Eighth USA/Europe Air Traffic Management Research and Development Seminar (ATM2009)

Time-Based Arrival Management for Dual Threshold Operation and Continous Descent Approaches

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Abstract

The paper deals with the successive application of time-based arrival management and automatic arrival-departure-coordination. DLR's arrival manager 4D-CARMA supports approach controllers with sequence and advisory information during two time-based human-in-the-loop experiments: First 4D-CARMA was used for dual threshold operation on a parallel runway system operated in mixed mode for arrivals and departures.

The dual threshold operation was performed within the context of the OPTIMAL project of the European commission. Particular consideration is given in this paper to the validation exercises performed with three different European controller teams. An increase of the inbound flow of 3 to 4 arrivals per hour without negative impact on the outbound flow and on controller workload is possible if automatic arrival-departure-coordination together with advisory information is provided to the controllers.

In an additional human-in-the loop experiment 4D-CARMA supports the controllers to integrate unequipped aircraft into a stream of 4D equipped ones performing a user-preferred CDA approach.

***Keywords:** ATM, 4D-CARMA, Time-Based Arrival Management, Dual Threshold Operation, Mixed Mode Operated Runway, CDA*

I. INTRODUCTION

Worldwide civil aviation traffic is expected to grow annually at rates between three and five percent [1]. This development will especially in Europe soon cause the capacity limits of today's air traffic management and airports to be reached [2]. Therefore ATM research concentrates on new concepts for planning and guidance of air traffic, based on planning systems especially so-called ground based decision support tools.

A key potential for further improving the efficiency of arrival management at airports can be seen in the better exploitation of new 4D capabilities of modern Flight Management Systems (FMS). Using the 4D-FMS capabilities of such 'equipped' aircraft, pilots can nowadays plan and execute fuel saving and low noise approach trajectories (especially CDAs), exhibiting remarkable precision in time and space. Both the European SESAR initiative (Single European Sky ATM Research) [3] and the American counterpart NextGen [4] rely on both ground and on-board generated trajectories, i.e. time-based arrival management.

Time-based arrival management is a basic technology which can be used similarly and simultaneously for different problems, in particular cross or head wind conditions, mixed mode operations, CDA, dual threshold operation … In order to cope with the new demands, the crucial question is how the human operators can be supported in performing their tasks in the best way. New automation in terms of advanced arrival managers (AMAN) is necessary to help the controller with appropriate time-based planning functions for all aircraft, matching with their respective equipage standards. Within the OPTIMAL project the Institute of Flight Guidance of DLR validated its AMAN 4D-CARMA (4D **C**ooperative **Ar**rival **Ma**nager) with respect to supporting time-based arrival management. In doing so we concentrated on the aspect of dual threshold operation. Chapter II briefly describes the OPTIMAL project and dual threshold operation. Chapter III introduces 4D-CARMA. In chapter IV we present our validation results, gained from three weeks human–in-the-loop simulations with three different European controller teams. Furthermore, the presented approach of 4D-CARMA can be used for different time-based applications. Chapter V describes the integration of unequipped aircraft into a stream of fully equipped aircraft performing a CDA approach. Finally, the last chapter summarises the outcomes.

The OPTIMAL project has been carried out under a contract awarded by the European Commission (contract number AIP3-CT-2004-502880).

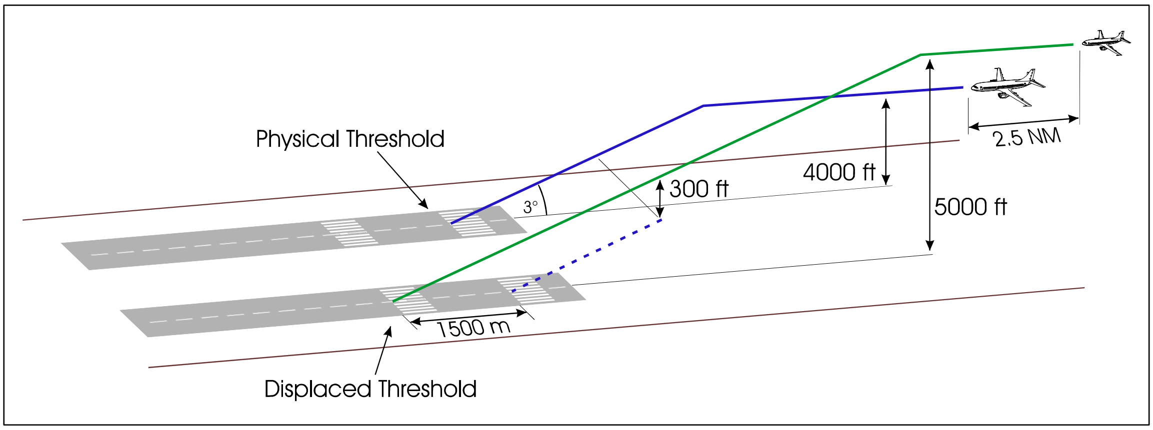

Figure 1. Displaced threshold approaches on a dependent runway system

An aircraft which flies behind another one of any weight class can be sure to avoid wake vortex hazards when it flies at least 260 ft higher than the preceding aircraft. Therefore reduced radar separation (2.5 NM) instead of wake vortex separation can be applied on the last 10 NM of the final approach. The first aircraft intercepts the ILS glide path in 4000 feet altitude whereas the following intercepts the ILS in 5000 feet.

II. BACKGROUND

A. *Project OPTIMAL*

OPTIMAL (Optimized Procedures and Techniques for Improvement of Approach and Landing) is an air-ground co-operative project which was funded by the European Commission within FP6. OPTIMAL was started in 2004 and ended in 2008. The project team was composed by the major European manufacturers of aircraft, rotorcraft and airborne & ground systems, major European research institutes, various ATS providers and key experts in procedures, specification and validation exercises.

OPTIMAL aimed to define and validate innovative procedures for the approach and landing phases of aircraft and rotorcraft in a pre-operational environment [5]. The goal was to minimize external aircraft/rotorcraft noise nuisance and increase the ATM capacity while maintaining and even improving safety. Different improvements of existing and new aircraft procedures were considered, e.g. advanced CDA approaches, ILS look-alike procedure, curved/segmented approaches, RNP 0.1 RNAV approaches, non-precision approaches, displaced threshold operation.

B. *Dual Threshold Operation*

At the end of the 90's a landing procedure called HALS/DTOP (high approach landing system/dual threshold operation) was developed in cooperation by the Frankfurt Airport AG and the Deutsche Flugsicherung GmbH (DFS – German Air Navigation Services) for the Frankfurt Airport [6]. The airport is equipped with three runways; each of them has a length of 4000 meters (13.100 ft.). One runway is only used for departures (runway 18), whereas runways 25L/07R and 25R/07L can be used for both arrivals and departures.

The dual threshold operation allows the simultaneous use of two different thresholds on a single runway, so approaching aircraft can touch-down at the physical first threshold or at the displaced second one depending on their weight class and the actual traffic and weather situation (Fig. 1).

The displaced threshold procedure is a less complicated form of the dual threshold operation, as during an operational period only one of the two thresholds is used. There are different reasons to displace the threshold: Reduce aircraft noise in the vicinity of the airport, obstacles in the final approach area, runway exit sites or independent approaches to parallel but narrowly spaced runways.

If technical equipment on board and on ground allow operating the dual threshold procedure (i.e. two active thresholds on one runway at the same time), we can expect an additional capacity gain compared to the displaced threshold procedure. Therefore we concentrated in our experiments on the dual threshold procedure for a dependent narrowly spaced parallel runway system based on Frankfurt Airport. Only one runway (25L) was equipped with a second displaced threshold. Under these conditions controllers can guide the arriving aircraft to three different thresholds, i.e. 25R, 25L and 26L the displaced one of runway 25L. Both runways are used in mixed mode operation, i.e. for arrivals and departures.

Parallel to the OPTIMAL project DFS and Frankfurt Airport (FRAPORT) conducted dual thresholds experiments in their human-in-the-loop simulation environment [7]. They determined an increase of 3 to 5 inbounds per hour depending on heavy-medium mix. However, they also observed an increase of the controller workload and a significant decrease of the outbound capacity. What were the reasons?

The controllers use the well known ICAO separation matrix for heavy, medium and light aircraft with 3, 4, 5 or 6 NM of separation between two successive aircraft. If we use the displaced threshold we may reduce the separation between an aircraft approaching the displaced threshold (26L) and its predecessor on 25L or 25R to 2.5 NM independent on their wake vortex category (except for heavy aircraft which are not considered to use the displaced threshold due to the shorter landing distance available). We get 64 allowed combinations which result in 5 different separation values (2.5, 3, 4, 5, or 6 NM), see Fig. 2 for more details.

SE QU		SUCCEEDING AIRCRAFT								
WTC		HEAVY			MEDIUM			LIGHT		
PRECEDING AIRCRAFT	THR	L	R	D	L	R	D	L	R	D
HEAVY	L	4	4	--	5	5	2,5	6	6	2,5
HEAVY	R	4	4	--	5	5	2,5	6	6	2,5
HEAVY	D	--	--	--	--	--	--	--	--	--
MEDIUM	L	3	3	--	3	3	2,5	5	5	2,5
MEDIUM	R	3	3	--	3	3	2,5	5	5	2,5
MEDIUM	D	3	3	--	3	3	3	5	5	5
LIGHT	L	3	3	--	3	3	2,5	3	3	2,5
LIGHT	R	3	3	--	3	3	2,5	3	3	2,5
LIGHT	D	3	3	--	3	3	3	3	3	3

Figure 2. Separation matrix for dual threshold operation.

The yellow entry means that the preceding heavy aircraft is on the right runway and the succeeding medium aircraft is landing at the second (dual) threshold of the left runway. Therefore a separation of 2.5 NM is necessary. The fields with "--" reflect that heavy aircraft do not use the displaced threshold.

Even more combinations exist, if departure traffic is involved. Considering the case of three aircraft with aircraft 1 landing, aircraft 2 starting, and aircraft 3 landing again (ARR→DEP→ARR), we already get 384 possible combinations.[1] Regarding this huge number of combinations, a computerized planning aid for the controller is necessary.

Due to the above mentioned problems observed by DFS and FRAPORT we concentrated on the following questions: How to avoid the significant decrease of outbound capacity? Is it possible to increase efficiency and predictability as well? How to reduce controller workload?

Our general approach is the introduction of time-based arrival management and the usage of an automatic arrival-departure-coordinator (ADCO). Therefore we improved our arrival manager 4D-CARMA, introduced in the next chapter.

III. Arrival Manger 4D-CARMA

A. *History*

The development of AMANs has a long tradition in the Institute of Flight Guidance, German Aerospace Centre (DLR). Uwe Völckers started the design of COMPAS, the forefather of all Arrival Managers in the early 80's [8], [9]. It was brought into operation at Frankfurt Airport. COMPAS already facilitates the scheduling and sequencing task by building an arrival sequence based on flight plans and early radar information. The COMPAS system introduced the time line as controller interface to display the arrival sequence and the planned landing times. COMPAS, however, fixed the sequence at a very early stage.

Since 2003 its successor, the 4D-Planner, being developed in close cooperation of DLR and DFS, is in operation at Frankfurt Airport. It improves the sequence planning task by constantly considering the actual radar data. The 4D-Planner is therefore able to adapt the schedule of arrivals to any ATC control action, even if this action deviates from the proposed plan [10], [11].

B. *4D-CARMA*

COMPAS, 4D-Planner and other AMANs currently in operation do not consider an appropriate advisory generation based on predicted trajectories. The latest AMAN development of the Institute of Flight Guidance 4D-CARMA has the additional features.

- It generates trajectories from aircraft position to the runway threshold, taking into account weather conditions and aircraft performance data extracted from the EUROCONTROL Base of Aircraft Data (BADA).
- It generates guidance instructions for voice or data link communication.
- Trajectory-based guidance comprises features for conformance monitoring, conflict detection, and resolution (CD&R).
- The sequence generation is based on optimization of several, partly contradictory evaluation criteria.

The future success of an AMAN will mainly depend on its integration with other controller decision support tools to achieve a smooth and efficient inbound flow whilst maintaining optimal runway utilization and taking into account airline preferred trajectories. Therefore 4D-CARMA addresses:

- The horizontal cooperation with DLR's departure manager CADEO (Controller Assistance for Departure Optimization) and a wake vortex prediction and monitoring system [12].
- The vertical cooperation with DLR's EFMS (Extended 4D Flight Management System) as a first step to trajectory based air-ground co-operation [13].
- The hierarchical cooperation with DLR's pre-tactical TOP (Total Operations Planner) [14].

C. *Modules of 4D-CARMA*

4D-CARMA uses a modular approach allowing both: tailored solutions for particular customers and evolutionary development/enhancement of singular decision support tools. We explain the functionalities of each module and show how a subset of the modules is combined to support different customer requirements (see Fig. 3):

- Radar Interface (RIfc): Interface for radar data, flight plan updates etc.

[1] For the two landing aircraft we have to choose the wake vortex category and the threshold, resulting in eight combinations for each inbound (heavy not allowed on 26L). For the departure we choose one of three wake vortex categories and one of two possible thresholds, because the departure will always start its take-off-run from the physical threshold. In total we get 384 combinations (8 * 8 * 6).

- Lateral Path Predictor (LPP) determines all lateral paths, which lead from the aircraft's present position to one of the runway threshold the aircraft may use.
- Arrival Interval Calculator (AIC) calculates for each lateral path an earliest and a latest arrival time at the assigned threshold.
- Runway Assignment (RA) determines for each aircraft a set of possible runways.
- Constraint Generator (CG) identifies hard and soft sequence constraints (e.g. DLH344 before AFR321). The constraints are derived from the aircraft positions, the calculated arrival intervals, the controller inputs (freeze sequence, move aircraft) etc.
- Scheduler (Sch) derives the best arrival sequence, which maximizes the specified evaluation criteria (e.g. stability and compactness) and satisfies the constraints (e.g. no arrival before its earliest possible arrival time, sequence constraint, blocked arrival times). The sequence is determined by a heuristic tree search algorithm and contains for each aircraft an arrival runway (i.e. the corresponding threshold), an arrival route and target times (for the threshold and other significant waypoints, if necessary).
- Trajectory Generator (TG) calculates a trajectory for each aircraft. It uses the assigned route and meets the assigned target times.
- Conflict Detection and Resolution (CD&R) detects trajectory conflicts and sets further sequence constraints avoiding the conflicts.

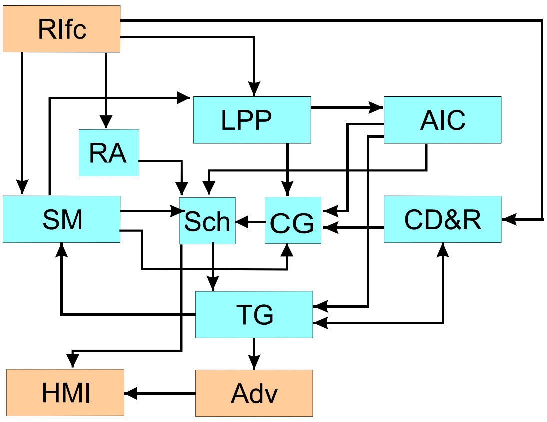

Figure 3. Interaction chain used in OPTIMAL.

New radar data triggers the calculation of lateral paths to the thresholds (LPP) which leads to determination of earliest and latest arrival times (AIC). These are used by the Constraint Generator (CG) and the Scheduler (Sch) to determine sequence constraints and an arrival sequence. CD&R and TG use the target times of the arrival sequence to determine trajectories, which result in advisories (Adv). This interaction chain is repeated again and again. Deviations of the aircraft status from the trajectory (SM) or adapted controller advisories are detected by 4D-CARMA via radar data. This leads to an update of the planning, e.g. adapted arrival sequences, adapted trajectories or adapted advisories.

- Advisory Generator (Adv) derives suitable advisories (speed, altitude, heading) to implement the trajectory, see Fig. 6 for the implemented HMI interface.
- HMI with radar, sequence, runway, and advisory information.
- Status Monitor (SM) detects deviations from the assigned trajectory and other status information.
- Route Assignment (RA) module is comparable to the LPP for supporting CDA and user preferred approaches. It assigns possible routes from the actual aircraft position to a late merging point.
- Air Ground Communicator (AGC) handles the data link communication between ground and board flight management system (FMS).

The communication between the modules is implemented via data base access functions. By selecting different sets of modules different applications are supported by 4D-CARMA. Fig. 3 shows the use case of OPTIMAL, calculating sequences and transforming trajectory information into suitable advisories.

Fig. 4 shows the modules which are necessary to run 4D-CARMA in passive shadow mode. Due to 4D-CARMA's adaptability to the current situation, this may be a cheap possibility for an airport to receive in a timely manner adequate estimates of the inbound traffic touch down times without the necessity of controller inputs.

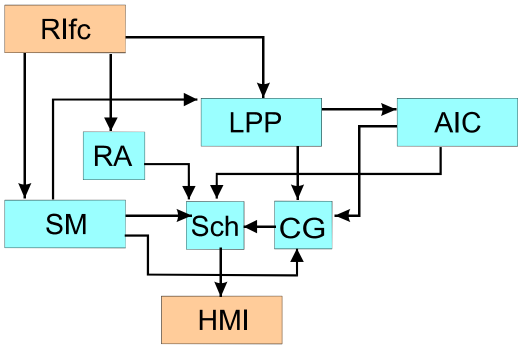

Figure 4. Interaction chain for a passive AMAN.

IV. VALIDATION

A. Validation Setup

During December 2007 and January 2008 three simulation campaigns were performed at DLR with three different European controller teams consisting of pick-up, feeder and coordinator from Vilnius, Warsaw and Frankfurt Airport. Each campaign lasted one week and consisted of 11 runs and one extra run (6-EX) which was conducted by two teams only (see Table I).

TABLE I. SIMULATION PARAMETER SPACE

No.	4D-CARMA Mode	RWY	ARR/DEP coordination	outbounds	Heavy-perc.
1	passive shadow	25R/25L	Master/Slave	15	20%
2	passive shadow	25R/25L	Master/Slave	15	40%
3	passive shadow	25L/25R/26L	Master/Slave	15	20%
4	passive shadow	25L/25R/26L	By voice	15	20%
5	Time line	25L/25R/26L	Master/Slave	15	20%
6	Time line	25L/25R/26L	Master/Slave	15	40%
6-Ex	Time line	25L/25R/26L	ADCO	15	20%
7	Advisory	25L/25R/26L	Master/Slave	15	20%
8	Advisory	25L/25R/26L	ADCO	8	20%
9	Advisory	25L/25R/26L	ADCO	15	20%
10	Advisory	25L/25R/26L	Master/Slave	15	40%
11	Advisory	25L/25R/26L	ADCO	15	40%

Green shaded rows use dual threshold operation.

The following parameters varied within the different simulation runs:

- AMAN support level (passive shadow mode, sequence information via time line, sequence and advisory support),
- Number of available thresholds in use (normal staggered operations with runway 25L/25R, dual threshold operation with additional third threshold 26L),
- Arrival-departure-coordination (master/slave mode with arrival priority, coordination via voice, automatic arrival-departure-coordination via ADCO tool [12]) ,
- Number of departures from runway 25R in the 60 minutes time frame,
- Heavy/medium inbound traffic mix (20% heavy and 40% heavy, light aircraft were not considered).

The baseline scenario was performed without AMAN support for the controllers. 4D-CARMA was used in passive shadow mode for data post processing only. The controllers use their normal radar screen and paper flight strips. The first AMAN support level offers a time line with sequence and assigned runway information to the controllers (see Fig. 5), who still use paper flight strips. The highest support level additionally offers advisories (speed, altitude and turn to base). They are displayed via electronic flight strips and via an advisory stack (see Fig. 6).

The controllers were briefed in all trials to be the only responsible authority, i.e. if they think that the AMAN advisories may result in an unsafe situation, they had to deviate. If, however, the AMAN plan deviates from the controllers' (preferred) planning, they were asked to follow the advisories respectively the sequence. This operational procedure of course requires an AMAN which does not freeze a sequence and always tries to adapt it to the current situation.

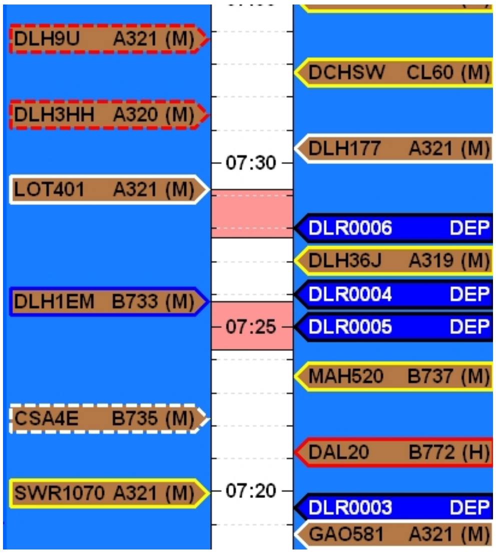

Figure 5. Time-line of 4D-CARMA.

The brown labels show arrivals and the blue ones departures. Pink boxes are reserved time slots for outbounds (arrival free intervals). On the right side we see the traffic scheduled for the right runway (25R). The inbounds with dotted labels on the left side (e.g. CSA4E) are planned for the displaced threshold (26L). Different colours in the inbound labels (white, yellow, black and red) are used for the four different initial approach fixes.

DLR's departure Manager CADEO was used for planning an optimized outbound sequence and target times for suitable clearances (e.g. start-up, push-back, taxi). Normally, AMAN and DMAN use master slave coordination, i.e. outbounds use suitable gaps in the arrival sequence, resulting in a significant decrease of the outbound capacity [7]. Then an outbound needs a gap of 6 to 8 NM between two arrivals if dual threshold operation is applied.

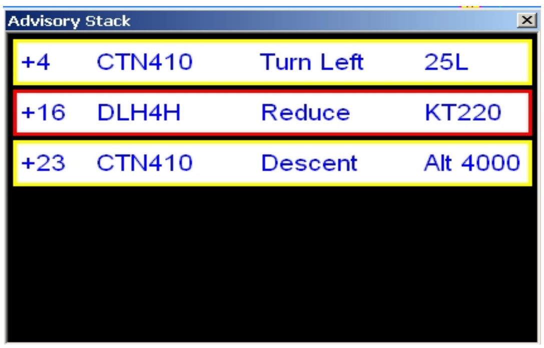

Figure 6. Advisory Stack of 4D-CARMA.

The advisory stack contains an advisory 30 seconds before it should be started by the pilot. The first column contains a counter counting down to zero. Columns 3 and 4 contain the advisory and its end value respectively. The controller decides when to issue a command to the pilot. Speed and altitude commands are not so time critical, whereas turn commands are.

Therefore we adapted our automatic arrival-departure-coordinator (ADCO) to support dual threshold operation. ADCO is a fuzzy rule based system which considers e.g. CFMU slots, present arrival and departure demand and determines suitable gaps for departures, so called AFIs (arrival free intervals), see [12] for more details. In case of dual threshold operation an AFI forces the next two arrivals to use 25L or 25R, because then a gap of 3 respectively 4 NM is sufficient. If, however, the displaced threshold 26L is used after the departure, a gap 6 to 8 NM would be necessary.

The departure traffic was completely simulated based on CADEO's planning, i.e. no departure controller was involved in the simulations.

B. *Validation Results*

In this section we present the results of the validation trials described in the previous section. Table II shows the measured arrival and departure flows, i.e. the average values of all three teams.

We expected an increase of the arrival flow when using the third threshold. This hypothesis was confirmed, because we measured an increase of 3.4 arrivals per hour. A higher percentage of heavy inbounds even allows an increase of 5.2 arrivals per hour (red font in Table II). Other measurements supported these observations. The average track length per aircraft reduces from 175 km to 154 km and the average flight time could be reduced from 23.9 to 20.2 minutes.

We expected the runway utilization to be improved if the level of automation is increased. The arrival flow does not significantly depend on the decision support level; the departure flow, however, does. Trial 8, 9 and 11, i.e. when using automatic arrival-departure-coordination with ADCO, show that all departures can leave the airport with only a small decrease of the arrival flow.

TABLE II. SIMULATION PARAMETER SPACE

Trial	THR-No.	Percent. Heavy	Coordi-nation	ARR / hour	Flow / Dem.
1	2	20%	none	42	15/15
2	2	40%	none	40	15/15
3	3	20%	none	45,2	6/15
4	3	20%	voice	45,6	13/15
5	3	20%	none	46	8/15
6	3	40%	none	44,8	12/15
7	3	20%	none	45,2	9/15
8	3	20%	ADCO	44,8	8/8
9	3	20%	ADCO	44,8	15/15
10	3	40%	none	45,6	12/15
11	3	40%	ADCO	43,2	15/15

Columns 1 to 4 show the trial number, number of used thresholds, the heavy/medium mix and the used arrival-departure-coordination (see Table I). The last two columns show the arrival flow and the departure flow, i.e. the average value from all three teams. Trials in red font used 40% heavy. Yellow shaded rows correspond to trials with no AMAN support, in blue shaded rows a time line is used and the green ones show trial with full AMAN support, i.e. with time line and advisory support.

The departure efficiency is also improved when using ADCO and an adequate level of arrival decision support, e.g. the average departure queuing time is reduced from 7.2 to 3.1 minutes, i.e. fuel burn time while waiting for line up is reduced by 4 minutes. The problem, observed by FRAPORT and DFS (outbound capacity drop-down) [7], could be solved by automatic arrival-departure-coordination.

The level of inbound decision support has a positive effect on touch down predictability, see Fig. 7. 15 minutes before touch down the touch down prediction error is round about 40 seconds with full AMAN support.

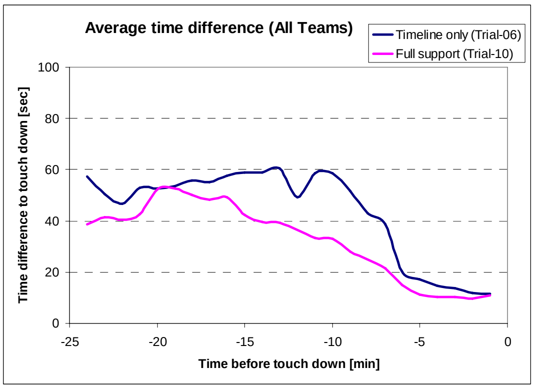

Figure 7. Influence of decision support level on touch down predictability.

Fig. 8 shows another finding of the validation trials: 4D-CARMA already helps an airport operator in passive shadow mode to increase the predictability of airport operations, i.e. to predict landing times with a suitable accuracy 15-20 minutes before the touch down event (see also Fig. 4 for the needed 4D-CARMA modules for this application).

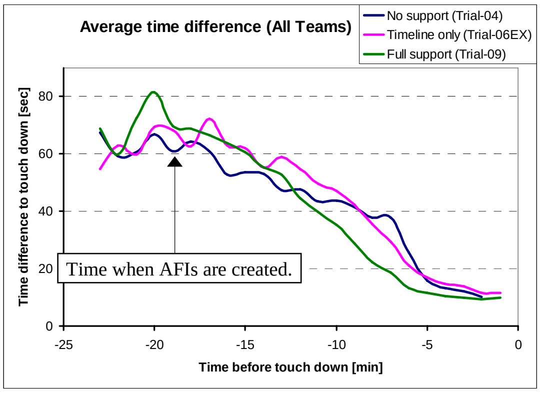

Figure 8. Passive AMAN has already good touch down predictability.

We verified the controller workload results of DFS/FRAPORT [7]. The number of voice instructions per hour is increased if dual threshold operation is in use (increase of 11.6% for pickup and 4% for feeder). If the controller is supported by sequence and runway information during dual threshold operation the number of instructions can be reduced by 9.5% (pickup) and 0.8% (feeder), see Fig. 9.

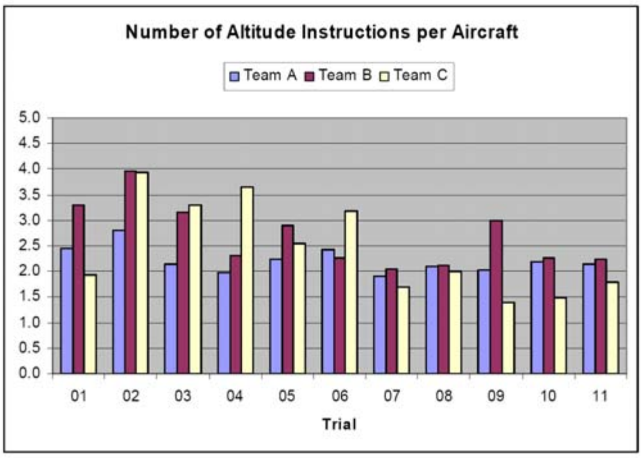

Figure 9. Number of altitude instructions.

Frequency utilization is reduced by 18.4% for the pickup respectively increased by 0.3% for the feeder, see Fig. 10. If advisories are offered the frequency utilization is even more reduced (21.1% pickup, 18.1% feeder) compared to the usage of dual threshold operation with no AMAN support. The training during the different trials, however, may also have reduced the controller workload (see [15] for more details).

C. Controller Feedback

The used scenario and simulation set-up were not realistic for Frankfurt TMA, e.g. all aircraft had to fly given transitions, no weather or other influences (e.g. emergency, medical or priority traffic) were considered at present stage, controllers had to stick to given routings, safety was not fully investigated., Nevertheless a first feedback concerning time-based arrival management supported by AMAN advisories is possible.

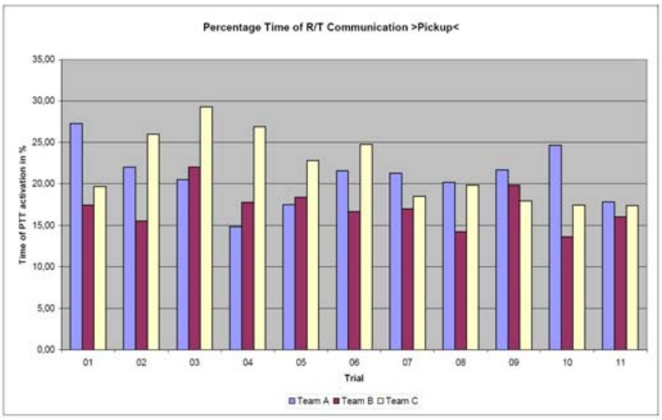

Figure 10. Frequency utilization of pickup.

If all instructions (speed, level and turns) are given to the controller by the system, the controller does not control the traffic anymore and will be "downgraded" into the position of an observer who tries to control the decisions done by the system. Especially in situations where he has to get in control of the traffic again (e.g. emergency or system failure) he will not be able or it will be harder to take over control in an efficient and - much more important - in a safe way. Independent of the fact if the controller has to follow given advisories their presentation in the HMI has to be improved. Multiple advisories (e.g. speed and altitude change) for the same aircraft should be grouped into one single combined advisory to reduce frequency blocking.

If using the AMAN not as an advisory system but as information support tool, i.e. an assistant comparable to the navigation system in a car, it will be useful. The "advisories" remind the controller that something has to be done in near future. In high traffic situation it could be a backup or a marker system for the controller. Especially the given sequence and runway assignment information were useful.

Nevertheless it is necessary that the AMAN understands and updates the traffic situation (for example: AMAN advices FL100, controller takes FL80, sequence order changed by controller). As a result out of controller's view the following improvements are necessary:

- Controller must be able to change the sequence if traffic causes or if it would be more efficient out of the controllers view.
- Controller must be able to freeze the sequence in order to prevent the AMAN from rescheduling the traffic.
- AMAN must be able to combine advisories.
- The controller needs the ability to individually switch off special advisories types or all of them, e.g. one of three controller teams preferred altitude advisories whereas another team did not like them at all.
- All deviating advisories executed by the controller have to be identified and considered by the AMAN.

If time-based sequencing and separation will be implemented in operational procedures, controllers will need a support or advisory system. Dual threshold operation is not the use case strictly requiring time-based arrival management. In the following chapter we present another application of 4D-CARMA with obvious benefits from time-based arrival management. It already considers the controller feedback of this section.

V. Lessons Learned

The results of the OPTIMAL trials were encouraging to continue our approach to support the controllers with advisories if time-based arrival management is required.

Currently we adapt 4D-CARMA to integrate unequipped aircraft into a stream of fully equipped aircraft following a user preferred trajectory, normally a continuous descent approach (CDA). The aim is a significant improvement of ATM with respect to fuel consumption and noise emissions, while eliminating the negative impact on capacity, which is today's penalty for implementing CDAs in high traffic situations.

A central element is a modified airspace and route structure, featuring the late merging of arrival routes. The late merging of arrival routes does not require a homogenous speed profile or speed constraints at top of descent (TOD). Instead, it relies on a modified route structure, where sequent aircraft use different lateral routes to a so called late merging point (LMP), see Fig. 11.

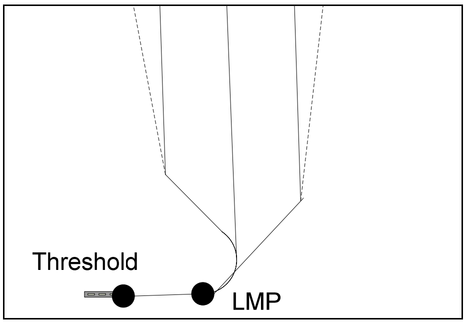

Figure 11. Late merging of different approach routes

The aircraft co-use only a short common flight segment starting near the LMP and ending at the runway threshold.

Before the aircraft are starting their CDA at the TOD, they should be on separated routes. Therefore, different routes are assigned to the aircraft when they are entering the extended TMA, see Fig. 12. The lateral separation between the routes allows each aircraft to choose an individual optimal approach profile. It is transferred into a time-based separation just shortly before reaching the LMP, i.e. the aircraft normally has to maintain a time constraint only at the LMP [16].

Today, however, not all aircraft are able to perform a precise 4D approach. Therefore the controller needs additional support to fit unequipped aircraft exactly into a stream of 4D equipped aircraft, i.e. advisories for time-based arrival management.

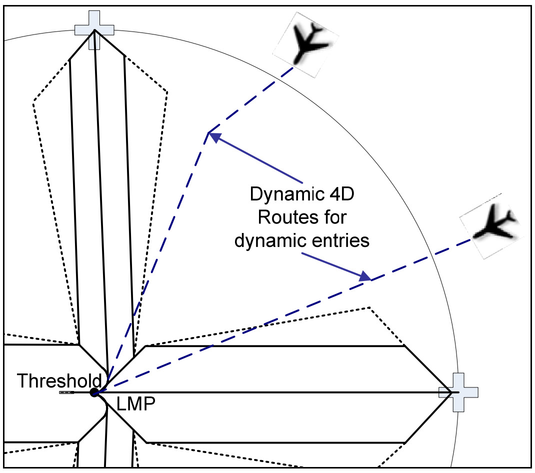

Figure 12. RNAV routes to the Late Merging Point.

The concept of late merging is developed and tested in DLR's project FAGI (Future Air Ground Integration). 4D-CARMA is extended by data link based negotiation functions to coordinate user-preferred trajectories with 'equipped' aircraft while also proposing radio-based clearances to the controller in order to guide 'unequipped' aircraft according to ground-based 4D-planning.

In order to support the controller effectively, both controller and AMAN must know the intension of each other. The AMAN communicates its intension via a suitable HMI to the controller. If, however, the only feedback loop from the controller to the HMI is via radar data, it may take a long time until the AMAN is able to adapt to a new controller intension, because there is a trade-off between adaptability and stability. We need a direct feedback loop.

The controller may change the sequence via *move commands*, i.e. changing the sequence position of two aircraft. This adds some constraints to the input of the constraint generator (CG) module. All future sequences will respect these constraints. 4D-CARMA can support the controller with suitable turn advisories immediately and is not forced to wait with the adaptation of the sequence until the status monitor (SM) detects a deviation between the radar data, indicating a turn, and the planned ground generated trajectory.

The opposite case occurs if the AMAN adapts the sequence for some reason whereas the controller wants to implement the previous sequence. Therefore a freeze command is implemented to generate further constraints for the module CG.

A first test campaign with a French controller team was conducted in October 2008 at DLR in Braunschweig. These trials will be continued in February and May 2009.

VI. Summary and Outlook

Trajectory-oriented, time-based arrival management operations have already shown potential benefits for throughput, efficiency, environmental impact and controller workload [17] and are meanwhile considered as a key element of SESAR [3]. On the ground side time-based arrival management requires an arrival manager with the key functions for trajectory-based aircraft scheduling, advisory generation, monitoring and conflict detection support to ensure situational awareness.

In this paper we described the usage of the AMAN 4D-CARMA to support time-based dual threshold operation. Preliminary benefit analysis shows a capacity increase of 3 to 4 arrivals per hour with dual threshold in use. The arrival flow does not significantly depend on the decision support level, but the departure flow does. Using automatic arrival-departure-coordination the outbound flow break-down observed in the DFS/FRAPORT experiments [7] could be compensated. The tool support for sequence, runway and advisory information on the arrival side and arrival-departure-coordination support reduces controller workload and increases the predictability of arrival and departure operations.

The controller feedback obtained during the three validation weeks gives valuable hints for future work especially on controller-system-interaction and on a suitable trade-off between stability/predictability on the one hand and adaptability/flexibility on the other hand: situational awareness requires stability, but (optimal) performance requires adaptability and flexibility. The controller should not be forced to stick to the suggestions of the system. Otherwise negative impact on controller skills in case of system failure or abnormal situations is probable.

Our first results of time-based arrival management to integrate unequipped into a stream of 4D equipped aircraft performing a user-preferred CDA approach show that an efficient AMAN support is still possible if the controller deviates from the AMAN advisories. If radar data, however, is the only input from the controller to the AMAN the feedback loop to reliably detect the controller's intension is very long. It could be reduced if the controller can directly manipulate (e.g. freeze, move an aircraft) a sequence on the time line.

ABBREVIATIONS

4D-CARMA	4 Dimensional Cooperative Arrival Manager
ADCO	Arrival-Departure-Coordinator
AFI	Arrival Free Interval
AMAN	Arrival Manager
CADEO	Controller Assistance for Departure Optimization
CFMU	Central Flow Management Unit
CDA	Continuous Descent Approach
DMAN	Departure Management
DTOP	Dual Threshold Operation
FAGI	Future Air Ground Integration
ILS	Instrument Landing System
OPTIMAL	Optimized Procedures and Techniques for IMprovement of Approach and Landing
TOD	Top Of Descent

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