Analysis of 2NM Separation for Minimal Pair Arrivals

Investigating the relationship between separation minima and runway occupancy time

Alan R. Groskreutz
Senior Researcher
CRIDA A.I.E.
Madrid, Spain
argroskreutz@e-crida.enaire.es

Gonzalo Ruiz Mayer
Aeronautical engineer
INECO (Systems Engineering Directorate)
Madrid, Spain
gonzalo.ruiz@ineco.com

***Abstract*— This paper presents preliminary results regarding the conditions in which a 2 NM arrival separation can be implemented taking into consideration the relationship between arrival separation, runway occupancy time, and exit location.**

The analysis was carried out through the use of expert workshops and Monte Carlo simulations, where the recommendations of the experts were put into simulated conditions. In order to better simulate various airport conditions, various traffic mix samples were used, varying the percentage of aircraft that could take advantage of the reduced separation between 50% and 80%. The proposed re-categorization (RECAT) separation matrix was also used to better simulate future conditions. Average arrival Runway Occupancy Times (AROTs) were given to each aircraft category defined and these values were varied to simulate different exit taxiway layouts.

In addition to the fast-time simulations, a workshop on the relation between minimal-pair separations and AROT was held. Controllers, pilots and operational experts were in attendance. The objective was to discuss not only the factors that can limit the AROT, but also means to reduce it in order to take advantage of the reduced separations.

It was then shown that these means are sufficient to reduce the AROT so that the 2 NM separations can be used for the majority of aircraft pairs that are not wake turbulence limited. It was also shown that the arrival results show between a 6% and 30% capacity improvement depending on the scenarios compared, even without using intelligent sequencing of the aircraft. Further studies are warranted with the inclusion of this type of arrival sequencing.

Keywords- safety; separations; airport; runway; occupancy

I. INTRODUCTION

At present, runway throughput is one of the main constraints to air transport growth. There are two main factors that limit runway arrival throughput, one being the arrival separation minima (SM). A lot of work has been dedicated to the optimization of the wake turbulence separations within the RECAT projects [1], but those efforts do not address the other pairs of aircraft; the non-wake turbulence restricted, or minimal-pair aircraft. Depending upon the particular traffic mix at an airport, this can make up a large percentage of the daily traffic.

At a certain point, reducing arrival separations is not enough to increase arrival capacity. Once aircraft pairs get sufficiently closely spaced, attention has to be paid to the second limiting factor, runway occupancy times, to prevent runway double occupancy. Various techniques can be utilized to keep the AROT short, but these techniques may not be able to be used at all airports or in all operational conditions, or for all minimal-pairs. In order to achieve the potential of these reductions, their interaction and possible interdependency needs to be understood.

This paper details an analysis of the viability of reducing the minimal non-wake turbulence longitudinal separation for arrivals to 2.0 NM (measured at the point that the leading aircraft in the pair crossed the runway threshold) along with means to determine and achieve the optimal AROT for a given traffic mix.

II. METHODOLOGY

A. Baseline separation matrix selection

In order to investigate the benefits of and operational restrictions on reducing the minimal-pair arrival separations, a separation matrix that shows the separations for the various leader-follower combinations first needs to be chosen. One obvious choice would be the separations that come from the rules taken from ICAO Doc 4444 Section 8.7.3.2 and 8.7.3.4.[2] This would be appropriate if the study were looking at near term changes. However, as this investigation is looking at longer term changes, it is more appropriate to incorporate the reclassification scheme that is being proposed by the Re-categorization-Europe (RECAT-EU) project [1] and has been approved by the European Aviation Safety Agency (EASA). These separation rules, applied on final approach to the runway landing threshold are shown in TABLE I. They take into account the wake turbulence separation minima which depends of the wake turbulence aircraft categorization; Jumbo (J), Heavy (H), Medium (M) and Light (L). Letters from A to F indicate the proposal for aircraft recategorisation included in the RECAT-EU project. Examples of the aircraft that fall into each category are shown in TABLE II.

TABLE I. APPROACH SEPARATION TABLE (RECAT-EU)

Arrivals			Follower					
			J	*H*		*M*		*L*
			A	*B*	*C*	*D*	*E*	*F*
Leader	*J*	*A*	3.0	4.0	5.0	5.0	6.0	8.0
	H	*B*	SM	3.0	4.0	4.0	5.0	7.0
		C	SM	SM	3.0	3.0	4.0	6.0
	M	*D*	SM	SM	SM	2.5	2.5	5.0
		E	SM	SM	SM	SM	2.5	4.0
	L	*F*	SM	SM	SM	SM	SM	3.0

TABLE II. AIRCRAFT WAKE VORTEX RECATEGORISATION

A (J)	B (H)	C (C)	D (M)	E (S)	F (L)
A388	A332	A306	A318	AN32	FA10
A124	A333	A30B	A319	AT43	FA20
	A342	A310	A320	AT45	D328
	A343	B703	A321	AT72	E120
	A345	B752	AN12	B462	BE40
	A346	B753	B737	(RJ85)	BE45
	AN22	B762	B738	B712	H25B
	B744	B763	B739	B732	JS32
	B748	B764	C130	B733	JS41
	B772	B783	IL18	B734	LJ35
	B773	C135	MD81	B735	LJ60
	B77L	DC10	MD82	CL30	SF34
	B77W	DC85	MD83	CL60	P180
	B788	IL76	MD87	CRJ1	C650
	B789	L101	MD88	CRJ2	C525
	IL96	MD11	MD90	CRJ7	C180
		TU22	T204	CRJ9	C152
		TU95	TU16	DC93	C421
		C17	B722	DH8D	C172
			A400	E135	BE20

It should be noted that the EASA approved categorization scheme lists the D-D, D-E, and E-E pairs as not being restricted by wake turbulence separation, but by the Minimum Radar Separation (MRS). This is because the current MRS is at least as, or more restrictive, than the wake separation value. The RECAT-EU project calculated wake separation values for all pairs, including those that are currently restricted by the MRS. Since this experiment will reduce the separation below 2.5 NM, the calculated wake value of 2.5 NM becomes more restrictive for those pairs, and thus not affected by the separation reduction.

B. *Scenario construction*

With these considerations, a reference scenario was created using an independent segregated runway configuration with Distance Based Separations (DBS) indicated in TABLE I considering 2.5 NM for the SM distance. A specific airport was not selected for the exercise. The fact that the simulation is focused only on final approach, landing and runway vacation combined with the variety of AROT times considered for the simulation allows covering a wide variety of airports with different runway lengths and exit taxiway locations and layouts.

C. *Choice of Independent variables*

After the reference was created, a set of solution scenarios were constructed combining different percentages of Medium aircraft and AROT averages.

The first independent variable defined in the scenarios was the aircraft fleet mix. Three different fleet mixes were taken into account as shown in TABLE III.

TABLE III. TYPES OF AIRCRAFT FLEET MIX

CATEGORY	Scenario 50%	Scenario 70%	Scenario 80%
Super Heavy (A)	5%	2%	0%
Upper Heavy (B)	10%	8%	5%
Lower Heavy (C)	30%	20%	15%
Upper Medium +Lower Medium (D+E)	50%	70%	80%
Light (F)	5%	0%	0%

The AROT has been included as another variable for the characterization of the scenarios and varied to simulate different possible runway exit taxiway configurations and locations that could take place in an airport. It is the time elapsed since the aircraft crosses the threshold until it vacates the runway and depends on different factors, such as:

- Aircraft characteristics (landing kinetic energy, braking systems)
- Weather conditions (dry or wet runway, headwinds or tailwinds)
- Runway layout (threshold displaced, location and angle of exit taxiways)

The influence of these factors in different situations determines whether a specific aircraft may have a favorable or an unfavorable AROT. Considering that, three different cases were considered to try to cover a wide variety of physical scenarios where the aircraft re-categorization could be studied:

- Unfavorable AROTs; real values based on current operational statistic times at ENAIRE airports
- Favorable AROTs; real values based on current operational statistic times at ENAIRE airports
- Optimal AROTs; predicted values based on future AROT reduction techniques implemented

The AROT times were implemented in the PICAP simulation as follows in TABLE IV considering each aircraft category performed in the simulation.

TABLE IV.

TABLE V. AROT MEAN & STANDARD DEVIATION PER AIRCRAFT CATEGORY

AIRCRAFT CATEGORY	Optimal		Favorable		Unfavorable	
	mean (s)	*desv σ*	*mean (s)*	*desv σ*	*mean (s)*	*desv σ*
A	60	2.3	69	3	81	1.7
B	55	1.8	65	2.8	79	2.9
C	45	4.7	48	3.4	58	3.4
D	38	3.6	45	2.8	55	5
E	38	2	45	3.1	50	4.8
F	40	2.7	45	5	50	3

Taking into account all of these considerations, the scenario number and characterization are reflected in TABLE V.

TABLE VI. HIGH LEVEL SCENARIOS FOR AIRPORT UTILIZATION

Scenario	Separation Minima (NM)	% of traffic in groups D+E (M)	AROT used (sec)
Reference (#0)	2.5	50%	Unfavorable
Run #1	2.0	50%	Unfavorable
Run #2	2.0	70%	Unfavorable
Run #3	2.0	80%	Unfavorable
Run #4	2.0	50%	Favorable
Run #5	2.0	70%	Favorable
Run #6	2.0	80%	Favorable
Run #7	2.0	50%	Optimal
Run #8	2.0	70%	Optimal
Run #9	2.0	80%	Optimal

D. Analysis tools

In order to analyze the separation reduction and its influence, and dependence upon AROT, two tools were selected. The first was the fast-time simulator PICAP [3]. PICAP has been certified by the Spanish Civil Aviation General Administration as a methodology to be followed for the calculation and determination of runway capabilities as defined within the ICAO Annex 14. PICAP has been also recognized by EUROCONTROL as a “best practice” being one of the best research program examples related with the optimization of airport operations.

The three distinct phases of the PICAP methodology are:

1. Acquiring and analyzing operational data.
2. Fast Time Simulation process using an application based upon the MIRMEX generic simulation tool that can faithfully reproduce the airport runway configuration.
3. Output data processing to show the following results:
    - The variation of the Maximum Runway Performance (**Arrival Capacity** in this case).
    - The Separation Assurance Percent (**Double Runway Occupancy** in this case). This percentage indicates the amount of arriving aircraft from the total movements in a period of time which are at a certain distance from the threshold when the preceding aircraft has vacated the runway.

In addition to the PICAP simulation, a second fast-time simulation was performed in order to fine tune the influence of some of the input parameters in a more dynamic manner. This study is referred to as the "theoretical study".

The major difference between the PICAP simulation and the theoretical study is regarding AROT values in that:

- The PICAP simulation assigns each aircraft an AROT value, randomized within a range as described in TABLE IV, depending upon the wake category of the aircraft. If the follower has reached the runway (e.g. threshold crossed) before the leader has vacated the runway according to this assigned AROT, the PICAP simulation registers the time until the leader vacates and uses this value to measure the degree of the follower occupancy time. This is referred to as the Separation Assurance Percent concept which is used to measure the go-around rate probability due to double runway occupancy. PICAP does not perform any go-around manoeuvre.
- The theoretical study uses the lead aircraft's AROT value to design a theoretically ideal scenario where there is no double runway occupancy. The start of the Elapsed Time is set when the first aircraft crosses the threshold, which is counted as the first operation. Every time an aircraft crosses that point it is considered an additional operation and the Elapsed Time is updated by adding the DBS maintained with the preceding aircraft. In case the AROT of the lead aircraft is greater than the DBS maintained with the follower aircraft (AROT>DBS), the AROT value is added instead of the DBS.

In the theoretical study the same AROT values were considered for all the categories of aircraft. These values are the result of an approximated weighted mean, taking into account that there are some predominant categories (D, E) and there are others that are residual (A, F). The AROT times were implemented in the theoretical study as follows in TABLE VI (instead of TABLE IV):

TABLE VII. AROT VALUES FOR THEORETICAL STUDY

	AROT values(s)		
AIRCRAFT CATEGORY	***Optimal***	***Favourable***	***Unfavourable***
All Categories	40	45	55

In order to perform the theoretical study, DBS spacing has been turned into time spacing which has been added to the total Elapsed Time. Once the DBS for a specific aircraft was defined, the aircraft model was identified in the EUROCONTROL Base of Aircraft Data (BADA v3.9) considering the synonym supported by this tool.

Two performance profile parameters for the final approach were used, taking into account flight levels from 4000 to 0 feet (FL40 to FL0):

- True air speed in knots (TAS)
- Rate of climb-descent in ft/min (ROCD)

Every time the aircraft reaches a certain flight level, BADA identifies the TAS and ROCD values at this point, so the theoretical study has assumed a continuous deceleration descent with known initial and final TAS in each sector, from one flight level to the next recorded and an average ROCD per sector. The following calculations and considerations were made:

- Average ROCD (ft/min), time spent (sec) and deceleration (kt/sec) per sector.
- Horizontal distance flown per sector (NM), ignoring the vertical component of the deceleration vector.
- Time spent to cover the DBS value adding distances flown per sector.

- Airspeed deceleration modeling extended till the runway threshold (aircraft approach speeds have not been stabilized).
- Wind considerations not included.

In addition to these two fast-time simulations, a workshop on the relationship between minimal-pair separations and AROT was held on the 1st of July, 2014 in Madrid. Controllers, pilots and operational experts were in attendance. The objective of the workshop was to discuss not only the factors that can limit the AROT, but also means to reduce the AROT in order to take advantage of the reduced separations.

III. Results

A. *Capacity*

In the Reference Scenario (Run #0), the MRS on final approach was 2.5 NM between succeeding aircraft on the same final approach track within 10 NM of the runway threshold. For the subsequent scenarios (Runs #1-#9), the radar separation was reduced to 2.0 NM. High AROT, Medium AROT and Low AROT values correspond to the unfavorable, favorable and optimal AROT times respectively.

Figure 1 shows the results for the arrival capacity in the PICAP simulation. Since the simulator is not able to perform go-around manoeuvres, the results have been post-processed to present values considering the maximum arrival capacity permitted when there is no double runway occupancy, that is, when the leader has vacated before the follower crosses the threshold. This post-process has been calculated assuming that the controller would act on the approach speeds so the pair separations are always compatible with the existing AROT limitations. Otherwise, there would be no limitations in the runway occupancy and there would be no change in the arrival capacity as a function of the AROT.

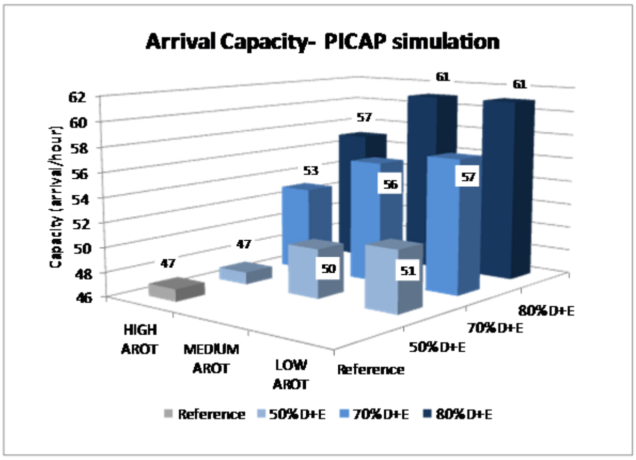

Figure 1: PICAP Arrival Capacity (without double runway occupancy

These results show between a 6% and 30% capacity improvement depending on the scenarios compared (see Figure 1). In these runs, the capacity change is more a function of the change in the fleet mix than with the AROT times.

In the theoretical study, a slight increase in the arrival capacity can be seen in Figure 2 as the AROT decreases, but again, not as much as with the change in traffic mix. On the other hand the arrival capacity is not as high as the values shown in the PICAP simulation for the best aircraft fleet mix configuration (80% of aircraft D+E). The reason for this is most likely the different AROT considerations between PICAP and the theoretical study previously discussed and the additional calculation hypothesis to perform the theoretical study.

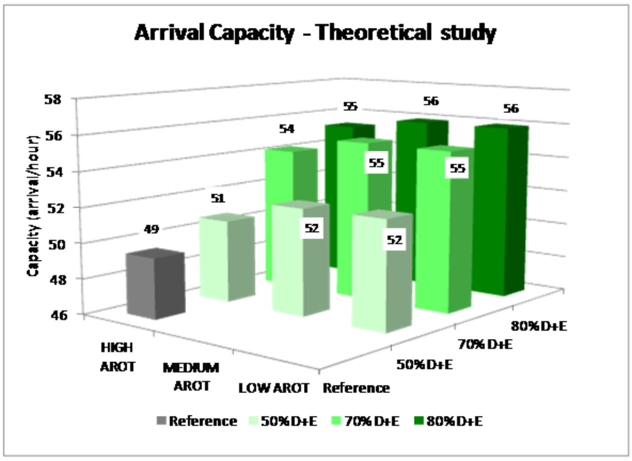

Figure 2: Arrival Capacity for the Theoretical study

In Figure 3 capacity has been presented as a function of different AROT values, for a given MRS. AROT=0 produces the value of ideal capacity, the same as if there was no AROT limitation, so the total elapsed time would be in this case an addition of the arrival pair separations (DBS).

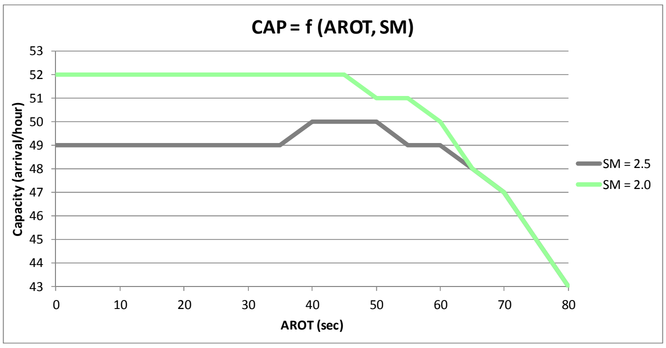

Figure 3: Capacity vs AROT and SM

Independently of the SM value, the capacity increases as the AROT limitation decreases up to a point where the capacity remains constant despite the low values of runway occupancy. The reason for the stabilization is that the AROT value becomes lower than the DBS required for pair separation arrivals becoming a non-limiting factor. Differences appreciated are:

- Ideal capacity (AROT=0) which varies from 49 to 52 arrivals per hour –approximated increase of 3 movements- when there is a reduction of the Separation Minima during final approach.
- Maximum Useful AROT is the value below which, the different occupancy times do not reflect any capacity improvements. For SM=2.5NM the boundary is approximately 60 seconds; for SM=2.0NM the

boundary is within the range of 50 seconds, so there is an improvement margin about 10 seconds.

If the aircraft fleet mix is considered as an additional parameter the distribution of capacity is shown in Figure 4 for SM=2.5 NM and Figure 5 for SM=2.0 NM. Ideal capacity is enhanced when the proportion of medium aircraft type increases in the fleet mix. This is an expected result since it has been previously demonstrated in the PICAP simulation. Which is more significant is the fact that Maximum Useful AROT is maintained within the same boundaries, independently of the fleet mix.

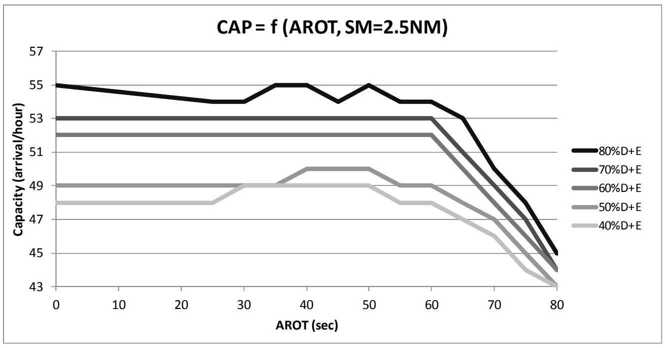

Figure 4: Influence of Aircraft Fleet Mix in Capacity (SM=2.5NM)

These figures confirm the more relevant influence in terms of capacity coming from the aircraft fleet mix and the direct connection between AROT and DBS values.

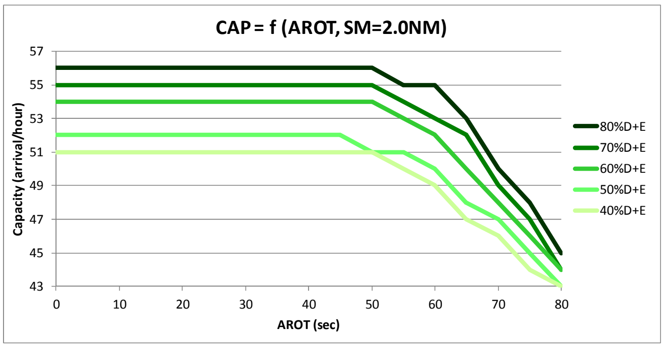

Figure 5: Influence of Aircraft Fleet Mix in Capacity (SM=2.0NM)

Further analysis was made modifying the AROT limitation from 45 to 55 seconds, increasing it by one second in each run, in order to research the dependency of the Maximum Useful AROT, this being the Maximum AROT that would allow the use of a 2.0 NM separation. The main conclusion from this analysis, as shown in TABLE VII is that the AROT limitation for the capacity stabilization is slightly different depending on the fleet mix. These results confirm that the Maximum Useful AROT is within the range of 48 and 52 seconds.

TABLE VIII. CAPACITY STABILISATION VS AROT LIMITS

AROT limit (seconds)	CAPACITY (arrival/hour)				
	80%D+E	*70%D+E*	*60%D+E*	*50%D+E*	*40%D+E*
45	56	55	54	52	51
46	56	55	54	52	51
47	56	55	54	52	51
48	56	55	54	52	51
49	56	55	54	52	50
50	56	55	54	51	50
51	56	55	53	51	50
52	56	55	53	51	50
53	55	54	53	51	50
54	55	54	53	51	50
55	55	54	53	51	50

As seen, the Maximum Useful AROT is finally not a single value, and modifications in the fleet mix might vary it, even for the same medium aircraft percentage, but with different distribution of aircraft between heavy categories A, B and C. For example a distribution of 8%A – 12%B – 35%C – 40%D+E -5%F stabilized (maximized) its capacity for a AROT limitation of 48 seconds and a distribution of 15%A – 25%B – 20%C – 40%D+E stabilized its capacity for a AROT limitation of 51 seconds.

The conclusion is that the influence of the arrival separation reductions in this aspect is more relevant, since they achieved higher differences of Maximum Useful AROT (improvement margin about 10 seconds previously mentioned) than the ones obtained via fleet mix modifications.

B. Safety

In the PICAP simulation, the double runway occupancy is translated directly into go-around rate probability. Double runway occupancy times ≥10sec might more realistically represent the go-around probability since occupancies between 5 and 10 seconds might be assumed in long runways when the lead aircraft is taxiing out on the rapid exit taxiway curve or part of the aircraft body is still inside the runway area. In those cases a go-around would be subject to local procedures more than to a real need.

Figure 6 shows that the reduction of the double runway occupancy percentages (non-compliance situations) is more pronounced with reduction of AROTs than with an increase of medium-medium pairs in the fleet mix. However the best scenario result is a combination of optimal AROT and 80% of D+E aircraft (since the non-compliance situations are provoked by heavier categories).

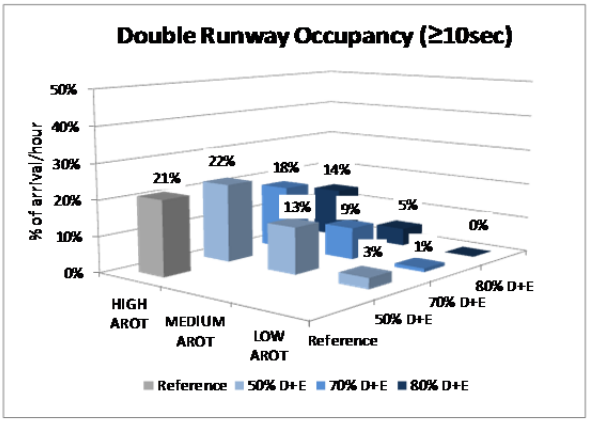

Figure 6: Double Runway Occupancy level in PICAP simulation

On the other hand, in the theoretical study the go-around probability was determined taking into account that the aircraft which had to increase their time separation with the leader in order to accommodate the arrival to the AROT limitation might be the potential one to perform a go-around manoeuvre.

Figure 7 shows the probability that aircraft had to increase their time separations (with current SM distances). In case of unfavorable AROT there is a maximum probability of 4.96%, which decreases as the percentage of medium aircraft D+E increases within the fleet mix. For favorable and optimal AROT this rate disappears since the separations manage the arrivals on the runway perfectly.

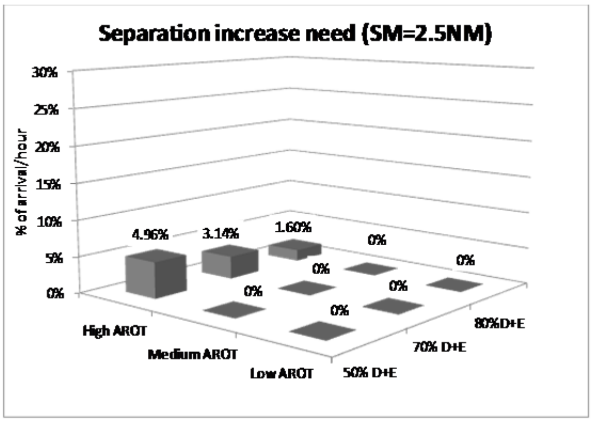

Figure 7: Probability of separation increase need with SM=2.5NM

Figure 8 shows the probability that aircraft had to increase their time separations with reduced SM distances, which is much higher in case of unfavorable AROT than the reference scenario from previous figure. The explanation for that is the reduction of SM distance between medium pair of aircraft D+E. In this case, favorable and optimal AROTs contribute to mitigate the adverse effects of the reduction of SM distances, as well as the increase of medium aircraft D+E in the fleet mix.

Both the PICAP and the theoretical study show that there is an increased risk that a go-around might occur with the reduction of the minimal-pair separations. The mitigation of this risk is the appropriate aircraft spacing on final so that a runway double occupancy does not occur. Appropriate spacing tools, like the TBS tool, can provide this mitigation by taking into account the aircraft's stabilization speeds, and predicted AROT. The influence of these tools, as well as the influence of the Controller and Pilot should be analyzed in the future.

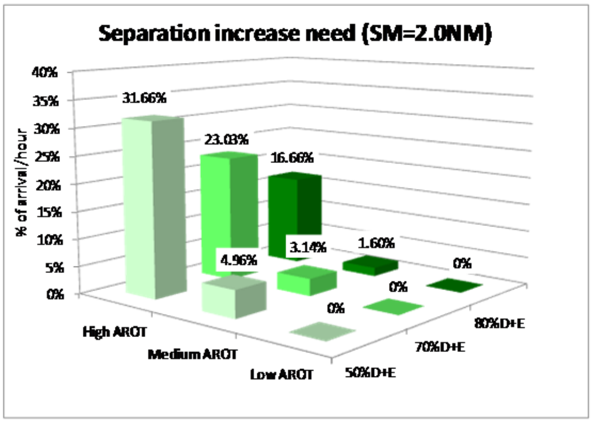

Figure 8: Probability of separation increase need with SM=2.0NM

C. *AROT influence factors*

In trying to identify the factors that influence AROT, previous research in [4] and [5] is very useful. Here the relation to various factors, both operational and infrastructural, is listed. Rankings taken from [5] for how various rollout and turnoff (ROTO) factors affect AROT are shown in Figure 9. The leading operational factor in this study is shown to be the runway exit speed.

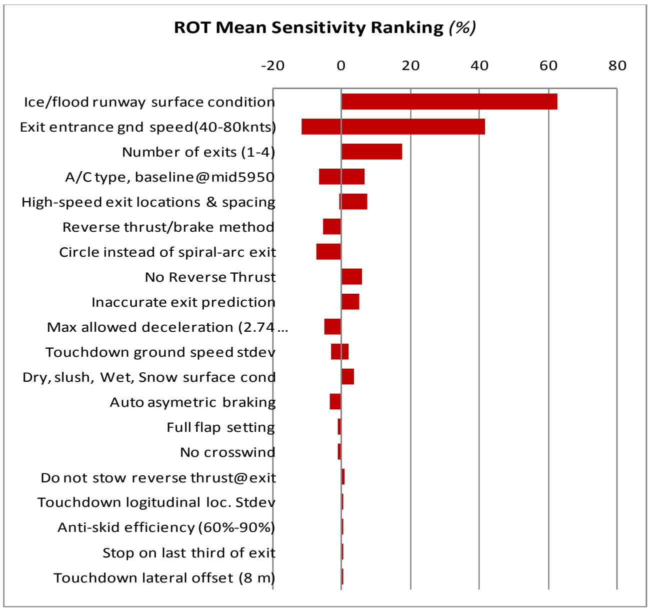

Figure 9: AROT mean sensitivity rankings for ROTO factors [5]

Also from the same study, Figure 10 shows the relationship between high exit speeds and AROT for various exit taxiway locations along a runway.

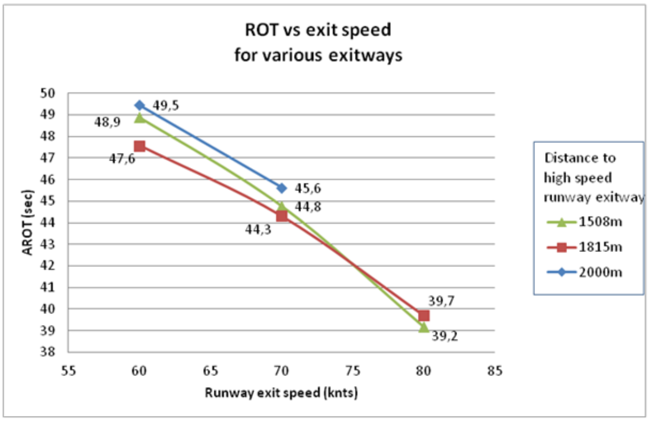

Figure 10: AROT vs Exit Speed for various exit taxiway locations [5]

If these results are combined with those from the theoretical study as shown in Figure 5, it can be seen that to achieve the desired AROT in the order of 45 sec, one way would be to increase the exit speed to 65-70 kt.

This is consistent with the comments received in the workshop, especially the one regarding the Ryanair policy of exiting the runway at 70 kt in the Boeing 737-800. It is also widely known that Gatwick has been able to increase their arrival capacity through the implementation of awareness programs with the Airspace Users to highlight the mutual benefits of exiting the runway rapidly.

D. *Significance of Results*

To better understand the main contributing factor to changes in capacity and whether there were dependencies between them, a "Hypothesis Contrast" testing was performed through the Analysis of variance test (ANOVA) for multiple factors (two parameters, traffic mix and AROT).

The following tables show the different run result distributions. These graphics include detailed histogram results for arrival capacity. Mean values and standard deviations of arrival capacity and double runway occupancy have been extracted from these distributions and are reflected in TABLE VIII.

TABLE IX. ARRIVAL CAPACITY MEAN & STANDARD DEVIATION (PICAP)

FLEET MIX	**Unfavourable AROT (s)**		**Favourable AROT (s)**		**Optimal AROT (s)**	
	mean (s)	***σ***	***mean (s)***	***σ***	***mean (s)***	***σ***
Reference	51.74	1.853	-	-	-	-
50% D+E	51.74	1.853	51.42	2.209	51.74	1.975
70% D+E	57,94	2.005	58.09	1.841	58.16	2.046
80% D+E	61.50	1.927	61.60	1.868	61.72	2.201

The null hypothesis says that there would be no difference between the capacity of sample with a certain fleet mix or a certain AROT limitation and another with different values of those variables.

TABLE X. ARRIVAL CAPACITY ANOVA TEST RESULTS (PICAP)

Variation Analysis				
Variation Origin	***Degrees of Freedom***	***F***	***Probability (p value)***	***Critical F value***
Traffic Mix	2	1,87	0,15	3,00
AROT	2	5542	0,00	3,00
Interaction	4	1,18	0,32	2,38

The ANOVA Statistical tests yield a p-value. The p-values cells in TABLE IX indicate the degree of statistical significance. In this case a confidence interval of 95% (α=0.05).

The analysis shows that there is sufficient confidence in the results concerning the capacity variations due to the change in AROTs (p-value<0.05 so null hypothesis rejected). However, there is not enough statistical significance to determine that there are capacity differences regarding the traffic mix (p-value>0.05 so null hypothesis not rejected), just to an 85% confidence level. This might be due to the limited amount of samples in the study. The analysis concludes that there is no statistical significance concerning the interaction of the two variables.

IV. CONCLUSIONS

As described in Figure 1 and Figure 2, reducing the minimal-pair separation to 2.0 NM does increase capacity. This increase is shown to vary between 6% and 30% where the degree of the increase is dependent not only upon the percentage of Upper and Lower Medium aircraft in the traffic mix, but also on the ability to predict and manage the lead aircraft's AROT so that it does not become the capacity limiting factor.

Even though the results of the PICAP simulation showed an increase risk in go-arounds, it can be reasonably assumed that with the implementation of the techniques coming out of the workshop, the go-around rate should not be expected to increase. Therefore, spacing minimal-pair arrivals between 2.0 and 2.5 NM, depending upon the predicted AROT of the leader, would help mitigate the risk of increased go-arounds. The successful integration of these methods should be an objective to test in future real-time simulation validation activities.

The main conclusions drawn from the investigation are:

- The concept helps increase arrival runway capacity.
- Capacity gains are more sensitive to changes in the traffic mix than to differences in the AROT values, but a sufficiently high AROT can null any capacity gains coming from the separation reduction.
- AROT can be reduced to levels where capacity gains can be optimized through use of procedural controls such as increasing the runway exit speed and advice from the controllers to pilots to expedite runway exit.
- There is a point at which a reduced AROT does not positively influence the separation reduction capacity gains. The capacity is known as Maximum or Ideal Capacity (for a fixed aircraft fleet mix)
- The mitigation of go-around risk, due to the reduction of separations is the appropriate aircraft spacing on final so that a runway double occupancy does not occur.

The ANOVA test shows that there is sufficient confidence in the results regarding the change in runway capacity with regards to the change in AROT. There is also no statistical significance for the two combined variables as result of the combined interaction in the ANOVA analysis. This means that there is no interaction between the influences of the two parameters.

It should be reiterated that these results were obtained from a limited study where certain operational conditions were not taken into account either because of the limitations of the tools being used, or to separate the results from other factors that would be analyzed in future investigations. The operational conditions include the influence of wind conditions whether they be headwinds, tail winds or cross winds. Headwinds and tail winds have an influence on the ground speed of the approaching aircraft, which influences their AROT. The use of TBS during headwind conditions can also lead to the 2.0 NM separations being applied to certain aircraft pairs that, under 0 kt headwind conditions, would be wake limited.

Further study is warranted to better develop the procedures and determine the constraints on the benefits due to differing operational conditions. The main recommendations to consider in further investigation are:

- ATC control spacing must be included somehow in order to adapt on the go the minimal-pair arrivals between 2.0 NM and 2.5 NM, depending upon the standard AROT of the leader. The clearance to land spacing will need to take into account the prevailing glideslope wind condition that will be experienced by the follower aircraft over this distance, in future studies.

- Separations from RECAT-EU combined with SM=2.0 NM must be improved using Pair-wise separations, focused more on different values of DBS depending on the aircraft pair more than on the aircraft category.
- The reduced 2.0 NM MRS has application to wake pairs when the required wake separation is less than 2.5 NM. This will be the case for the RECAT-EU D-D, D-E and E-E wake pairs in TABLE I when TBS is applied in moderate and strong headwind conditions to provide headwind resilience to the landing rate. This will also be the case for the full Static Pairwise Separation (S-PWS) wake pairs with a wake separation of 2.5 NM or less, including selective B-B and C-C aircraft type pairs, when TBS is applied in moderate and strong conditions to provide headwind resilience to the landing rate.
- The transition from the intermediate approach 3.0 NM MRS to the reduced 2.0 NM MRS needs to be considered with respect to the benefits validation; particularly with respect to transition to the same glideslope such that 1,000 ft vertical separation cannot be utilized during the transition.
- Enhanced Runway Braking systems must be included to predict in advance the AROT. This system would not only contribute to reduce the AROT time using the desired rapid exit taxiway but also to help the ATC to adjust the spacing between the follower one, for a complete optimisation of the runway throughput and reduce the risk of go-around.
- Go-around reasons should be consolidated, since they may be ordered by ATC or decided by the Flight Crew in command. As a go-around does not itself constitute any sort of emergency (although it can be in response to an emergency) it will be also subject to local procedures.
- While the traffic mix has a greater influence than AROT limitations on capacity gains achieved through the 2.0 NM separation reductions, there is not much an airport can do operationally to increase this influence. Airports will need to look at the Airspace User fleet mix future projections and purchase agreements to see what their particular traffic mix will most likely be in the near future. They can then decide if the capacity gains achieved through the implementation of this separation reduction might be worth the associated costs.

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