29th Congress of the International Council of the Aeronautical Sciences
St. Petersburg, Russia; September 7-12, 2014

OPTIMISED ALGORITHMS FOR EXTENDED ARRIVAL MANAGERS

Rocío Barragán*, Javier A. Pérez Castán, Mario Sadornil**,**
Francisco Sáez Nieto, Javier Crespo**, Rosa Arnaldo**, Cristina Cuerno****
***CRIDA, **Technical University of Madrid (UPM)**

Keywords: *AMAN, Extended AMAN, algorithms, sequencing, merging, metering*

Abstract

State of the art

The main mission shared by current Arrival Managers (AMAN's) is to assist the Air Traffic Controller (ATCo) in the tasks related to the traffic synchronisation in its arrival, relieving his workload. AMAN's goals are: sequencing, metering and merging with the only objective of optimising the time of arrival. On the other hand, AMAN's should be interconnected with other decision support tools which provide eficiency to ATM. It is expected that this versatility will convert them into a key collaborative tool within the air traffic synchronisation process.

Social demands

Among the Priority Strategic Business Needs of SESAR are: Moving from Airspace to Trajectory Based Operations that will require better Traffic Synchronisation [9]. It covers all aspects related to improving arrival and departure management. In that respect, new designed AMAN's must be able to harmonise Reference Business Trajectories (RBT) into an optimised traffic sequence, resulting in significantly less Air Traffic Control (ATC) tactical intervention and the optimised descending traffic profiles. As a result, aircraft are able to fly more suitable trajectories, bringing benefits in terms of Predictability, Efficiency, Safety, Capacity and Environment.

Within SESAR conops, the arrival queue management aspects in the execution phase of the concept are covered by the so called dynamic Demand and Capacity Balancing (dDCB) at the network level, and real-time Queue Management at the ATC sector level [13]. It consists of the fine tuning of the state vector of an individual aircraft in the traffic flow, which will permit the optimisation of the use of the limited resource which is the runway. The coarse tuning between capacity and demand would have been established previously by the ATM Network Manager, whilst the fine tuning, which is expected to be achieved by the evolution of current AMAN systems, is known as Real Time Arrival Queue Management. See Figure 1 for the timeframe of the different items and temporal horizons in SESAR.

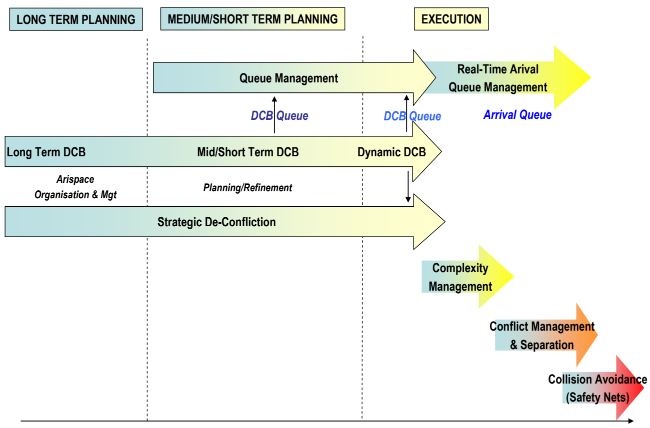

Fig. 1. Items and temporal horizons in SESAR

Arrival management was originally designed to optimise traffic flow for various runway configurations and to benefit capacity by maintaining the throughput on the runway [8]. The challenge now is to keep these original goals whilst improving the predictability and efficiency of the trajectories of arriving aircraft.

Motivation

Building real time and optimized algorithms for AMAN's which are aligned with SESAR goals of *traffic synchronisation and flow management as defined in [12] would bring benefits to the ATM community. Traffic Synchronisation brought by the AMAN is highly interconnected with the broader SESAR objective "4D Trajectory Management", supported by a Network Collaborative Management and Dynamic Capacity Balancing, in a largely Automated environment using the technical enabler SWIM.*

Approach

The criteria for sequencing established up until now includes:

- *First-Come – First-Served (FCFS)*
- *Minimum separation*
- *Priorities agreed between ATC and aircraft*
- *Local limitations in the destination airport*

In this paper different strategies for optimising sequencing are presented, taking into account different criteria, among which are:

- *Wake vortex turbulence*
- *Minimum average delay*
- *Minimum total delay*
- *Maximum use of the airspace and capacity of the runway*
- *ATCo workload*
- *Minimum operational cost*

The mathematical formulation of the problem under the point of view of sequencing includes decision variables, like the landing time and the sequence; general parameters like the number of aircraft and the set of aircraft; and finally, each of them has its own parameters: Estimated Time of Arrival (ETA), Scheduled time of arrival (STA), time ahead or delayed which they are asked to meet, threshold of times the aircraft are capable to meet, minimum separation between each pair of aircraft, etc.

Merging and metering are processes derived from sequencing which add costs to the procedure. In this paper a formulation of the costs based on these variables and parameters, constraints and object functions are to be stated with the goal to minimise the overall performance under the viewpoint of the different strategies.

1 Optimisation Algorithms

The problem of aircraft sequencing is an optimisation problem that has been studied under different strategies: linear programming, non-linear programming, heuristic methods, etc. Still there is room for original resolution.

The statement is: the re-sequencing of aircraft competing for a limited resource, which is the runway, following a determined optimisation method.

1.1 Transport problem

The previous statement laid out as a transport problem, the optimisation is obtained by minimising or maximising a cost function holding a set of constraints. It is then an optimization problem that can be solved using different methods as dynamic programming formulation based on the fact that the cost due to the execution of a work depends only on the previous works.

Mathematically, let A be a set of aircraft subject to be optimally sequenced:

$$A = (a_1, a_2, \dots, a_n) \qquad (1)$$

A set of constraints are defined to bound solutions:

$$R(i)_{min} \le g(a_i) \le R(i)_{max} \qquad (2)$$

A cost function is defined with the goal to be optimised:

$$f(a) = \sum_{i,j=1}^{n} c_{ij} * a_i \qquad (3)$$

or:

$$f(a) = \sum_{i,j=1}^{n} c_{ij} * (a_i - a_j) \qquad (4)$$

where c_{ij} is a weighting factor dependent on each pair of consecutive elements in the sequence.

Finally, every permutation of aircraft is defined as:

$$P(n) = [\dots a_k \dots], \forall k \in (1, \dots, n) \quad (5)$$

It is an integer optimisation problem as it is defined in the $\mathbb{Z}^+$ domain.

However, the position shifting has been deeply studied due to the advantage concerning the shared resource might cause disadvantages in terms of time of flight, predictability, fuel consumption and it is subject to certain constraints like Terminal Manoeuvring Area (TMA) configuration, operational costs associated to the changes in the scheduled time of arrival, fuel remaining, etc. Algorithms are frequently limited using a technique called Constrained Position Shifting (CPS) defined in [1] and [4].

For each aircraft, the set of constraints $g(a_i)$ defined in (2) are bound by the Programmed Time of Arrival (PTA), it helps determine two characteristics which are the Earliest Landing Time (ELT) and the Latest Landing Time (LLT), so the time window is defined as:

$$\begin{gathered} ELT(i) \leq PTA(i) \leq LLT(i) \\ ELT(i) \leq STA(i) \leq LLT(i) \\ ELT(i) = PTA(i) - \delta^- \\ LLT(i) = PTA(i) + \delta^+ \end{gathered} \quad (6)$$

being δ^- the time that the aircraft can gain overtaking other aircraft, and δ^+ the time that the aircraft can lose. δ^- is typically bounded between 5 and 10% of the remaining of the flight while δ^+ is constrained by the remaining fuel, usually more restraining. Nevertheless, to ease calculation, δ^+ and δ^- have been defined equal.

Although currently position shift is constrained by the distance to the merge point, , focusing on an Extended AMAN (E-AMAN) will increase the time left to re-sequencing to more than 200 NM, relaxing the CPS and increasing the time windows which an aircraft can shift its position.

All things considered, time windows will be a function of the type of aircraft which will roughly approximate the nominal speed and the ranges of maximum and minimum speed they can achieve as a function of the variability of the nominal speed (say $\pm 5\%$). This minor change in speed can be done at the pilot discretion, without any ATCo's intervention [13].

Thus the coarse approach to δ^- and δ^+ for this research is:

Light	Medium	Heavy
2 min	3 min	4 min

1.2 Runway capacity

To obtain the maximum runway throughput the characteristic which will be minimised will be the occupancy time of the runway per aircraft, which means the latest aircraft should arrive as early as possible. The arrival time depends on:

- The type of aircraft: light, medium or heavy,
- The Programmed Time of Arrival (PTA),
- The time windows which the aircraft can meet.

The cost matrix which expresses the gap between aircraft in order to respect the wake vortex can be expressed as shown in the Figure 2. Note that fixed amount of time has been stated based on [4]. Nevertheless, it could be possible to establish a function which defines the time separation between aircraft based on multiple factors.

Previous aircraft \ Following aircraft	L	M	H
Light	96	69	60
Medium	136	96	60
Heavy	186	136	96

Fig. 2. Recommended time gap between different type of aircraft (in seconds)

Using this data, the cost matrix $[r_{ij}]$ is defined depending on each aircraft type and the type of the following aircraft. Then the cost function of each permutation that would be minimised will be defined as:

$$f(P(n)) = \sum_{i=1}^{n-1} r_{i,i+1} \quad (7)$$

1.3 Minimum average delay

The goal of this algorithm is obtaining a sequence in which each difference between the PTA and the updated STA is minimised.

The cost function is defined as:

$$f(P(n)) = min \sum_{i=1}^{n} |PTA(i) - STA(i)| \quad (8)$$

A variation of equation (8) is proposed for obtaining the minimum deviation with respect to the PTA. This would aim at early arrivals, as a lack of predictability, as well as delays.

$$f(P(n)) = min \sum_{i=1}^{n} (PTA(i) - STA(i))^2 \quad (9)$$

Or

$$f(P(n)) = min \sum_{i=1}^{n} z(i) \; where \; z(i) = \quad (10)$$
$$= \begin{cases} -(PTA(i) - STA(i))^2 \; if \; PTA(i) \geq STA(i) \\ (PTA(i) - STA(i))^2 \; if \; PTA(i) < STA(i) \end{cases}$$

1.4 Minimum total delay

The goal of this algorithm is obtaining a sequence in which the overall difference between the PTA and the updated STA is minimised.

The cost function in this case is defined as:

$$f(P(n)) = |min \sum_{i=1}^{n} (PTA(i) - STA(i))| \quad (11)$$

Like in the previous algorithm, the stress is set on the predictability of the arrival at TMA, so early arrivals and delays are considered analogously.

1.5 Minimum fuel consumption

The goal of this algorithm is obtaining a sequence in which the overall fuel consumption due to the change in the sequence is minimised. A function that shows the fuel consumption as a function of the difference between PTA and STA is defined as:

$$fc(i) = (PTA(i) - STA(i)) * g(i) \quad (12)$$

Where $g(i)$ ia a weighting factor associated to the aircraft model.

So that, the cost function for fuel efficiency is set as:

$$f(P(n)) = \sum_{i=1}^{n} (PTA(i) - STA(i)) * g(i) \quad (13)$$

Nevertheless, the main challenge is finding a realistic fuel consumption function. In [7] the strategy is to absorb the delay en route, where the engine has a more efficient behaviour. Howbeit, in [2] and [3] the fuel consumption due to an early landing must be taken into account. The graphical plot of this function is shown in Figure 3.

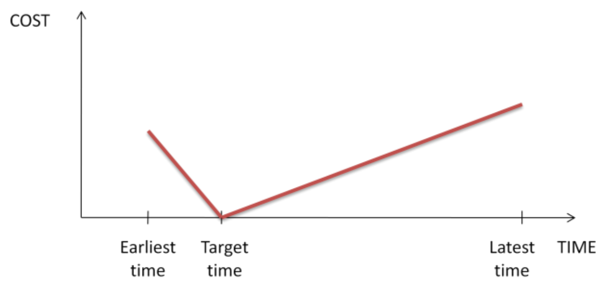

Fig. 3. Graphical representation of a fuel consumption function

The formulation of the function is not as easy though, but it is known it has the following shape:

$$fc(X(i)) \geq 0 \; if \; ELT(X(i)) \leq X(i) \leq LLT(i) \quad (14)$$

being $X(i)$ the actual landing time of aircraft number *i*. Also:

$$fc(X(i))) = 0 \iff X(i) = PTA(i) \quad (15)$$

2 Extended AMAN: Sequencing in En-Route phase

Currently, even though high density airports use AMAN systems, the temporal horizon of actuation is limited to 30 - 35 minutes before landing [13], because the stability of the sequence cannot be guaranteed mainly due to predictability issues and coordination between airspaces queries.

Simple Horizon Extended AMAN (Step1 in SESAR) will include traffic from 180 to 200 NM [11], including the traffic surrounding other airports. SESAR has developed a Concept of

Operation for Extended AMAN systems based on the following items:

- Eligibility Horizon (EH): from which AMAN will capture the traffic and include it in its flows.
- Active Advisory Horizon (AAH): from which AMAN will start influencing the traffic.
- Frozen Horizon (FH): from which flow metering can be applied.
- Metering Point (MP): where the aircraft will be sequenced with an approximated separation.
- Landing Time Update Point (LTUP): updates both systems, airport and AMAN, with an accurate predicted landing time.

However, Long Distance Extended AMAN (Long term SESAR) proposes to further extend the EH to the much greater distance of 400-500NM [11] to include mainly high altitude traffic which will be subjected to early pre-sequencing to allow delay to be absorbed over a much greater distance. This proposal is linked with two new horizons: the Long Range Eligibility Horizon (LREH) and the Initial Metering Horizon (IMH), plus a new point: the Initial Metering Point (IMP).

In this paper, the focus is on the Simple Extended Horizon showed in Figure 4.

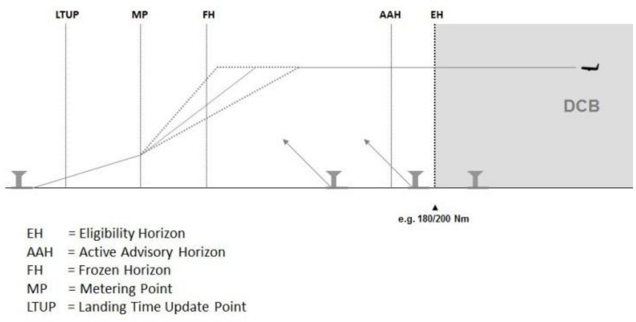

Fig. 4. Vertical View of the Framework – Simple Extended Horizon

The former algorithms express theoretically different costs functions which represent strategies in sequencing the aircraft. Nevertheless, merging and metering processes to meet the sequencing are procedures that must be analysed contributing to the cost functions.

There is a number of argumentation to state that the sooner the sequencing is made, including merging and metering processes, the less overall cost the system would incur in. The main reason is that the sooner an aircraft adapts its speed and trajectory to the required by the AMAN sequencing, the more gradual those changes can be done. Also, when en-route phase and for high flight levels, the variations on fuel consumption, due to speed changes, decreases. In general, automation in ATM reduces the number of ATCo's tactical interventions, but in particular, allowing aircraft to merge and meter before the entry to the TMA allows a decrease in their workload in areas where there is typically high density traffic. The simple horizon extended AMAN provides a long distance EH, however costs would dramatically decrease when long distance extended AMAN is fully implemented. Likely, the best case would be if the sequencing is made before the aeroplane takes off, so all the time shifts would be absorbed in land.

The number of overtaking to be carried out are limited by the distance from the EH to the MP, the ranges of speed with which the aircraft can comply and the fuel remaining in each aircraft.

3 Merging and Metering mechanisms

Additionally to the optimisation algorithms different merging mechanisms to meet the optimised sequence have been studied: in the horizontal plane, in the vertical plane or through time adjustment, varying the speed of the aircraft.

Apart from the maximum and minimum speed and the ETA at TMA of each aircraft, other constraints are:

- The sequence of the aircraft.
- Wake vortex restrictions among different aircraft, both longitudinal and lateral.
- Distance between aircraft on their arrival at the EH.

The assumptions for the merging mechanisms are based on:

- Aircraft arrive at the EH at a constant speed.
- Turning does not mean any additional distance in the trajectory.

- There is no wind influence.

3.1 Parallel routes

The extrapolation of parallel routes shown in this paper is based on the operational concept described in [4]. It minimises the extra fuel consumption and the separation with respect to the original trajectory, while permitting the shift in the sequence advised by the AMAN before the entry in the TMA. The main constraint is the configuration of the airspace, which determines the number of parallel routes.

The grounds of the algorithm consist of unfolding the trajectory of the aeroplane S which will be overtaken by the aeroplane F following the same route. The trajectory of aeroplane S will be parallel to the F, they will maintain the same flight level and the distance between them will be the separation minima applied in the scenario. Also, aircraft S will reduce their speed to v_{min} while aircraft F will fly at v_{max}. For each aircraft, the initial speed v_0 and its en-route speed range are $v_{min} \leq v_0 \leq v_{max}$. Typically the maximum changes in the speed will be $v_0 \pm 5\% v_0$. The common methodology consists of an aeroplane F (will arrive first) with an ETA at TMA of $t_{0,i}$ which overtakes another one S (will arrive second) arriving at $t_{0,j}$, to be merged into its place in the optimised sequence. Note that:

- both $t_{0,i}$ and $t_{0,j}$ correspond to the ETA at TMA flying each at v_0 speed,
- the new calculated ETA after merging is $t_{TMA,j} > t_{0,j}$ and $t_{TMA,i} \leq t_i$,
- once S has been overtaken and returns to the original path, it increases its speed to $v_{0,j}$, while F decreases its to $v_{0,i}$; the maximum limit is $v_{0,i}$,
- the new TMA times of arrival will be calculated the following way:

$$t_{TMA,j} = t_{0,j} + \frac{d_j}{v_{min,j}}$$
$$t_{TMA,i} = t_{0,i} + \frac{d_i}{v_{max,i}} \qquad (16)$$

where $t_{TMA,j}$ and $t_{TMA,i}$ are the new calculated times to TMA, d_j is the distance to TMA in the parallel route and d_i is the distance to TMA through the central path.

Finally, the difference of times of arrival to TMA is:

$$t_i - t_j = (t_{TMA,i} - t_{TMA,j}) + (\frac{d_i}{v_{max,i}} - \frac{d_j}{v_{min,j}}) \qquad (17)$$

A typical parallel route of minimum distance allowed, e reached by S following a 45^o path, the increase of distance flown is $(\sqrt{2}-1)e$. In Figure 5 a parallel overtaking route consisting of three aircraft is shown, being the original sequence 1, 2, 3 and merging into 3, 2, 1.

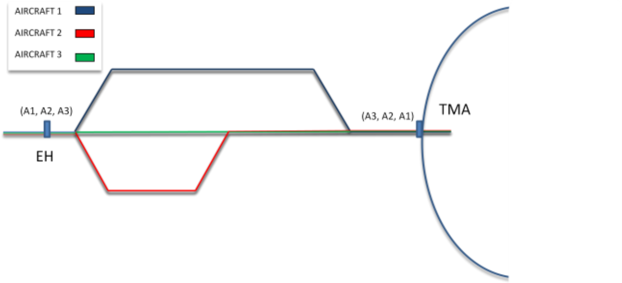

Fig. 5. Aircraft overtaking in parallel trajectories

For $e > 5NM$, it is proven that this mechanism cannot be used for more than 3 aircraft.

Wake vortex intervals are defined in this mechanism in terms of distance.

3.2 Elliptic path stretching

Based on [5] and [6], path-stretching is used for the aircraft S to be overtaken by aircraft F in order to meet the suggested sequence in the AMAN. The overtaking in this mechanism is built upon two trajectory segments, one which leads into deviation and the second that heads for return. Both join at a fixed point. It could be defined through its coordinates or the distance from the original track and its angular deviation. Wake vortex intervals are defined in these mechanisms in terms of time and the distance between each pair of aircraft (i, j) is characterised by r_{ij}.

Aircraft fly at the same flight level and v remains constant. Like in the previous mechanism, e is the minimum separation and so, the lateral separation can be defined as

$$\left|(x,y)_i - (x,y)_j\right| \geq e \qquad (18)$$

The separation between aircraft F and S will be here expressed as

$$t_{TMA,j} = t_{TMA,i} + r_{ij} \qquad (19)$$

The increase of time flown following this elliptic path stretch is

$$\Delta T = t_{TMA,j} - t_{0,j} = t_{0,i} + \frac{d_{TMA,i}}{v_i} + r_{ij} - \frac{d_{TMA,j}}{v_j} \qquad (20)$$

So the increase in distance can be expressed as in (21)

$$\delta = \Delta T * v_j \qquad (21)$$

The locus of the possible solutions which make δ remain a constant is an ellipse whose focal points are the TMA entry point and the EH (see Figure 6). The angle with which the aircraft leaves the planned trajectory (θ) determines the point in the ellipse and the triangle formed by the original trajectory (d_{TMA}), the first segment of the deviation (a) and the second segment of the deviation (b). Note that

$$\delta = a + b$$
$$b^2 = a^2 + {d_{TMA}}^2 - 2ad_{TMA}cos\theta \qquad (22)$$

In order to ease aircraft manoeuvring, θ is less than 60º and usually is 15º, 22.5º or 30º. So the extra distance that the overtaken aircraft must fly is

$$a = \frac{d_{TMA} + {}^{\delta}/_{2}}{1 + \frac{d_{TMA}}{\delta}(1 - cos\theta)} \qquad (23)$$

The new trajectory must keep lateral separation between aircraft F and S at all times which restrains the possible θ.

The fewer manoeuvres that the overtaken aircraft has to follow the easer the workload of the ATCo will be. On the other hand, the main setback of this mechanism is the long distance that it must fly which relevant increases fuel consumption (around 15%). This solution seems to be more feasible if it is done once the aircraft has entry into the TMA and the distances are shorter.

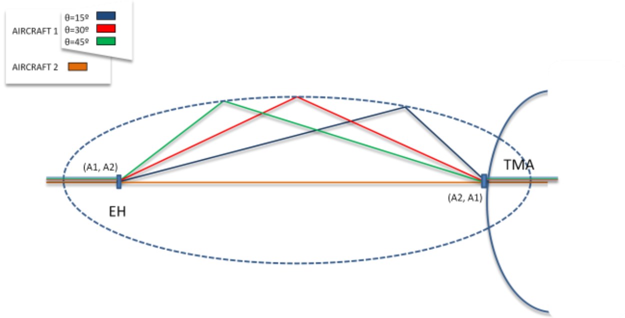

Fig. 6. Aircraft overtaking in elliptic path stretches

Due to the extra cost this mechanism brings (ATCo workload and new equipment on board), it has not been further studied in this paper.

3.3 Further overtaking possibilities

As stated in [5], some other overtaking mechanisms could consist of vertical passing or change in the speed. They have not been included in this study.

4 Research

In this section, it will be analysed how enhancements in the modification of the arrival sequence affect the operational capacity and how they affect the manoeuvres that the aircraft will have to do in their en route flight phase. The mechanism of parallel routes has been applied to each of the optimisation functions. Data is detailed in Figure 8 while a graphical representation of results is shown in Figure 9.

The hypothesis states all aircraft do Continuous Descent Approaches (CDA) and all aeroplanes entry into TMA in the same metering point already merged into the proposed sequence. A comparison among the optimised STA's from the different algorithms is shown in Figure 7, being aircraft type 1=light, 2=medium, 3=heavy.

For the sake of assessing ATCo's workload, by convention, it has been established that if there is no change in the trajectories, it is defined as 0; if there is one change in the sequence, it is 1; and if there is two changes in the sequence, it is 2.

In the following sections a study of each algorithm in sequencing and the parallel trajectory mechanism in merging is applied to the natural sequence in order to propose conclusions. Finally, in Figure 8 there is a comparison of different characteristics obtained in each optimisation method leading to some conclusions.

4.1 Runway capacity

Minimising equation (7) the obtained sequence of the seven aircraft would maximise the runway capacity. Details of the sequence and its associated costs are shown in Figures 7, 8 and 9.

4.2 Minimum average delay

Optimising minimum average delay means minimising (8). The sequence is shown in Figure 7. Only aircraft 3 flying at v_{min} and 4 flying at v_{max} change its order and its speed.

4.3 Minimum total delay

Optimising minimum total delay means minimising (11). Note that what is important is the predictability so there is an absolute value in the equation that shows the adherence to the expected times of arrival. The minimised sequence is shown in Figure 7.

4.3 Analysis of results

All algorithms produce an increase in the distance flown although they will avoid holding patterns or path legs. However, maximum runway capacity and minimum total delay show a better overall performance.

Overtaking is a cost manoeuvre under the point of view of tactical ATC. Nevertheless future enhancements on board or trajectory based operations could replace ATCo's tactical interventions.

In the example, optimising runway capacity, in 10 minutes of operation saves 1 minute of time. Extrapolating to 1 hour, it could be possible to save 6 minutes which would bring an extra capacity to the airport of 2 to 4 extra landings. Yet, minimum individual delay algorithm reduces runway capacity to levels lower than the original sequence.

4.3.1 Maximum runway capacity

It is the optimum algorithm for the airport operator. However, it brings the maximum workload to the en-route ATCo's and the maximum extra distance to fly. Nevertheless, the maximum delay attributed to an aircraft is 1.73 minutes which does not penalise considerably any particular aircraft.

4.3.2 Minimal individual delay

It produces the best results for minimum extra distance, and ATCo's tactical interventions. However the sequence is not optimal for the airport operator, as it increases the runway occupancy and total delay.

4.3.3 Minimal total delay

It does provide an enhancement in runway occupancy and on average aircraft land before their PTA. On the other side, aircraft have to fly the longest distance and some aircraft are particularly penalised in their STAs with respect to the original PTAs which is a setback to airspace users.

5 Conclusions

After applying different strategies to optimise one or more characteristics of the destination airport, it is advisable to define a set of mechanisms which will allow the aircraft to meet their sequencing at the metering point.

Nowadays, the main constraint that avoids re-sequencing is governance, and so FCFS strategy is the most commonly used. Under the point of view of airspace users, they are willing to land as soon as they enter the TMA, in order to save time and fuel. On the other hand, under the point of view of ANSP's the workload caused by a FCFS strategy using holding patterns for the potentially unsafe operations is smaller than the one based on tactical intervention to make additional manoeuvres for several aircraft.

Natural sequence				Runway capacity		Minimum average delay		Minimum total delay	
Sequence	Aircraft type	PTA	STA	Sequence	STA	Sequence	STA	Sequence	STA
1	3	0	0	2	0	1	0	3	0
2	1	2	3.1	1	1	2	3.1	2	2.27
3	3	4	4.1	4	3.27	4	4.2	1	3.27
4	2	5	6.37	3	4.37	3	5.2	4	4.87
5	3	6	7.47	7	6.63	5	6.8	7	6.47
6	3	8	9.07	5	7.73	6	8.4	5	8.73
7	2	10	10.33	6	9.33	7	10.67	6	9.83
TOTAL		35	40.39		32.33		38.37		35.44

Fig. 7. Table of aircraft sequences under different optimisation algorithms

	Natural sequence	Runway capacity	Minimum average delay	Minimum total delay
Extra distance (NM)	0	**16.56**	**4.14**	**16.56**
Time in advance (min)	0	**1**	**-0.33**	0.5
ATCo extra workload	0	**4**	**1**	**4**
$\sum_{i=1}^{n-1} r_{i,i+1}$ (7)	10.33	**9.33**	**10.67**	9.83
$min \sum_{i=1}^{n} \lvert PTA(i) - STA(i) \rvert$ (8)	5.44	11.53	**4.97**	**15.76**
$\lvert min \sum_{i=1}^{n} (PTA(i) - STA(i)) \rvert$ (11)	**|-5.44|**	|2.67|	|-3,37|	**|-0.44|**

Fig. 8. Table of comparison of some characteristics under different optimisation algorithms

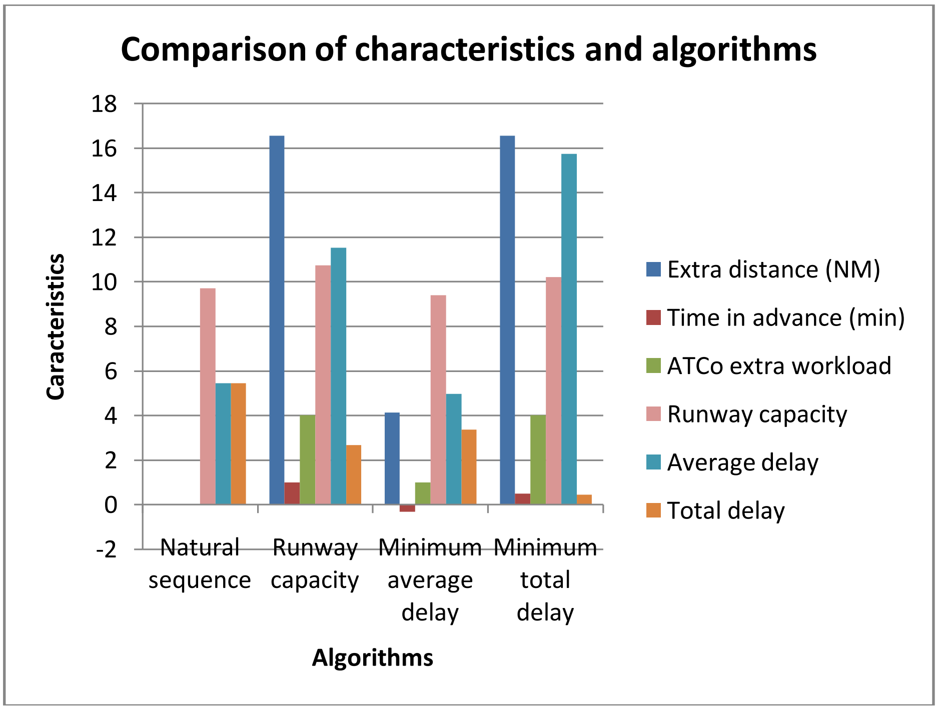

Fig. 9. Comparison of some characteristics under different optimisation algorithms

Only in exceptional cases where there is a large difference in the speed of two aircraft flying the same route, the main mechanisms currently used to modify the sequence at a metering point are:

- Overtaking in the horizontal plane. The fastest aeroplane takes a parallel route and merges back at a point in the original route.
- Overtaking in the vertical plane. The fastest aeroplane climbs up to an upper route, typically 1,000 or 2,000 ft above, while overtaking. It saves it more fuel

Although this mechanisms have been studied based on former researches, the main goal of the project is defining supplementary manoeuvres under the point of view of an arrival airport, recommending an automated tool for its implementation, like an AMAN is.

Further research would study a compound cost function which would weigh the different cost functions in order to define different strategies that airports could offer to the airspace users.

6 Acknowledgments

This work has been developed under the Spanish Centre for Industrial Technological Development (CDTI) project INNPRONTA-ADAM in cooperation with Boeing Research & Technology Europe.

7 References

[1] Balakrishnan H, Chandran B. Scheduling Aircraft Landings under Constrained Position Shifting, *AIAA Guidance, Navigation and Control Conference*, Keystone, CO, August 2006.

[2] Beasly JE et al. Scheduling Aircraft Landings – The Static Case, *Transportation Science*, 2000.

[3] Beasly JE et al. Displacement Problem and Dynamically Scheduling Aircraft Landings, *The Journal of the Operational Research Society*, Vol. 55, No. 1. 2004, pp. 54-64.

[4] Bencheikh G, Boukachour J, El Hilali Alaoui A. Improved Ant Colony Algorithm to Solve the Aircraft Landing Problem, *International Journal of Computer Theory and Engineering*, Vol. 3, No. 2, 2011.

[5] Erzberger H. Automated Conflict Resolution, Arrival Management and Weather Avoidance for ATM, *27th International Congress of the Aeronautical Sciences, ICAS 2010*.

[6] Erzberger H. Automated Conflict Resolution for Air Traffic Control, *25th International Congress of the Aeronautical Sciences, ICAS 2006*.

[7] Erzberger H. Design Principles and Algorithms for Automated Air Traffic Management, *AGARD Lecture Series No. 200 on Knowledge-based Functions in Aerospace Systems*, 1995.

[8] Eurocontrol: AMAN status review 2009, Feb-2010.

[9] Helmke H et al. Time-Based Arrival Management for Dual Threshold Operation and Continuous Descent Approaches, *8th USA/Europe Air Traffic Management Research and Development Seminar (ATM Seminar 2009)*.

[10] SESAR-JU: European ATM Master Plan Edition, Oct-2012.

[11] SESAR-JU: Preliminary Operational Service Environment Definition for Tactical TMA and En-route Queue Management, Jul-2012.

[12] SESAR-JU: Programme Management Plan, Apr-2013.

[13] SESAR-JU: Step 1 Initial Operational Service Environment Definition for Tactical TMA and En-route Queue Management, Dic-2010.

8 Contact Author Email Address

For contacting the authoress, please refer to the following email addresses: rbarragan@e-crida.aena.es; rocio.barragan@upm.es.

Copyright Statement

The authors confirm that they, and/or their company or organization, hold copyright on all of the original material included in this paper. The authors also confirm that they have obtained permission, from the copyright holder of any third party material included in this paper, to publish it as part of their paper. The authors confirm that they give permission, or have obtained permission from the copyright holder of this paper, for the publication and distribution of this paper as part of the ICAS 2014 proceedings or as individual off-prints from the proceedings.