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.

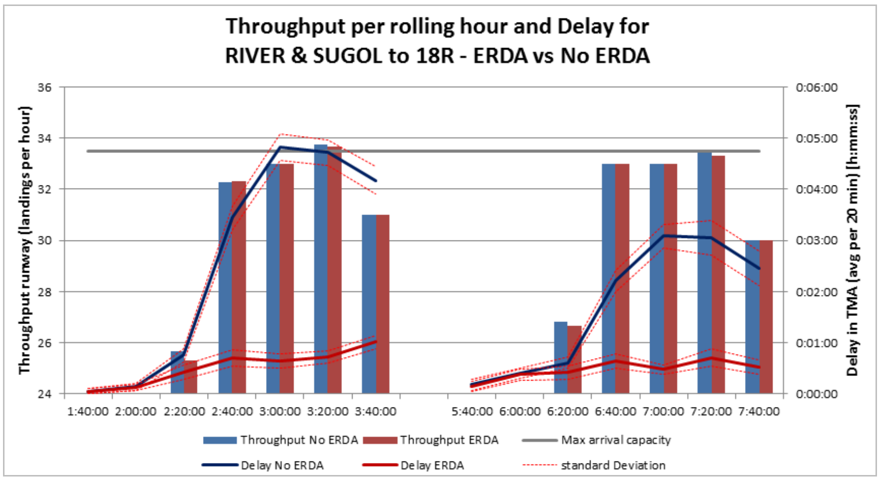

Figure 6 Throughput per rolling hour for two arrival peaks from RIVER and SUGOL to 18R with and without ERDA. The second vertical axis on the right side gives the average delay per aircraft per 20 min time period. The delay is shown with a standard deviation.

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 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 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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