Operational Evaluation of an
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 Cooperative Local Resource Planner (CLOU), which has been developed as a prototype to assist in “airport-centered flow management”. An overview of the first steps to be taken to guarantee a smooth operational implementation is also given. Different runway-use strategies will be discussed, using the German Frankfurt Airport as an example. Furthermore, the display of the planning results of CLOU and the integration into the air traffic controller work area are addressed. Finally, embedding of CLOU into existing system environment is presented.

Keywords: Air Traffic Flow Management, Network and Strategic Traffic Flow Optimization, CLOU

I. 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, the smallest 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 complete European airspace in terms of a “reactionary delay” (compare [3]).

Expanding a hub airport results in complex runway systems, with complex interdependencies between 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.

To use the capacity of the runways optimally, 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. It provides suggestions for the chronology of runway-use strategies based on demand and capacity prognoses. After a detailed technical examination of the system with live data, the supervisors of Tower and Approach Control at the German hub Frankfurt Airport (EDDF) will now perform an operational validation of the prototype.

CLOU is a database-based airport-centered flow management tool, which extracts flight information of Stanly_CDM and INFO+ (via CAPMAN and only at Frankfurt Airport). With a planning horizon from 30 min up to six hours CLOU fills the gap between tactical systems like AMAN/DMAN and pre-tactical network planning like CFMU. Based on demand and capacity considering constraints and optimization parameter CLOU generates a prediction of expected runway in use, an optimal operation procedure, runway workload, and parameters every five minutes. This parameters are flow, punctuality, adherence to schedule, delay, and queue. The planning results of CLOU are shared with other prediction tools like CAPMAN (compare [9]). The algorithms that are used to optimize the runway-oriented flow management have already been presented before (compare [5] and [6]) and aren’t be part of this paper.

In addition to the underlying idea behind the flow management of complex runway systems concept, this paper also presents the first results of the operational validation. These results emphasize the challenges presented by the integration of this concept into operational procedures.

II. PRESENT SITUATION

At airports with runway systems, it is possible to handle flights over different runways. However, as a rule, all departures with the same destination direction leave from the same runway, since non-systematic runway assignment can quickly result in confusing situations in the airspace. Unfortunately, this may mean that one runway is overloaded, while there is unused spare capacity on another. A better balance can be achieved by shifting departures, grouped by Standard Instrument Departure (SID), among the different runways.

Fig. 1 shows an example of such an operational procedure for Frankfurt Airport. In addition to the dependent parallel runway system 25/07 for arrivals and departures, Frankfurt Airport also features runway 18, or ‘runway west’, for departures only.
At Frankfurt Airport, flights leaving to the north and northwest usually take off from the parallel runway system. Departures to the south, west and east are assigned to runway west. Arrivals are handled exclusively by the parallel runway system.

To ensure adequate arrival capacity during an arrival peak on runway 25/07, it is possible to move either north or northwest departures to runway 18.

The supervisors on duty take the decision to relocate the departure flow from one runway to another based on a personal assessment of the situation. This does not pose a problem as long as the alternative runway has enough capacity to handle the additional departure flow without causing delays. However, as a rule, this decision is not so trivial. An assessment must be made as to whether any resulting delay from relocating the departure flow is indeed less than the delay from using the standard runway.

The decision-making process is further complicated by the necessary negotiations between Tower supervisors and Approach supervisors. Naturally, Tower supervisors focus on departures, whereas Approach supervisors prioritize arrivals. The fact that Tower and Approach Control belong to different DFS business units makes a holistic point of view rather difficult.

This is also reflected in the systems currently available to support supervisors in their decision-making. The ‘arrival manager’ controls inbound traffic without taking departures into account, while, on the departure side, a flight data processing system is used which does not take inbound traffic into account. The long-term planning of CFMU does not allow a holistic view of the traffic processing at airports either.

The situation is becoming more and more complex, as international hub airports add new runways, which result in ever increasing interdependencies among the runways. The optimal utilization of the available capacity over the daily peaks in inbound and outbound traffic is just the start. Further factors that must be optimized include the impact of weather and noise abatement procedures on runway operations.

III. PURPOSE: FLOW MANAGEMENT

The purpose of CLOU is to optimize the traffic flow of an airport’s runway system. CLOU supports coordinated decision-making between Tower and Approach as regards the prioritization of both arrival and departure traffic. It provides suggestions for optimal runway-use strategy and the point in time to change strategy.

For example, during an arrival peak at Frankfurt Airport, CLOU might suggest shifting the departure flow from the normally used parallel runway system to runway west to minimize the overall delay.

In addition, CLOU proposes a prioritization of the remaining arrivals and departures on the parallel runway system. The planning suggestions generated by CLOU are based on a dynamic capacity and demand prognosis, taking into account interactions between in- and outbound air traffic. The surface and turnaround flight phases are reproduced by simple logic and flight information.

Supervisors can manually enter previous experiences into the system or visualize the flow behavior following a proposed change in strategy. Hence, CLOU provides a basis for discussion for a more collaborative decision-making process among supervisors.

IV. DISPLAY/VISUALIZATION OF PLANNING RESULTS

CLOU displays the planning results which allow supervisors to see basic planning suggestions for a planning horizon of three or more hours. Additional tab sheets provide access to more detailed information on individual flights or such calculated parameters as flow, punctuality and delay.

The results are assigned from left (actual point of time) to right (increasing planning horizon), divided into ten-minute intervals (see Fig. 2). The bottom line “time” shows the UTC time in half-hour increments.

The first row contains the prognosis for the expected runway-in-use. This information is based on the weather forecast and may be manually modified by the supervisor.

The suggestion regarding which runway-use strategy to apply is shown in the second row “DEP 25/07”. Every runway-use strategy is assigned a color and a designator.

The third row illustrates the overall capacity of the runway system, presenting the basis for the optimization. This information is supplied by the airport system “CAPMAN” (operated by Fraport, the operator of Frankfurt Airport). If a supervisor judges the available capacity to be greatly different, it is possible to replace the values manually as well. This option exists both for overall capacity and for partial capacity (individual runways or individual capacity of arrivals or departures).

The visualization of arrival or departure prioritization follows in the rows below (“Rwy 25/07” and “Rwy 18”). The number of flights per ten-minute interval is color-coded – using different colors for arrivals and departures – as well as bar graph-coded. Departures act like stalactite, in contrast arrivals behave like stalagmite. Furthermore, the caused delay by the ten-
minute interval is shown as two steps over 15 minutes and over 30 minutes (limits are adjustable). As additional information, the average delay per flight during the shown intervals and according to the runway are displayed on the right-hand side.

The bar graph at the bottom pictures the ratio between delay of the initial and flow optimized result. It is presented in minutes and contains the amount of all flights.

The visualization means that supervisors can create a mental picture of the optimized traffic situation, which in turn, provides a basis for discussion. It should be borne in mind that the suggestions are not binding; they merely provide decision-making support for supervisors. The system should not replace the supervisor’s decision, as situations may arise where the system does not have all necessary information to create an optimized solution.

V. OPERATIONAL EVALUATION

In September 2008 and from May through July 2009, first tests within the operational environment were carried out (compare [7] and [8]). This will be followed by a field test scheduled for the fourth quarter of 2009. One of the aims of the field tests was to allow supervisors of Tower and Approach to evaluate the usability of CLOU in an operational environment. Furthermore, it has determined any additional requirements that are still lacking from the supervisors’ point of view. At this point, this paper will present first results and problems of the operational tests. The design of the supervisor’s working position during the field test will be covered, including any changes needed. The steps necessary to increase supervisor acceptance of the system will be addressed.

A. Integration into the working position

The algorithms behind CLOU have been tested with live data. For this purpose, an internal network with live data access was created. The next step is to test the usability of the prototype in an operational setting. The question arises how best to integrate the new planning information into the supervisor’s working position.

CLOU is still a prototype which means that it is not possible to integrate the planning information into a live operating system. In addition, severely limited space means that it is not possible to set up an additional monitor at the supervisor’s workstation. There is generally no free space available in the Tower and the supervisor workspace in Approach Control is already filled with various monitors so that there is no room for a new display there either. Hence, an additional screen is neither reasonable, nor realizable.

Therefore, a different approach was taken for the first tests. The CLOU computer itself remains in the research laboratory and the planning data was exported via intranet to a computer that is not connected to any operating systems. This test arrangement presents the only means of performing an operational evaluation within the means available. One of the disadvantages of this solution is the fact that the chosen screen is also used to retrieve other information, so that CLOU can not be displayed all the time.

After analyzing the information from field tests, the best method to integrate CLOU into the existing working position will have to be determined in cooperation with engineering and operational staff.

B. Change Management

During the development phase of the CLOU prototype, the operational staff contributed by describing the various operating procedures and the interdependencies between in- and outbound traffic. Usually, real-time simulations using operational personnel are conducted to assess the user benefit of new prototypes. However, this approach could not taken because CLOU is a system supporting pre-tactical work.
In this case, an alternative procedure was adopted and in-depth discussions about the optimization concept were held with Tower and Approach supervisors. These discussions not only helped clarify the need for a support system, they also highlighted the supervisors’ reservations about such a system. This underscored once again the importance of a carefully planned implementation of the new system.

The three main reservations of the supervisors and the suggested solutions are described below.

1) **Trust in planning systems**

During the first tests and the discussions with the supervisors, it became clear that air traffic controllers harbored general doubts about planning systems such as CLOU. These doubts result from experiences with the introduction of various planning systems in the past and lack of knowledge of the new system.

During previous implementations of different planning systems, the role of change management had been underestimated. Staff were often instructed to strictly adhere to the decisions and suggestions produced by such systems, although they had no background information about the underlying processes. They did not know what basis the system used to produce its decisions. Hence, the staff could not develop the necessary trust in the system’s reliability. The fact that decision-making was taken away from the supervisors and given to a system with an unclear mode of operation resulted in the complete rejection of such systems.

CLOU will run in parallel with the other systems, without the need for extra inputs from the air traffic controller. The system updates itself every five minutes with new initial data. The results are presented as a suggestion to the air traffic controller. The air traffic controller may then use this information to evaluate his decision-making process. The air traffic controller may possess additional information not included in CLOU. If the air traffic controller makes a decision that is not in line with the system’s suggestions, CLOU will automatically update the initial setting of the flight plan data. The air traffic controller can also directly enter the information or decision into CLOU.

2) **Transparency of optimization**

Nowadays, air traffic controllers concern themselves mainly with their own sector. A consideration of the long-term traffic situation or the situation in neighboring sectors does not yet take place. With CLOU, the controller’s view of the air traffic situation is enlarged. The optimization process that is working in the background does not only consider Approach or Tower prioritizations, but also the best compromise for all airport sectors. It is important that the air traffic controllers do not only focus on the technical output of some optimization algorithm, but in fact change their way of thinking overall.

When air traffic controllers understand the importance of the optimum solution for the overall situation, they will be more likely to accept a potential temporary worsening of the situation in their own sector if called for.

Besides developing trust in the system’s ability to find an optimal overall solution, it is also essential to create outputs that present the situation and suggestions explicitly. Air traffic controllers will have to get used to the display of the results. If they feel comfortable and familiar with the display, they will extract the necessary information from the display quickly and without any hesitation or doubt.

By introducing punctuality as an optimization criterion, air traffic controllers will have to develop the capability to evaluate the present traffic situation accordingly. For air traffic controllers, it is rather difficult to categorize a flight as punctual or unpunctual without the help of systems like CLOU. Therefore, such flow management systems are necessary when introducing new means to air traffic optimization.

3) **Adequate data quality**

Adequate data quality is the linchpin of the entire flow management. An optimization is only as good as the initial data quality. But of course it is also possible that the system is missing some boundary conditions, such as information on the reduced flow in preceding sectors. In order to avoid an optimization based on false data, CLOU must have the capability of manual input, allowing supervisors to modify parameters manually.

Therefore, the CLOU interface contains a tab sheet to allow the modification of parameters with minimal effort (see Fig. 3). The interaction tab sheet appears in the same design as the tab sheet display.

The following parameters may be changed: runway-in-use, operations procedure, overall capacity, partial capacity of runways as well as numbers of arrivals and departures per runway.

Inputs in the tab sheet will be recognized automatically by CLOU and trigger the refreshing of the optimization to guarantee results that are always up-to-date.

The ability to change parameters manually introduces a new requirement. Air traffic controllers are not used to handling direct capacity values, although these are needed for CLOU.

### VI. Embedding into existing systems

The general concept of “balancing of demand and capacity” is not new at all. Based on demand and available capacity, target times are generated for every single flight. Nowadays, this happens with the help of the CFMU – a pre-tactical system – as well as with the help of tactical systems, such as the arrival (AMAN) and departure managers (DMAN). The main difference between pre-tactical and tactical planning is

![Fig. 3. Interaction tap sheet](image-url)
the increasing accuracy of the boundary conditions and hence improved planning quality.

CLOU closes a gap both between pre-tactical and tactical systems, as well as in respect of coordination of the interaction between in- and outbound traffic at an aerodrome.

The different levels of “balancing of demand and capacity” have different goals, as depicted in Fig. 4.

A. CFMU

The CFMU aims to avoid overload within sectors. The focus is on the approach sectors in this case. CFMU is comparable with an open-loop control. Flights are assigned with slots but no update is carried out during traffic handling.

Furthermore, the CFMU is a network planning system with no special focus on airports.

B. CLOU

With CLOU, a changeover to “closed-loop” control will be introduced to air traffic control. CLOU 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.

CLOU is an airport-oriented system that also considers network issues.

C. AMAN/DMAN

Arrival and departure managers concentrate on minimizing separation, as well as on the coordination between air traffic controllers. This tactical system is arrival-oriented only and provides current times.

VII. PRELIMINARY RESULT

During field tests so far the prognosis of expected-runway in use was very well. With manually inputs it was possible to define an explicit time to change operation direction.

The capacity forecasts was reliable as well. But exceptional cases have needed manually input, for example, borderline tailwinds at runway west combined with pilot decisions.

Based on these results and an adequate data quality, air traffic controller review the suggestions of operation procedure and runway workload. As basis of decisionmaking appears three characteristics: number of shifted flights, value of delay improvement, and forecast stability.

1) Number of shifted flights

One reason to refuse the suggestion is only a small number of shifted flights between runways. The fairly low delay improvement doesn’t justify the accelerated coordination effort.

2) Value of delay improvement

As main basis of decisionmaking emerges the value of delay improvement over the planning horizon. This value is visualized as bar graph (compare Fig. 2). In case of a delay improvement of over one hundred minutes between the initial first-come first-serve and the flow-optimised result based on an optimal operation procedure, the air traffic controller follow the suggestions of CLOU, usually. In this instance an improvement of the traffic situation was noticeable.

3) Forecast stability

It turns out, that a forecast stability has to be guaranteed. For example an operation procedure switch takes up to half an hour. From this point an operation procedure forecast has to be stable the next hour. Therefore, an optimal response due to traffic changes is only aggravated possible.

A. Restrictions of field tests

Due to the fact, that CLOU is a prototype, all supervisors and air traffic controller were asked to have a look at CLOU and review the suggestions with their own expertise. From it, they are free to follow the suggestion and to prove it. But this is volunteer in doing so. The air traffic controller accounts for his decision.

B. Air traffic controller résumé

After these two first field tests a mainly positive response of air traffic controller is noticed. The estimated benefit of CLOU with the actual airport topology is elusive from the air traffic controllers point of view. But with the upcoming four-runway-layout according to the much higher runway complexity, air traffic controllers expect a noticeable benefit with CLOU.

VIII. CONCLUSION

The development of the algorithm in the CLOU prototype is nearly finished. Research with live data has proved that CLOU has the potential to reduce delay and at the same time improve punctuality. To validate the system, field tests are indispensable. These experimental tests have shown in which way the provided information represent helpful support for the air traffic controllers concerns.

With the help of flow management, capacity bottlenecks at hub airports can be detected 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 and record them per input into CLOU.

The 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 and its human-machine interface. These points will be considered in the further development of CLOU.

Furthermore, field tests should indicate whether the optimization results should be given to the supervisors only, or if they could also be of help to the air traffic controller. Normally, a supervisor does not deal with individual flights. This is part of the controller’s duties. Therefore, it seems reasonable to provide the air traffic controller with the results of CLOU.

IX. 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 national research program “Innovative Airport (iPort)” and the SESAR initiative. These include:

A. Optimization regarding punctuality

By using a modified objective function, traffic handling can be optimized to also take account of punctuality instead of just aiming at minimizing delays as is the case today.

B. Use by airlines and airports

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.

C. Implications for the CFMU

By considering arrivals and departures as integrated processes over a longer lead time, the CFMU will be more precisely informed about time changes. The CFMU can thus adapt CFMU slots as necessary and ensure better use of airspace in analogy to the early take-off time used in A-CDM.

D. Prioritization by means of AMAN/DMAN

Traffic handling can be further optimized by combining the systems CLOU and the sequence-oriented planning of the arrival and departure managers.

E. Target time management

Thanks to the long lead times, optimum management of individual flights can be initiated at an early stage taking airline preferences into account. Reliable planning of departure and arrival times is essential for the future 4-D trajectory management since start and end of a trajectory are defined by these times.

References