COORDINATED ARRIVAL DEPARTURE MANAGEMENT

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Abstract

The paper deals with a new concept for the coordination of arrival and departure management when applying mixed mode operations at an airport. It is based on an appropriate tailoring of arrival gaps by automatic introduction of so-called arrival free intervals (AFI) and a corresponding path stretching for the respective arrivals. Thereby the coordination system takes into account both the departure traffic situation on ground and the arrival situation in the TMA, which is contained implicitly in state and planning information coming from controller decision support tools for the arrival and departure management (AMAN and DMAN).

The paper describes the coordination concept with particular consideration of operational and implementation issues. It outlines the required features for AMAN and DMAN and explains the communication between the connected systems. The paper explains in detail the coordination algorithm, which is based on fuzzy rules expressing expertise.

Particular consideration is given to the concept evaluation. The evaluation was done on the example of a traffic scenario which was modified by stochastic disturbances. A large number of simulations were run to enable a comparison of the coordinated and the uncoordinated case. The calculated statistics shows the potential benefits of this coordination concept. The results indicate not only an enhancement of total throughput but also an increase of efficiency, punctuality and predictability of the departure operations on ground.

1 Introduction

For larger airports mixed mode operations are commonly considered as one important mean to increase the capacity of their runway systems [5][7]. From this point of view the paper introduces a method for the coordination of arrival and departure management (CADM), which is based on an appropriate, automatic tailoring of arrival gaps. Thereby it is assumed that at a considered airport controller assistance systems are already implemented, e.g. so-called arrival (AMAN) and departure manager (DMAN), which support the planning of inbound and outbound traffic operations. The coordination itself is done with the help of a new arrival-departure coordination system (ADCO) [4]. The CADM concept is designed to be applicable for any AMAN and DMAN as long as they meet a set of well-defined requirements. The concept has been worked out by DLR within the German KATM project, but under consideration of the results of both the relevant European projects, like Gate-to-Gate [19] and the PHARE [18]. The Total Airport Management Concept (TAM), which was elaborated jointly by EUROCONTROL and DLR was also taken into account [10].

The paper is structured as follows: The next chapter describes the coordination concept, where after specifying the objectives, questions of the operational implementation are considered in more detail. The coordination principle, which is characterised by using so-called arrival-free intervals (AFI) in order to tailor arrival gaps is described and illustrated. Finally, the system architecture is shown and the requirements of AMAN and DMAN are specified, with regard to the coordination issues. Chapter 3 describes the coordination algorithm which is implemented in the ADCO. The first section of this chapter is dedicated to the fuzzy inference mechanism with the help of which the ADCO "decides" over the implementation of AFI, whereas the next section answers questions about AFI dynamics caused by planning updates. Chapter 4 outlines the simulation scenario as well as the used planning systems. Chapter 5 explains the evaluation method, their objectives and shows the results of the statistical analysis. Finally, the last chapter summarises the outcomes and gives an outlook on further work.

2 Coordination Concept

2.1 Objectives

Obviously the coordination of arrival and departure management targets on an improved runway utilisation resulting in an increased total number of landings and take-offs during a given interval in time. So ideally, throughput shall match the available runway capacity. Besides throughput, enhancement of punctuality, also mirrored in CFMU-slot compliance, is clearly another objective of CADM. Furthermore improved efficiency, mainly caused by less fuel burn, is a commonly agreed target for ATM research in general and for the CADM in particular. Savings of fuel will also reduce environmental impacts with respect to noise and pollution [7] and may become a primary target with regard to the implementation of regulated (permissible) maximum values. And finally, an improved reliability of planning information, in particular of planned off-block and take-off schedules, is another objective of CADM as this is considered as important contribution to A-CDM.

2.2 Operational and Implementation Considerations

When examining options for Coordinated Arrival Departure Management (CADM) one should take into account that the management is currently organised in a de-centralised manner. The arrival management is processed by approach control including the TMA and the surrounding sectors whilst the (tactical[1]) departure management is (mainly[2]) performed by the tower control. Of course, a handover of control must take place when the arrival has reached a certain intercept of the glide path. However, coordination is focussed more on inbound traffic than on runway utilisation. This restriction not only results from a lack of information, but mainly from the level of workload. Most of the time it is nearly impossible for the approach controllers to consider the actual departure traffic situation. On the other hand, the present fragmentation of control allows a clear attribution of responsibility and is of fundamental importance for the sake of safety. Therefore, the conclusion that can be drawn is that a CADM concept must not change the existing areas of responsibilities, but should enable a better coordination with respect to runway utilisation without increasing workload. It seems to be clear that the underlying information exchange needs technical systems as enablers and, since tactical planning information has to be included, too, the implementation of an arrival (AMAN) and a departure manager (DMAN) in particular.

For safety and efficiency reasons the “priority of arrivals” is maintained. Thus, take-off operations must use the howsoever created arrival gaps. However, the CADM concept requires for the arrival management one fundamental change (sect. 2.5.1) from minimum separation sequencing to time-based scheduling.

The proposed CADM concept contributes to the ambitious intentions of the ATM R&D programmes like “Vision 2020”, “ACARE”, and “Episode 3” [20], whilst aiming for evolutionary rather than revolutionary changes of current operations. Thus, an airport may implement gradually an AMAN and a DMAN first, and apply the coordination of both tools later in order to improve mixed mode operations. The method is independent of the particular instances of AMAN and DMAN as long as both meet well-defined requirements (sect. 2.5) In the framework of these programmes a CADM concept should also take into account that the technology level with respect to air ground cooperation and on board (FMS) capabilities will change [11]. Therefore the concept is applicable in the current situation, where approach control is done using VHF only, but should also benefit from future technology levels enabling CPDLC and air-ground trajectory negotiations. Additional benefits will be gained from aircraft self-separation capabilities provided by the next FMS generation.

2.3 Coordination Principle

Under the condition of mixed mode operations it can be assumed that there is less arrival demand (compared to a solely used arrival runway) in order to allow take-offs at the same time. Thus, minimum separation between arrivals cannot be constantly applied. An equably larger spacing of the arrivals is not favourable in the general case of a varying inbound traffic demand as it would result in arrivals gaps which are not optimal for a whole-number of the take-offs between the landings. If the arrival management is done without taking into account the departure demand the resulting (and varying) arrival gaps are not optimal either for the same reason. It might also happen more frequently that an urgent (slotted) departure cannot be released in time as there are too many landings in a row preventing the take-off.

Obviously, an appropriate spacing of the arrivals is a key factor for CADM. As approach procedures are generally designed to have minimum flight times, spacing can hardly be done by speed-up but by delaying of arrivals. Of course, speed reduction in the surrounding sectors is one means to influence the size of arrival gaps on the runway threshold, but will be used mainly to separate the aircraft at the metering fixes. The proposed CADM concept therefore tailors the arrival gaps through extension of the flight path (fig. 1). This must be supported by an AMAN capable to deal with 4D-trajectories within the TMA (sect 2.5.1). It must be emphasized that this CADM concept implies a change from a minimum separation to a time-based arrival management.

[1] after initial call of the Clearance Delivery by the pilot
[2] Apron control might be done from distinct control centre(s).

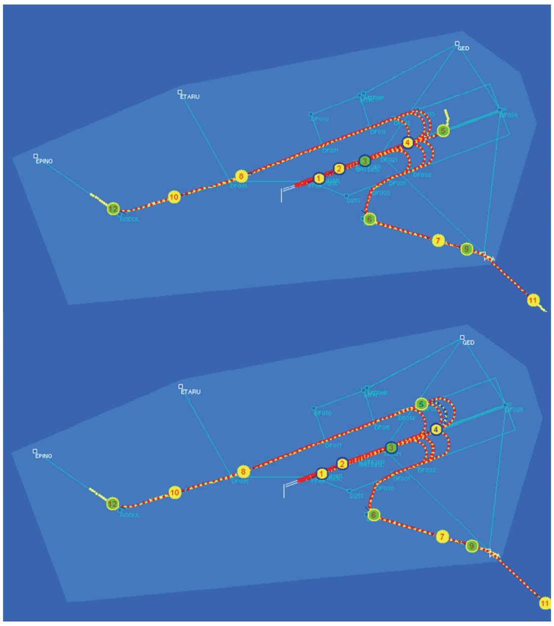

Fig. 1: ***Extension of flight paths.***
The lower part of the figure shows the extensions of flight paths (dotted lines) caused by the introduction of an AFI and a resulting larger required spacing between aircraft number 2 and 3. The example was drawn from a set of test runs for Frankfurt Airport (TMA is marked in light blue), parallel runway systems 25L and 25R (sect. 4.1). In comparison to the uncoordinated case (upper part) aircraft 3, 4, and 5 suffer a delay for the departure operation(s) between landing 2 and 3.

The CADM concept introduces so-called Arrival-Free Intervals (AFI) with the help of which the tailoring of arrival gaps is done. An AFI is a certain period of time during which no landing shall take place. Every AFI is attached to a particular arrival and requires additional spacing for the next landing. So, at first glance it might be considered as an artificial increase of the aircraft's wake vortex category which would require a larger wake vortex separation. However, in case of an update of the planned landing time the coordination algorithm must "decide" whether the AFI should be kept or not and if so, whether it should "follow" the aircraft or should remain unchanged (sec. 3.2).

The CADM concept can be summarised as follows: A specific coordination system (ADCO) repetitively introduces AFI. The AMAN accordingly reschedules affected arrivals. The updated sequence is sent back to the ADCO system which forwards this data to the DMAN. Hence the changed gaps in the arrival stream can be used by the DMAN and the consequential rescheduled departure sequence is transmitted to the ADCO and AMAN again.

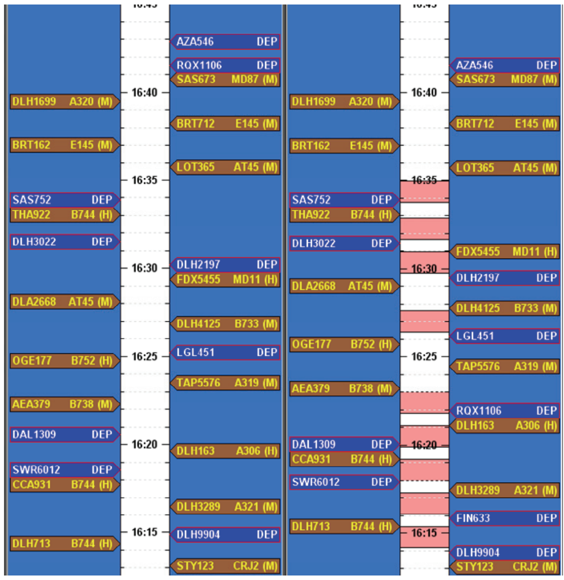

Fig. 2: ***Comparison of planned arrival and departure schedules.***
The figure shows the two time lines for the uncoordinated (left part) and coordinated case (right part). Each time line contains the planned landing (brown) and take-off events (blue) for runway 25L (left side of each time-line) and 25R. In consequence of the introduced AFI (red rectangles of the right time-line) ten arrivals and one departure (LGL451) will be delayed. However within the next 30 minutes, seven departures gain an expedition. In addition, departure throughput increases by one.

2.4 System Architecture

The developed arrival-departure coordination system (ADCO) allows the dynamic coordination of an arbitrary arrival and departure manager, as long as both systems meet a set of requirements (sect.2.5). The connected planning systems must provide appropriate interfaces to exchange information which is needed for the coordination (sect. 3 and table 1). The AMAN now receives additional constraints in terms of AFI by the ADCO, whereas the DMAN must consider landings in the same manner as in the uncoordinated case (master-slave configuration).

Although the ADCO works fully automatically, it has a human machine interface allowing controllers to change configuration parameters and to insert or remove AFI.

The ADCO is ready for use according to the Total Airport Management Concept [10] where a Total Operations Planner (TOP) assigns dynamic arrival and departure flow rates which result from an overall optimisation.

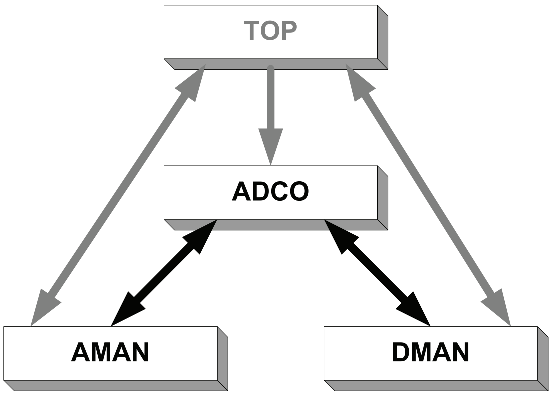

Fig. 3: ***System architecture for CADM with ADCO***
The CADM concept needs the ADCO for the coordination of AMAN and DMAN. The TOP is an optional system, which will be implemented with the TAM Concept.

TOP → ADCO: • arrival flow rate • departure flow rate
AMAN → ADCO: • arrival flight plan data • planned arrival schedules • latest possible landing times (without holdings) • allocated runways
DMAN → ADCO: • planned take-off schedule with consideration of landings • earliest possible take-off times • CFMU-slots • allocated runways
ADCO → AMAN: • introduced AFI • removed AFI
ADCO → DMAN: • flight plan data and planned arrival schedules

Table 1: Communication of CADM systems

2.5 Required Features of Coordinated Systems

In order to enable the use of arbitrary (e.g. already implemented) AMAN and DMAN tools the following sections describe the conditions precedent for a successful coupling.

2.5.1 AMAN Features

The AMAN must be capable to adapt repetitively to the current traffic situation when supporting the implementation of time-based landings. This requires the use of sophisticated 4D-trajectory models with the help of which the progression of the current traffic situation can be predicted. Such models must also be the basis for the design of appropriate trajectories which corresponds to the planned schedule of landings. Of course, as the AMAN is considered as controller assistance system, advanced radar displays for approach control have to be developed, allowing not only ATC without paper flight strips but providing in addition assistance for conflict detection and guidance. However this is not the focus of this paper.

When planning the (optimum) arrival sequence(s)[3] the planning algorithm must consider both a constraint model for the required minimum separations of arrivals and a list of intervals (AFI by ADCO and other origins) which are blocked-out for landings.

2.5.2 DMAN Features

First of all the DMAN must be a tactical planning system, which is provided with the complete flight plan data. It has to be able to adapt the planning to the current traffic situation as well as to the current status of each aircraft. The departure manager must incorporate the landing schedule in its own planning. Due to the fact that the DMAN always has to react on the given arrival situation it is unconditionally necessary that a full operational constraint model is implemented. Wake vortex separations, SID constraints as well as constraints due to runway occupancy times must be considered when planning departures into the arising gaps between arrivals.

Besides these functional aspects the DMAN has to provide some additional information to enable a successful generation of AFI. For every departure the current planned take-off time (TTOT) must be provided together with an earliest possible take-off time and a latest permissible take-off time due to an existing CFMU-slot.

A further improvement of the coordination can be achieved by provision of a confidence interval for each TTOT.

3 Coordination Algorithm

An appropriate CADM concept must consider the overall traffic situation. Thus the concept must provide a good compromise between the needs of the outbound traffic on the one hand and the “potential” for delaying aircraft by Approach Control on the other hand, since tailoring of arrivals

[3] Usually an AMAN provides several arrival (sub-) sequences for the different metering fixes and one overall sequence for the runway threshold.

gaps naturally increases workload for Approach Control. The potential is limited by the loss of controllability, which occurs when an extended flight path reaches the TMA boarder.

As the AFI concept can be perceived intuitively, the underlying coordination algorithm can be based on expertise which is expressed by rules. In particular an expert would formulate some rules in favour of the introduction of an AFI as well as rules against additional spacing. Examples for such rules are: “IF there is one departure, which is supposed to violate its CFMU-slot, THEN introduce an AFI” (at the considered time) or “IF too many arrivals are affected by the AFI (as an indicator for raising workload), THEN do NOT introduce the AFI.” In order to allow a smooth transition between cases where a rule should apply or not the algorithm uses fuzzy rules for a fuzzy inference mechanism (sect. 3.1).

3.1 AFI Implementation

The implementation of AFI is the core functionality of the ADCO. The first step is to determine repetitively (e.g. once a minute) promising points in time. A fuzzy inference system is used for evaluation and selection of a suitable time for placing an AFI. Provided with data from approach control (AMAN) and tower control (DMAN) which characterize the actual traffic situation, ADCO can derive values for particular attributes as input for a fuzzy inference system. The attributes describe the impact on the arrival sequence, the remaining flexibility of arrivals, the exigency for an AFI in view of DMAN and the probability of using the AFI efficiently for take-offs.

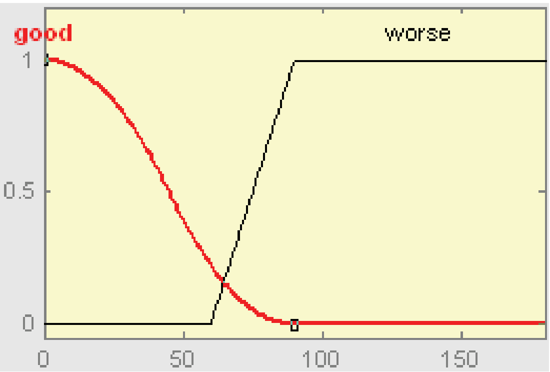

Fig. 4: Membership function
The graphic depicts an exemplified membership function for one attribute. The attribute is mapped to the features (good, worse) with the help of a fuzzy membership function.

A set of rules is defined which describe whether it is advisable to have an AFI at a selected time or not. Membership functions (fig. 4) are mapping the derived attributes to features which are combined to rules by logical compositions of terms. The consequences of all rules are aggregated by a fuzzy inference system (fig. 5) according to Mamdani [12], which yields a total value indicating the suitability of the AFI. Finally a comparison of the value delivered by the fuzzy inference system and a threshold leads to a decision whether the AFI actually is to be introduced or not. In the latter case remaining auspicious points of time have to be evaluated.

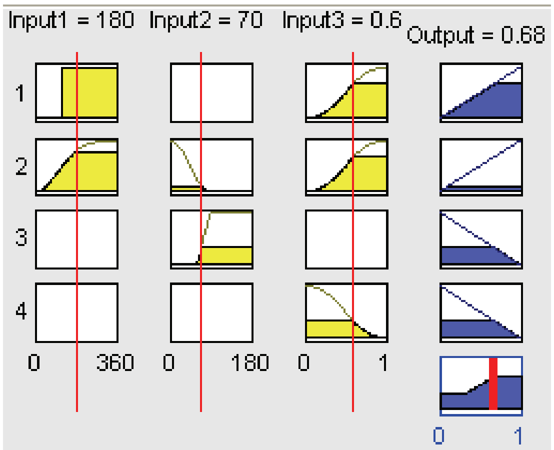

Fig. 5 Fuzzy Inference System
Three attributes used in a set of four rules are shown in this extract of the fuzzy inference system.

3.2 AFI Dynamics

It seems to be appropriate to have a time horizon of about seven to thirty minutes in future for introduction of an AFI. An introduction of an AFI earlier than seven minutes in future is not practicable because arrivals can hardly adjust within that proximate time before landing. This is also true for some departures. The more the scope of evaluation is extended towards future the more uncertain is the planned take-off schedule with respect to accurate implementation. A point in time selected by the fuzzy inference system is usually placed after the target landing time of an arrival. In case of updates of the landing time the related AFI has to be chronologically adjusted within certain limits in order to prevent a loss of capacity. Therefore a “sensitive” buffer of a few seconds ahead of the AFI is implemented which allows detection of a slight delay by the arrival without forcing the arrival to be scheduled beyond the AFI. In case that the arrival is scheduled for an earlier target time it is opportune to have the AFI adjusted accordingly as long as the AFI is still used by a departure.

In case no departure is scheduled for take-off within an AFI the abandoned AFI is removed after a pre-defined time allowing minimum separated landings again.

4 Experimental Setup

4.1 *Simulation Scenario*

In order to show the effectiveness of the CADM with ADCO a special simulation scenario was created to test the common uncoordinated master-slave configuration against the coordinated case.

The simulation scenario was designed for mixed mode operations on the parallel, but interdependent runway system 25L/25R of Frankfurt Airport (EDDF) without considering departures on runway 18. The airspace was structured according to EAM04 [6][13] but with some extra waypoints needed for path stretching.

The traffic scenario with a total length of about 2.5 hours consisted of a realistic traffic mix of 49 departures, out of which 26 had a CFMU-slot, and 66 arrivals. For the departures the runway assignment was pre-determined according to destination and/or parking position. In particular, 22 departures were assigned to runway 25L and 27 departures to 25R. The arrivals were assigned alternately to the left or right runway by the AMAN depending on arrival sequence only.

The scenario was diversified by random variation of events concerning the departure operations on ground, like "readiness for push-back", "end of taxiing" etc. This created different conditions for the coordination algorithm resulting in a diverging AFI introduction which in turn induced a diverging response of the AMAN, e.g. a modified arrival schedule.

The AMAN applied ICAO standards for arrival separation (table 2) whilst the DMAN used several constrain models simultaneously (sect. 4.2.2). The constraint model for minimum separation between arrivals and departures was built under consideration of runway occupancy times (tables 3 and 4), which also depend on aircraft weight classes.

		follower		
		light	**medium**	**heavy**
leader	**light**	2	2	2
	medium	5	2	2
	heavy	6	5	4

Table 2: Arrival separations in nautical miles

In order to come up with a statistic-based evaluation a large number of tests were run. However, this could not be done with Human-in-the-Loop simulation. Hence, no deviation was assumed from the provided plans by approach or tower controllers.

In order to simplify the simulation the mutual interdependence between aircraft during ground operations was not considered. Also all departures were cleared for take-off ignoring slot violation of any degree.

		departure on same runway	**departure on parallel runway**
arrival	**light**	45	25
	medium	48	28
	heavy	53	30

Table 3: Arrival-departure separations in seconds

		arrival on same runway	**arrival on parallel runway**
departure	**light**	60	55
	medium	70	60
	heavy	73	63

Table 4: Departure-arrival separations in seconds

4.2 *Used Planning Systems*

For the aspired simulation trials appropriate controller support tools which fulfil the postulated requirements have been developed and are presented shortly in the next two sections.

4.2.1 *AMAN (4D-CARMA)*

The 4D-CARMA (4 Dimensional Cooperative Arrival Manager) is a further development of DLR's previous arrival managers COMPAS [14][16] and the 4D-Planner [8][9]. The 4D-Planner was developed in close cooperation with the DFS, the German Air Navigation Service Provider.

Planning of an arrival sequence is the basic task of any arrival manager. The 4D-CARMA determines the most probable, the shortest and the longest trajectory of each arrival based on their radar positions and the airspace structure. With the help of the corresponding earliest and latest landing times an optimum arrival sequence is calculated, where the target landing times meet the required wake vortex separations. In addition, the 4D-CARMA is able to consider AFI.

4.2.2 DMAN (Eurocontrol/DLR)

DLR has been developing departure planning systems since the early 90's and designed the first operational prototype of a DMAN for Zurich Airport, which became operational in 2003 [15]. A more generic variant of this tool named ROPS [1] was developed within the DLR project TARMAC in 2002 [17]. In the year 2003 Eurocontrol commissioned DLR to develop a departure manager which can be easily adapted to different airports and has the ability to act as a stand-alone demonstrator or embedded tool in a simulation or real ATC/airport environment [2] [3].

The Eurocontrol/DLR DMAN is a tactical planning system, which optimises the planned departure take-off times by taking into account several evaluation functions for different aspects of departure management e.g. capacity, efficiency and CFMU-slot compliance. From the thereby calculated target take-off times (TTOT) the DMAN derives corresponding recommendations for timely engine start-up, push-back and taxi clearances. Thus the DMAN supports a varying number of controller working positions like clearance delivery, ground or runway control. The DMAN adapts its planning to the progress of all departure procedures and the current traffic situation and also incorporates estimated or planned landing times.

When running as a stand-alone demonstrator an event-driven stochastic simulation is comprised, which enables a stochastic variation of the departure operations on ground. This internal simulation was used for all test runs.

5 Evaluation

5.1 Objectives

In order to evaluate the CADM Frankfurt Airport was used as an example. However, it was not intended to conduct a dedicated study but to show general benefits. The evaluation was based on a comparison of the uncoordinated case, were AMAN and DMAN work in master-slave configuration and the coordinated (CADM) case. The three main hypotheses for the CADM case were:

There will be

- an increase of departure throughput.
- a better CFMU slot compliance.
- some average arrival delay, but no decrease of arrival throughput

Slot compliance was investigated in terms of the probability and the degree of violation. In addition to throughput and slot compliance, taxi-out delays and the accuracy of planning information was measured in order to gain an insight into beneficial or disadvantageous side effects.

5.2 Results

In this section the results from the simulation runs are presented. During each simulation run the following performance measures were calculated:

- throughput for arrivals and departures,
- mean taxi-out delay,
- mean CFMU-slot delay: mean delay time between the end of a CFMU-slot and the actual take-off time for each slotted departure,
- number of CFMU-slot violations,
- mean TTOT error: mean take-off time prediction error for each departure with respect to actual take-off time.

Afterwards an overall mean value for these indicators based on 30 simulation runs for each setup was calculated to compare the uncoordinated system configuration with an ADCO-coordinated one.

Throughput:

The underlying traffic scenario consisted of 49 departures and 66 arrivals. Only the arrivals and departures which made their touchdown/take-off during the simulation time of about 2.5 hours counted for statistics.

In both setups all the arrivals managed their touchdown within the simulation runs while the number of take-offs deviated. In the uncoordinated case there was no simulation run where all departures could be released. The number fluctuated between 46 and 48 with a mean value of 47.3. With ADCO-coordination all 49 departures in each simulation run could take-off so that the overall throughput was increased by 1.7 departures. In order to calculate the time-variant throughput the landing and take-off events were divided into 10 minute intervals and afterwards six intervals were accumulated for a value per hour. Since the first take-off in each run took place between 15:30 and 15:40 the remaining relevant span of time was from 15:30 until 16:40. Figure 6 shows the progress of this performance indicator over time.

	mean departures per hour	**mean arrivals per hour**	**maximum overall throughput per hour**
coordinated	21.41	31.25	54
uncoordinated	18.97	31.43	52

Table 5: Throughput per hour statistic

Within the considered period the average gain was 2.44 departures in the selected hour whilst the mean arrival throughput only dropped by 0.18 (table 5).

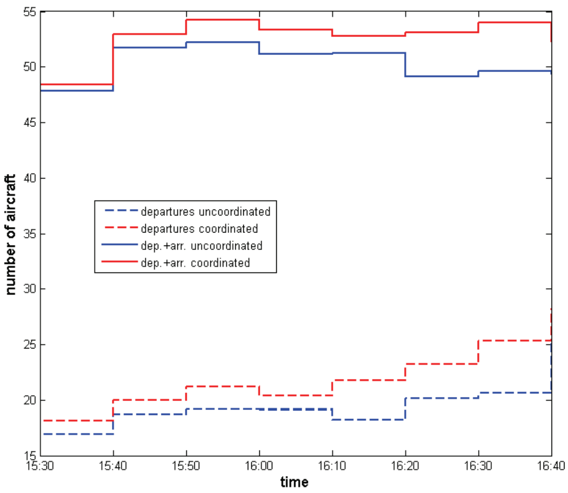

Fig. 6: Throughput per hour
The value of each interval shows the throughput per hour beginning at this point in time.

Taxi-out delay, CFMU-slot delay, CFMU-slot violations:

The three performance measures taxi-out delay, CFMU-slot delay and number of CFMU-slot violations are indicators for punctuality in departure management (tables 6 and 7). The dependencies between these measures are presented in scatter plots (fig. 7-9)

	min	max	average
number slot violations	4	9	6.1
slot delay seconds	127	270	194.19
taxi-out delay seconds	265	381	315.73

Table 6: Results for punctuality – uncoordinated

	min	max	average
number slot violations	0	4	1.86
slot delay seconds	0	263	180.48
taxi-out delay seconds	211	314	244.17

Table 7: Results for punctuality – coordinated

It becomes apparent that all delay measures decreased when using ADCO as coordinator system. The number of slot violations dropped down by almost 70% while the mean exceed of a CFMU-slot decreased by 7% (fig.7). The mean taxi-out delay calculated in seconds is decreased by about 23% and, as it can be seen in figure (fig. 9) the decrease of this indicator additionally affected the number of CFMU-slot violations. Finally figure (fig. 8) shows a light dependency between taxi-out delay and CFMU-slot delay for the uncoordinated case whereas in the coordinated setup these indicators are totally uncorrelated.

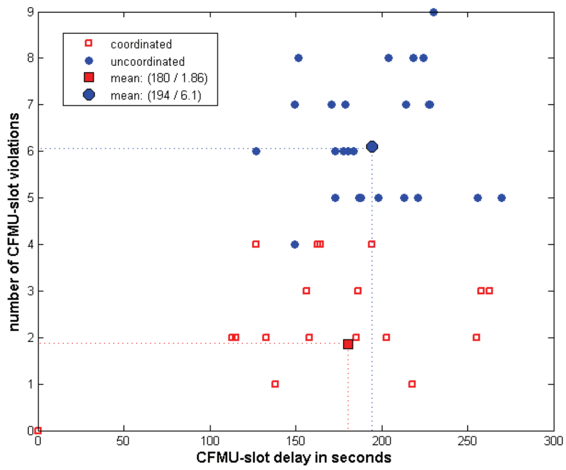

Fig. 7: Number of CFMU-slot violations vs. CFMU-slot delay
Note that two coordinated runs had no slot violations and therefore no delay time.

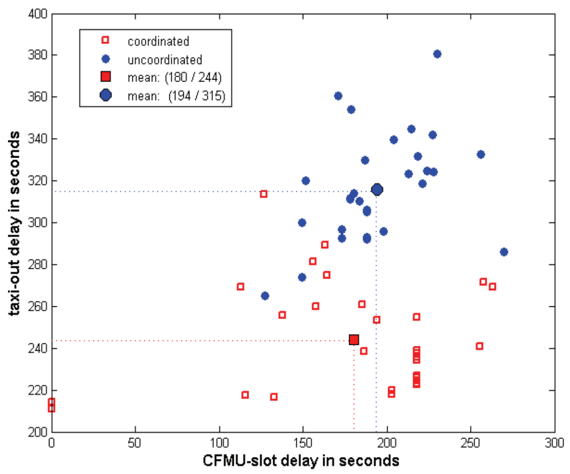

Fig. 8: Taxi-out delay vs. CFMU-slot delay
Note that the two measures show a minor correlation for the uncoordinated case

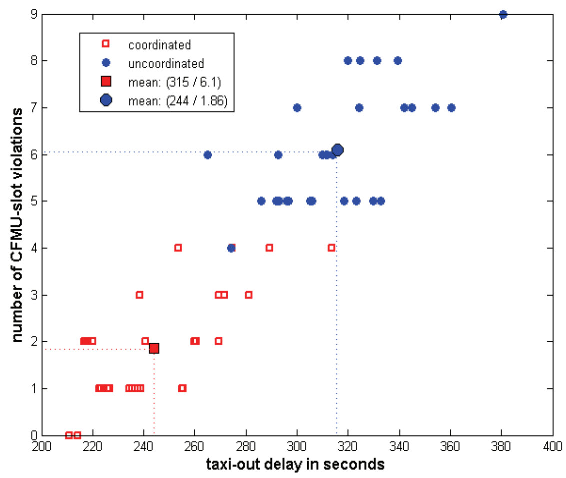

Fig. 9: Number of CFMU-slot violations vs. taxi-out delay
Note the correlation between these indicators for both system configuration

TTOT error:

The TTOT error is defined as the difference between the planned target take-off time calculated by the DMAN and the actual take-off time. It is used as a retrospective measure for the planning accuracy of the DMAN. In order to show the characteristics of the average TTOT error the time scale was normalised on the take-off event (fig. 10). The improvement of the CADM case is indicated as green area and shows a big increase of planning accuracy particular in the interval from 30 to 22 minutes before take-off.

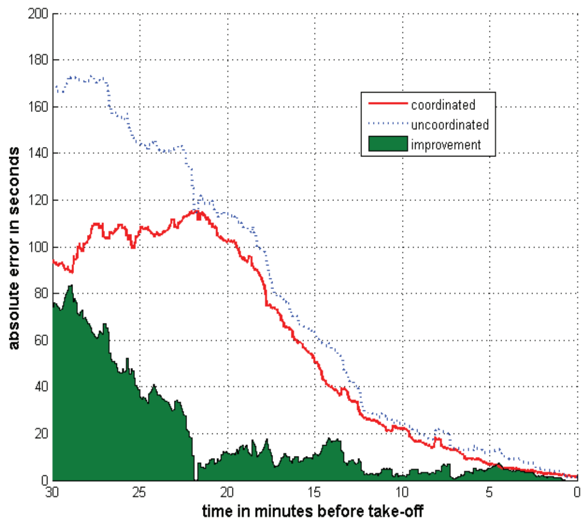

Fig. 10: Characteristics of average take-off prediction error
The green area indicates the improvement with respect to planning accuracy when applying CADM.

Figure 11 presents a TTOT error distribution for the events of en-route and taxi clearance. For the en-route clearance, which in simulation was given about 30 to 20 minutes before take-off, CADM leads to an increase of "exact" predictions (error within -30s and +30s) and an decrease of "over-optimistic" predictions (error lower than -10 minutes). At the moment of taxi clearance both system configurations show excellent results with a probability of an exact prediction of about 90% whereas the ADCO-coordination even could reach an additional improvement of about 3%.

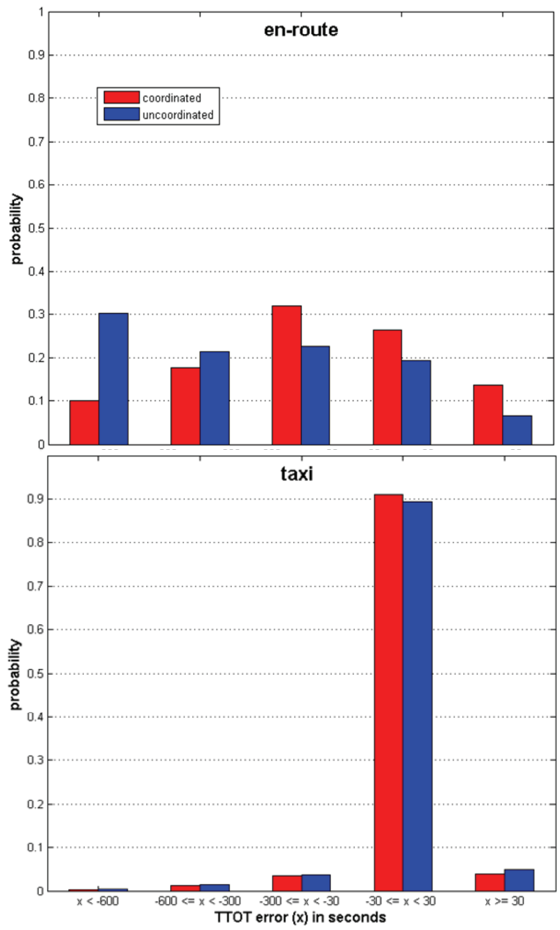

Fig. 11: Distribution of the TTOT error at en-route and taxi clearance
The probability of the TTOT error (TTOT-actual take-off time) to fall in a predefined time interval is compared at two clearance instances

6 Summary and Outlook

The proposed CADM concept has been developed to improve mixed mode operations by enhanced coordination of arrival and departure management. It enables the coordination of arbitrary controller decision support tools for arrival (AMAN) and departure management (DMAN), which however have to fulfil a well-defined set of requirements. The concept takes into account the given distribution of responsibility for arrivals and departures between approach and tower control as well as the natural limitations in assessing the departure situation on ground by approach controllers. Since the concept is based on an appropriate tailoring of arrival gaps by automatic introduction of AFI and a corresponding path stretching for the respective arrivals, it requires for the arrival management one fundamental change from minimum separation sequencing to a time-based scheduling. For the evaluation it was assumed, that the concept can be implemented with the help of an enhanced AMAN, which not only enables a 4D-trajectory-based planning but, also provides assistance for guidance and conflict detection. Future development of air-ground coordination, enabling CPDLC and trajectory negotiation will support this CADM concept. However, further investigations are necessary to assess the interrelation between data link technology level and practicability of time-based arrival management. This will be done in the frame of an internal project (FAGI).

The simulation results support the hypotheses that this CADM concept can enhance total throughput, and for departures can increase the punctuality and CFMU-slot compliance with only minor extension of arrival flight time. It is assumed that further improvements can be gained by an extension and optimisation of the fuzzy rule set and a more sophisticated treatment of dynamic AFI. The advancement of the coordination algorithm is an ongoing topic for research at DLR.

Abbreviations

4D-CARMA	4 Dimensional Cooperative Arrival Manager
ACARE	Advisory Council f. Aeronautics Research i. Europe
A-CDM	Airport CDM
ADCO	Arrival Departure Coordination Layer
AFI	Arrival Free Interval
AIP	Aeronautical Information Publication
AMAN	Arrival Manager
CADM	Coordinated Arrival Departure Management
CFMU	Central Flow Management Unit
CDM	Collaborated Decision Making
CPDLC	Controller Pilot Data Link Communications
DMAN	Departure Management
EAM04	Eurocontrol Airspace Model
FAGI	Future Air Ground Integration
ICAO	International Civil Aviation Organization
ROPS	Runway Operations Planning System
TARMAC	Taxi And Ramp Management And Control
TMA	Terminal Manoeuvring Area
TOP	Total Operations Planner
TTOT	Target Take-Off Time

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Key Words

ATM, Airport Capacity Enhancement, Arrival Management, Coordinated Management, Departure Management, Mixed Mode Operated Runway

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