Runway Pressure Research

The effect of En-Route Delay Absorption on the runway throughput

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***Abstract*— Major airports in Europe experience a number of arrivals close to the maximum of their capacity throughout the day. Due to this, multiple aircraft can arrive at the airport in a too short time window and thus have to be delayed in the airspace surrounding the airport before they are cleared to land. A higher fuel burn and costs for the airlines is the result, but it also has a negative effect on the environment in terms of additional pollution and noise. The Cross-border Arrival Management (XMAN) project, which is part of the Single European Sky program, tries to reduce the negative effects of delay in the proximity of airports. The main idea is to shift the necessary delay from the Terminal Maneuvering Area (TMA) or holding towards the cruise flight phase by reducing the speed of aircraft. Although the shift of delay absorption from the TMA to the en-route phase shows promising results for fuel consumption and reduced emissions, the question rises whether this En-Route Delay Absorption (ERDA) can also have a negative impact on the effective use of runway capacity. If aircraft are delayed too much in an earlier flight phase due to e.g. inaccuracy of the expected arrival times, so called gaps appear in the landing sequence. As a result, the total number of aircraft that actually landed per time period decreases. The idea is that in order to maintain an optimal runway throughput, some expected delay should be left in the TMA for the approach controller to absorb. The approach controller can use this additional time to fine-tune a tight landing sequence without any gaps that would result in an underused runway when the demand for landings is high. This planned delay in TMA is defined as runway pressure.**

The main goal of this research project is to investigate the effect on the runway throughput when the expected delay is absorbed in the en-route phase. To achieve this goal, different fast time simulations are performed with a model of Amsterdam airport (Schiphol) in AirTOp software.

Based on the simulation outcomes, it can be concluded that ERDA can sometimes result in a small decrease of runway throughput, with a maximum of one aircraft per hour. By the end of an inbound peak which last two hours, the actual landing time of an aircraft with ERDA is between 30 and 90 s later than the same aircraft with no ERDA. The inbound peak is thus effectively extended with at most the time for one extra landing when ERDA is applied. The benefit is that aircraft spend up to four minutes less in the TMA or holding pattern near the airport.

Keywords-AMAN; XMAN, SESAR; ATM; aircraft delay; runway efficiency; fast time simulation, AirTOp

I. Introduction

Major airports in Europe experience a number of arrivals close to the maximum of their capacity throughout the day. Due to this, multiple aircraft can arrive at the airport in a too short time window and thus have to be delayed in the airspace surrounding the airport before they are cleared to land. A higher fuel burn and costs for the airlines is the result, but it also has a negative effect on the environment in terms of additional pollution and noise [1]. The Cross-border Arrival Management (XMAN) project, which is part of the Single European Sky program, tries to reduce the negative effects of delay in the proximity of airports. The main idea is to shift the necessary delay in the Terminal Maneuvering Area (TMA) or holding towards the cruise flight phase by reducing the speed of aircraft. If an aircraft is inbound for an airport and the expected arrival time is too close to the arrival time of a leading aircraft, the trailing aircraft can be asked to slow down such that it arrives at the airport when the runway is available. One of SESAR's goals is to implement the XMAN concept at five main airports in Europe; London Heathrow, Paris Charles de Gaulle, Frankfurt, Munich and Amsterdam. Live trials for Heathrow airport started in April 2014 in cooperation with the English (NATS) and French (DSNA) Air Navigation Service Providers. Although the shift of delay absorption to the en-route phase shows promising results for fuel consumption and reduced emissions, the question rises whether this shift can also have a negative impact on the efficient use of runway capacity. If aircraft are delayed too much in an earlier flight phase due to e.g. inaccuracy of the expected arrival times, so called gaps appear in the landing sequence. As a result, the total number of actual landing slots decreases. Such a decrease in runway throughput is not acceptable by many stakeholders.

The idea is that in order to maintain an optimal runway throughput, some expected delay should be left in the TMA for the approach controller to absorb. In that case, the approach controller can create a tight landing sequence without any gaps in the landing sequence that would result in an underused runway when the demand for landings is high. This planned delay in the TMA is defined as runway pressure. However, research on the working principles and parameters behind runway pressure has not been performed so far in the academic world. If the amount of runway pressure is known for each airport mentioned above, the benefits of XMAN can be used while minimizing the negative side effect of a decreased runway throughput.

The main goal of this research project is to investigate the effect on the runway throughput when expected delay is absorbed in the en-route phase. To achieve this goal, different fast time simulations are performed with an airside model of Amsterdam airport.

II. ARRIVAL MANAGEMENT PROCEDURES

A. Amsterdam airport Terminal Maneuvring Area

Aircraft inbound for Amsterdam airport will in general be guided from one of the five main upper airways towards one of the three Initial Approach Fixes (IAFs). The TMA of

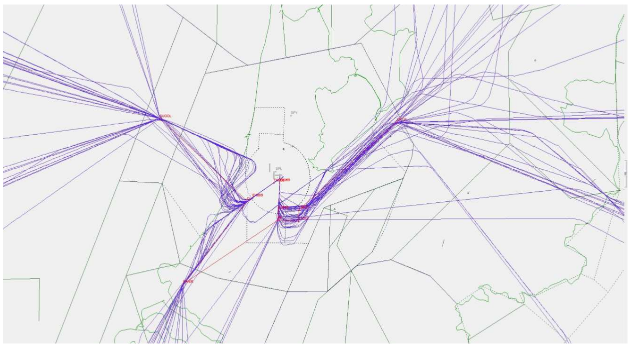

Figure 1 Radar tracks (blue) of a morning inbound peak on 1st June 2014 landing on runways 06 and 36R of Amsterdam airport

Amsterdam airport has a radius of approximately 30 NM. Although any route towards the runway can be instructed to the pilots, most aircraft will be guided along the same and possibly shortest approach path. An example of actual radar tracks of a morning inbound peak on 1st June 2014 landing on runway 06

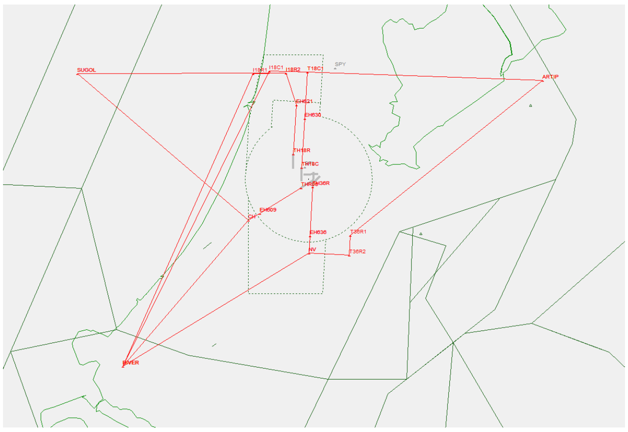

Figure 2 Shortest flight paths (red) in Amsterdam airport's TMA used by the Trajectory Predictor of the ATM system.

and 36R is given in Figure 1, together with the location of the three IAFs (SUGOL in the northwest, RIVER southwest and ARTIP in the east). These radar tracks are used as a reference to create the model, which is further described in part III.

Amsterdam airport has six runways in different directions of which three runways are parallel. Depending on the wind direction, the preferred main runway for landing is either 18R or 06 and 18C or 36R can be used if extra capacity is needed. During an inbound peak, at most two runways are available for landings and can be used independently. To limit the amount of work for analysis and simulations during this research, only landings on those four runways are investigated and simulated. Figure 2 gives an overview of all the shortest approach paths towards the four runways used in the simulation model.

B. Inbound planning

Inbound planning is the process in which traffic inbound for the TMA of Amsterdam airport is regulated by an approach planner, usually the approach supervisor, in order to get an optimized traffic flow towards the runway(s). Each inbound aircraft that is picked up by the radar (often already outside the flight information region of the Netherlands) will be correlated with its flight plan in the ATM system and get an Estimated Time of Arrival (ETA) predicted by an algorithm of the Trajectory Predictor (TP). The inbound planning will calculate the landing slots of multiple aircraft on each runway based on their ETA and the required landing separation settings. If two adjacent landing slots have overlap, either the leading aircraft needs to arrive earlier or the trailing aircraft needs to arrive later and thus experiences delay. The predicted flight time between the IAF and the runway threshold is subtracted from the landing slot time to form the Estimated Approach Time (EAT). The EAT is the time an aircraft has to leave the stack or arrive at the assigned IAF to be handed over from the Area Controller to an Approach Controller. The amount of time that needs to be gain or lost by an inbound aircraft is made available to the Area Controllers. The current margin in which aircraft have to be at the IAF on this EAT is ± 120 s. As a result, some time to gain or lose per aircraft has to be resolved in the TMA, which is not always possible. Furthermore, if the required flight time to gain for multiple aircraft is too large for an Area Controller to achieve by only heading and speed changes, a holding pattern needs to be flown near the IAF. The method of this inbound planning system is also used at other major European airports, including the five airports that will implement XMAN [2].

C. En-Route Delay Absorption

The XMAN project aims to reduce the negative effects of delay and holding in the proximity of airports by anticipating earlier on the predicted Estimated Time of Arrival of aircraft towards the same airport. By absorbing the expected delay of aircraft earlier, in the en-route part of the flight, holding and large vectoring patterns near the airport can be avoided. In this research, the amount of delay that is absorbed before the IAF is limited to five min per aircraft.

III. SIMULATION MODEL

A. *Fast Time simulation software*

The fast time simulation software used for this research is AirTOp. This software package has the tools to design every required airspace structures to simulate incoming traffic. It can perform Monte-Carlo simulations and can simulate time based separations standards between aircraft. AirTOp version 2.3.15 is used during this research. AirTOp has the ability to import Base of Aircraft Data (BADA) files in order to use more representative aircraft performance data during the simulations. BADA version 3.12 is used for the aircraft performance calculations of the simulations.

A model is always a representation of the real world and is limited to some assumption to make the development of the model and the complete research feasible. For example, the approach procedure at Amsterdam airport in which traffic from three IAFs is divided over two runways is too complex to simulate simultaneously for this research. In the real situation, two IAFs are assigned each to one runway and the traffic coming from the third IAF is divided over the two runways, depending on the available landing slots and traffic from the other two IAFs. Because each landing runway is independent of the other, a simulation scenario can be created where traffic flies over two IAFs and the traffic flow is merging to one runway. The outcome of this simulation is not affected by traffic that is landing on the other runway and therefore it does not need to be simulated. The following main assumptions are used in all simulations:

- Normal weather conditions are assumed to calculate the parameters (weather does not affect arrival demand, runway capacity or air traffic handling by controllers);
- No wind model is implemented in AirTOp;
- Each runway is served by two IAFs at most;
- Only one (independent) runway is active per simulation scenario to limit the amount of traffic that needs to be simulated simultaneously;
- No outbound and overfly traffic is simulated;
- To calculate the shortest flight time in the TMA, jet aircraft are assumed to all have the same average speed. The same is assumed for propeller aircraft.

B. *Simulation model set-up*

The simulation environment consists of two main parts. The first one is the en-route part and includes all the routes up to the Initial Approach Fixes. The second part is the most important one for this research and contains a highly detailed model of Amsterdam's TMA where aircraft are lined up towards the glideslope to land.

Each simulation scenario simulates a number of aircraft during an inbound peak of two hours and each aircraft has a reference time to the assigned IAF with an accuracy of ± 30 s. There are scenarios that simulate traffic from one IAF to a single runway and scenarios that simulate traffic from two IAFs to a single runway. For each scenario, there is a traffic sample with a surge in demand for landings which is higher than the runway capacity, in order to force the use of ERDA. The same scenario is also simulated with a lower and more realistic demand that equals the runway capacity. For each scenario, the same traffic samples are simulated with and without the use of ERDA.

C. *En-Route Delay Absorption simulated*

In order to investigate the effect of ERDA, an algorithm is created that adjust the reference times of the simulated aircraft at the IAFs, such that the required Controlled Time Over (CTO) the IAF of each aircraft is obtained. The algorithm works in analogy with the principles of the inbound planning system of Amsterdam airport explained earlier.

Each aircraft in a traffic sample receives an initial ETA and a corresponding CTO of its IAF. The distribution of the initial ETAs is based on the amount of traffic planned to land within each 20 min. If no ERDA is applied, aircraft will fly to the airport and will receive vectoring instructions or have to maintain in holding if delay is required due to the high amount of traffic. When ERDA is applied, the algorithm calculates the required separation between two consecutive flights in the sequence and adjusts the reference flight time or CTO of the assigned IAF. This is made visual in Table I. The algorithm will only create a new CTO for the IAF if delay is required. If there is a gap in the landing sequence (e.g. aircraft #21 has a separation of 2:00 min instead of the required 1:40 min), the new CTO will be the same as the original planned reference time and no (negative) ERDA, equivalent to an aircraft speed increase, is applied.

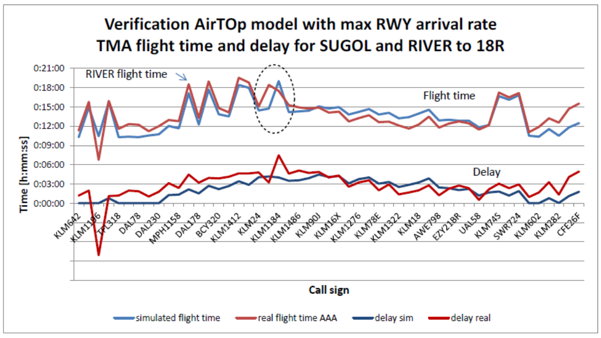

Figure 3 Comparison of the flight times and delays between the simulated and actual flight data for traffic from RIVER and SUGOL to 18R.

IV. VERIFICATION OF THE MODEL

In order to verify if the constructed AirTOp model of Amsterdam airport behaves the same as if the traffic would be handled by real ATCOs, actual traffic data are implemented in

TABLE I EXAMPLE OF THE EN-ROUTE DELAY ABSORPTION ALGORITHM CALCULATIONS FOR AMSTERDAM AIRPORT

Sequence nr.	WTC	IAF	Initial ETA	Separation	Required separation	Difference	New ETA	New CTO IAF
14	SuperHeavy	SUGOL	10:17:43				10:17:43	10:07:10
15	Medium	SUGOL	10:19:43	0:02:00	0:03:00	-0:01:00	10:20:43	10:10:10
16	Heavy	RIVER	10:21:43	0:01:00	0:01:45	-0:00:45	10:22:28	10:07:42
17	Medium	SUGOL	10:23:43	0:01:15	0:02:00	-0:00:45	10:24:28	10:13:55
18	Medium	SUGOL	10:25:43	0:01:15	0:01:45	-0:00:30	10:26:13	10:15:40
19	Medium	SUGOL	10:27:43	0:01:30	0:01:45	-0:00:15	10:27:58	10:17:25
20	Heavy	RIVER	10:29:43	0:01:45	0:01:45	-0:00:00	10:29:43	10:14:57
21	Heavy	RIVER	10:31:43	0:02:00	0:01:40	0:00:20	10:31:43	10:16:57

the model. The actual landing times, throughput, flight time and TMA congestion delay measured with AirTOp are compared with the actual radar track data. At least two inbound peaks are found in which the external circumstances like wind or runway maintenance do not affect the data needed to verify the model. Three scenarios are verified; one scenario with traffic flying from ARTIP to runway 18C and one scenario with traffic from ARTIP to runway 36R. The third verification is the scenario with traffic from RIVER and SUGOL merging in the TMA and landing on runway 18R. As stated in the previous section, the most important part of the model is the TMA environment. The main idea of the verification is to implement the Actual Time Over (ATO) the IAFs in the flight plans as a reference time, run the simulation and compare the simulated flight time in the TMA with the actual flight time. The congestion delay is compared as well. The congestion delay for the radar track data is based on the reference (shortest) flight time calculated by the TP the moment the aircraft passes the IAF. The congestion delay of the simulated aircraft is calculated with the same principle.

Figure 3 shows the comparison of the flight time and the congestion delay in the TMA between the real and simulated traffic during an inbound peak. As the approach path from RIVER to 18R is longer than the one from SUGOL, the flight time graph shows 'spikes' each time an aircraft approaches from RIVER. There are two events that need further explanation. The first one is a shorter flight time of flight KLM1196, due to a direct heading given towards the runway at the beginning of the inbound peak. This results in a significant time saving which is measured as a negative delay (red line) and can be ignored, because the airplane does not cross the planned IAF. The second event is a lower delay that occurred in the simulation, compared to the actual radar track data. In the simulation, the landing sequence is switched between KLM1260 coming from RIVER and KLM1184 passing SUGOL. In the actual situation, KLM 1184 had to encounter up to 7.5 min of delay to allow KLM1260 in front of it. In the simulation, KLM1184 arrives first which results in lower total delay of both aircraft: 8 min instead of 10.5 min. Apart from those two events, the flight time and delay per aircraft is similar. The same verification results are obtained with the other data sets. Therefore, it can be concluded that the simulation model is similar enough to the real situation to be used for this research.

V. RESULTS

Various scenarios are simulated with a variation in fleet mix composition, traffic demand, and route structure. Each scenario is simulated with and without ERDA. Because there is a random variation of ± 30 s implemented in the accuracy in which the aircraft arrive at the assigned IAF, each scenario is simulated multiple times. One of the reasons to keep the variation of the reference time within 30 s is to keep the conflicts and separations inside the TMA during the simulations manageable and the sequence stable. If aircraft in the flight schedule are separated by two min, but the first aircraft arrives 1 min 15 s later at the IAF and the second one 1

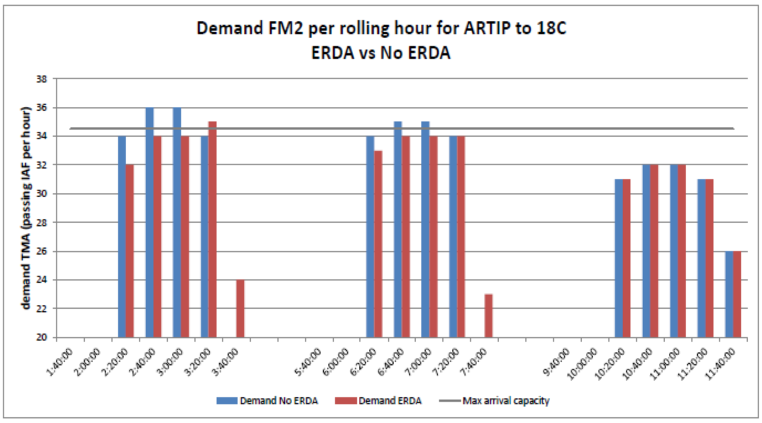

Figure 4 Demand per rolling hour of the second fleet mix traffic sample for three arrival peaks at ARTIP to 18C. Both the demand with (red) and without (blue) En-Route Delay Absorption is given, together with the maximum arrival capacity based on the fleet mix order and required separation.

min 30 s too early, a re-sequence of the traffic flow occurs. As a result, a different wake vortex separation could be needed and the calculated times of the ERDA algorithm are no longer valid. Another reason to keep the margin within 30 s is that in order to facilitate the use of fixed arrival routes in the TMA, the accuracy of the ATO IAF should be reduced to ±30 s [3].

The outcome of the simulations is the average amount of delay in the TMA per 20 min and the amount of landings per rolling hour. A rolling hour consists of three consecutive time periods of 20 min. Each scenario is simulated 20 times to obtain the statistical data.

A. *The effect on demand*

To see the effect of ERDA on the demand of various scenarios, the amount of arrivals entering the TMA is shown in Figure 4 together with the maximum arrival rate. The demand, throughput and average delay are measured and shown per 20 min time period. The fleet mix represented here consists of only medium aircraft. A time separation of 105 s between medium aircraft allows 69 landings per two hours, or an average of 34.5 aircraft per hour, which is made visual by the grey line. The effect of ERDA is clearly visible in the amount of aircraft passing the IAF per time period of 20 min. Due to the ERDA algorithm, the arrivals at the IAF are shifted backwards and one aircraft in each inbound peak arrived just in the 3:40 and 7:40 time period. This explains the extra bar at 3:40 and 7:40 for the ERDA scenario in the first and second arrival peak given in Figure 4.

B. *The effect on delay and runway througput*

The main research question is to find out what the effect is of En-Route Delay Absorption on the landing throughput. The benefit of ERDA should be a reduction (or in the most optimal way, a disappearance) of the congestion delay in the TMA. In order to show both effects, the results of the different simulations regarding throughput and delay are presented in one graph.

Figure 5 shows both the throughput and delay for the simulated traffic coming from ARTIP and landing on runway 18C. In blue, the results without ERDA are given and in red, the results when ERDA is applied. It can be observed that the maximum delay when no ERDA is applied, reaches 5 min 57 s (σ=18 s) during the first arrival peak. When ERDA is applied, not all delay can be absorbed en-route during the first inbound peak and the delay per aircraft in the TMA rises significantly above one min (red line). The delay in the TMA during the second inbound peak for the ERDA scenario behaves more constant throughout the peak and stays below one min per aircraft. Due to ERDA, the stream of traffic at the IAF is already optimized for the separation at the assigned runway. However, there is still delay in the TMA left due to the inaccuracy of the arrival time at the IAF. The results for the third arrival peak with a low demand (represented at the right side of Figure 4) are not shown in this graph, because there is no significant difference between the ERDA and non-ERDA simulation.

TABLE II OVERVIEW OF THE THROUGHPUT FOR THE FIRST (TOP) AND SECOND (BOTTOM) ARRIVAL PEAK SHOWN IN FIGURE 5.

Throughput \Time	1:40:00	2:00:00	2:20:00	2:40:00	3:00:00	3:20:00	3:40:00
20 min: No ERDA	4,0	10,0	11,0	11,0	11,0	11,0	10,0
20 min: ERDA	4,0	10,0	10,4	10,8	11,7	11,0	10,0
Rolling hour: No ERDA			25,0	32,0	33,0	33,0	32,0
Rolling hour: ERDA			24,4	31,3	33,0	33,6	32,7
Throughput \Time	**5:40:00**	**6:00:00**	**6:20:00**	**6:40:00**	**7:00:00**	**7:20:00**	**7:40:00**
20 min: No ERDA	4,2	10,8	11,0	11,0	11,0	11,0	9,0
20 min: ERDA	4,1	10,9	10,7	10,9	10,9	11,3	9,2
Rolling hour: No ERDA			26,0	32,8	33,0	33,0	31,0
Rolling hour: ERDA			25,7	32,5	32,5	33,1	31,4

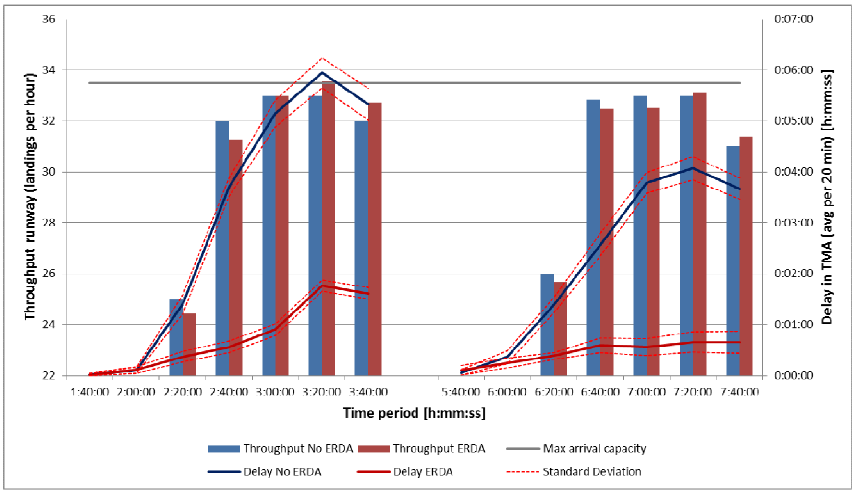

Figure 5 Throughput per rolling hour for two arrival peaks from ARTIP to 18C. Both the throughput with (red) and without (blue) En-Route Delay Absorption is given, together with the maximum arrival capacity based on the fleet mix order and required separation. The second vertical axis on the right side gives the average delay per aircraft per 20 min time period. The delay is shown with a standard deviation.

The effect on throughput when ERDA is applied is represented by the bars in Figure 5. The throughput does not decrease significantly with ERDA. In fact, it is even increasing in the second hour of the arrival peak. The differences in throughput are very small and to have a good overview, the exact numbers are given in Table II. The effect on throughput with or without ERDA for traffic coming from one IAF and landing on one runway is the same for all three different fleet mixes simulated.

When two approach legs merge in the TMA to one final approach path, the approach sequencing gets more complex. Aircraft on one approach leg must maintain enough spacing between them to allow other aircraft coming from a different approach leg to be merged on the common flight path. The accuracy of passing the IAF at the CTO of both IAFs is very important in this situation, because the CTOs are related to each other. For example, if the ATO SUGOL of one aircraft deviates too much from the required CTO, but the ATO RIVER of another aircraft is exactly equal to the CTO, the planned separation between both aircraft at the merging point and on the final approach leg will be lost. During an inbound peak, this scenario can disrupt the planned sequence and result in additional delay in the TMA which was not foreseen. If aircraft already encountered delay absorption en-route, but have to endure the same amount of delay in the TMA that was predicted in the first place, the benefits of ERDA no longer holds.

in the TMA between aircraft categories deviates more than one min, it can be necessary to use different approach paths to the final approach fix for each aircraft category, in order to maintain safety and a sufficient runway throughput.

It is important that the calculations of the inter-arrival times at the threshold and IAF are as accurate as possible. If the inter-arrival time for each aircraft is wrongly increased by five to ten s, as the throughput then decreases with two landings per hour. It is meaningful to take this into account when a dynamic time based separation for the threshold is calculated in order to compensate for strong headwinds [4]. Especially when these

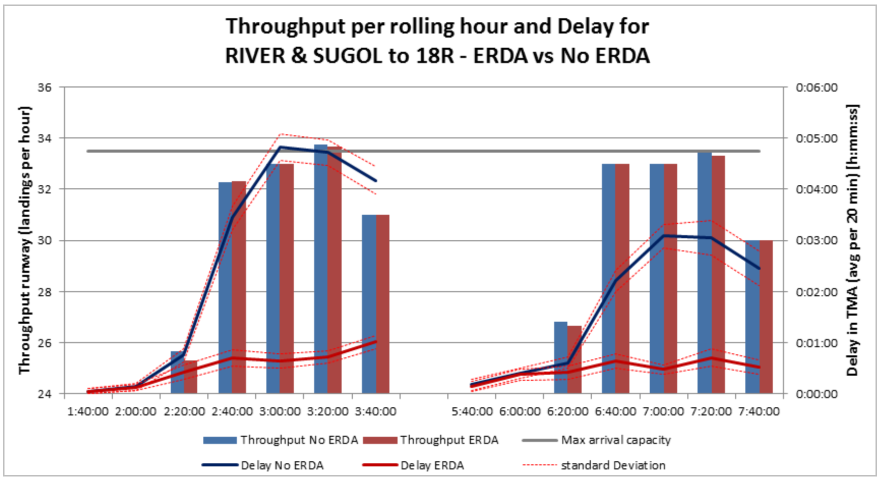

Figure 6 Throughput per rolling hour for two arrival peaks from RIVER and SUGOL to 18R with and without ERDA. The second vertical axis on the right side gives the average delay per aircraft per 20 min time period. The delay is shown with a standard deviation.

Figure 6 shows the effect on delay and throughput for traffic coming from two different IAFs and merging to one runway. The maximum delay during the first arrival period has an average value of 4 min 50 s (σ=15 s) when no ERDA is applied and 1 min (σ=8 s) when there is ERDA. For the second arrival peak, the maximum delays are 3 min 5 s (σ=13 s) and 43 s (σ=10 s) for the scenario No ERDA and ERDA, respectively. The difference in delay in the third arrival peak is not significant and therefore not shown. The maximum delay stays below one min for both situations.

Also in this scenario with two approach legs, the throughput does not decrease when ERDA is simulated. The values for the throughput in each arrival peak are similar to the ones for the single approach leg.

C. Discussion

An important parameter that determines the runway throughput is the inter-arrival separation. This separation between different aircraft wake vortex categories is translated from distance to a time based separation. The same time interval at the threshold is used for the interval times between aircraft passing the IAF. The required passing time at the IAF can be calculated by an average flight time for each aircraft category, where a distinction has to be made between the flight time of jet and turboprop engine aircraft. If the total flight time

calculations for the separation at the threshold are used as an input for the inbound planning system and the required arrival times at the IAF.

The difference between the three fleet mixes has an effect on the actual runway capacity and this has a great impact on the delay propagation. More super and heavy aircraft mixed with medium aircraft has a bigger (negative) impact on the runway throughput than the use of ERDA. This research did not investigate the effect of resequencing the upcoming arrival stream with the aid of an AMAN system, but resequencing the order and swap some aircraft's place with another will increase the runway throughput with one extra landing per hour.

It is assumed that the maximum amount of delay that can be absorbed en-route is five min. With a minimum flight distance of approximately 800 NM, five minutes of ERDA is possible by only applying a speed reduction [5]. However, for short haul flights, additional techniques like route deviations will be required to absorb enough time en-route. How the required time for delay absorption is achieved, is left outside the scope of this research.

The definition of runway pressure suggests that there is a minimum amount of delay that should be left for the approach controller to absorb, in order to guarantee sufficient runway throughput. From the results of this research, it can be concluded that there will always be a minimum amount of resulting delay that needs to be absorbed in the TMA to optimize the landing sequence. However, the minimum amount of delay in the TMA is a consequence of the difference in flight time and wake vortex separation between aircraft types and the accuracy of the actual time passing the IAF. If the inter-arrival times at the IAF are set correctly, a minimum amount of delay is not required to maintain sufficient runway throughput.

Although a minimum amount of delay in the TMA is not required to maintain runway throughput, not all delay can always be absorbed in earlier flight phases. Therefore, it is recommended to investigate the effect on the workload of air traffic controllers and the delay absorption capacity of the different airspace sectors along the route. If the expected delay is divided and absorbed in the different flight phases along the trajectory towards the airport, the arrival process is easier to manage for all controllers involved.

VI. CONCLUSIONS

The purpose of this research is to investigate the effect of En-Route Delay Absorption (ERDA) on the runway throughput. Based on the simulation results, it can be concluded that ERDA can result in a small decrease of runway throughput, with a maximum of one aircraft per rolling hour. However, a decrease does not always occur. By the end of the inbound peak, the actual landing time of an aircraft with ERDA is between 30 and 90 s later than the same aircraft with no ERDA. So the inbound peak is enlarged in time and extended with at most one extra landing when ERDA is applied. The benefit of this technique is that aircraft have to spend considerably less time in the Terminal Maneuvering Area (TMA) of an airport, without a large increase of the total delay.

From the results of this research, it can be concluded that there will always be a minimum amount of resulting delay in the TMA. This minimum amount of delay in the TMA is a consequence of the difference in flight time between aircraft types and the range of accuracy of the ATO IAF. A minimum amount of delay does not need to be planned in order to maintain sufficient runway throughput, as there will automatically be a minimum amount of delay left to be absorbed in the TMA.

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