[EN-007] A Prototype of an pre-tactical Airport Centered Flow Management

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Abstract: As hub airports become larger and larger, it is vital that available runway capacity is used optimally to prevent them turning into air traffic bottlenecks. This paper presents the concept and technical background of the Cooperative Local Resource Planner (CLOU), which has been developed as a prototype to assist in "airport-centered flow management". An overview of the working principle of CLOU is given. CLOU provides a proposal of the optimal runway-use strategy and supports the decision-making between Tower supervisors and Approach supervisors. Furthermore, an insight into the used flow management algorithm Flow Manager (FMAN) will be addressed. Among others, the implementation concept, the linear optimization model, and program components are described. Finally, results of validation of the CLOU-FMAN-cluster will be presented. An outlook shows the planned developments being objected at the further improvement of the usability of the prototype.

Keywords: airport centered flow management, CLOU, air traffic management

1. INTRODUCTION

Nowadays the European central hub airports often operate at their capacity limits (compare [1] and [2]). More and more, they are becoming the bottlenecks of the air transport network. Even today, a small incident (which might either be a reduction of available capacity or a shift in demand) at a hub airport can cause huge delays and adversely impact operating efficiency. These impacts are not limited to the operations of a single airport, but can negatively affect the European airspace in terms of a "reactionary delay" (compare [3]).

Expanding a hub airport often results in complex runway systems, with complex interdependencies between the traffic on the runways. These interdependencies result either from mixed-mode operations or from interactions with the adjacent airspace. Despite such expansions, it can be assumed that capacity bottlenecks will remain an issue, at least at traffic peaks (compare [4]).

In order to achieve and support an optimal runway-use, a prototype of a Flow Management System as a Cooperative Local Resource Planner (CLOU) has been developed at the German Aeronautical Research Program sponsored by the Federal Ministry of Economics and Technology of the German Government. DFS GmbH – German Air Navigation Services – acts as client. Research fellows are the Institute of Flight Guidance, Technische Universität Braunschweig, and Institute of Logistics and Aviation, Chair of Traffic Flow Science, Technische Universität Dresden. The development takes place for Frankfurt Airport (EDDF) and Munich Airport (EDDM).

CLOU provides suggestions for the chronology of runway-use strategies based on demand and capacity prognoses. The results are represented on an HMI.

In addition to the underlying idea behind the concept of flow management of complex runway systems, this paper also presents the technical background for implementing such a supporting tool.

2. CLASSIFICATION

The general concept of "balancing of demand and capacity" is not new at all. The Central Flow Management Unit (CFMU) by Eurocontrol aims to avoid overload within en-route sectors. From it, the CFMU is a pre-tactical network planning system with no special focus on airports. Flights are assigned with slots but no update is carried out during traffic handling.

However, Arrival Manager (AMAN) and Departure Manager (DMAN) are tactical local systems, concentrated on minimizing separation, as well as on the coordination between air traffic controllers. These systems are only arrival- and departure-oriented, respectively.

Concerning an airport the main difference between pre-tactical and tactical planning is the increasing accuracy of the boundary conditions and hence improved planning quality.

CLOU fills a gap both between pre-tactical network and tactical local systems (as shown in Fig. 1), as well as in respect of coordination of the interaction between in- and outbound traffic at an aerodrome. It distributes the demand among the available runways and assigns priorities between in- and outbound traffic. By keeping the system updated with the newest traffic information, CLOU ensures a permanent ongoing balancing of demand and capacity.

3. WORKING PRINCIPLE

The purpose of CLOU is to optimize the traffic flow of an airport's runway system in order to minimize delay and increase punctuality. These aims will be achieved by providing an optimized runway-use strategy, the point in time to change strategy, and target time management. Furthermore, CLOU supports coordinated decision-making between Tower and Approach as regards the prioritization of both arrival and departure traffic.

3.1 Input data

The results of CLOU are based on demand and capacity forecast.

Only at Frankfurt Airport capacity information is delivered via Capacity Manager (CAPMAN) by Fraport AG, which calculates and forecasts the available airport capacity. In case of unavailable CAPMAN, default values are used. Air traffic controller can modify all capacity values.

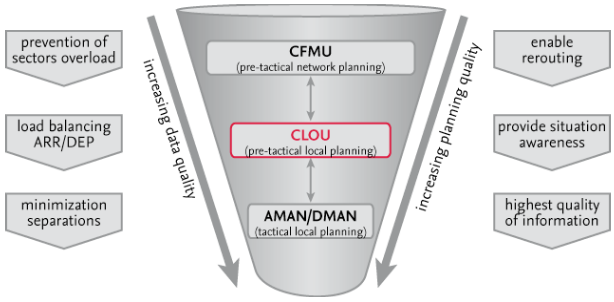

Fig. 1: Phases of balancing demand and capacity

CLOU extracts flight information of the Stanly_CDM system, as well as from INFO+ (via CAPMAN and only at Frankfurt Airport).

3.2 Runway-use strategy

At airports with a multi-runway system, it is usually possible to handle flights over different runways. However, as a rule, all departures with the same Standard Instrument Departure route (SID) leave from the same runway and all arrivals coming from the same Standard Terminal Arrival Route (STAR) touch down on the same runway, since non-systematic runway assignment can quickly result in confusing situations in the airspace and increased workload for the controller.

Unfortunately, this may mean that one runway is overloaded, while there is unused spare capacity on another one. A better balance of demand and capacity can be achieved by shifting departures or arrivals among runways, as well as by prioritization.

Prioritization defines the ratio between in- and outbound traffic, which is performed on a runway. An operation procedure defines the flow of traffic handling at the runway system with capacity ratios both between in- and outbound, as well as between runways. Operation procedures could be demand-dependent or weather-dependent (for example CAT II and CAT III condition) and exist for all possible operation directions. Operation procedure and operation direction make up the runway-use strategy.

CLOU provides suggestions for optimal runway-use strategy and the point in time to change strategy (except the point in time to change an operation direction, this will be done in further work). This result will be presented at Tower and Approach among other things.

3.3 Decision-making support

The supervisors on duty take the decision to relocate an operation procedure based on a personal assessment of the situation. However, as a rule, this decision is not that trivial. An assessment must be made as to whether any resulting delay from new operation procedure is indeed less than the delay from using the previous operation procedure. Furthermore, shifting departures or arrivals requires a lead-time up to one hour (depends on airport conditions). A change of prioritization can be performed faster, usually.

The decision-making process is further complicated by the necessary negotiations between Tower supervisors and Approach supervisors. Naturally, Tower supervisors show the tendency to focus on departures during departure peaks, whereas Approach supervisors trend to prioritize arrivals. Currently, there is no system available to support supervisors in their decision-making process.

From it CLOU supports coordinated decision-making between Tower and Approach as regards the prioritization of both arrival and departure traffic with the help of visualization of the optimal runway-use strategy and different decision criteria like runway workload, caused delay, and delay improvement (compare [5]).

3.4 Target times management

Target times represent a binding time, which have to comply with those involved, as for instance air traffic controller or pilots. In case of an unpredictable failure, target times need to be updated. Reliable planning of departure and arrival times is essential for the future 4-D trajectory management since beginning and end of a trajectory are defined by these target times.

For every flight CLOU generates a target time, to minimize delay and increase punctuality. Due to the fact that CLOU influences arrivals starting at departure airport, target times will be useful with a new air traffic management infrastructure given in SESAR.

In order to be able to use CLOU without SESAR, CLOU points out flow optimized target times, which refer to the Terminal Maneuvering Area (TMA), as well as a natural result (first-come-first-serve solution based on optimal runway-use strategy).

3.5 Cycle of planning

Every five minutes CLOU performs a planning to take actual, updated flight information into account. This cycle can only be interrupted by a manually input. When received an input, CLOU restarts a planning automatically. After a planning all CLOU HMI (Human Machine Interfaces, compare [5]) will be updated.

CLOU will run in parallel with the other systems, without the need for extra inputs from the air traffic controller.

4. TECHNICAL BACKGROUND

The Flow Manager (FMAN) represents the core of CLOU. It is an independent optimization kernel from the pre-tactical planning system. This part describes the systemic modeling of FMAN in CLOU context. FMAN

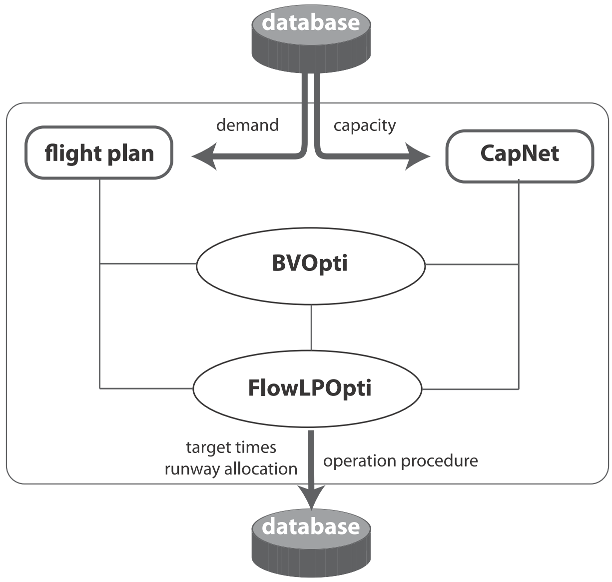

Fig. 2: Schematic view of FMAN

is connected to the CLOU system by a database interface. All interaction between CLOU and FMAN works within this database interface.

FMAN has two optimization program parts: BVOpti to optimize the use of operation procedures and FlowLPOpti to optimize target times management and runway allocation (as shown in Fig. 2). The CapNet is a capacity network, which describes the capacity usage of the underlying airport.

4.1 CapNet Model

Overall airport capacity is usually characterized by three limiting bounds, the maximum number Amax of arrivals, the maximum number Dmax for departures and a bound for the number of total movements with $A + D \leq tot$ (compare Fig. 3).

Airspace capacity must be carefully distributed among the runway system and between arriving and departing streams. To do this, FMAN uses a network, which is called capacity resource counter network. Each node

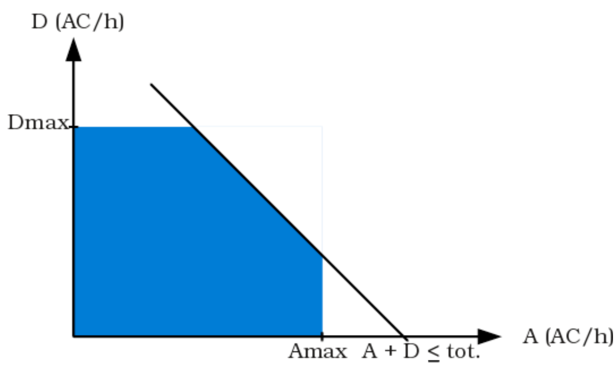

Fig. 3: Capacity limits of an airport

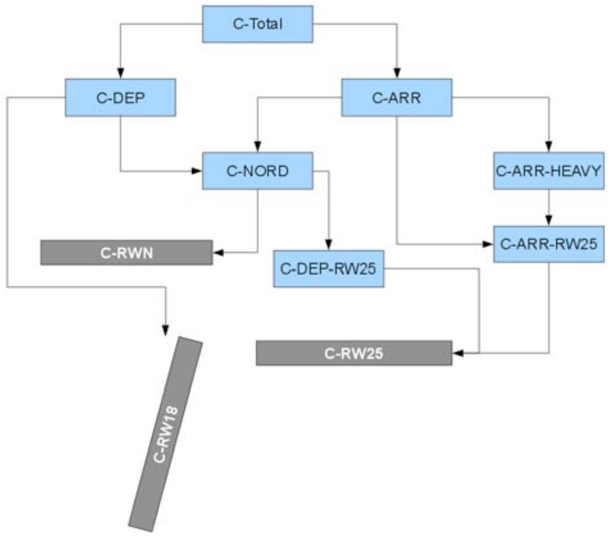

Fig. 4: FMAN capacity network for the upcoming runway layout at Frankfurt Airport

represents a partial amount of capacity, which is allowed to be used by only departures, only arrivals, or both types of flights. The task of each such node is twofold: on the one hand it has to control, that only flights of the correct type (arrivals and/or departures) are allowed to use this capacity resource and on the other hand it has a counter function for watching the limited capacity, which is distributed over time.

Each flight allocates capacity by using a certain route or path through this network (compare Fig. 4 as an example for the upcoming runway layout at Frankfurt Airport). This path starts at the source node, which is the counter for the total airport movements (C-Total) and terminates at one of the possible sink nodes in the network. For departing flights, the definition of the sinks is done by significant waypoints of the different departing routes within the airport surrounding area. By differentiating the permeability of the counter nodes by the departure destination directions, this network model is flexible enough to cover operational rules used in practice.

4.2 Operation procedure optimization

The first optimization module of FMAN tries to find the best operation procedure with respect to total delay. Demand depending operation procedures must be maintained for at least 40 minutes so that the proposal is realizable for the controllers. The optimization task is solved by a dynamic program approach and finds an optimal configuration of operating procedures.

4.3 Flow Optimization

For the flow optimization time- and route-indexed binary decision variables are used as in (1).

$$x_{f,T}^{R} = \begin{cases} 1, \textit{if flight } f \textit{ takes route } R \textit{ with target time } T \\ 0, \textit{ else} \end{cases} \quad (1)$$

To define 'counter' capacity appropriately time discretization is applied, for example time is divided into a partition of periods $I_1, \ldots, I_n$ at which for each an integer valued capacity $c(I_j) \in \mathbb{Z}$ is defined. Using the previous explained time transformation 'calculated time until', the left hand of the sum in (2) counts all flights, which are planned to use capacity resource r during the time period I_j.

$$\sum_{r \in R \wedge ctu_{f,r}^{j}(T) \in I_j} x_{f,T}^{R} \leq c_j \quad (2)$$

This load number is limited by the capacity c_j. The collection of all flow constraints (including all different counters) is denoted by the set FC and indexed by $j \in FC$.

The cost coefficients $\omega_f^R(T)$ define the costs for scheduling flight f with target time T on route R. Note, that this general model allows arbitrary complex cost function.

After operation mode optimization the optimization of the target times starts for all flights. The basic models following the LP Model in (3).

$$totalcost = \sum_{(f,T,R)} \omega_f^R(T) x_{f,T}^R \rightarrow \min \quad (3)$$

(3) subjects to (a), (b), and (c).

$$\forall f \in F \sum_{T \in \Delta(f), R \in R(f)} x_{f,T}^R = 1 \quad (a)$$

$$\forall j \in FC \sum_{r \in R, ctu_{f,r}^{j}(T) \in I_j} x_{f,T}^R \leq c_j \quad (b)$$

$$x_{f,T}^R \in \{0,1\} \quad (c)$$

Constraints of type (a) guarantee, that each flight will be assigned with exactly one resource route R and one target time T. The inequalities (b) define the capacity constraints, which allow a maximum number c_j of movements for each time period and each resource counter j. The left hand sum of (b) counts the number of flights, which allocate capacity during the considered time period. Subject (c) defines the binary variable $x_{f,T}^R$. The function $\omega_f^R(T)$ represents the cost function of CLOU-FMAN-cluster and contains various functions in part.

5. VALIDATION

Since 2007 CLOU is running in shadow mode at the research center of the DFS GmbH to evaluate and to improve the airport centered flow management system.

In September 2008, in June 2009, and in July 2010 tests were carried out within the operational environment of Frankfurt Airport. Further field tests are scheduled. One of the aims of the field tests is to allow supervisors of Tower and Approach to evaluate the usability of CLOU in an operational environment. Furthermore, it has determined additional requirements that are still lacking from the supervisors' point of view.

Presenting target times and single flight information has been faded from the spotlight. Focus has been put to the suggestion of the operation procedure. Due to the fact that CLOU is a prototype, all supervisors and air traffic controller were asked to have a look at CLOU during field tests and review the results with their own expertise. From it, they are free to follow the suggestion of runway-use strategy and to prove it.

6. CONCLUSION

All in all, CLOU is an airport-centered flow management system, which can detect capacity bottlenecks at hub airports in a timely fashion, allowing to take corrective action much earlier than at present. This means that not only the airport that uses CLOU profits from the system, the situation in the surrounding airspace is relieved as well.

The CLOU interface informs the controller about the future air traffic situation and about a possible solution for the runway- use strategy. Based on this information, Tower and Approach could agree on further procedures.

Field tests offer the possibility to get a first validation by air traffic controllers during operations. Furthermore, air traffic controllers are able to voice constructive criticism and make further suggestions concerning the functions of CLOU.

7. OUTLOOK

On the basis of the runway-related demand and capacity forecasts, further applications of CLOU will be developed both within the framework of the German Aeronautical Research Program and the SESAR initiative. These include: use by another stakeholders, coupling of AMAN/DMAN, and dynamic operation direction change.

7.1 Modulation of complex runway layouts

Due to the upcoming runway layout at Frankfurt Airport CLOU needs to be adapt to the new infrastructure and topology. Thereof, new complex interdependencies arise between in- and outbound traffic. As a consequence, new operation procedures need to implemented and validated.

From the controllers point of view the CAPMAN-CLOU-coupling has a high potential as a supporting tool for the traffic handling on the upcoming runway system.

Likewise, an adaption to the upcoming runway layout at Munich Airport is envisaged.

7.2 Use by another stakeholders

Particularly in the case of major problems in traffic handling (reduced capacity or shift in demand), airlines and airports will be better informed about the effects of such disturbances with regard to delay and punctuality. They will thus be in a position to plan their processes (aircraft turnarounds, parking positions, etc.) with longer lead times in a proactive instead of a reactive manner.

7.3 Coupling of AMAN/DMAN

Combining the systems CLOU and the sequence-oriented planning of AMAN and DMAN can further optimize traffic handling. As a basis for the AMAN flow calculation CLOU can predefine an amount of arrivals for a certain time interval, which takes into account the departure demand. Furthermore the pre-tactical operation procedure optimization can be input for the DMAN. The exact evaluation of the tactical target times remains in the responsibility as AMAN and DMAN, respectively.

7.4 Operation direction change

CLOU focus can be up to six hours. In this time operation direction changes are possible. Currently FMAN optimizes traffic only by using the current operation direction for the whole focus. In the case of a change during the current CLOU focus FMAN shall optimize including this operation direction change.

The problem can be described as follows (as shown in Fig. 5):

- Between t_S and t_E two operation directions OD_A and OD_B are predicted.
- Between $t_{C,S}$ and $t_{C,E}$ the operation direction change is necessary.
- The best time $t_{C,O}$ to change operation direction relating to inducing delay is unknown.

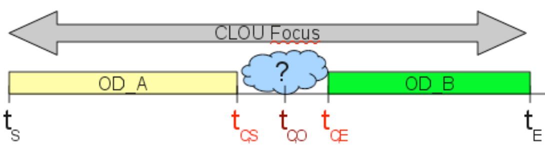

Fig. 5: Description of an operation direction change

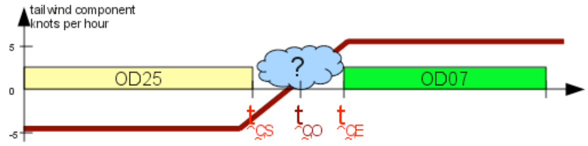

Fig. 6: FMAN optimization depending on the operation direction

For example at the Frankfurt Airport the selection of operation direction depends mainly on the tailwind component at the parallel runway system. According to airport specific regulations operation direction 25 is usable until a five knots tailwind component, then it must be changed to operation direction 07 (as shown in Fig. 6).

The idea to optimize the best time of operation direction change $t_{C,O}$ is a combination with the operation procedure optimization.

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