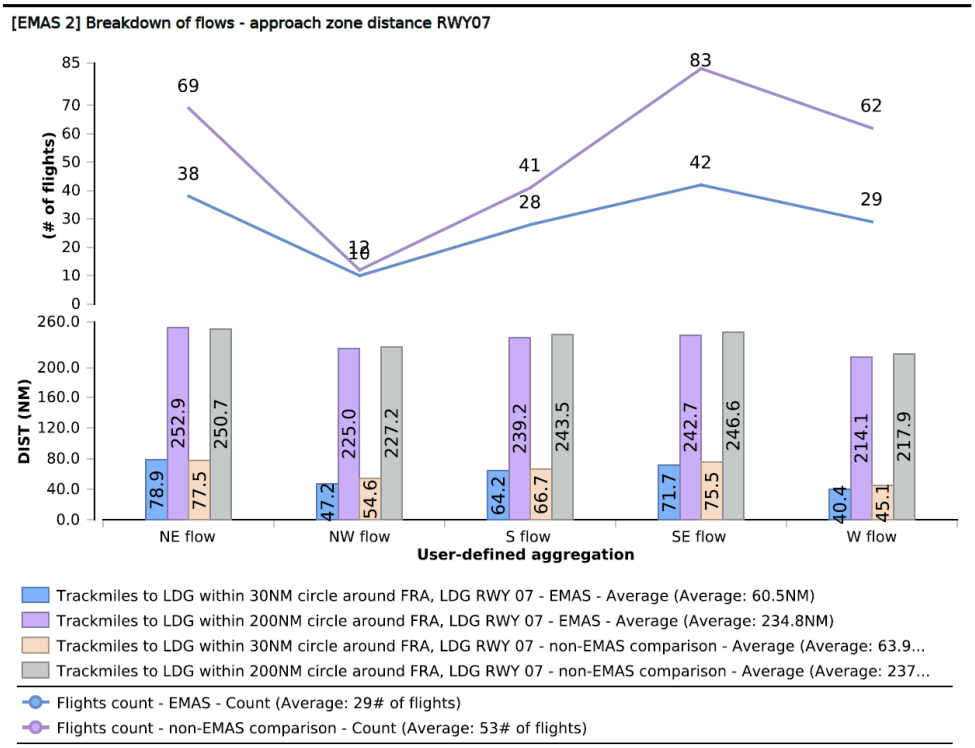

Figure 16: Distance flown for all flights within a 200 NM and a 30 NM circle for 5 different arrival flows for runway direction 07.

For runway direction 07 a small positive effect (~ 5%) of the EMAS procedure can be seen in the TMA area for all flights compared to the reference period.

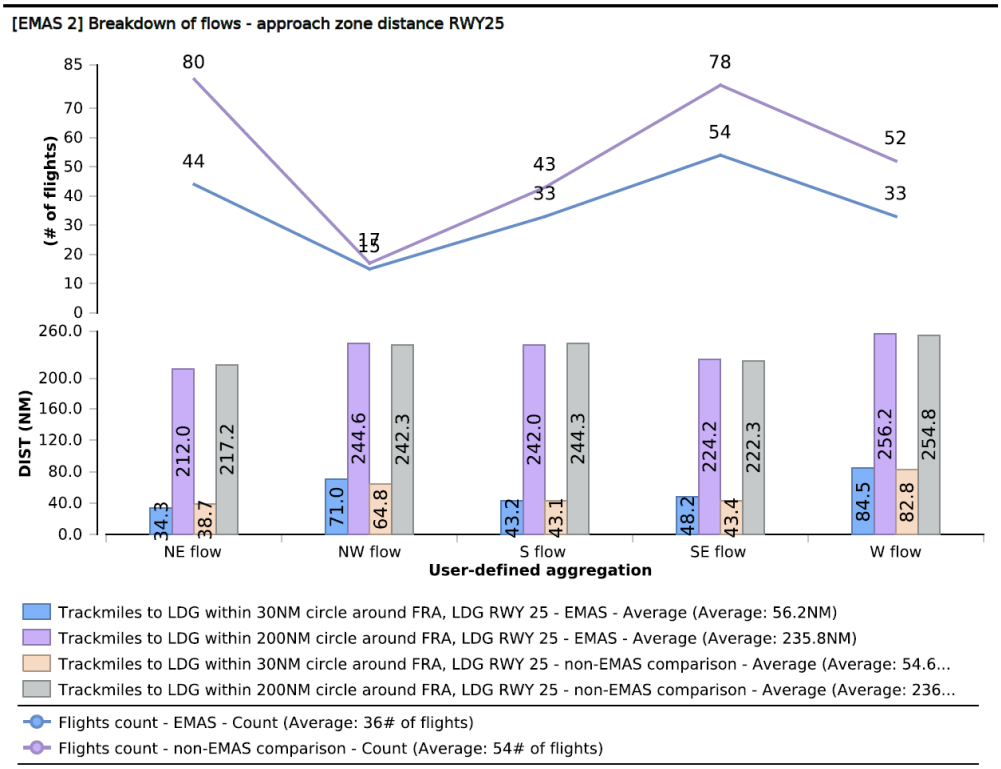

Figure 17: Distance flown for all flights within a 200 NM and a 30 NM circle for 5 different arrival flows for runway direction 25.

For runway direction 25 a small negative effect (~ 3%) of the EMAS procedure can be seen in the TMA area for all flights compared to the reference period.

For **aircraft participating in the EMAS trial**, the evaluation of distances flown in the 200NM and within the 30NM circle around Frankfurt airport, differentiated by runway direction and arrival flow, result in the following breakdown:

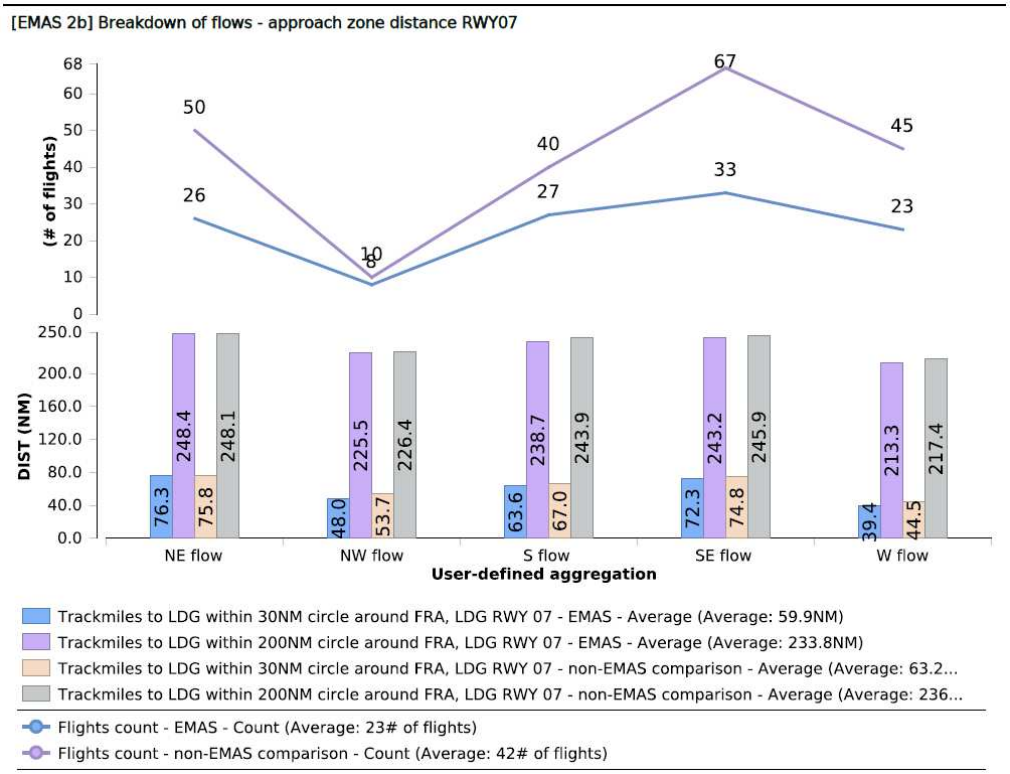

Figure 18: Distance flown for EMAS flights only within a 200 NM and a 30 NM circle for 5 different arrival flows for runway direction 07.

For runway direction 07 a small positive effect (~ 5%) of the EMAS procedure can be seen in the TMA area for flights participating to the EMAS procedure compared to the reference period (also only taking into account the flights which were participating to the EMAS procedure during the EMAS trial period).

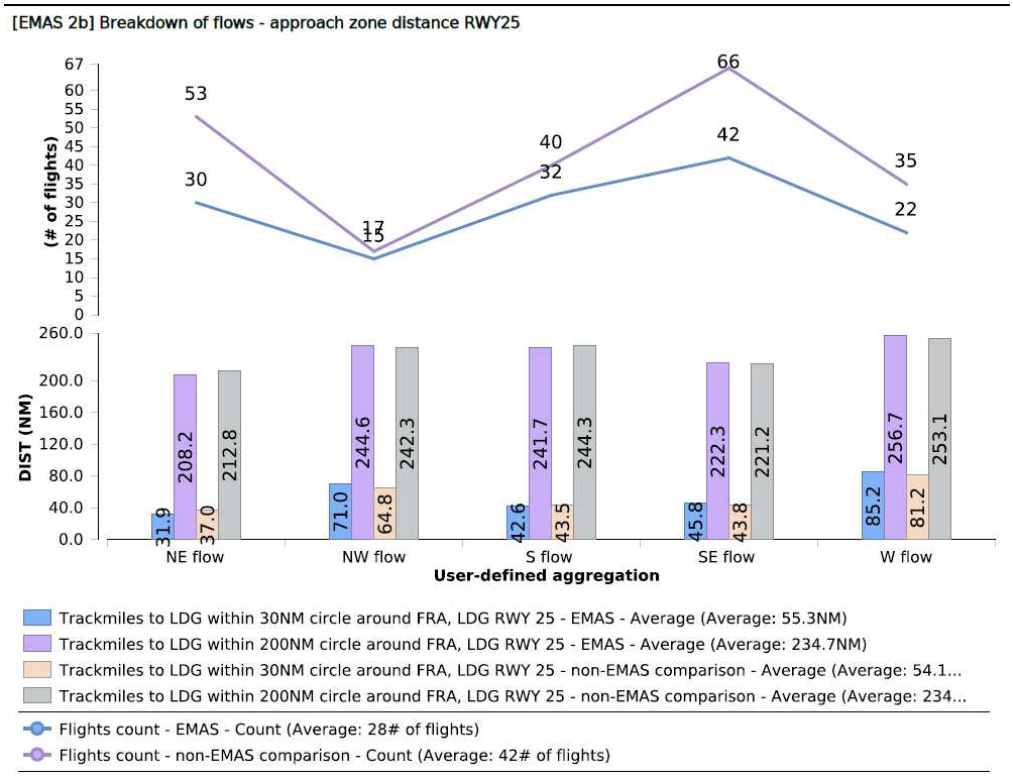

Figure 19: Distance flown for EMAS flights only within a 200 NM and a 30 NM circle for 5 different arrival flows for runway direction 25

For runway direction 25 a small negative effect (~ 2%) of the EMAS procedure can be seen in the TMA area for flights participating to the EMAS procedure compared to the reference period (also only taking into account the flights which were participating to the EMAS procedure during the EMAS trial period).

Overall the effect of EMAS on Air Transport Time and Distance Efficiency is similar and slightly positive on average, but is hardly statistically relevant.

More important seem to be the differences between runway direction 07 (positive effect) and runway direction 25 (negative effect). Further analysis is needed to pinpoint the reasons for this behaviour.

Time in level flight during approach

The KPI Time per Level flight in the TMA provides a measure on how much time is spent at a certain flight level in the descent phase of the aircraft. Environmentally ideal would be a continuous descent, but in reality there are always some level flight segments. How much time is spent in level flight segments in EMAS compared to the reference period is an indication of the flight efficiency and therefore also cost efficiency of EMAS. In this analysis only level flight segments below 8000 ft are considered.

For **aircraft participating in the EMAS trial**, the evaluation of time in level flight flown in APP zone, differentiated by two level segments, result in the following breakdown:

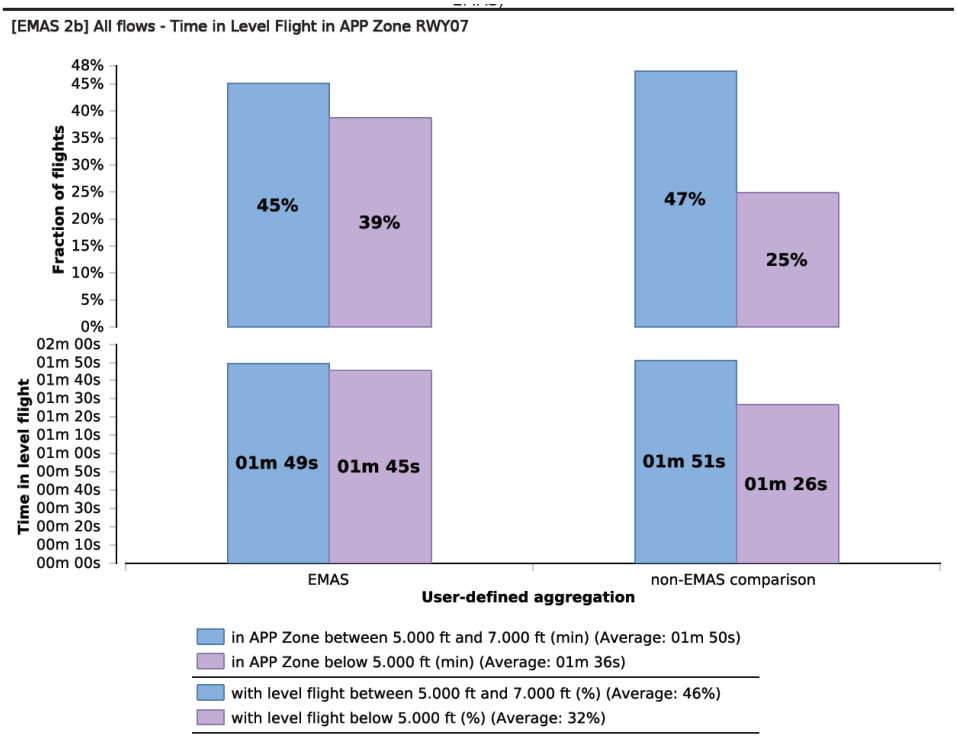

Figure 20: Time in level flight in APP zone for RWY07 and for EMAS flights only.

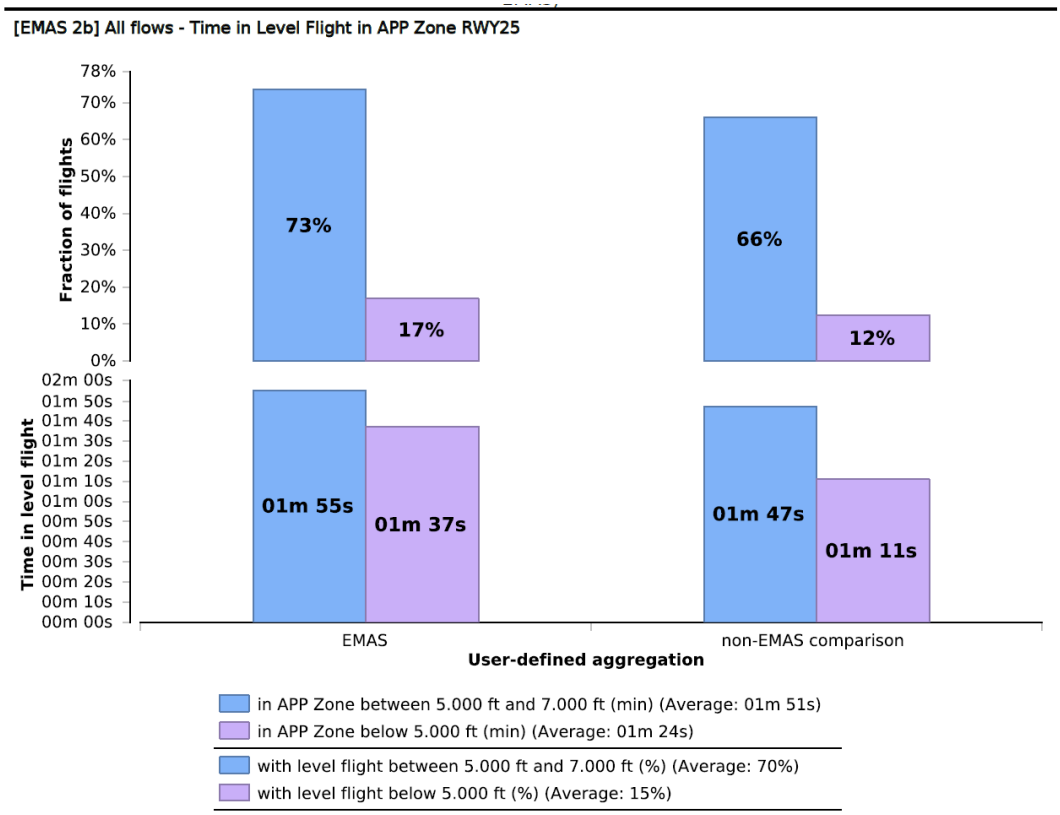

Figure 21: Time in level flight in APP zone for RWY25 and for EMAS flights only.

The average absolute values for times flown in level flight segments are small: In the order of about 1-2 minutes per altitude segment between 7000 ft and 5000 ft and below 5000 ft. However, there is a small negative effect visible for EMAS flights compared to the reference period.

Distance in level flight during approach

The KPI Distance per Level flight in the TMA provides a measure on how much distance is flown at a certain flight level in the descent phase of the aircraft. Environmentally ideal would be a continuous descent, but in reality there are always some level flight segments. How much distance is flown in level flight segments in EMAS compared to the reference period is an indication of the flight efficiency and therefore also cost efficiency of EMAS. In this analysis only level flight segments below 8000 ft are considered.

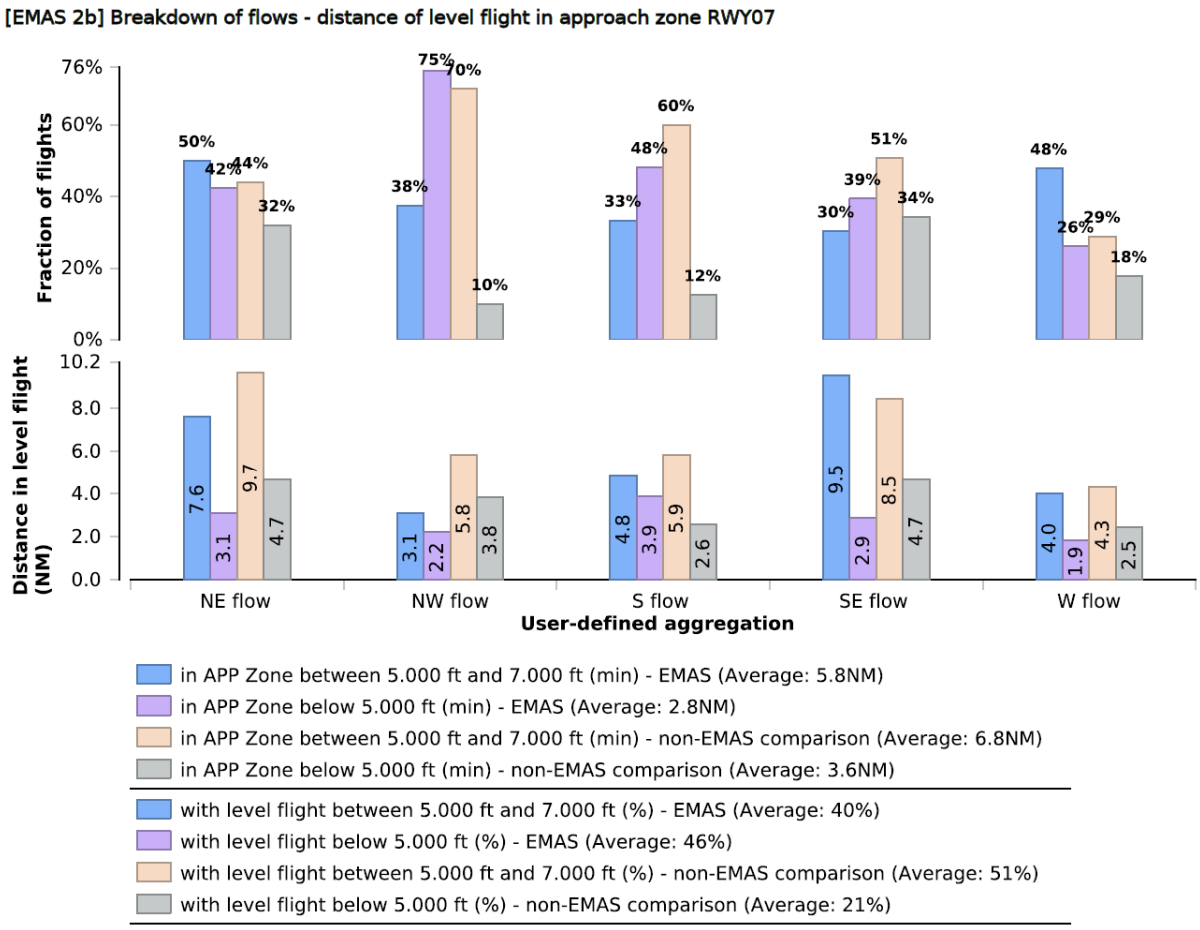

Figure 22: Distance in level flight in APP zone for RWY07 and EMAS flights only.

The average absolute values for distances flown in level flight segments are small: In the order of about 6 NM in the altitude segment between 7000 ft and 5000 ft and about 3 NM below. For the EMAS trial period the values were about 20% smaller than for the reference period for runway direction 07.

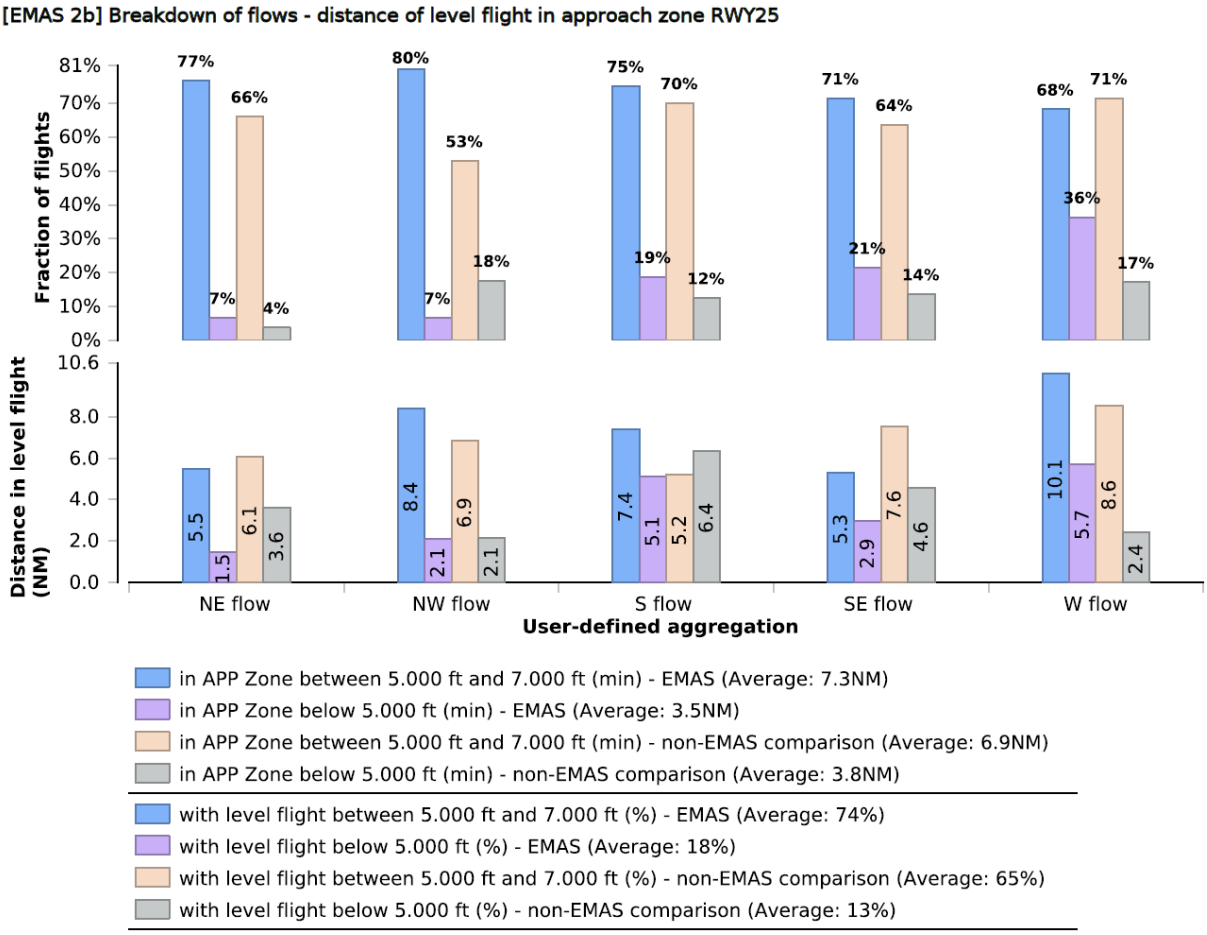

Figure 23: Distance in level flight in APP zone for RWY25 and for EMAS flights only.

For runway direction 25 the comparison of the EMAS trial period to the reference period is less favourable: In this case the EMAS values of distances flow in flight level segments are slightly higher than for the reference period.

As for the other KPIs on cost efficiency an overall small positive effect can be recorded for the KPI "Distance in level flight during approach".

ii. Qualitative Assessment

Tracks flown in the TMA

A graphical representation of the tracks flown in the TMA for the EMAS trial period (red) and the reference period (blue) is given below.

Runway direction 07:

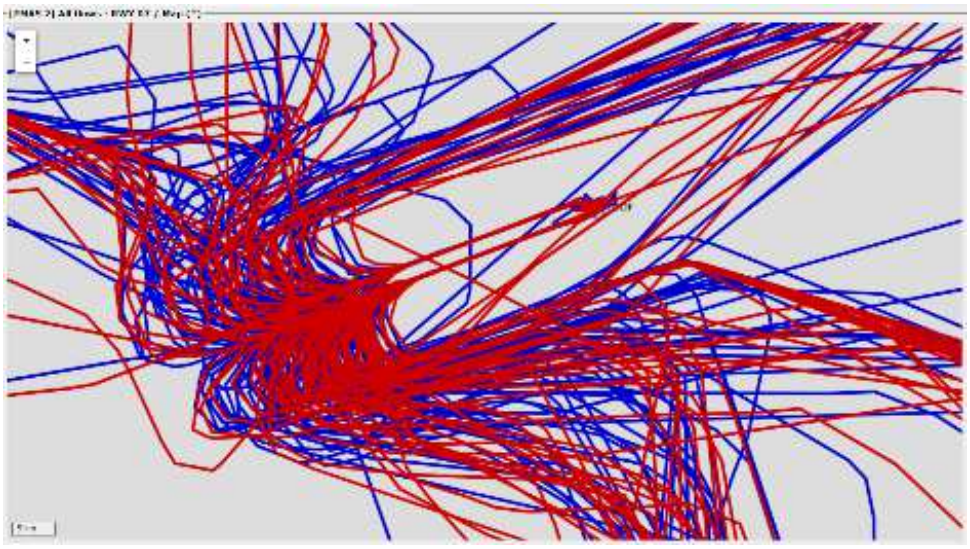

Figure 1024: Flight tracks for runway 07 (EMAS: red, Reference: blue).

Runway direction 25:

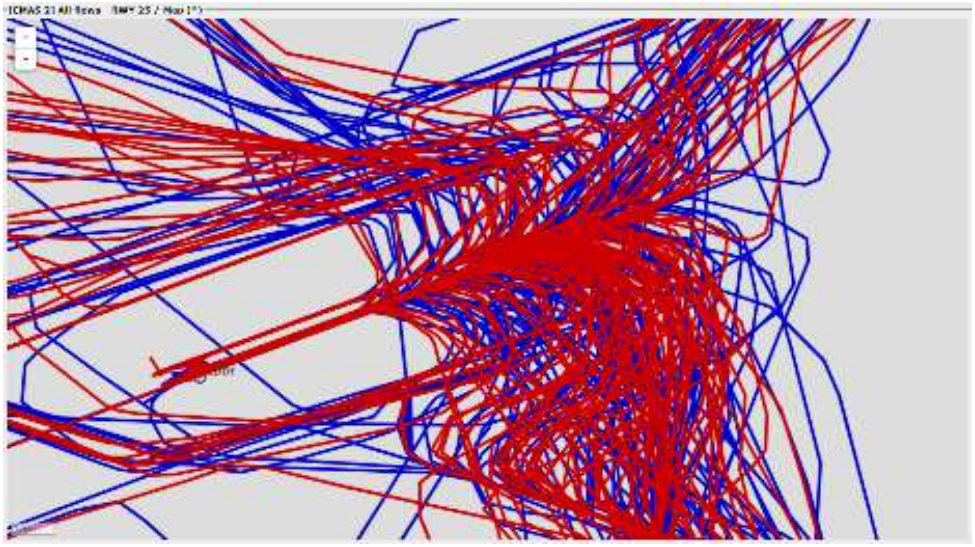

Figure 1125: Flight tracks for runway 25 (EMAS: red, Reference: blue).

From the graphical representation of the tracks it is difficult to assess any differences between the EMAS trial period and the reference period.

e. KPA Capacity

The KPA Capacity is not on the list of validation objectives from the Demonstration Plan. Nevertheless some findings concerning KPA capacity are derived from the evaluation of the exercise.

i. Quantitative Assessment

Runway Throughput

The EMAS procedures had no impact on the average runway throughput at FRA, because the demand in the first hour after the night curfew is not higher than the offered runway capacity when both runways dedicated for landings are available. However, one of the objectives of EMAS was to avoid a bunching of arrivals directly after the end of the night curfew, i.e. closely after 0500 local time.

Below, the distribution of arriving flights between 0300 and 0400 UTC (0500 and 0600 local time) is shown. For runway direction 25 a shift of arrivals to later times can be seen for the EMAS trial period, whereas for runway direction 07 no obvious differences between EMAS and reference scenario can be observed.

Distribution of Landings in the first hour

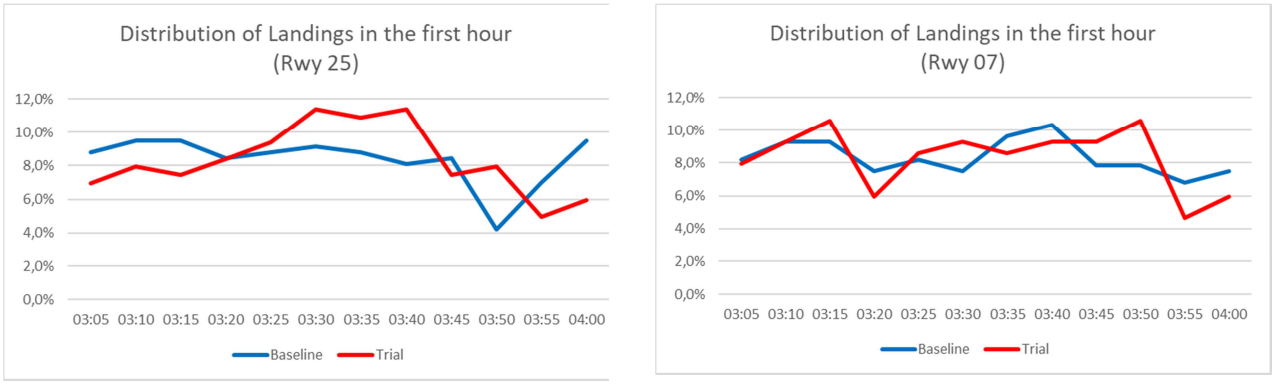

Figure 1226: Distribution of landings in the first hour; separately for RWY25 (left) and RWY07 (right)

In the EMAS trial period for runway direction 07 a more steady and continuous arrival flow can be observed than for runway direction 25. The reasons for this need a deeper analysis in terms of arrival flows (direction and quantity) and their interdependency with the runway direction. The following tables show a comparison of landings in the first 15 minutes after re-opening of the airport.

Date	Active runway	Landings		Percentage
		05:00-06:00 lcl	05:00-0515 lcl	
28. Aug	BR25	28	9	32%
29. Aug	BR25	29	10	34%
01. Sep	BR25	32	9	28%
02. Sep	BR25	29	9	31%
03. Sep	BR25	31	13	42%
04. Sep	BR25	36	10	28%
05. Sep	BR25	32	11	34%
07. Sep	BR25	32	9	28%
08. Sep	BR25	32	9	28%
Average BR25		**31**	**10**	**32%**
22. Aug	BR07	27	10	37%
23. Aug	BR07	33	10	30%
24. Aug	BR07	32	8	25%
25. Aug	BR07	33	10	30%
26. Aug	BR07	24	4	17%
27. Aug	BR07	29	9	31%
30. Aug	BR07	33	8	24%
31. Aug	BR07	33	8	24%
06. Sep	BR07	37	8	22%
Average BR07		**31**	**8**	**27%**

Figure 13~~27~~: Number of landings per day, Reference period

Date	Active runway	Landings		Percentage
		05:00-06:00 lcl	05:00-0515 lcl	
09. Sep	BR25	27	5	19%
10. Sep	BR25	33	11	33%
11. Sep	BR25	32	10	31%
12. Sep	BR25	33	7	21%
13. Sep	BR25	33	8	24%
16. Sep	BR25	25	8	32%
Average BR25		**31**	**8**	**27%**
14. Sep	BR07	30	8	27%
19. Sep	BR07	30	8	27%
20. Sep	BR07	32	10	31%
21. Sep	BR07	31	8	26%
22. Sep	BR07	29	8	28%
Average BR07		**30**	**8**	**28%**

Figure 14~~28~~: Number of landings per day, EMAS trial period

For equally distributed arrival times during the first landing hour one would expect 25% of the flights to land within the first 15 minutes after re-opening of the airport at 0500 local time. The results of the EMAS trial and the reference period show, that this number is a little bit higher, i.e. 28% or 27 % respectively. This leads to the conclusion, that the EMAS procedure – on one hand - did not shift the number of landings on average into later times, and – on the other hand – still fully used the available runway capacity, i.e. did not waste early arrival slots. Nevertheless, for EMAS the percentage of flights landing in the first 15 minutes have a smaller spread than for the reference period, pointing to the desired “smoothing effect” which should be achieved with EMAS. However, also this effect is small.

ii. Qualitative Assessment

Not foreseen.

2. Results impacting regulation and standardisation initiatives

For a fully efficient EMAS procedure all airlines and flights need to participate. In order to achieve this it should be considered to make the EMAS procedure mandatory via AIP or similar means. Nevertheless, this should be discussed with all relevant stakeholders on the basis of a common understanding of the benefits of EMAS.

O.3.2 Analysis of Exercises Results per Demonstration objective

1. EXE-VLD-09-002 OBJ-VLD-01-001 Results

This objective was to show that xStream operational improvements are respecting the current level of safety in air traffic management.

The corresponding success criterion is fulfilled when the safe management of traffic by ATC is not compromised and new procedures do not cause critical incidents.

Results:

During the EMAS trial period no incidents were caused and/or reported due to the EMAS implementation, neither from Airlines nor from ATC.

Feedback from Air Traffic Controllers at ACC Langen was neutral or positive. Some approach controllers which were on duty during the EMAS trials remarked that the arrival situation was more relaxed for them than during normal operations due to a more continuous inbound traffic flow.

The objective can be considered fulfilled.

2. EXE-VLD-09-002 OBJ-VLD-02-001 Results

This objective was to show that xStream operational improvements provide a better predictability and punctuality of air traffic in TMA / terminal sectors.

The corresponding success criterion is fulfilled when differences between planned / predicted and actual traffic flow at prominent points or at the runway are reduced.

By receiving and using airborne estimated times over Metering Fixes from the aircraft FMS the predictability of arrival times strongly increases. These estimates are also the basis for a meaningful target time procedure which maintains an economic flight/speed profile. Also the punctuality of arrivals could be increased slightly compared to their scheduled in-block times.

The objective can be considered partly fulfilled.

3. EXE-VLD-09-002 OBJ-VLD-03-001 Results

This objective was to show that xStream operational improvements provide benefits in terms of environmental sustainability of air traffic.

The corresponding success criterion is fulfilled when fuel efficiency of air traffic is increased while emissions (and noise pollution) are reduced.

Environmental sustainability was investigated in terms of distance and times in level flight during the descent phase and in the TMA.

Although the absolute flight time and distance spent in level flights was small, there was - on average - no improvement of EMAS flights compared to the reference period. If one differentiates per arrival flow then some flow directions show small positive effects which need to be further analysed to fully understand the potential of EMAS for environmental sustainability.

The objective can be considered as partly fulfilled.

4. EXE-VLD-09-002 OBJ-VLD-04-001 Results

This objective was to show that xStream operational improvements increase cost efficiency from more efficient processes for airspace user.

The corresponding success criterion is fulfilled when flight efficiency is increased and flight management / flight coordination costs are reduced.

Cost efficiency was investigated in terms of distance and times flown within the TMA and within a bigger 200 NM radius (i.e. from top of descent) around Frankfurt Main Airport. In addition also distance and times in level flight during the descent phase was investigated.

Small positive effects of about 5 % reduction have been observed in the EMAS trial period for runway direction 07 compared to the reference period. However, for runway direction 25 even a small negative effect of 2-3 % has been found. The reason of the difference is not clear yet and needs to be explored in more detail.

The objective can be considered as partly fulfilled.

5. EXE-VLD-09-002 OBJ-VLD-05-001 Results

This objective was to show that ATC capacity usage in TMA is optimized by xStream operational improvements.

The corresponding success criterion is fulfilled when Traffic load, ATC workload or complexity in terminal sectors is reduced.

This objective was not required by the demonstration plan but is nevertheless covered by the assessment.

The EMAS procedures had no impact on the average runway throughput at FRA, because the demand in the first hour after the night curfew was not higher than the offered runway capacity when both runways dedicated for landings are available. However, one of the objectives of EMAS was to avoid a bunching of arrivals directly after the end of the night curfew, i.e. to smoothen out the demand and to provide a steady and continuous arrival flow.

This objective could partially be achieved, however only a small effect was observed. One effective measure in this respect was the ability to steer short haul flights to later arrival times.

O.3.3 Unexpected Behaviours/Results

The results of the EMAS trial showed only very small effects for most of the investigated KPIs. In pre-trials bigger potentials for improvements had been observed. The reasons for the results “below expectation” need further analysis.

O.3.4 Confidence in the Demonstration Results

1. Level of significance/limitations of Demonstration Exercise Results

During the EMAS trial 11 usable datasets of about 30 flights each were recorded and analysed. The reference period contained 18 usable datasets with also about 30 flights each. Since the observed effects of the EMAS trial compared to the reference period were in the few % scale, the statistical significance of the results is small.

2. Quality of Demonstration Exercise Results

The quality of the demonstration results was influenced by various factors:

The demonstration exercise was very complex and many parameters had to be considered, some of them out of control of the actors.

Nominally about 70% of the flights were participating to the trial, but 30% of the flights did not. From the 70% participating flights it was not always clear in how far they fully executed the EMAS procedures. The other 30% of flights could disturb the arrival sequence severely, especially if they were arriving too early at the Frankfurt TMA.

Sometimes during the coordination phase flight plans were still missing due to late filing. This disturbed the arrival sequence calculation and the target time allocation.

The transfer and the processing of the estimates at the Metering Fixes from the Aircraft FMS was largely automated and relied on compliance to a certain data format. However, some aircraft did not send the information in the required data format and therefore some estimates could not be taken into account.

The calculation of the arrival sequence depends largely also on the runway direction. This runway direction had to be assumed in the coordination phase of the EMAS procedure and was based on the best weather and wind forecast available at that time. Nevertheless, on three trial days a different runway direction was activated in the morning by ATC operations. The data of these three trial days have therefore been discarded which diminished the data sample used in the evaluation.

3. Significance of Demonstration Exercises Results

The observed effects of the EMAS trial compared to the reference period were only in the few % scale. The statistical significance of the results related to the KPAs is therefore small.

Nevertheless, in pre-trials a bigger potential of the EMAS procedure has been observed than the results of the EMAS trial imply. The significance of the demonstrations also lies in the fact that a very complex coordination and execution process for target times could be implemented with a variety of stakeholders in a fairly automated fashion.

The findings of the trial point to several improvements which still can be made and should be followed up:

- Larger participation of airlines,
- Full automation of the EMAS coordination and data distribution process,
- Better awareness of neighbouring ATC units related to predicted and planned flight routes,
- Better steering of medium and short haul flights related to their target times.

With optimized conditions positive effects in the relevant KPAs of around 10% should be possible.

O.4 Conclusions

The EMAS trial could be executed during 2 weeks of September 2019 as planned. A reference period in August/September 2019 was identified with similar operational conditions.

Participating stakeholders engaged in the EMAS coordination process and procedure in a positive way. The developed EMAS tool helped to automate the process considerably and allowed to reduce the workload for most actors. Feedback of the actors indicated, that automation of the EMAS process still should be improved and completed to be ready for a regular application in arrival management.

Related to the KPA Safety a very important and positive conclusion can be drawn: There were no safety related issues reported. Additional workload of pilots was rated not safety relevant. Air traffic controllers feedback was neutral or positive concerning the handling of the arrival traffic in the TMA.

The comparison of the other KPAs (Environment, Cost Efficiency, Capacity) for the trial phase and the reference phase did not reveal significant improvements, which came a little bit as a surprise as pre-trials had shown more positive effects.

There were only small effects observed for distance and time spent in the TMA. However, these were different for the two runway directions 07 and 25 and also for different arrival flows. The reason for this needs to be analysed further. Arrival streams directly targeting at the runway directions could be improved, but specifically arrival streams with long downwinds seemed to be penalized. So improvements could be generated in certain areas (e.g. related to noise), but not significantly on average.

O.5 Recommendations

O.5.1 Recommendations for industrialization and deployment

If the general idea of the EMAS target time determination was deployed, further enhancements of the operational process would be recommended. Airlines with single flights affected by EMAS might support a manual process of providing the estimated times and distributing the target times, whereas airlines with a significant number of flights during that time need more support by

automation. Additionally the fixed sequence after the initial target time determination does not reflect operational changes like updated wind data, circumnavigation of significant weather, directs given by ATC, changing runway in use and actual departure times of flights not airborne at that stage of the process.

Therefore an automated provision of updated estimated times and dynamic updates of the arrival sequence and target times is required to achieve a realistic target picture.

The target of less fuel consumption during the approach phase should be compared to possible additional fuel consumption en-route caused by uneconomic flight speeds. More information like current speed and aircraft type in addition to the estimated times should be incorporated in a more complex target time determination to keep the overall flight efficiency.

In addition the steering of medium and short haul flights by adjusting their take-off time should be improved in order to achieve an even more continuous arrival flow into the TMA:

Possibly, the positive effect of target time flying can be increased if other operational ATC processes are better matched to the EMAS procedures, e.g. in the coordination between en-route Control Centres and in TMA procedures.

The EMAS process should be incorporated in an overall European concept to reduce operational complexity for airspace users flying to various European hubs. It should also reflect the capability of aircraft arriving from various regions around the world with more or less flexibility to adapt the speed (e.g. NAT crossing).

O.5.2 Recommendations on regulation and standardisation initiatives

For a fully efficient EMAS procedure all airlines and flights need to participate. In order to achieve this it should be considered to make the EMAS procedure mandatory via AIP or similar means. Nevertheless, this should be discussed with all relevant stakeholders on the basis of a common understanding of the benefits of EMAS.

In order to deal with the problem of missing flight plans during the coordination phase of EMAS it should be made mandatory for the Airline Operators to provide their flight plans – at least an initial version – at the latest 6 hours before departure. This requirement should be part of the EMAS procedure published in the AIP (see point above).

The arrival sequence algorithm implemented for this trial assumed that each aircraft adheres to the determined target time. Even if not all airlines and flights are participating a concept must be in place to guarantee the calculated landing time if an aircraft arrives according to its target time. ATC should be enabled to give preference to those flights which are compliant with the target time procedure instead of simply serving all aircraft on a “first come first served” basis.