PHARE

EUROPEAN ORGANISATION FOR SAFETY AIR NAVIGATION, EUROCONTROL

PHARE Advanced Tools
Departure Manager

Final Report

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EUROCONTROL

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EXECUTIVE SUMMARY

This document is part of the final report for the PHARE Advanced Tools (PATs). Within the PATs project decision support tools for controllers were developed for research purposes. This document focuses on the development of the PATs Departure Manager. The Departure Manager is one of the PATs tool and provides aids to manage departure traffic at an airport. It has been designed to be adaptable for any airport configuration. The Departure Manager is a ground based planning tool which mainly provides departure schedules to achieve an optimal use of the runways and to improve the organisation of the outgoing traffic within Terminal Airspace (TMA). For each departure, as soon as the flight plan is available, a runway is allocated and a Scheduled Time of Departure (STD) is computed. Several types of constraints are taken into account to build the sequence such as safe separations to be ensured at runways, CFMU slots or conflicts in TMA. Moreover, since take-off management is closely linked to surface movements management, the Departure Manager needs to be informed of surface traffic progression and has to take airport constraints into consideration. The departure sequence is regularly updated to cope with the current traffic situation.

As an additional functionality, the Departure Manager provides the Departure Planning Controller with optimised and conflict-free climbing trajectories for pre-departure flights. The proposals rely on a set of predefined climbing procedures in accordance with operational rules. The function is used in association with trajectory editing facilities and is integrated in the air-ground negotiation process for 4D equipped aircraft.

The Departure Manager has been designed following two main guidelines. Firstly, the Departure Manager was required to respond to short term operational needs and to be adapted to current working methods. This was achieved by involving controllers in the design process. The second objective was to cope with the PD/3 operational scenarios based on the underlying EATCHIP concepts. The requirements of the Departure Manager were elaborated in respect with traffic organisation, air-ground integration and, partly, free-flight concepts. The objective of « keeping the man in the loop » was also achieved by supplying controllers with means to interact easily with the Departure Manager.

The Departure Manager has been integrated successfully on the PD/3 platform at CENA and used services of other PATs tools such as the Negotiation Manager and the Conflict Probe in a Common Modular Simulation environment. The managed airport was Roissy, Charles de Gaulle in a configuration with two runways used in mixed mode. Since arrival traffic was not controlled, co-operation between the Departure Manager and an Arrival Manager was not simulated.

PD/3 experimentation provided many outputs and, as far as the Departure Manager was concerned, this was emphasised due to the novelty of the subject. Mainly, the services supplied by the Departure Manager sequencing function can respond to short-term operational needs. The underlying concepts and hypothesis are valid and the sequences provided usually acceptable. However, algorithms could be improved and the operational usage of the tool should be defined more precisely. Furthermore the tool should be validated in a more realistic environment including the simulation of surface movements and airport control position.

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LIST of CONTENTS

1.   INTRODUCTION

1.1   SCOPE

This document has been produced as part of the PATS project within the PHARE program. The document is the final report for the PATS Departure Manager tool.

1.2   DOCUMENT CONTEXT

This document is one volume within the final report produced by the PHARE Advanced Tools project within the PHARE program. The document represents the final report for the PATS Departure Manager tool that is identified within the PATS final report umbrella document, reference TBD.

1.3   SUBJECT

The PATS Departure Manager is a ground based planning tool. It assists airport controllers in managing departure traffic, by providing takeoff schedules as well as optimised and conflict-free climbing trajectories, in order to achieve optimal use of runway capacity and TMA airspace.

For each departure, as soon as the flight plan is available to the ground system, the Departure Manager allocates a runway and computes a scheduled takeoff time. The departure sequence is regularly updated to cope with the current traffic situation.

To build an optimised sequence, the Departure Manager takes into account many factors that encompass surface movement constraints, usage of runways, traffic organisation in the TMA and transfer conditions to the ETMA.

The Departure Manager provides facilities for controllers to modify the computed sequences, and includes a « what-if mode ».

The departure controller plans trajectories within the TMA and negotiates with 4D equipped aircraft while flights are in taxiing phase. The Departure Manager assists the controller in performing this task by searching for optimised and conflict-free climbing trajectories in respect with operational rules.

The Departure Manager has been designed to be adaptable to any airport configuration, i.e. runways used in single or mixed mode. It is able to support a safe and optimised handling of the share of runway usage between incoming and outgoing flows, in co-operation with an Arrival Manager.

1.4   REPORT STRUCTURE

Section 2: describes the operational concept of the PATS Departure Manager tool.

Section 3: describes the requirements for the PATS Departure Manager tool.

Section 4: describes the implementation of the PATS Departure Manager tool.

Section 5: describes the usage of the PATS Departure Manager tool.

Section 6: describes and interprets the results of real time trials relative to the PATS Departure Manager tool.

Section 7: provides conclusions and makes recommendations for future work utilising the PATS Departure Manager tool.

Section 8: provides definitions of acronyms used throughout the document.

Section 9: provides references used throughout the document.

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2.   OPERATIONAL CONCEPTS

2.1   OPERATIONAL CONTEXT

2.1.1   Overview of operation
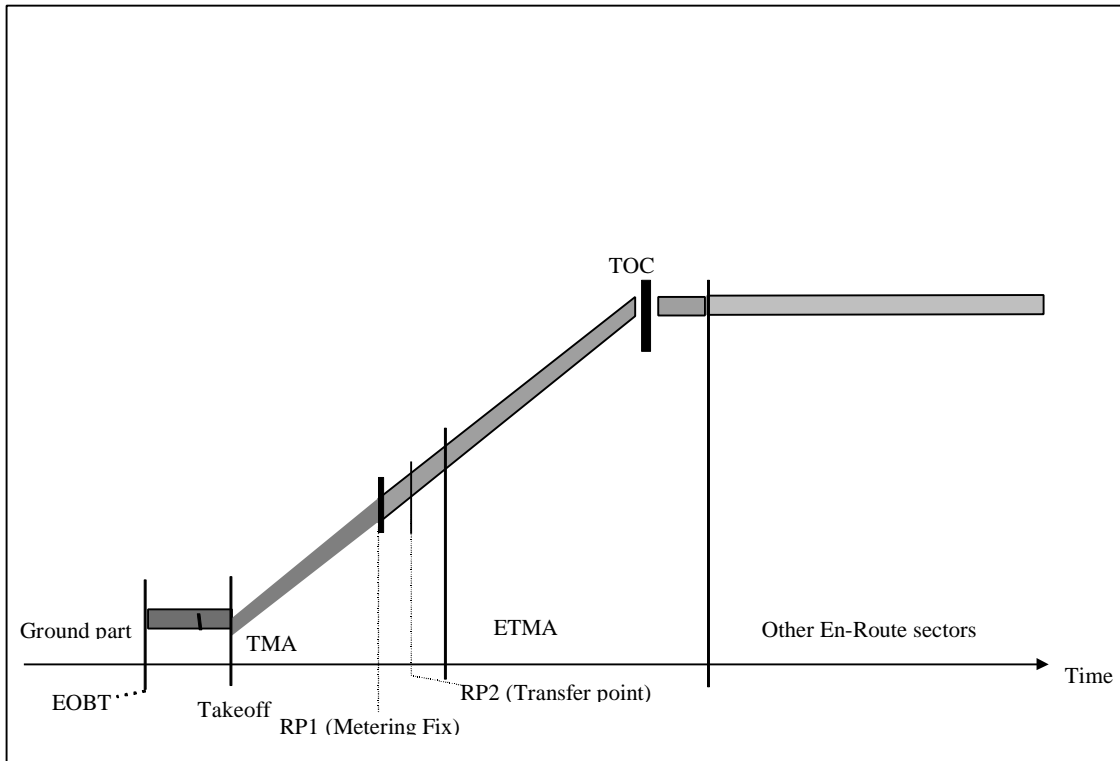
Figure 1 : Flight life

PHARE studies focus on three main concepts which are traffic organisation, trajectory negotiation and multi-sector planning (see OSD for more details, ref. [1] and [2]). But the validity of these concepts relies on enhanced anticipation and accuracy.

As soon as the proportion of departing flights compared to the whole traffic is significant, managing departure traffic before take-off is mandatory.

Two controllers are managing departure traffic (see OSD for more details, ref. [1] and [2]):

- the departure planning controller (DEP PC) which performs traffic organisation in the TMA
- the departure tactical controller

Airport surface traffic management is outside the scope of PHARE. Therefore the airport tower cab working positions (Start up, Ground, Tower) are not implemented and ground traffic is neither controlled nor simulated. That does not imply that flight's life starts at take-off for a departure (within PHARE scenario). Since trajectories are planned before take-off, tools and controllers need to be informed, at least roughly, of flight status prior take-off, to perform traffic organisation in the TMA. Some events such as pilot calls (or login for 4D equipped), block times, arrivals at runway threshold must be known by the ground system.

Within the TMA, two main flows of traffic, arrivals and departures, are managed and have to share the same resources. Potential competition for their use may occur at three levels:

- parking and taxiways : this is not in scope of PHARE ;

- runways, depending on airport configuration : in case of dependent runways or runways used in a mixed mode, there is a strong dependence between takeoff and landing times ;

- TMA airspace: in the PD/3 scenario, TMA sector is divided into volumes of airspace dedicated to each kind of traffic and standard procedures have been designed to be in respect with these separations. In theory, no potential conflict is possible between arrival and departure trajectories. Nevertheless, these standard procedures are usually not optimal in terms of flight times and fuel consumption, and controllers frequently infringe on standard rules whenever it does not affect safety.

An other important issue is the integration of departure flow in en-route traffic. In PD/3 operational scenario, departures trajectories within TMA airspace are planned before takeoff, though their integration is planned subsequently since no co-ordination between the DEP PC and ETMA PC is allowed before take off. Yet, the integration can be roughly prepared by the multi-sector planner who has visibility on departures before take-off.

2.1.2   Key operational concepts

The Departure Manager has been designed to assist the departure planner in:

- optimising runway usage

- organising the departure traffic in TMA

- minimising flight times and delays

- improving co-ordination with en-route and arrival controllers

- allowing anticipation for downstream controllers and tools to plan traffic

To achieve these goals, the Departure Manager provides takeoff schedules and optimised climbing trajectories in TMA.

The requirements and the design of the Departure Manager are based on several concepts or hypothesis:

Accuracy of estimated and scheduled times of departure. A main issue about departures is the uncertainty about surface movements timing. Nowadays, it is quite impossible to know with accuracy an estimated time of departure (ETD: defined as the arrival time at runway threshold) even a few minutes before take-off. Since all Departure Manager computations rely on these ETDs, the following assumptions have been made:

- CFMU slots will be more and more respected by companies and ATC. Therefore accuracy of estimated off block times will be enhanced, but not enough to allow an accurate scheduling for flights still on block ;

- Major airports will, in the next years, be equipped with surveillance systems that will provide positions reports. That will allow implementation of surface movements management tools which could provide accurate ETD for flights in taxiing phase, updated according to current positions of aircraft ;

- The operational use of the Departure Manager will imply an involvement of all airport controllers managing departure traffic. All of them will have a visibility on the departure sequence and will contribute to implement it.
- The STDs can be computed with a precision of about 1 minute for flights in taxiing phase. For flight still on block, the uncertainty will remain important though reduced compared from current practises. Nevertheless, it is useful to schedule those flights to provide an overview of the incoming traffic to allow anticipation for strategic actions such as runway balancing or tuning of arrival runway rates.

Sequencing and traffic organisation in TMA airspace. One main objective of sequencing departures is to optimise runway usage, taking into account ground constraints such as taxiing times.   It is important, however, to notice that sequencing departures has a direct impact on traffic organisation in the TMA airspace. Since flight times are very short and trajectories strongly constrained, the majority of potential conflicts are more easily and safely avoided at a sequencing level. This must be taken into consideration during the optimisation phase of the departure sequence.

Controllers stay in the Loop. Keeping controllers in the loop is one of the basic concepts on which PHARE relies on. In keeping with this principle, a tool like the departure Manager must fulfil the two following conditions:

- the tool must be interactive and provide controllers with facilities to modify the sequence such as runway allocation change, flight move, etc. A « what-if » mode is also useful to enable controllers to be informed of the consequences of any action before applying it ;
- the computed sequences must be « understandable » by controllers : the natural sequence is based on the « first come, first serve » concept with each flight allocated on a default runway. Any change from this basic sequence performed by the system for optimisation purpose should be explainable by operational arguments.

Adaptation of free-flight concept in TMA. Currently, trajectories within TMA are strongly constrained due to three main reasons:

- a large amount of traffic is controlled in a small volume of airspace
- to maintain safe separations between incoming and outgoing traffic
- to take into account environmental constraints

These reasons explain why standard procedures (SIDs and STARs) do not cope with aircraft preferences which are normally the shortest route with no altitude or speed constraint. Due to environmental constraints, the free-flight concept cannot be fully applied in TMA.

However, in some conditions, it is possible for the trajectories to be partly unconstrained. Ground based tools can assist controllers in performing this task by searching for the constraints that can be removed. This search must be based on accurate trajectory prediction and conflict detection and deep knowledge of TMA airspace structure and operational rules.

2.2   CONTEXT DESCRIPTION

2.2.1   System components Interaction with Departure Manager

The following diagram illustrates the interactions of the Departure Manager with the system. The central bubble represents the Departure Manager tool. The surrounding boxes represent each of the PHARE system components that the tool interacts with, and the connecting arrows represent the direction of communications between the system components and the tool.
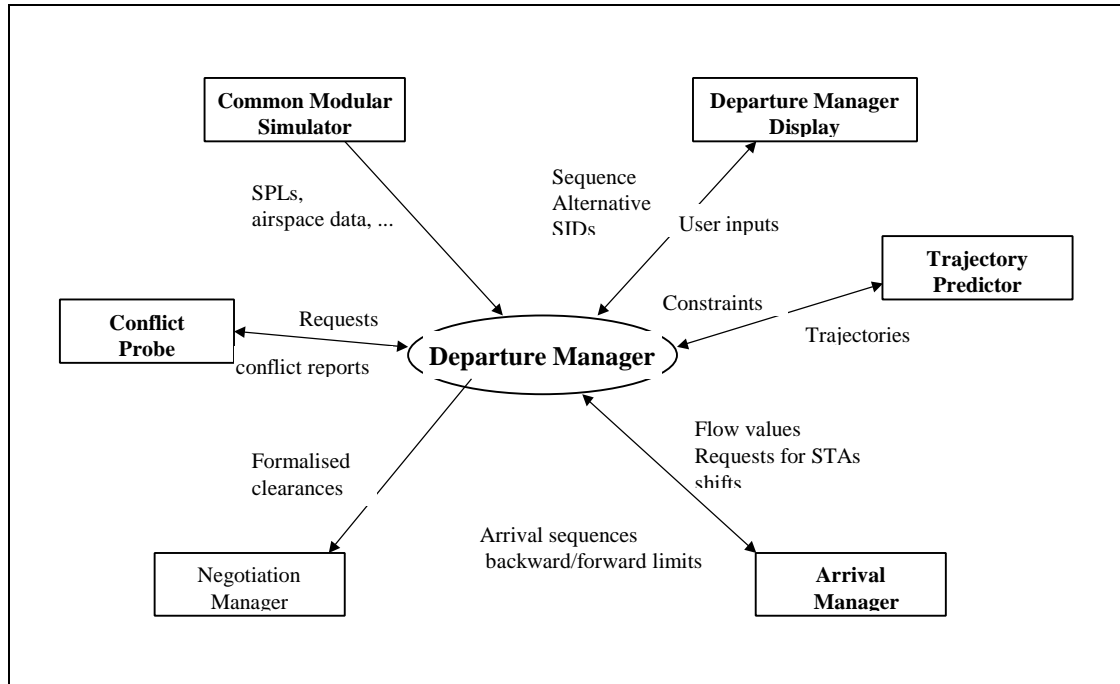
The diagram identifies that the PATS Departure Manager tool interfaces with three other PATS tools, the Negotiation Manager, the Trajectory Predictor and the Conflict Probe.

The following sections describe the PATS Departure Manager tool external interfaces.

2.2.2   PATS Trajectory Predictor

The Departure Manager utilises the PATS Trajectory Predictor to generate aircraft trajectories from the takeoff runway to the top of climb during the conflict resolution phase. The kinds of constraints set by the Departure Manager are 2D points describing standard or non standard SIDs (alternative SIDs), and associated altitude constraints.

2.2.3   PATS Negotiation Manager

The Departure Manager utilises the PATS Negotiation Manager to update sequencing constraints (i.e. allocated runway and STD) in the ground and air systems. Formalised clearances are used since no co-ordinations or negotiations are required.

2.2.4   PATS Conflict Probe

The Departure Manager utilises Conflict Probe facilities during the search for optimised conflict-free trajectories. The Conflict Probe is requested to probe for conflicts between an alternative SPL against a set of other alternative SPLs (departures in trajectory planning phase) and all other SPLs in real context.

2.2.5   PATS Arrival Manager

In case of runways used in mixed mode, negotiation between the Departure Manager and the Arrival Manager is required for the share of runway resources. The Arrival Manager provides the departure Manager with arrival sequences and backward and forward limits. These values define the limits in which tactical negotiations can be performed.

The Departure Manager sends requests for individual STA shifts (tactical negotiation) and for arrival flow values modifications (strategic negotiation).

2.2.6   DMD (Departure Manager Display)

The Departure Manager supplies the DMD with the following data:

- the departure sequence which includes mainly, for each flight :
    - the ETD
    - the STD
    - the allocated runway
    - the standard SID corresponding to the allocated runway
- results of the processing for optimised conflict-free trajectories. They are provided by context identifiers that allow the DMD to retrieve from CMS servers the associated trajectories and constraints.

The inputs from the DMD are:

- requests for sequence modifications such as :
    - runway change
    - move a flight in the sequence
    - freeze flight in the sequence
    - swap two flights
- requests for trajectory planning
- selection of an « alternative SID »

2.2.7   CMS Platform

The Departure Manager uses the following facilities provided by CMS servers:

- flight plan events and data
- description of standard SIDs
- constraints and contexts management
- simulated time

2.3 DEVELOPMENT PROCESS

2.3.1 History of Tool Development

The PATS Departure Manager project was initiated in 1993 and originally led by DLR. A first draft URD was produced by DLR in 1995 and the software production was then transferred to CENA.

The tool was developed in several steps:

- 1995: Design and development of a standalone mock-up
- April 1996: Delivery of a second draft of the Departure Manager URD
- April 1996-May 1997: Development of the departure sequencer to be in accordance with the URD, and integration into CMS environment. A technical HMI and a stub of ground traffic management system were also implemented.
- Jan 1997-May 1997: Arrival Manager-Departure Manager co-operation was designed, implemented and tested with MAESTRO, used as an arrival manager ;
- May 1997: Delivery of a third draft of the Departure Manager URD that focused on trajectories management in TMA ;
- May 1997-Dec.1997: The TMA function of the Departure Manager was designed, developed and integrated into CMS environment. The sequencer was evaluated and consolidated. What-if mode was implemented ;
- Jan-April 1998: Connection to other PATS (Conflict Probe, Negotiation Manager) and final integration into PD/3 platform

2.3.2 Why it was developed that way

Due to the novelty of the subject, the development of a mock-up was necessary, as a basis for further researches in co-operation with controllers.

The Departure Manager software was split in two main clients, sequencer and TMA function, for several reasons:

- to minimise the response times of the Departure Manager,
- to make the tuning of each component easier,
- to separate the function for which a short term operational usage is possible from the function that will require an enhanced ATC environment. This will make the reuse of the Departure Manager software easier in the scope of an operational implementation.

The development of the TMA function started quite late, since it was an additional feature to the departure sequencing and additionally was strongly dependent on the availability of other PATs such as the Trajectory Predictor, the Conflict Probe and the Negotiation Manager in TMA conditions.

2.3.3   Dropped ideas and concepts

En-route integration. One main issue of departures management is their integration into en-route traffic. Some researches were carried out and showed that for some flows of traffic, taking into consideration the integration issues (such as the cruise level that could be obtained) during the sequencing phase could be a subject for research. The idea seemed basically interesting but was dropped due to complexity of the issue.

Connection of an Arrival Manager and a Departure Manager managing distant airports. In Europe, major airports are close to one another. Assuming that the time horizon in which the Arrival Manager provides a schedule is about 45 minutes, a significant proportion of flights could be scheduled (by the Arrival Manager) while they are not yet airborne. For those, for which the delay computed by the Arrival Manager is significant, the easiest way to absorb it is by delaying the take-off. That, naturally leads to a negotiation between an Arrival Manager and a distant Departure Manager. The implementation of this negotiation was envisaged but not realised since a low level priority was attributed to this task.

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3.   REQUIREMENT DESCRIPTION

A formal definition of the requirements can be found in PAT Departure Manager URD document (ref. [9]).

3.1   USER REQUIREMENTS

3.1.1   Planning Assistance

The tool shall provide departure planning assistance to the air traffic controller through:

- the computation of an optimal departure sequence taking into account the arrival sequence and airport constraints (operational runways, current configuration, runway allocation rules etc.),
- ensuring that correct separations between departure flights and arrival flights are respected and wake vortex separation between departures as well,
- ensuring that aircraft with CFMU slot have priority,
- ensuring that runways loading is optimal,
- ensuring that the provided sequence satisfies, in the best way, the rules for safety and efficiency in the climb phase,
- ensuring that ground information (pilot call, push-back, taxiing, holding point) are taken into account.
- propositions of arrival runway rates to the Arrival Manager, taking into account the departure and arrival traffic flows.

3.1.2   Traffic organisation in the TMA

The tool shall organise the traffic in the TMA by providing:

- a climb procedure taking into account the runway, the exit point and the aircraft type,
- a climb trajectory taking into account the LOA,
- the conflicts between departures and other traffic (departure traffic, arrival traffic and en-route traffic).

3.1.3   Controller Interaction

In order to enable manual intervention of the air traffic controller, the tool shall provide facilities to:

- influence the sequence computation algorithms (move a flight, exchange flights, freeze a flight),
- perform 'what if' sequence modelling,
- select climb procedures others than standard procedures,
- modify the description of the climb procedures whether standard or not.

Additionally, many parameters used by the sequencing may be modified to suit controllers' practice (periodicity of scheduling, time period of a 'penalised' flight, reallocation benefit time value, distances separation values).

3.2 FUNCTIONAL REQUIREMENTS

3.2.1 Sequencing

The sequencing is divided into 3 steps:

- Scheduled Time of Departure (STD) calculation,
- Reorientation,
- Constraints optimisation.

STD calculation. The STD is the take-off time calculated by the Departure Manager. Before giving a STD, the tool allocates each departing flight to a runway, taking into account the rules used on the airport. An ETD is assumed to be available to the Departure Manager from a surface movement control system (simulated by the ground stub in PD/3 context).

Then, for each runway, the tool creates two lists:

- departure with a CFMU slot, sorted by the lower bound of flights' CFMU slot.
- departure without CFMU slot, sorted by the ETD of each flight.

These two lists are used to attribute a STD to each departure flight (the first one being scanned first, in order to respect the priority of the flights with a CFMU slot).

- If the flight has no CFMU slot, the STD must be such as:

  STD >= ETD.

- If the flight has a CFMU slot, the STD must be such as:

  STD >= Max (ETD, lower bound of its CFMU slot).

In all cases, STD is calculated taking into account:

- the gaps found into the arrival traffic,
- the gaps found into the runways closures,
- the wake vortex separation between departures,
- the separation between arrivals and departures.

The result of this step is, for each runway, an initial list of flights with STD.

Reorientation. This process is applied after the STD calculation process. In some traffic conditions, the standard runway allocation rules and flights priorities applied during the previous step may create some unbalanced runway load or penalised flights. So, the reorientation is used as a method to correctly balance the traffic load between each runway, during peak periods, and as a method to avoid having 'penalised' flights.

- A flight which has no CFMU slot is 'penalised' if :

  STD > ETD + Time period (for PD/3 demonstrations, the Time period was set to 10mn).

- A flight which has a CFMU slot is 'penalised' if :

  STD > upper bound of its CFMU slot.

Constraints optimisation. This process is applied after the reorientation process. Once the traffic load has been reasonably balanced between the two runways and the delay of most penalised flights improved as much as possible through reorientation, there might be some conflicting departure combinations, as SID constraints are concerned.

So, the Departure Manager checks for all flights (by consecutive pairs in the list sorted by STD) that the following rules are respected:

- two consecutive flights do not have the same exit point;
- a slow flight is never before a fast flight,
- a heavy flight is never before a light flight.

If a couple of flights fail to respect one or several of these constraints, the Departure Manager attempts to change the sequence order, permuting one flight of the pair with another flight in the sequence. If no permutation is possible, the tool warns the controller.

3.2.2   'What if'

The Departure Manager provides facilities to perform 'What if' mode and is capable of managing both a 'What if' sequence and a 'Real world' sequence simultaneously.

The Departure Manager provides facilities to modify the modelled 'What if' sequence without affecting the 'Real world' sequence. The operations that will be allowed in the 'What if' mode are:

- Amend the scheduled take-off time of an aircraft (move aircraft),
- Swap two aircraft in the sequence (sequence change),
- Amend the take-off runway of an aircraft (runway change).

When the controller has initialised the 'What if' function, only the 'What if' sequence can be modified, but the external events are taken into account in both the 'What if' sequence and the 'Real world' sequence.

The controller will have the option to either accept or reject the 'What if' sequence generated by the Departure Manager. If the sequence is accepted, then the 'Real world' sequence will be updated. If the sequence is rejected, then the 'Real world' sequence is unaffected. When the 'what-if' function is closed, all the controller actions will apply to the 'Real world' sequence again.

3.2.3   TMA function

The tool provides facilities to:

- propose a standard climb procedure (SID) for each departure flight,
- propose for each standard climb procedure a catalogue of non standard climb procedures, that we name 'alternative' procedures.

As soon as a flight is sequenced, the TMA function proposes, a standard climb procedure taking into account the exit point, the allocated runway and the aircraft type.

When the flight is 'to be integrated', the controller has two possibilities:

- select it to determine its best climb trajectory,
- do nothing, so the flight will follow the standard climb procedure initially allocated.

A flight can be integrated only when it is taxiing, or if it is not taxiing but there is less than 10mn before its scheduled time of departure calculated by the Departure Manager (STD).

To determine the best trajectory for a flight, the TMA function successively tries all the possible climbing procedures (standard and alternative, sorted in a catalogue from the less constrained to the most one) until a conflict-free trajectory is found. For each one, the Departure Manager sends to the Trajectory Predictor the associated constraints to obtain the corresponding trajectory. When the TMA function receives the trajectory, a request is sent to the Conflict Probe in order to detect conflicts between this trajectory and the others in the TMA area. If a conflict is detected, the TMA function analyses the conflict and attempts to solve it by adding a level constraint. If the trajectory is still conflicting then the next climbing procedure is tried. The search stops when a conflict-free trajectory is found or when all climbing procedures have been processed. In the second case, the standard procedure is selected. The final choice is proposed to the controller who can accept or modify the proposition and then initiates the negotiation for a 4D equipped aircraft.

3.2.4   Arrival Manager /Departure Manager co-operation

When runways are used in mixed mode, the Departure Manager provides two mechanisms to optimise the share of the runway usage between arrivals and departures.

Firstly, to book slots for departures, the Departure Manager proposes arrival flow values to the Arrival Manager. The flow values are computed taking into the incoming and outgoing flows. They are updated regularly and apply only to the arrival traffic that will reach the runways after a time horizon since this strategic measure requires anticipation.

Subsequently, to tune the slots booked through the mechanism described above, the Departure Manager sends requests to the Arrival Manager for individual shifts of STAs. This co-operation task is performed with an anticipation of a few minutes when accuracy of STDs has become sufficient.

To elaborate these proposals, the Departure Manager considers the backward and forward limits provided by an Arrival Manager. For a given arrival, these values determine the time window in which the STA can be shifted either by accelerating or delaying the flight. They are computed taking in account aircraft performances and standard separations with the preceding and succeeding arrivals in the sequence. The values are updated according to the current position of the flight. The backward and forward limits guaranty that a Departure Manager STA proposal is feasible and have no impact on STA of other arrivals.

This process corresponds to what the tower controllers presently do sometimes when they put off an arrival flight allowing a departure flight to take-off.

3.3   IMPLEMENTATION DEPENDENT REQUIREMENTS

3.3.1   Integration

The Departure Manager has been successfully integrated into the DAARWIN platform at CENA.

APIs are provided through a CMS compliant server.

3.3.2   Client / server architecture

The Departure Manager has been developed to work on a client / server architecture.

The Departure Manager has been developed to allow communications synchronously or asynchronously. In this way, delayed responses to requests for data made by the Departure Manager do not cause processing of other inputs to be delayed.

3.3.3   Platform independent

The Departure Manager has been developed so that there is no reliance on any underlying operating system (for example, UNIX). The developed software does not make reference to platform specific functions.

3.3.4   Configuration data source

The Departure Manager is able to accept configuration data from either the servers within the simulation platform or from configuration files. Additionally, a specific CMS server, named Approach Server and dedicated to the management of approach environment and communication, is provided.

The data that are not available from the standard servers can be classified into two categories:

- the data used by a sole client for internal processing are retrieved from configuration files during initialisation
- the data shared by several clients (such as the description of alternative SIDs) are provided by the CMS Approach Server.

It should be noted that the operational rules used as sequencing constraints are described off-line in configuration files.

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4.   IMPLEMENTATION

4.1   HOW DEVELOPED

4.1.1   Initial Research

Following an initial research period, a mock-up was designed and developed using ADA programming language. For the design, an object oriented methodology elaborated at CENA was used. Some components of the MAESTRO tool were re-used and adapted. This mock-up included, in a single process, the Departure Manager sequencer, a technical HMI and traffic simulation facilities. This initial light architecture allowed easy testing and rough evaluation of Departure Manager algorithms but was too limited for further evaluations.

4.1.2   Integration

The integration into CMS environment was performed by splitting the mock-up into two main components, a sequencer and an HMI. These were integrated as CMS clients by developing an interface layer for each of them. A CMS server, called Approach server, was developed to allow the communications between the clients and to provide some environment data (mainly about airport configuration) that were not available from the standard CMS servers.

ADA language was used for the development of the server and CMS standards were followed for the generation of the APIs (APIs of the Approach Server were also generated in C for ease of integration with the Arrival Manager which was in C/C++).

The Maestro sequencer was integrated as a new CMS client to test Arrival Manager-Departure Manager negotiation.

4.1.3   System Test and Evaluation

At this step, a period of test and evaluation of the overall system was carried out, and the V1 version of the Departure Manager was delivered.

Subsequently, new clients were developed and integrated:

- the « ground stub » that simulated roughly surface movements
- the « TMA function which computes optimised climbing trajectories
- a technical HMI to test TMA outputs and interactions with controllers.

These clients were developed using C language.

 Since the TMA function needed inputs from others PATS that were not yet available, stubs (for Conflict Probe and Negotiation Manager) or tools developed at CENA providing similar facilities (Trajectory Predictor), were integrated. At each integration step, tests of the overall platform were carried out.

4.1.4   Final Integration

The final integration into the PD/3 platform, consisted mainly of tuning the communications between the Departure Manager and PD/3 GHMI, Negotiation Manager and Conflict Probe.

The following diagram illustrates the architecture of the platform. The central bubble represents the Common Modular Simulator. The surrounding grey boxes represent Departure Manager components. The surrounding white boxes represent each of the PHARE system components that the Departure Manager interacts with, and the connecting arrows represent the direction of communications between the system components.

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        ┌─────────────┐   ┌─────────────┐   ┌─────────────┐
        │ Trajectory  │   │ Negotiation │   │  Conflict   │
        │  Predictor  │   │   Manager   │   │   Probe     │
        └─────────────┘   └─────────────┘   └─────────────┘


                                                      ┌──────────────┐
                                                      │ Arrival Manager
                        ┌──────────┐                  │     Stub     │
┌──────────────┐        │  Common  │                  └──────────────┘
│Air simulator │        │  Modular │
│   (MASS)     │◄──────►│ Simulator│
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                                              └──────────────┘


                        ┌──────────────┐
                        │   DM TMA     │
                        │  Function    │
                        └──────────────┘

              ┌──────────────────┐
              │  DM Sequencing   │
              │    Function      │

┌──────────────┐                        ┌──────────────┐
│   Ground     │◄──────────────────────►│   Approach   │
│    Stub      │                        │    Server    │
└──────────────┘                        └──────────────┘
```
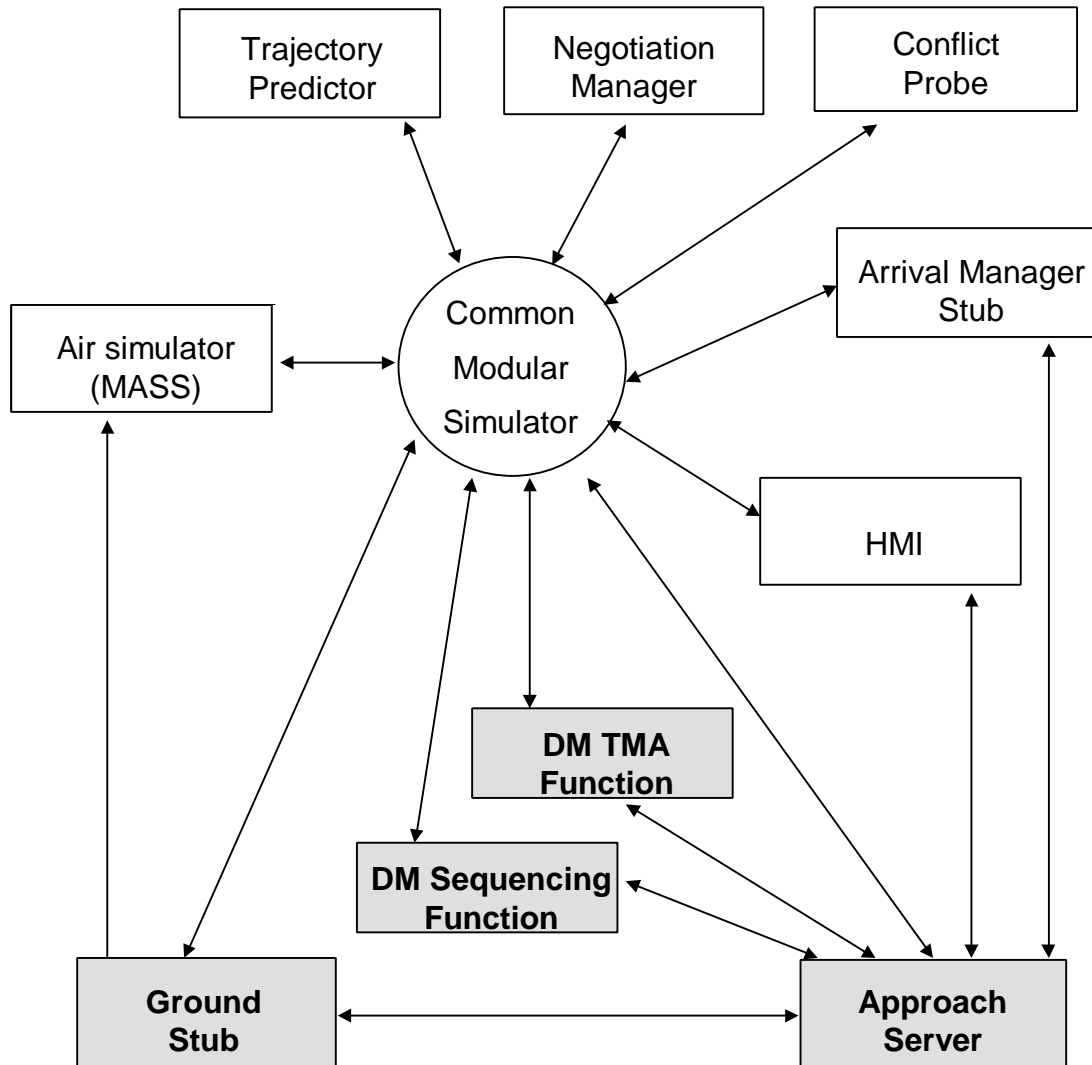
4.2   TECHNICAL ENVIRONMENT

ADA and C languages have been used for the development of Departure Manager components. The source code is available at CENA on a UNIX file server accessed from a network of SUN workstations. Modifications to the source code have been managed using the RCS source code control tool.

For ADA components, the VERDIX V3.0 compiler was used.

For C components, the GNU C compiler was used.

The Departure Manager was integrated into CMS technical environment and some facilities provided were used to manage Departure Manager source files and executables such as:

- a set of installation procedures based on recursive « make » files,
- a set of CENA tools named CASTOR., POLLUX and ZEBULON to generate automatically some source files from the ADA APIs of the Approach Server. The generated files contained mainly C APIs, XDR encoding and decoding procedures and RPC procedures.

4.3   PERFORMANCE ISSUES

4.3.1   Sequencing function

The performance issue is not critical during regular background re-sequencing. Yet, re-sequencing is also performed to answer controllers' requests for sequence modifications. In that case, though this is only a planning task, response times must remain within an acceptable time frame to avoid users' frustration. During the PD/3 experiments the response times did not exceed 3 seconds which was found to be acceptable by controllers.

Apart from external factors (tools, system, etc.), the response time of the sequencing function depends mainly on the following parameters:

- the number of departing flights in the sequence,
- the number of arrivals when runways used in mixed mode,
- the number of penalised departing flights,
- the number of runway managed.

4.3.2   TMA function

The TMA function is triggered on controller request. As for the sequencing function, the response times are not critical but must not be excessive. Since to perform computations this function uses Trajectory Predictor and Conflict Probe facilities (from 1 to 3 requests), its performance depends heavily on Trajectory Predictor, Conflict Probe and CMS platform response times. For the PD/3 experiments, during peak periods, response times could exceed 10 seconds which was unacceptable.

A solution envisaged to reduce response times was to anticipate controllers' requests by performing computations as soon as trajectories are available for planning. This solution implies to update computations on reception of any trajectories updates. It was rejected to avoid the risk of crashing the whole ground system by overloading some common resources such as the SPL server or the Trajectory Predictor.

Apart from external factors (tools, system, etc.), the response time of the TMA function depends mainly on the following parameters:

- the number of alternative SIDs tested,
- the number of flights managed by the ground system.

4.4   PROBLEMS FOUND AND SOLVED

4.4.1   Propagation of sequencing constraints to ground system and aircraft

Whenever the departure sequence is updated by the Departure Manager, the modifications have to be propagated in the SPL server, to ensure that the trajectories are in accordance with the computed sequence. The flight simulator has also to be notified of any sequence change, to make the simulated traffic follow the same sequence (during the PD/3 experiments there was no controller managing takeoffs).

Therefore, whenever the departure sequence is updated, a formalised clearance is sent for each departure for which a change has occurred. To avoid to overloading the Negotiation Manager, the SPL server and the traffic simulator, the formalised clearances are sent only when changes are significant.

For 4D equipped aircraft the Negotiation Manager will propagate sequencing constraints to both ground and air systems. For 3D aircraft, the constraints are only propagated to the ground system. A direct connection from the Departure Manager to the traffic simulator is necessary to send automatic takeoff orders (for 3D aircraft).

Two issues were raised during the implementation:

- formalised clearances were sometimes rejected by the Negotiation Manager or the ground system due to collisions with negotiations in progress. To solve this problem, formalised clearances were sent, for a departure, only in the time period starting at the reception of the initial down-linked trajectory and ending at the first edition of the trajectory by the DEP PC. The solution was appropriate for simulated aircraft. For the real one, no formalised clearances were sent, since the initial trajectory was down-linked after take off ;

- it occurred that the number of formalised clearances sent was important, and each one needed an acknowledgement by the pseudo-pilot in charge of departing simulated flights. Therefore the pseudo-pilot was quite overloaded. The problem was solved by configuring the air traffic simulator, so that the sending of acknowledgements was made automatically.

4.5   UNSOLVED PROBLEMS

4.5.1   Management of unpredictable events

An event such as a departing flight missing its slot is a common occurrence, particularly when runways are used in mixed mode. Whenever this occurs, all the sequence should be slipped backward. That would imply the modification of the take-off time for a large number of departures, among which some have already a negotiated trajectory. The consequence of this would be several re-negotiations in a very short time scale, which seems unfeasible. The issue was avoided by freezing positions of flight in the sequence as soon as a trajectory edition was initiated by the controller and by not simulating any unpredictable exception events.

4.5.2   Conflict detection in TMA sector

The Departure Manager uses Conflict Probe facilities to perform conflict resolution. Some problems were raised and not solved, mainly due to the tight schedule of the final integration:

-   In Roissy-Charles de Gaulle, runways are separated by 3 kilometres. That was less than the separations standards and simultaneous takeoffs (or landings) were detected as conflicts by Conflict Probe. A solution for this problem was provided by the NLR Conflict Probe team but not implemented;

-   Though separation standards were respected, they were not considered as safe enough by controllers for conflict detection involving a departure against an arrival. This probably could have been solved by using the Conflict Probe in a probabilistic mode;

-   According to controllers, conflict detection for flight that is not airborne should be performed using larger separations to take into account the uncertainties about take-off duration;

-   Conflict resolution is performed once for each departure, by the Departure Manager on controller request. This resolution could subsequently become obsolete due to the occurrence of a new conflict. It was a Departure Manager requirement to provide a kind of monitoring of conflict resolutions but it was not implemented due to the risk of overloading the Conflict Probe and to avoid mismatches with Problem Solver conflict detection.

4.6   LESSONS LEARNT

4.6.1   Project management

During the development process, much more time was spent in co-ordination and integration tasks than in improving Departure Manager algorithms. This was due to several reasons:

-   The interactions between the tools and the platform were complex and required important co-ordination effort to be defined precisely. As the design and development of the system components were distributed at several sites the difficulty of building an overall coherent system was considerably increased.

-   The PHARE project was split into too many groups and too many levels of decision were created. Furthermore, in each group there were usually too many participants. This resulted in difficulty to take decisions and sometimes-contradictory recommendations issued from different groups. Consequently, tools requirements and APIs provided by the integration platform had to be updated frequently.

-   The final integration of the tools was planned at a very late stage of the project. If some issues (such as performance issues) had been raised before, they probably could have been solved in a more efficient way.

To manage, in the future, such kind of project the following conditions should be fulfilled to improve efficiency:

- The number of partners involved, groups and levels of decision must be reduced to the minimum.
- A more central place (and more means) should be given to the team in charge of developing the simulation platform. This team should also design the overall system and should carry out the integration of the tools in co-operation with the tools developers.
- IOCPs had been planned at early stage of the PD/3 project to clarify operational issues. Technical issues should also be clarified with anticipation in the same way.

4.6.2   System architecture

The Client-server architecture was well adapted for most of the operations performed on the platform with the exception of the use of the Conflict Probe and the Trajectory Predictor. These tools were triggered for two different purposes:

- to update in the flight database trajectories and conflicts according to the current traffic situation
- to allow others tools to carry out trajectory planning tasks in 'what-if' mode.

In the second case, the client-server model was not well adapted since intensive uses of the Conflict Probe and Trajectory Predictor were necessary and the consequences were:

- excessive response times (Departure Manager TMA in PD/3, Arrival Manager of PD2),
- inconsistency since the Problem Solver, for example, used its own trajectory generator and conflict detection to minimise response times.

Distributing the computations by executing several instances of the tools probably would have improved response times but would not have completely solved the performance problem.

4.7   OPERATIONAL USAGE

Originally, it was foreseen that the Departure Manager would be integrated on two PD/3 platforms:

- At EUROCONTROL Bretigny, the Departure Manager would have managed the Roissy TMA in a configuration with 4 runways used in single mode (2 runways dedicated to departures).
- At CENA Athis-Mons to manage the Roissy airport in its current configuration.

In this section we will focus on the operational usage of the Departure Manager at CENA as it is the only site where the integration of the Departure Manager was achieved.

Since runway configuration changes were not simulated during CENA PD/3 runs, the description of the airport was limited to a unique configuration, the most frequently used 2 runways, 27 and 28, facing West used in mixed mode. Take-off from secondary airports such as Le Bourget, or inbound airports such as Orly were not taken into account at a sequencing level. This was a simplification since there is actually a dependency between these airports.

Fifteen outer fixes and about forty standard SIDs were defined for the configuration described above. SIDs were allocated according to the take-off runway, the outer fix and the aircraft type. Some operational rules concerning runway allocation had also to be taken into account. For example, the runway 28 was forbidden for flights going to the north or for aircraft types classified as noisy.

For each standard SID, one or two alternative climbing procedures were described based on controllers working methods.

Some additional airport features were also modelled such as terminals, mean taxiing times from terminals to runways (from 5 to 18 minutes), and terminal allocation rules.

The outputs of the Departure Manager were provided to both Planning and Tactical controllers, but the DEP PC was the only active user of the tool. GHMI supplied the controllers with Departure Manager results through two main displays:

- The Departure Manager Display (DMD) presented on timelines (one per runway) both departure and arrival sequences and was configured to be interactive to allow the DEP PC to amend the departure sequence.
- The Trajectory Editor and Problem Solver (TEPS) displayed the climbing trajectories proposed by the Departure Manager TMA function. For a given departure, the trajectory was provided at the first activation of the TEPS. The Departure Manager proposal could be modified by the DEP PC either by using trajectory edition facilities or by selecting an alternative SID in a menu.

Flight plans were available to the ground system, approximately twenty minutes before take-off. Usually, the DEP PC analysed the sequence and sent requests for sequence changes with, at least, fifteen minutes of anticipation.

The DEP PC was allowed to edit the trajectory of a departure (and so to trigger the TMA function) as soon as the flight has started taxiing. The position of a flight in the sequence was automatically frozen by the Departure Manager at the reception of a trajectory edition event.

4.8   TECHNICAL USAGE

The Departure Manager is supplied as a set of CMS clients and a CMS server (APPROACH server).

An installation procedure is provided through a set of recursive «make» files and is similar to PARADISE installation procedure. Some CMS configuration files have to be adapted to allow a full integration of the Departure Manager into the CMS environment.

The Departure Manager V2.1 Installation Notes document (ref. [12]) provides a full description of the installation procedure.

ADA and C APIs of the Approach Server are provided. That allows any CMS client developed using either ADA or C to retrieve outputs and events generated by the Departure Manager or to interact with it.

The Departure Manager V2.1 Approach Server User's Guide document (ref. [13]) provides a full description of these APIs.

In the CENA PD/3 demonstrations, the Departure Manager managed one airport at one time. Nevertheless, one instance of the Departure Manager is able to manage several airports as soon as they belong to the same TMA entity and runway names are distinct. To manage several TMAs, multiple instances of the Departure Manager are needed, each one configured to treat departures from one TMA. In that case, only one instance of the CMS Approach Server is necessary since it supports multi-TMA management.

5.   RESULTS

This chapter will focus on the results from CENA PD/3 experimentation as the Departure Manager was not used during any IOCP trials or PD/3 trials at other sites.

5.1   RUNS ORGANISATION
The simulated operational environment was Roissy Charles De Gaulle, facing West.

Three dependent variables were defined in PD/3:

- controller rotation,
- system organisation,
- traffic volume.

Three different organisations have been defined:

- a baseline system which is closed to the today's operational with limited planning aids,
- an advanced system in which the PHARE Advanced Tools and a new GHMI are implemented to assist controllers (referred to as « Adv 0% D /L »),
- « Adv 30% D/L » and « Adv 70% D/L » which have the same functionality as « Adv 0% D/L », but in which are respectively introduced 30% and 70% of 4-D FMS and datalink equipped aircraft.

In each organisation, three different traffic volumes have been employed:

- 'Low' corresponding to today's traffic demand (June 96),
- 'Medium' corresponding to 'Low' x 1.5,
- 'High' corresponding to 'Low' x 2.25.

The experiments were based on repeated measurements with two teams (one by main phase session) of two controllers. All teams performed identical tasks after an adequate training period. Each team performed low, medium and high loaded traffic runs. Controllers rotated between the tactical and planning positions for the Departure working positions.

5.2   PILOT PHASE
This was the first time that controllers used the Departure Manager. It was used to adjust Departure Manager parameters such as:

- criteria used to know if a flight is 're-orientable' or not,
- values used to preserve separations between departure flights and arrival flights, wake vortex between departure flights.

Once these parameters were tuned, controllers re-examined the sequence and facilities offered by the Departure Manager to modify it.

Their feelings were that the sequence was reasonable. They needed to make few interactions on the sequence. However, they sometimes found possibilities of modifications on the sequence were too restricted.

For example, controllers considered it restrictive that Departure Manager algorithms forbade the 're-orientation' of a flight from runway 27 to runway 28 when it was taxiing. Generally, equivalent ground movements are not possible to realise (because of others flights and taxiways configuration). But, they would have liked the Departure Manager to allow this possibility to controllers (because of emergency or other similar exceptions).

Concerning manual actions on the sequence, two modes were provided by the Departure Manager:

- Etd_Used mode: in that mode, when a flight is moved in the sequence by the controller using GHMI facilities, the new position is not considered by the Departure Manager as an imposed time of departure, but as a new time of arrival at runway threshold (ETD). This value overrides the ETD provided by the Ground Stub. The Departure Manager takes this new ETD as reference to re-compute a STD (see STD Calculation paragraph 3.2.1).

- Std_Used mode: the new position is considered as an imposed time of departure, and the Departure Manager will not be allowed to change the STD given by the controller.

The controllers preferred to work in Std_Used mode as they felt they had a better control of the sequence.

When controllers focused on the alternative climb procedures and standard climb procedures, they modified almost all the descriptions of the procedures, as they did not match the standard procedures used by controllers in the TMA.

The PILOT PHASE was very useful to adjust Departure Manager behaviour and to tune environmental parameters.

5.3   MAIN PHASE

5.3.1   Operating context

Surface movements and arrivals controller positions were not simulated during the PD/3 demonstrations. So two stubs were used to provide the Departure Manager with environment information:

- the first stub provided the Departure Manager with ETD and the following ground events for each flight :

    - pilot-call event (when the pilot calls the controller),

    - push-back event (when the flight begins its push-back),

    - taxiing event (when the flight begins moving on taxiways),

    - holding point event (when the flight is waiting take-off order),

- the second stub provided the Departure Manager with an arrival sequence, with a scheduling period set at 1mn for these demonstrations.

The GHMI did not provide departure controllers with the capability to perform the 'What if' function of the Departure Manager.

In the concept of a PC and a TC departure position, a part of the co-ordination between PC and TC controllers is realised by advisories. Thus, when the PC modifies a trajectory, the TC will have, for 3D aircraft, advisories along the trajectory in order to take into account the Trajectory Predictor work.

During the PD/3 experiments, there were the following limitations:

- the advisories provided were not always correct,
- the advisories were not always displayed along the trajectory.

Therefore, the TC controller could not take into account the advisories generated by the work of the PC controller. Thus, the controllers decided to work without the advisories.

The conflicts involving departures were not displayed before take-off. So, the DEP PC planning activity was distorted.

5.3.2   Algorithms

The PD/3 traffic samples did not offer many opportunities for the optimisation of the departure sequencing ('re-orientation' of flights, exchange of flights).

Firstly, most of the flights had the same characteristics:

- speed = fast,
- weight = medium.

Thus, the configurations, a slow flight before a fast flight and a heavy flight before a medium flight, never occurred.

Secondly, there were very few 'penalised' flights, even with the most loaded exercises. It was the case of flights without CFMU slot, and unfortunately all the flights before it in the sequence, were flights with a CFMU slot and not 're-orientable'.

Lastly, the only constraint not satisfied being detected several times was 'the same exit point constraint'. For controllers, this was not representative, because the separation was sufficient due to aircraft performances. In addition, according to controllers, too many flights were going to the North compared with real traffic flows. This Northerly flow was particularly loaded since only the north en-route and ETMA sectors were simulated during the simulations.

In conclusion, the situations allowing to use the optimisation algorithms of the sequencing were limited.

5.3.3   Interactions

The main interactions were requests for runway allocation changes to avoid simultaneous take-off on the two runways with crossing trajectories.

Also, depending on the controllers teams, they used and modified more or less the 'alternative' trajectories provided by the TMA function.

This depended on:

- their working methods,
- the level of confidence they had on the tools.

5.3.4   Controllers reactions

Their main remarks were:

- *we cannot evaluate the feasibility of the departure sequence, because to move a flight in the sequence is easy with the HMI, but we doubt it will be so easy in the reality of ground movements,*
- *you should have simulated a more loaded tr*affic,
- *your system is not operational because of response time,*
- *we will need a tool such as this one in a few years,*
- *we are ready to help you to improve the* Departure Manager*, to add functions making it more operational* (i.e. answering to the controllers needs).

5.4   ACHIEVEMENT OF CONCEPT

5.4.1   Areas achieved

The PATs Departure Manager developed for PD/3 has been the first prototype of a departure management tool and has reached an acceptable level of technical maturity to be integrated and evaluated in a large scale simulation, especially as far as sequencing is concerned.

According to controllers' remarks, the Departure Manager has shown promising features such as:

- the sequences provided seemed usually correct and did not need too many amendments from controllers;
- the proportion of CFMU slots respected would be increased by using the Departure Manager;
- the display of a global sequence, including departures and arrivals was welcomed by controllers. It allowed a synthetic view of the traffic to come and was a helpful decision support for strategic measures such as runways balancing.

Nevertheless the experimentation has raised many aspects where further investigation is necessary to improve sequencing because:

- the selection of candidate flights for re-orientation should be enhanced (optimisation algorithm used to avoid having 'penalised' flights);
- flights with a CFMU slot have priority, it happens that a flight without CFMU slot is given excessive delay. A solution should be found, because the criteria is too much rigid;
- potential conflicts between departures within the TMA should be considered more accurately at sequencing level:
    - avoid consecutive take-off of flights having two SIDs with different exit points but with a common portion of trajectory (for example MARGY and ARSIL)
    - the constraints management of the sequencer should encompass flights taking off from different runways
    - aircraft performance should be taken into account more accurately.
- the controllers require to be able to move a flight before its ETD (that means to accelerate the flight);
- conflicts between the take-off time should be displayed on the sequence;
- delay (STD-ETD) should be indicated only when the flight is out of its CFMU slot with an indication whether the flight is before or after. The notion of delay for flights without CFMU slot should be re-defined;
- the controller should be allowed to define off line the description of 'alternative' climb procedures used in his catalogue. All controllers do not use the same 'alternative' climbs procedures;
- the controller should be allowed to modify the sequence even for flights waiting at the holding point.

5.4.2   Areas not achieved

<u>Arrival Manager/Departure Manager negotiation</u>.   Arrival Manager-Departure Manager negotiation was not tested since the arrival traffic was not controlled. Nevertheless, according to controllers' remarks, it appeared that its implementation would have improved the use of runway capacity in many occasions.

<u>TMA function</u>. This function cannot be considered as validated due to, at least, the limitations of the experiments (excessive response times, no conflict displayed before take-off, etc.). Furthermore, there were more fundamental objections from controllers that concerned more specifically the negotiation scenario before take-off on which the TMA function relies on. The controllers raised two main issues:

- there is no way to reduce the uncertainty about take-off duration. Taking it into account during the planning task would decrease efficiency. Not taking it into account would lead to unsafe plan;
- performing planning without co-ordination with downstream controllers is not acceptable.

<u>What-If Modelling</u>. The « What-if » mode was not tested due to GHMI limitations.

6.   CONCLUSION AND RECOMMENDATIONS

6.1   CONCLUSION

The PD/3 experiment has been the first occasion that the Departure Manager could be judged by controllers in the context of large scale simulations. Despite the limitations inherent in all experimentation, many lessons have been learnt mainly about the sequencing function.

Firstly, according to controllers, there is a real operational need for a tool like the Departure Manager to be installed in major airports. Although thought self-evident, this was not the case a few years ago when the project was initiated.

The concepts on which the sequencing function relies on are valid, and substantial benefits could be derived from the usage of the Departure Manager mainly in terms of runways occupancy, respect of CFMU slots and improvement of traffic organisation in TMA. But the Departure Manager is not mature enough for an operational usage at a very short term. Some important issues have to be solved more specifically related to the traffic organisation in the TMA and management of surface movements.

Furthermore, a main requirement of the Departure Manager is to provide to all controllers involved in departure traffic management a common interface as a basis for co-operation tasks. This aspect of the Departure Manager has not been validated in the context of PD/3 demonstrations and further research and experiments need to be carried out.

Concerning the TMA function, though the idea of providing a catalogue of alternative SIDs seems promising, the concepts have not been validated. This remark could be extended to the whole concept of trajectory negotiation before take-off. Before any further research and development concerning the TMA function, the operational scenario of departure management should be reviewed.

6.2   RECOMMENDATIONS

To raise the Departure Manager from its current state to an operational implementation, further development and experiments will be necessary. The algorithms need to be improved and the operational usage of the Departure Manager needs to be defined more precisely.

To achieve these goals, the development process should go on with more regular and small scale simulations in order to maintain a deep involvement of controllers.

Finally, the integration of the Departure Manager with a ground control environment will need to be mandatory to allow controllers to judge the feasibility of the sequences computed and to validate the operational usage of the tool.

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7. MAIN ABBREVIATIONS AND ACRONYMS

7.1 ABBEVIATIONS

Arrival Manager	Arrival Manager
API	Application Programming Interface
ATC	Air Traffic Control
ATM	Air Traffic Management
Conflict Probe	Conflict Probe
CFMU	Central Flow Management Unit
CMS	Common Modular Simulator
CWP	Controller Working Position
DEP PC	Departure Planning Controller
DEP TC	Departure Tactical Controller
Departure Manager	Departure Manager
EEC	EUROCONTROL Experimental Centre
EFMS	Experimental Flight Management System
EOBT	Estimated Of Block Time
EPLC	En-Route Planning Controller
ERS	En-Route Sector
ETC	En-Route Tactical Controller
ETD	Estimated Time of Departure
ETMA	Extended TMA
ETMA PC	ETMA Planning Controller
ETMA TC	ETMA Tactical Controller
FPL	Flight Plan
FPM	Flight Path Monitoring
GHMI	Ground Human Machine Interaction
LOA	Letters Of Agreement
LOC	Local Controller
MAESTRO	Means to Aid Expedition And Sequencing of Traffic with Research of Optimisation
MSA	Multi-Sector Area
MSP	Multi-Sector Planner
Negotiation Manager	Negotiation Manager
OTF	Operational Task Force

PARADISE	Prototype Adaptable and Re-configurable ATM Demonstration and Integration Simulator Environment
PHARE	Program for Harmonised Air Traffic Research in EUROCONTROL
Problem Solver	Problem Solver
SEQ	Sequencer
SID	Standard Instrument Departure route
SPL	System Plan
STA	Scheduled Time of Arrival
STD	Scheduled Time of Departure
STD_MF	Scheduled Time of Departure over Metering Fix
TMA	Terminal control Area
TOC	Top Of Climb
Trajectory Predictor	Trajectory Predictor

7.2   DEFINITIONS

NOTE: Definitions marked with * have been extracted from ref. [3].
Definitions marked with ** have been extracted from ref. [7].

2D constraint	* A point specification i.e. a route point on a trajectory.
3D	* 3 Dimensional - used to denote a position in space defined relative to the Earth. Can be considered as being lat., long and altitude.
3D constraint	* A 2D constraint with added altitude specification.
4D	* 4 Dimensional - used to denote a position in space defined relative to the Earth and time. Can be considered as being lat., long, altitude and time.
4D constraint	* A 3D constraint with added time specification.
4D trajectory	* A list of 4D way-points.
4D way-point	* A 4 dimensional geographical point defined by latitude, longitude, altitude and time - used to denote a position in space defined relative to the earth and time.
Alternative context	** A context that can be modified without affecting the 'real world' flight plan of an aircraft.
Alternative SID or climbing procedure	A climbing procedure that differs from the standard SID either in horizontal or vertical profile. Usually alternative procedures are less constrained than standard ones.
Arrival Backward Limit	The limit of additional delay that the Departure Manager is allowed to propose for an arrival in order insert a take-off before. This value is computed by the Arrival Manager taking in account aircraft performances and standard separations between arrivals.
Arrival Forward Limit	The limit of forward shift in the sequence that the Departure Manager is allowed to propose for an arrival in order insert a take-off after. This value is computed by the Arrival Manager taking in account aircraft performances and standard separations between arrivals
CFMU slots	Departure times are allocated by the CFMU which is responsible for providing ATFM services within airspace of participating European states. A CFMU slot is a time window around a departure time allocated in which the flight is required to take-off.
Constraint	* Limitations placed upon the (trajectory) prediction process in terms of pairs of altitudes and times at specified locations.
Context	** Contains all flight plan information for an aircraft within the ground system.
Equipped aircraft	** Aircraft equipped with 4D-FMS and datalink.

ETD	The earliest possible time of Departure
Formalised clearance	** A type of negotiation request made to the PATS Negotiation Manager that results in the related arrival constraints being passed directly to the associated arrival without co-ordination with upstream controllers.
Initial trajectory	** The first 4D trajectory passed to the tool for an arrival, generated without any arrival constraints.
Metering fix	* The TMA entry point and the first point in a STAR (derived from the definition of STAR in ref. [3]).
Outer Fix	The last point of the SID
'Real world' context	** A context that represents the 'real world' flight plan of an aircraft.
'Real world' trajectory	** The 4D trajectory that the associated aircraft is currently contracted to fly.
STD	The departure time computed by the Departure Manager

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