Coordinated Arrival Departure Management

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Motivation & Objectives (I)

- Many airports in the world face capacity problems
- Very often the runway system and its usage are a bottleneck limiting the number of operations
- As the building of new runways is expensive and even impossible in many cases a better utilisation of the runway system is necessary
- Two options to improve runway utilisation
  - introduce controller assistance systems for arrival and departure management (AMAN, DMAN)
  - reinforce mixed mode operations
    typical configurations:

No. of RWY	Arr	Dep	Arr & Dep
1			1
2			2
3	1	1	1
4	**1**	**1**	**2**

Motivation & Objectives (II)

- **Combine these options (!)**
  - reinforce mixed mode operations and
  - support controllers with assistance tools AMAN and DMAN

- **Coordinate Arrival- and Departure Management**
  - change from Master-Slave Configuration to coordination of AMAN and DMAN (CADM)

Motivation & Objectives (III)

- **Aim of this presentation is**
  - **neither** to address benefits which can be achieved by reinforcement of mixed mode operations
  - **nor** to deal with benefits which can be reached when mixed mode operations are supported by controller assistance tools AMAN and DMAN
    but
  - to show the **additional benefits** when performing mixed mode operations with the help of **coordinated AMAN and DMAN**, i.e. performing
    Coordinated Arrival- Departure Management
- **Benefits**
  - improvement of throughput
  - reduction of taxi-out delays
  - enhancement of punctuality and CFMU-slot compliance
  - enhancement of reliability of planning information
- **Questions of "practicability", esp.**
  - impact on arrival and departure management
    (workload, complexity, difficulty)
  - maintaining established areas of responsibility (approach, tower) and "priority" of arrivals over departures
  - interdependence from particular AMAN/DMAN implementations
  - step-wise implementation

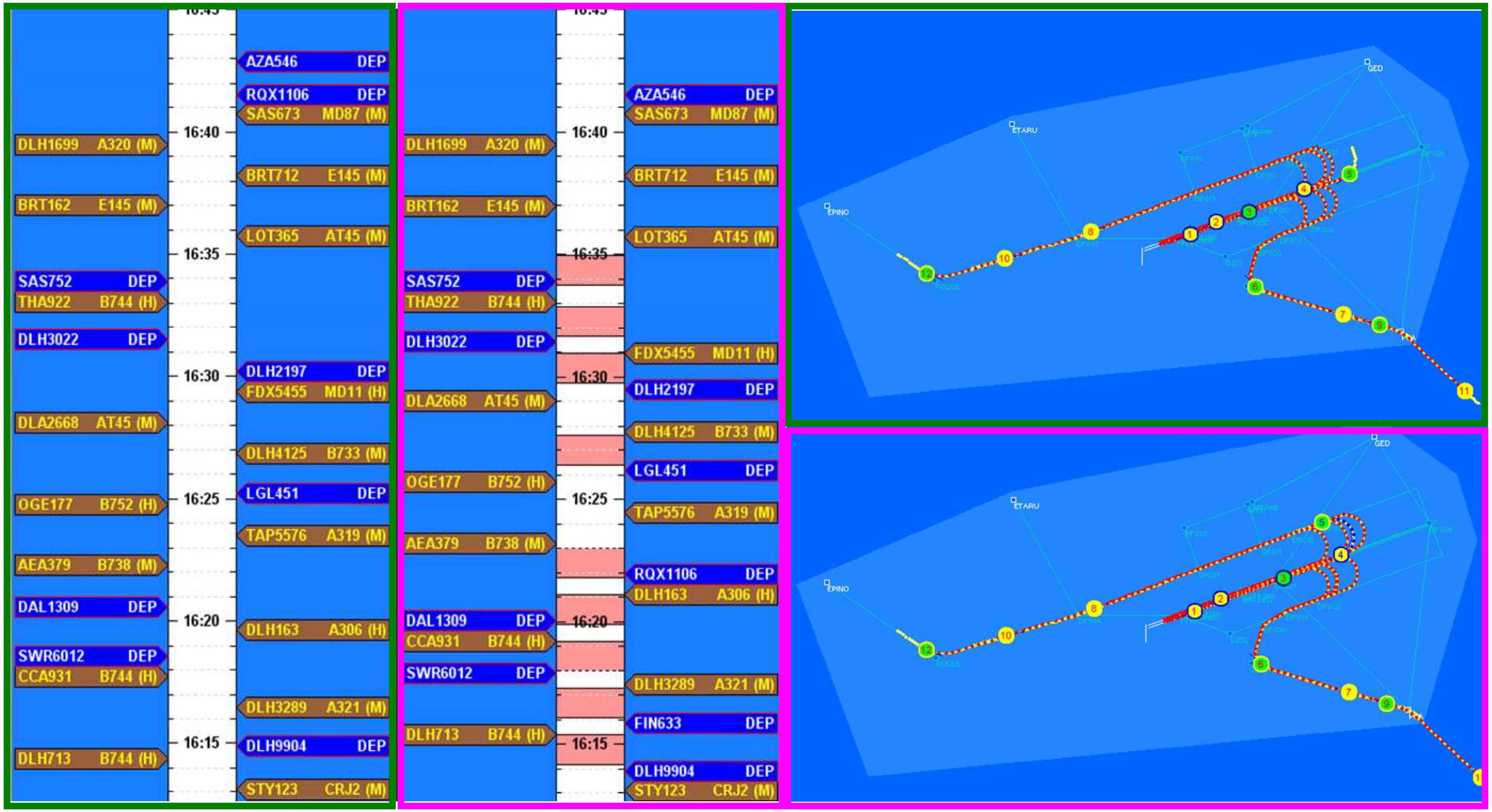
AMAN-DMAN Coordination: Concept (I)

- **Basic considerations**
  - **for operational reasons, like workload and safety, maintain**
    - de-centralised organisation of arrival- and departure management
    - priority of operations: landings over takeoffs
  - **less arrival demand -> minimum separation cannot be constantly applied**
  - **equably larger spacing of arrivals is not favourable (in the general case)**
    - resulting arrival gaps are not optimal for departure operations
    - solution cannot lead to optimum runway utilisation
      when arrival demand is unequal departure demand
  - **arrival management without considering departure situation would result in**
    - varying, but non-optimum arrival gaps
    - risk to prevent urgent departure operations
      in case of too many landings in a row

AMAN-DMAN Coordination: Concept (II)

- **Conclusions**
  - **appropriate tailoring of arrival gaps is key-factor of CADM**
  - **-> change from minimum separation to time-based arrival management (from “early as possible” to “right in time”)**
  - **-> support controllers by 4D-trajectory based planning tools (next generation AMAN)**
- **Approach**
  - **influence/control arrival spacing by “arrival-free intervals” (AFI)**
  - **determine automatically and dynamically appropriate points in time (landing events) for implementation of AFI**
    - determine automatically and dynamically -> coordination algorithm
    - appropriate points in time: taking into account both arrival and departure situation

Illustration of Concept



AMAN-DMAN Coordination: Algorithm (I)

- **Approach**
  - **Coordination with AFI may require a non minimum separation, i.e. a certain delay of arrival**
  - **Experts/controllers can formulate rules when they would delay an arrival respectively when they wouldn't do so**
  - **Examples:**

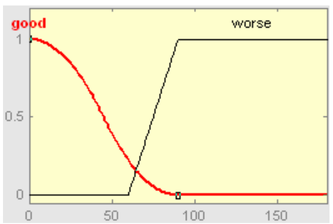
    (1) IF the resulting interval can be used (will probably be used) by an urgent departure **THEN** introduce an AFI.

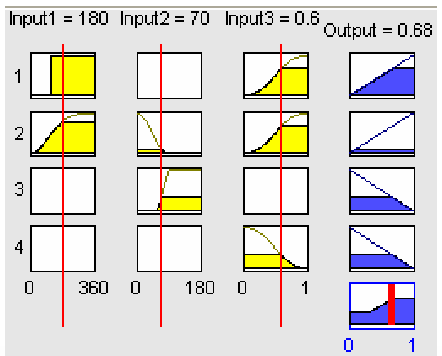
    (2) IF the resulting interval can be used by a departure **AND NOT** too many arrivals are effected **THEN** introduce an AFI.

    (3) IF the introduction of an AFI would cause an holding operation **THEN** do not introduce an AFI.
  - **A "fuzzy rule-based" inference mechanism allows the intelligible use of**
    - expert knowledge
    - all rules, even if they might be contradictive (e.g. rule 1 and 3)

AMAN-DMAN Coordination: Algorithm (II)

- **Modelling expert knowledge**
  - **Expert rule:**
    IF
    the resulting interval can be used (will probably be used) by an urgent departure
    THEN
    introduce an AFI.
  - **Fuzzy rule:**
    IF
    departure_probability_of_use is high
    AND
    departure_urgency is high
    THEN
    AFI.suitability is good





- **Features/Attributes**
  - basic information about the overall situation
  - must be derived from flight plan data and **planning and status data of AMAN and DMAN**
  - values **depend on a considered point in time**
- **Properties/Characteristics**
  - characterising the overall situation with the help of fuzzy membership functions
- **Fuzzy inference**
  - fuzzy expressions for AND, NOT, (OR)
  - composition of (weighted) rules
  - leads to **one output value** for the considered point in time
- **Decision** (AFI at a certain time?)
  - comparison of output with threshold value (control parameter for balancing)

AMAN-DMAN Coordination: Algorithm (III)

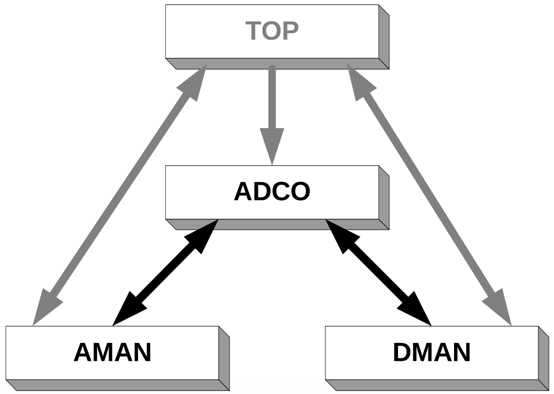
- **Cyclic repetition of coordination**
  - **determine points in time as candidates for AFI introduction out of a look-ahead scope**
  - **apply repetitively fuzzy inference mechanism for the candidates**
    - stop in case of decision “yes”
    - continue in case of decision “no”
    - in case of no AFI introduction at all raise frequency of repetition

- **AFI dynamics**
  - **delete abandoned AFI (no planned take-off operation within)**
  - **adapt AFI (beginning and end) in case of “sliding” variation of planned landing times (not described in paper)**

AMAN-DMAN Coordination: Required Features

- **AMAN**
  - support time-based landings (based on 4D-trajectory planning)
  - adapt repetitively to current traffic situation (approach)
  - be able to consider intervals blocked out for landings
  - provide state information, e.g.
    - separation matrices
    - earliest/latest times for landings

- **DMAN**
  - provide a take-off schedule
  - adapt repetitively to current traffic situation and status of aircraft (ground)
  - be able to consider landings
  - provide state and flight plan information, e.g.
    - earliest/latest possible take-off times
    - confidence interval for each TTOT (target take-off time)



Evaluation: Experimental Setup

- **Airport: Frankfurt (EDDF)**
  - airspace structure EAM04 (with additional waypoints for path stretching)
  - parallel, interdependent runway system 25L / 25R
- **Traffic Scenarios**
  - one arrival scenario
    - 66 arrivals
    - approx. 2.5 hours
  - one departure scenario
    - 49 departures (26 with CFMU slot, 22 assigned to 25L, 27 assigned to 25R)
    - random variation of "ready-for-events"
- **AMAN (4D-CARMA, DLR)**
  - tactical planning system with focus on TMA
  - with models for type-specific aircraft trajectories
  - ICAO separation standards
  - automatic runway assignment (alternating)
- **DMAN (Eurocontrol/DLR)**
  - tactical planning system supporting different CWP, i.e. CLD, GND, RWY
  - with complex operational models for departure operations on ground
  - complex constraint models for runway occupancy- (incl. landings), wake vortex- and SID constraints

Evaluation: Objectives

- **General**
  - **Frankfurt Airport used as (general) example**
  - **comparison of**
    - uncoordinated case (AMAN and DMAN work in master-slave configuration) with
    - CADM case (AMAN-DMAN coordination) with ADCO (**A**rrival **D**eparture **CO**ordination Layer)
- **Test of hypotheses for CADM case**
  - **increase of departure throughput**
  - **better CFMU slot compliance (probability and degree of violation)**
  - **some average arrival delay, but no decrease of arrival throughput**
- **Additional measurements**
  - **taxi-out delay**
  - **accuracy (reliability) of planning information**

Evaluation: Results (I)

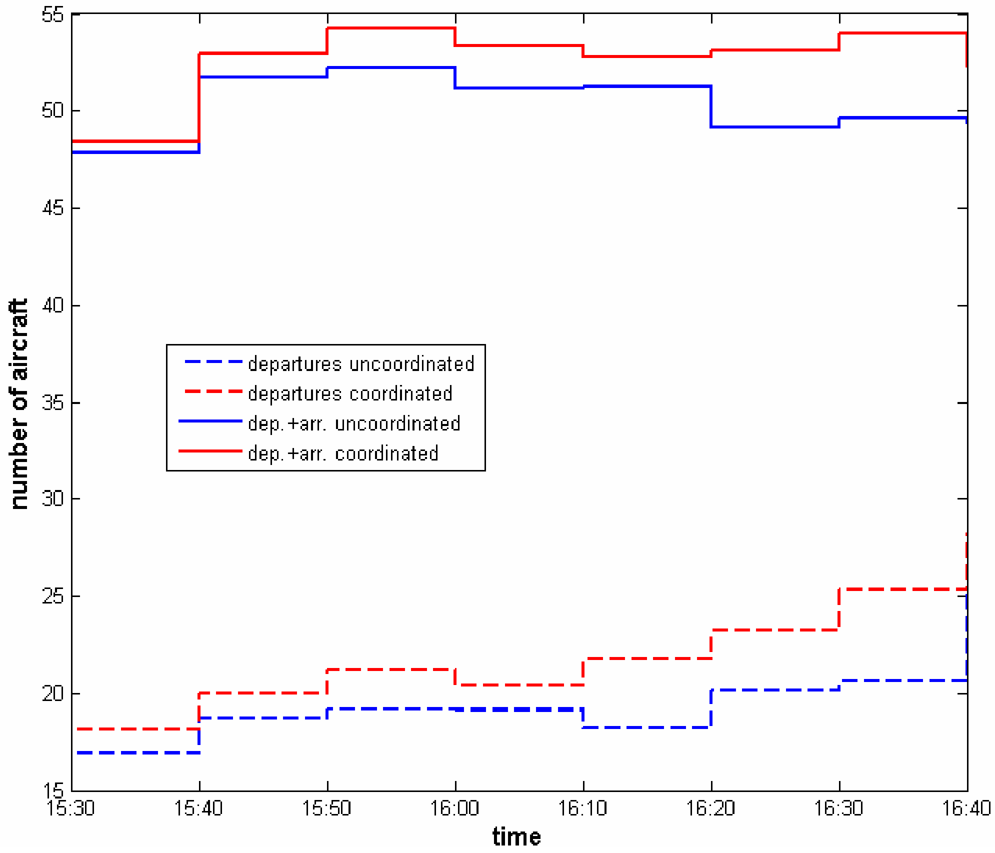


Fig.: ***Throughput per hour***

Evaluation: Results (II)

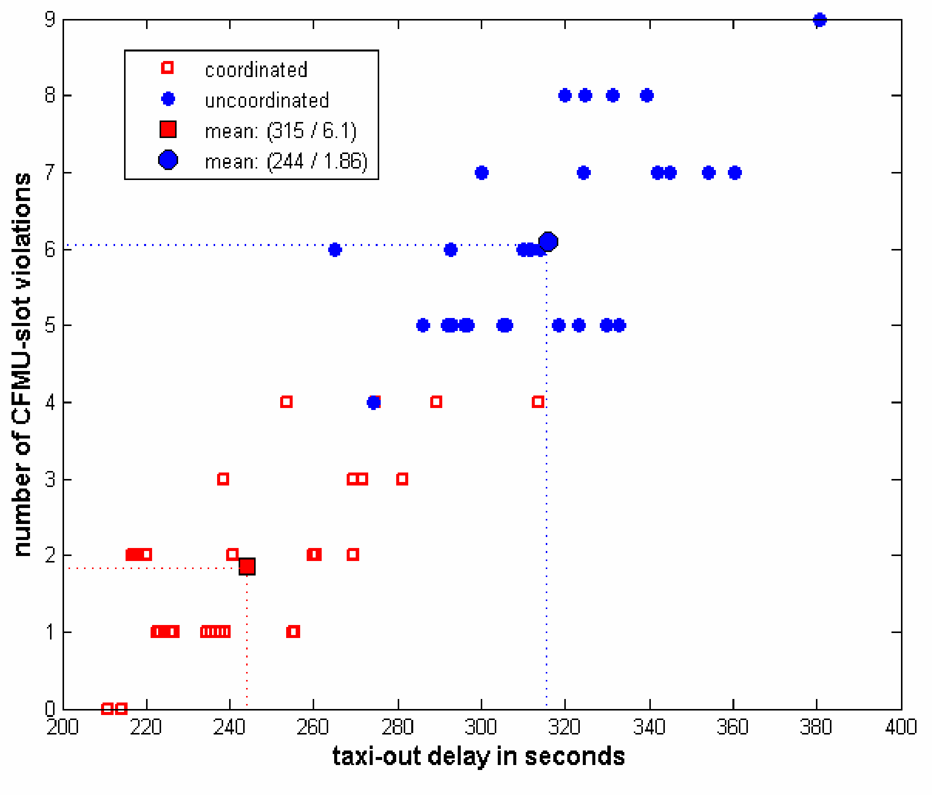
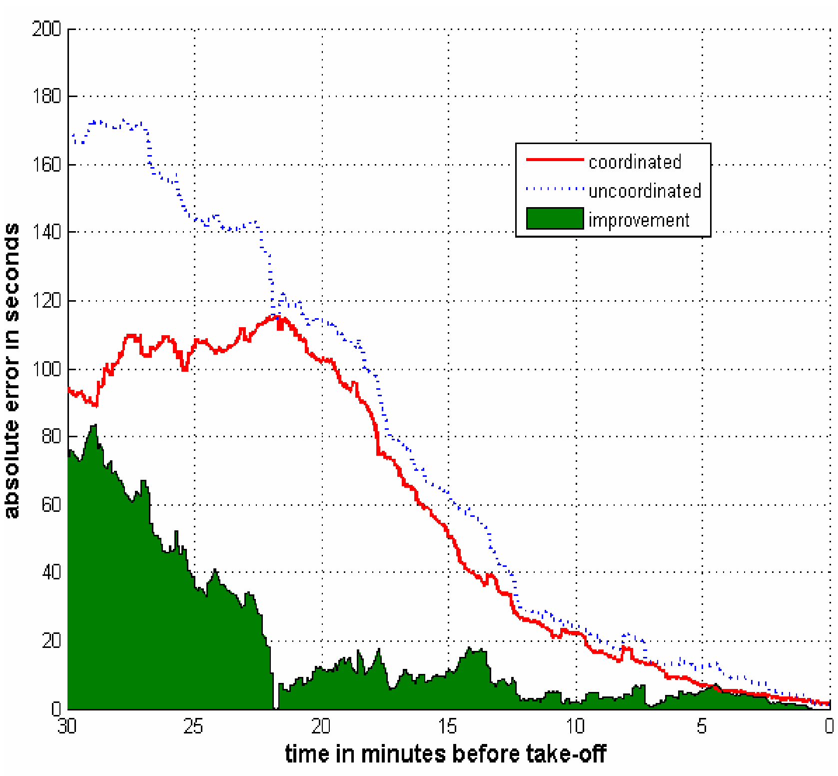


Fig.: ***Number of CFMU slot violations vs. taxi-out delay***

Evaluation: Results (III)



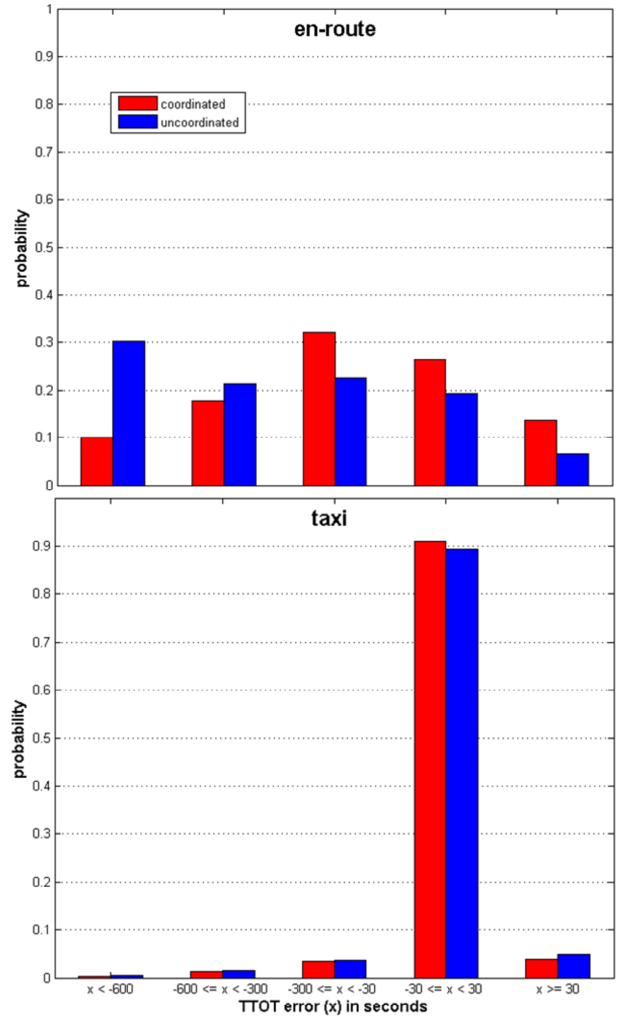


Fig. left: ***Characteristics of average take-off prediction error***

Fig. right: ***Distribution of the TTOT error at en-route and taxi clearance***

Summary and Outlook

- **Concept/algorithm for CADM to improve mixed mode operations**
  - **based on tailoring of arrival gaps**
  - **automatic introduction of AFI and corresponding path stretching for the respective arrivals**
  - **requires fundamental change of arrival management “philosophy”: from minimum separation sequencing to time-based scheduling of arrivals**
  - **addresses the impact on arrival and departure management**
    - workload, complexity, difficulty
    - maintaining established areas of responsibility (approach, tower) and “priority” of arrivals over departures
  - **addresses questions of implementation**
    - does not require particular AMAN and DMAN
    - allows step-wise implementation (AMAN, DMAN, ADCO)
  - **ADCO algorithm**
    - based on expert knowledge
    - uses planning and state information of AMAN and DMAN

Summary and Outlook (II)

- **Simulation results show significant improvements (coordinated operations vs. master-slave) with respect to**
  - **throughput (more departure operations)**
  - **better punctuality and CFMU slot compliance for departures**
  - **reduction of taxi-out delays**
  - **improvement of reliability of planning information**

- **Expectation of further improvements caused by**
  - **fine-tuning of rule set and parameters**
  - **improved runway assignment strategy (for parallel runway systems)**
  - **dynamic AFI**
    - “sliding” AFI in case of sliding planned landing times
    - change of arrival sequence