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

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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 (Arrival Departure COordination 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