Sequential steps towards a Multi Airport System (MAS)

KDC-Mainport, 1117 ZN Schiphol

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Version 1

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(Cover page: Up in the sky (Heijden, 2021)*)*

(Logos: (Amsterdam University of Applied Sciences, sd) *&* (KDC-Mainport, sd)*)*

Preface

This report was created because of a graduation internship assignment that was carried out for KDC-Mainport. This internship was carried out by an Aviation Engineering student which is studying at the University of Applied Sciences in Amsterdam. The intern is writing his graduating thesis at the company and works fulltime on his graduation thesis. This report was written for KDC-Mainport and can therefore only be used specifically by this client.

Together with the client, the researcher has drawn up a main question and sub-questions which will be answered throughout the report, so it is advised to the client to read the entire report and then to set action points. The management of the stakeholders is advised to at least read the conclusions and the further work so that they are clear to them, and follow-up studies can be conducted.

First a word of thanks to Koos Noordeloos for supervising and coordinating the internship and the opportunity to carry out this research. Also, a thank you to Catya Zuniga for guiding the research from the University of Applied Sciences in Amsterdam. Finally, a word of thanks to all the companies, interviewees, and colleagues who provided input for the research.

Amsterdam, May 2022
Wesley Vork

Summary

Dutch airports have grown considerably over time. This growth takes place almost autonomously. No mechanisms are established to balance this growth among airports, routes, or airspace strategically. It is assumed that, without profound reformation, the maximum airspace capacity will soon be reached. The Ministry of Infrastructure and Water Management has initiated the Dutch Airspace Redesign Program (DARP) or Programma Luchtruimherziening to reform the Dutch airspace. In this program, there are various ongoing policy activities. The Knowledge Development Centre (KDC) performs research in support of some of these activities. Based on a preliminary study conducted by Ferway, NLR and To70, this study is limited to contributing to the development of the MAS for the Netherlands only. Rapid development of MAS is necessary as the first delays in Sector 3 have already been observed during the summer of 2018. The study is limited to the four Dutch airports EHAM, EHEH, EHRD and EHLE.

"In this report the following question is leading: What aeronautical studies are necessary/beneficiary to further implement MAS in the Netherlands?"

For this purpose, similar studies on the MAS are compared with the Dutch airport characteristics. Based on these results, follow-up studies on the further integration of the Dutch MAS can be conducted. In addition to the comparative analysis, the characteristics of several international MAS cities are described to clarify the ways in which MAS has been integrated there. To conduct a comparison analysis, only the available online information and the information provided by the client will be used. In doing so, it is desirable that as much information as possible be made available by the client or by other interested parties who have conducted previous studies on the subject.

The research revealed that the following studies need to be conducted to further integrate MAS in the Netherlands:

- Departure scheduling in a MAS
- Metroplex-wide route planning and airport scheduling tool
- CAP: Collaborative Advanced Planning
- Runway configuration management depending on a MAS
- Usage of short-term ATFCM measures
- Coordinated slot allocation
- Strategic flight scheduling
- National daily ATFCM entity and plan
- Traffic synchronization

Also, the MAS of Paris, London, and Berlin, among others, should be further investigated to discover which MAS system is successful at them and which can also be integrated in the Netherlands.

It is recommended that the above studies will be conducted, and it is important that the MAS of several international cities will be investigated such as Paris, London and Berlin among others. In addition to the MAS cities mentioned above, it is important that other MAS cities are also investigated.

Glossary

Explanations for words that cannot be understood independently

MAS	Multi-Airport System
ATC	Air Traffic Controller
LVNL	Lucht Verkeersleiding Nederland
DARP	Airspace Redesign Program
KDC	Knowledge Development Centre
TMA	Terminal Maneuvering Area
CTR	Control Zones
CTA	Control Areas
CAP	Collaborative Advanced Planning
ATM	Air Traffic Management
LVNL	Luchtverkeersleiding Nederland
ACC	Area Control Center
UTC	Universal Time Coordinated
EHAM	Amsterdam Airport Schiphol
EHEH	Eindhoven Airport
EHRD	Rotterdam The Hague Airport
EHLE	Lelystad Airport
CNS	Communication, Navigation and Surveillance systems
MET	Meteorological Services
ASM	Air Space organization and Management (ASM)
ATFCM	Air Traffic Flow and Capacity Management
ATCO	Air Traffic Controller
FPL	Flight Plan
DST	Decision Support Tool
ANSP	Air Navigation Service Provider
CD&R	Conflict Detection and Resolution
CONOPS	Concept of Operations
DAC	Dynamic Airspace Configurations
DCB	Demand Capacity Balancing
MUAC	Maastricht Upper Area Control
IFR	Instrument Flight Rules
KPD	Key Planning Decision
TWR	Aerodrome Control Tower
APP	Approach Control
GA	General Aviation
ILS	Instrument Landing System
TMA	Terminal Maneuvering Areas
MilATCC	Military Air Traffic Control Centre
TS	Tabu Search
FCFS	First Come First Served
SID	Standard Instrument Departure
CPS	Constrain Position Shifting
MPS	Maximum Position Shifting
IADS	Integrated Arrival Departure and Surface
JFK	John F. Kennedy
LGA	LaGuardia Airport
EWR	Newark International Airport
IAI	Intelligent Automation Incorporated
TBFM	Time-Based Flow Management

TSS	Terminal Sequencing and Spacing
AP	Airport Planner
MP	Metroplex Planner
CADS	Combined Arrival Departure Scheduler
ASM	Airport Surface Manager
TMI	Traffic Management Initiatives
OCC	Operations Control Center
RCCE	Runway Configuration Capacity Envelope
ATDM	Air Traffic Demand Management
RCM	Runway Configuration Management
EMOE	Efficient Multi-Objective Evolutionary
OGIS	Objective Guided Individual Selection
SRCM	Static Runway Configuration Management
DRCM	Dynamic Runway Configuration Management
STAM	Short-Term ATFCM Measures
FMP	Flight Management Positions
CDM	Collaborative Decision Management
ANSP	Air Navigation Service Provider
CDG	Charles de Gaulle
DCB	Demand Capacity Balancing
CASA	Civil Aviation Safety Authority
ANS	Air Navigation Services
TMA	Terminal Manoeuvring Area

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1. Introduction

Dutch airports have grown considerably over time. This growth takes place almost autonomously. No tools are established to balance this growth among airports, routes, or airspace strategically. It is assumed that, without profound reformation, the maximum airspace capacity will soon be reached. The Ministry of Infrastructure and Water Management has initiated the Dutch Airspace Redesign Program (DARP) or Programma Luchtruimherziening to reform the Dutch airspace. In this program, there are various ongoing policy activities. The overarching theme within the Center of Excellence (CoE) is to research how to facilitate continuous sustainable growth of Schiphol mainport.

In the policy development, the relationship between Schiphol Airport and regional airports is examined closely. Presumably, further independent growth of these airports will lead to bottlenecks in the Dutch airspace. In case of autonomous growth at the four airports and without mitigating measures, it will result in a localized hotspot in sector 2 and 3 in the 2035 scenario. Although the DARP aims to address these bottlenecks, the Ministry and KDC also want to carefully consider the ways air traffic can be better handled by jointly managing air traffic. Managing air traffic into multiple, nearby airports is regarded as a multi-airport environment. (Verboon, et al., 2020)

Various conceptual solutions to this problem are performed for other cities and the Netherlands, each of which naturally has its own advantages and disadvantages. By conducting thorough research into the MAS, it becomes clear which problem the MAS solves and how this concept can be used for Dutch aviation.

In this report the following question will be answered: “What aeronautical studies are necessary/beneficiary to further implement MAS in the Netherlands?” This research will be conducted using various literature reviews that have a relationship to implementing a MAS. The research contributes to the collection of relevant studies that have been done on the MAS to indicate to what respect studies differ or add to the outcome of realizing a successful MAS. The outcome of the research are the necessary/beneficiary studies which must be performed for the further implementation of the MAS.

During this research, all documents that have a relation to the MAS will be included in the research, however, the research should be relevant to the implementation of the MAS for the Netherlands. Also, the information should be available to the researcher.

The structure of this report is as follows. Chapter 1 is the introduction of the research this section describes the problem, the objectives, and discusses the methodology. Chapter 2 describes the important definitions which summarizes and structures all the necessary literature. Chapter 3 describes the MAS around the globe to have an insight in the MAS for several international cities. Chapter 4 is the analysis and highlights of the literature in which all the important outcomes of the literature have been given. Chapter 5 comprises the research findings and the recommendations to the research findings. Chapter 6 provides the conclusion and chapter 7 provides further work to the conclusion.

1.1 Problem Statement

This section contains a summary of chapter 5 from the work (Verboon, et al., 2020) to make the problem statement of the assignment clear. Previous studies have looked at the growth and management of Schiphol Airport, The Hague Airport, Eindhoven Airport and Lelystad airport. If they act and or grow independently of each other smaller capacity bottlenecks will appear in 2023 reaching a continuous bottleneck in 2035. This is the case for both airspace as ground operations, but this assignment is only focusing on the airspace operations. If capacity bottlenecks are not solved, for this assignment it could cause disrupted flight planning/ flight execution for the airlines.

Table 1, Table 2 and Table 3 provide an overview of the location of the bottlenecks and their development in future scenarios. The crosses in the tables mean that hotspots are present or estimated to develop in the traffic flow. The color codes indicate whether the hotspot occurs or is predicted to occur during 1-2 hours of the day (yellow), 3-5 hours of the day (amber) or during large parts of the day (red), see the legend below the tables.

		Summer	Winter
Sector 1	Inbound	V	V
	Outbound	V	V
Sector 2	Inbound	V	V
	Outbound	V	V
Sector 3	Inbound	X	V
	Outbound	X	V
Sector 4	Inbound	V	V
	Outbound	V	V
Sector 5	Inbound	V	V
	Outbound	V	V

Table 1: Occurrences of hotspots in 2018 scenario

		Summer	Winter
Sector 1	Inbound	V	V
	Outbound	V	V
Sector 2	Inbound	V	V
	Outbound	X	V
Sector 3	Inbound	X	V
	Outbound	X	X
Sector 4	Inbound	V	V
	Outbound	V	V
Sector 5	Inbound	V	V
	Outbound	V	V

Table 2: Occurrences of hotspots in 2023 growth scenario

		Summer	Winter
Sector 1	Inbound	V	V
	Outbound	X	V
Sector 2	Inbound	X	X
	Outbound	X	X
Sector 3	Inbound	X	X
	Outbound	X	X
Sector 4	Inbound	V	V
	Outbound	X	V
Sector 5	Inbound	X	V
	Outbound	X	V

Table 3: Occurrences of hotspots in 2035 growth scenario

Legend
V = capacity surplus during the entire day
X = capacity shortage during 1-2 hours per day
X = capacity shortage during 3-5 hours per day
X = capacity shortage during large parts of the day

Clearly, sector 3 is of most concern. Hotspots already exist in sector 3 in the summer period and will develop during the winter season. Thereafter, in sector 2 hotspots will also develop based on the growth scenarios. In 2023 still limited, but in 2035 for both inbound and outbound flows and both seasons.

Finally, in sector 1 a specific hotspot is estimated to occur in the 2035 scenario. This is caused by the departures at Schiphol, which show in a large peak of outbound traffic in sector 1 at 19:00-20:00 UTC (see also Figure). In case of autonomous growth at the four airports and without mitigating measures, it will result in a localized hotspot in the 2035 scenario.

In case of autonomous growth at the four airports (Schiphol, Lelystad, Rotterdam and Eindhoven) and no mitigating measures are being taken to alleviate traffic hotspots, the data analysis of traffic flows to and from the considered airports shows:

In the 2018 scenario there is currently a hotspot In ACC sector 3 in the period 7:00 to 8:00 LT. This coincides with the opening hour of both Rotterdam-The Hague airport and Eindhoven airport, these airports generate relatively large outbound peaks after opening at 7:00 LT. Currently there are no hotspots in ACC sectors 1, 2, 4 and 5.

In the 2023 & 2035 scenario the hotspots will (further) develop in ACC sectors 1, 2 and 3. With an autonomous growth of the four airports, traffic flow hotspots will appear during large parts of the day in sectors 2 and 3. No hotspots will develop in ACC sectors 4 and 5 based on the growth scenarios.

1.2 Research objectives

The objective of this assignment is to do desk research on which aeronautical studies are necessary/beneficiary to further implement MAS in the Netherlands. All literature related to the terminal manoeuvring area (TMA) capacity shortage which can help to solve the problem by implementing a MAS will be summarized and included in the project. The objective is met when a plan is developed in which a comparative analysis is made between the available literature and the current Dutch situation. Afterwards it will then become clear what follow-up studies still need to be conducted to further implement a MAS for the Netherlands.

1.3 Main question and sub-questions

Main question:

"What aeronautical studies are necessary/beneficiary to further implement MAS in the Netherlands?"

Sub questions:

1. What is a Multi-Airport System and what are the key features and characteristics of a Multi-Airport System?
2. Which problems are solved by implementing a Multi-Airport System?
3. What aeronautical studies are available regarding the Multi-Airport System related to the problem?
4. What are the current characterizations of the airports within the scope of the project in the Netherlands?
5. What are the differences between the theoretical and practical studies conducted around the world and the arisen problem in the Netherlands?

1.4 Methodology

This chapter explains how the research is done to evaluate the reliability and validity of the study. The paper of Ferway, To70, and NLR: "Multi-Airport Concept: Improved management of air traffic flows in The Netherlands" (Verboon, 2020) was the basis of this research. The research will be based on qualitative research. Concepts will be conceived/developed to carry out follow-up research. A MAS has already been integrated for several international cities, but the question is how the concept could be successful integrated in the Netherlands to optimize Dutch airspace.

The biggest part of the research will consist of desk research and interviews to ascertain the necessary data. The desk research part is mainly in the form of examining the published literature in relation to the MAS. Other literature studies related to ATM optimizations will also be examined and incorporated into the research. Interviews will be conducted with stakeholders, supervisors, and authors of related literature studies. These research methods were chosen because they best fit the topic, there is no testing required at this stage of the research. There is also no need to conduct experiments at this stage, this will be done in the follow-up research.

The product is in the form of a comparative analysis between the characterizations of the available literature and the features and characteristics of the four Dutch airports within the scope. First, the studies will be analyzed in terms of characteristics and then the timeframe on which the study can be fitted (strategic, pre-tactical or tactical) will be indicated. From this, the follow-up research needed for further implementation of the MAS will follow.

The layout has five main points which are:

1. Explanation what a Multi-Airport System is
    - Explanation what the key features and characteristics of a Multi-Airport System are.

2. Problems solved by implementing a Multi-Airport System
    - Figuring out what problems are being solved provides insight into how the implementation of the Multi-Airport System contributes to the mitigation of the problem.

3. Available aeronautical studies regarding the Multi-Airport System
    - Through desk research it becomes clear which studies have been written regarding the implementation of the Multi-Airport System.

4. Characterization of the airports within the scope
    - Create insight into the characterization of Dutch airports within the scope.

5. Differences between the theoretical and practical studies and the problem in the Netherlands
    - Analyze the problem differences between the literature reviews and the problem in the Netherlands.

1.5 Phase 1: Review of existing literature

The first phase will be a qualitative literature review of the available documents and studies that provides an overview of MAS objectives in general with a focus point on capacity issues. The document from (Verboon, et al., 2020) is the most recent paper on the topic and is already defining the problem for the Netherlands. Many other documents on the subject are available that serve as the main source of information. These include:

- (Katsigiannis & Zografos, 2021)
- (Wang & Sui, 2009)
- (Neufville, 1995)
- (Murça & Hansman, 2018)
- (Sidiropoulos, Majumbar, & Han, 2018)
- (Bertsimas, Frankovich, & Odoni, 2011)
- (Lohr, Phojanamongkolkij, & Lohr, 2013)
- (Wang & Zhang, 2021)
- (Yin, Ma, Tian, & Chen, 2020)
- (Choroba & Van der Hoorn, 2016)
- (Bolic, Castelli, Corolli, & Rigonat, 2016)
- (Clarke, Ren, & McClain, 2012)
- (Hu & Geng, 2020)

The scope is not limited to these documents, but it provides an initial step to commence the project in an orderly manner. As the project continues, more will be added to the list. The literature review will serve as backbone of this research, providing a solid understanding of the current problem. So can already be found what related problems were faced in other MAS studies and what kind of characteristics that MAS have.

1. What is a Multi-Airport System and what are the key features and characteristics of a Multi-Airport System?

Several studies have been conducted on the definition of the Multi-Airport System, each with different outcomes. To be able to carry out the research, it should first be determined what the characteristics and features of a Multi-Airport System are. These characteristics and features will be indicated differently again in the various literature resulting in a mix of outcomes.

2. Which problems are solved by implementing a Multi-Airport System?

It should be investigated exactly what problem has arisen and what problem there will be in the future with increasing growth. It should be examined whether these problems are solved by implementing a multi-Airport system. What are the problems that emerge in related MAS studies?

3. What aeronautical studies are available regarding the Multi-Airport System?

To gain a thorough understanding of the various studies that have been conducted on related airspace capacity problems, enough literature needs to be analyzed. These literature studies will have a relation to a similar airspace capacity problem as it arises in the Netherlands and will develop in the future. The literature reviews will be summarized, and the characteristics and properties of the MAS will be examined. Where has a MAS already been implemented, and what are the characteristics of the MAS?

4. What are the current characterizations of the airports within the scope of the project in the Netherlands?

It should be identified what are the characteristics and features of the four airports in the scope of the project. By identifying these data, the international Multi-Airport Systems and other related studies can be compared based on the characteristics and properties. There will be investigated how many aircraft movements take place, how many runways are present and what the orientation of these runways are, what the distance between them is, what procedures are handled (VFR and IFR), and how the airspace is classified.

1.5.1 Phase 2: Implementation of literature for MAS Netherlands

1. What are the differences between the theoretical and practical studies conducted around the world and the arisen problem in the Netherlands?

Various studies have been set up each with its own problem definition, the problem definition of which should be compared with the problem arising in the Netherlands. Besides literature, as much insight as possible will be collected from other international Multi-Airport Systems with related problem settings.

1.5.2 Phase 3: Finalizing the project

Because all the answers have been given to the sub questions with literature review and interviews, the main question of the project can now be answered by doing extra research:

“What aeronautical studies are necessary/beneficiary to further implement MAS in the Netherlands?”

A plan will be developed in which a comparative analysis is made between the available literature and the features and characteristics of the airports within the scope in the Netherlands. Afterwards it will then become clear what follow-up studies still need to be conducted to further implement the multi-airport system for the Netherlands.

Underneath in figure 1 is a timeline projected for the whole project

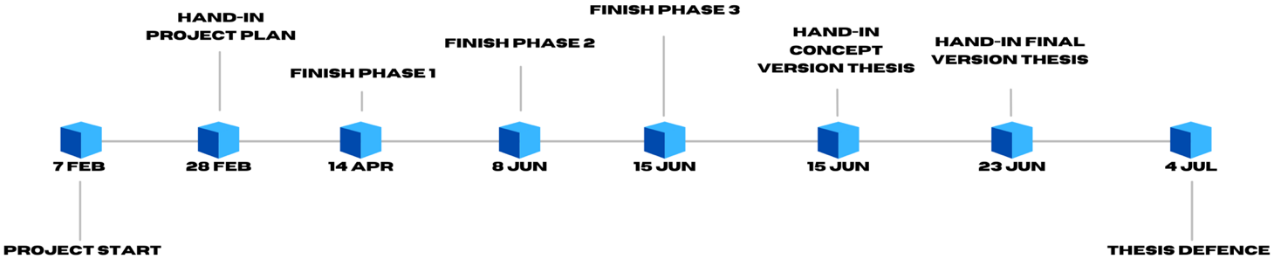

Figure 1: Timeline thesis from project start until thesis defense

2. Important definitions

This section contains a summary of the literature (ICAO, 2012) in which the Air Navigation Services (ANS) are explained. The ATM aims at ensuring the safe and efficient flow of air traffic, based on the technological capabilities (and limitations) of the Communication, Navigation and Surveillance systems (CNS) and the Meteorological services (MET) available. Related ATM services encompass different planning decision-making phases, such as the strategic Air Space organization and Management (ASM), the strategic, pre-tactical and tactical Air Traffic Flow and Capacity Management (ATFCM) services, and the tactical decision-making of Air Traffic Control (ATC) provided to every single flight during the execution phase. Figure 2 provides an overview of the management layer in ANS.

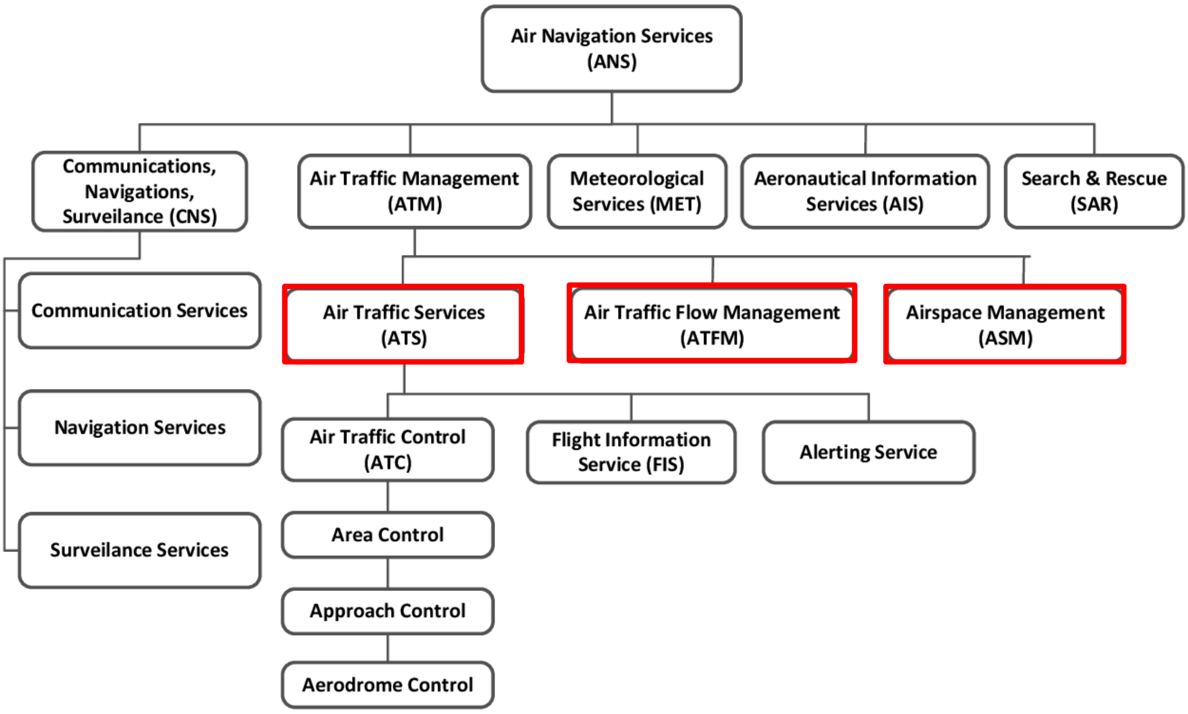

Figure 2: Figure elaborated according to the source ICAO doc 9082 (ICAO, 2012). Three basic air traffic management layers are presented, the ASM (long-term strategic phase), the ATFCM (strategic/pre-tactical and tactical phase) and the ATC (execution phase).

ASM service is in charge of the planning and publishing of the civil and military air routes, the air sectors and the reserved areas, altogether by making use of the information derived from long-term demand and capacity predictions (e.g. one year look-ahead).

- The resulting airspace configuration (i.e., the available airways and sectors), together with the available ground infrastructures (i.e., airports, navaids, ATC officers…) determines the maximum airspace ATM supply/capacity at the day of operations.
- Airlines make use of the (fixed) routes network published by ASM to issue their Filled Flight Plans (FLPs) several days or even months in advance, which express the expected demand of the airspace infrastructures (i.e., airways, sectors, airports…) and ATM services at day of operations.

ATFCM service: is established to utilize the European airspace capacity to the maximum extent possible, while enabling safe, orderly and expeditious traffic flows. The current ATFCM authority in Europe is Eurocontrol CFMU (which will act as network manager in the future ATM-system).

- The main goal of this service is to ensure that supply and demand match in order to avoid (unsafe) overloaded sectors at any time, i.e. Demand and Capacity Balancing (DCB), performed at the day of operations D.
- ATFCM makes a prediction of the airspace demand by computing (through roughly accurate models) the expected trajectories and their evolution over the time from the information of each individual FPL. Also, from the pre-declared information of the ATC operators it is possible to anticipate the available capacity of every airspace sector. Those predictions are refined as the day of operations becomes closer, since the quantity and quality of information used for predictions usually increases.
- ATFCM presents 3 levels of decision-making actions i.e. strategic (from 1 year up to 1 week before the day of operations D), pre-tactical (from 1 week to 1 day before D) and tactical (during all day D).
- In case that any imbalance is detected at day of operations D between the predicted traffic and the available network capacity, the ATFCM shall apply regulations (a regulation is a method of matching traffic demand top available capacity by limiting the number of flights planned to enter in a given airspace or aerodrome, and it is achieved by issuing new departure slots and/or new routes to selected specific flights) to some selected flight (usually but also re-routings and flight level changes).
- ATFM decisions are made using aggregated airspace demand models (i.e., Traffic Flows) with the purpose of not oversaturating the pre-declared capacity of any sector. However, decisions made over individual flights during flight execution are delegated to the ATC services of each specific airspace sector. Therefore, the ATFCM actions do not ensure traffic separation/synchronization at individual flight level, neither there is a precise insight of how ATFCM decisions impact over the ATC sectors workload.

ATC service: is provided by the different ANSPs for the purpose of guiding and facilitating the navigation of each individual aircraft through the different airspace sectors while preserving safety distances among all aircraft during the flight execution.

- The ATC service is provided to each individual flight by different Air Traffic Control Officers (ATCOs) during all the execution phases of a particular flight, i.e. take-off, climbing, cruise/ en-route, descent/approach, landing and taxiing.
- Each of the ATCOs helps different flights crossing their assigned ATC sectors (i.e., with a local/specialized sector view).
- To preserve the safety distances among the traffic, the ATCOs oversee the tactical management of conflicts (i.e., predicted loss of maximum separation between two or more aircraft), also called interactions, and give instructions to pilots whenever necessary to modify their trajectories within the local sector.
- ATCOs of different Air Navigation Service Providers (ANSPs) may use different technologies and Decision Support Tools (DSTs) to assist the traffic in the sectors under their responsibility.
- Conflict Detection and Resolution (CD&R) processes for tactical planning purposes are currently executed with a look-ahead time typically limited to a maximum of 20 minutes (i.e., tactical applications) and with no global Air Traffic Management (ATM) perspective of how the decisions made at local/sector level may affect the rest of the network, i.e. considering the traffic only at local airspace sector level and with little or none coordination with other downstream sectors. In other words, ATC decisions are made with no regards of the potential ATM system.
- ATCOs tasks currently are highly human-dependent. In recent times, some automated tools have been developed to assist ATC during the tactical conflict management. However, in all cases the CD&R processes (automated or not) are making decisions with a local specialized view of the traffic crossing a specific sector and with little or no coordination with other downstream sectors about how the local decisions mutually affect each other and the rest of the network.

Figure 3 illustrates a simplified conceptual representation of the current ATM system (Thomas Prevot, 2003), in which the ATFCM evaluates the inputs received (i.e., current airspace capacity state and intentions of the airlines) in order to predict the future airspace demand, with a look-ahead that comprehends from several hours up to some minutes before flight execution, and apply regulations when needed, i.e. flow constraints.

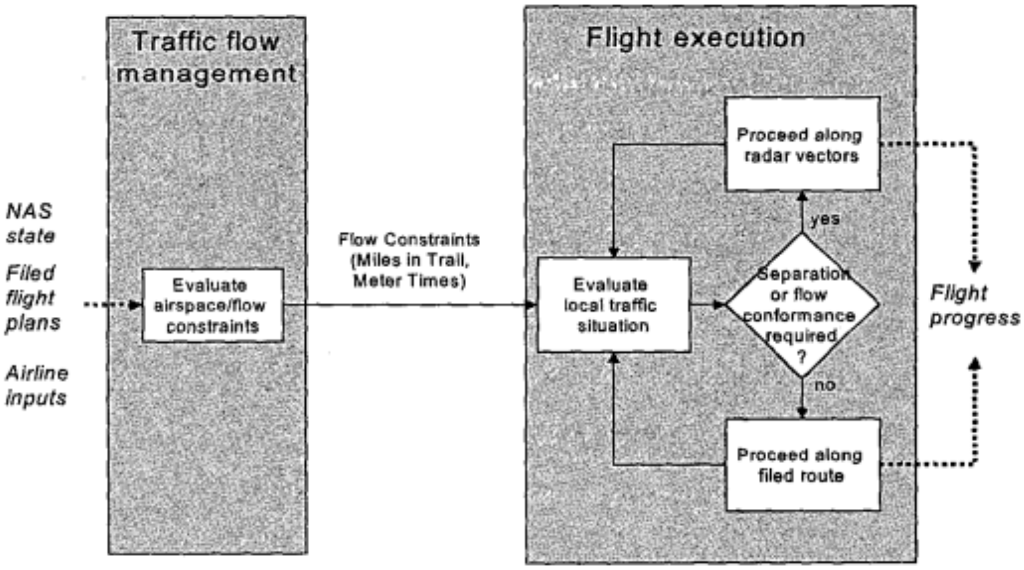

Figure 3: Simplified representation of the current ATM system (the focus of the current ATM is on avoiding any ATC sector oversaturation to ensure the safe aircraft separation; little negotiation opportunities are available for the airlines to re-plan their flights in response to the changing constraints of the network).

When the flights are in the execution phase, the air traffic controllers evaluate the local traffic situation within their sector and then determine whether each individual flight is separated sufficiently from the other traffic and whether the flow restrictions are met. If an action must be taken to maintain the required separation or to achieve the flow conformance (ATFCM actions do not ensure traffic separation/synchronization at individual level), the air traffic controllers typically issue tactical heading, altitude, or speed changes to the aircraft, which are often referred to as radar vectors. Note that these ATC actions, due to their sector-specialized ATM view, do not consider potential downstream traffic interactions and/or de-synchronization. If no controller intervention is required, the flights proceed along their filled routings (but still with no care about traffic synchronization at other sectors). Note that in this (simplified) ATM model the flight planning is conducted by the airlines off-line and prior to the execution phase and expressed through the FPLs. Thus, under this framework there is little flexibility (almost null) on either re-planning a flight or reconfiguring the airspace structure (e.g., routes) during the tactical ATFCM and/or the ATC procedures at execution phase.

2.2 CONOPS

This section contains a summary of the work (SESAR JU, 2019) in which the CONOPS are explained in detail. The Concept of Operations (CONOPS) acts as the primary point of entry to the concept for organizations and individuals both external and internal to the SESAR Program. The context of the CONOPS sees only those concept elements that are relevant to SESAR 2020. This captures development in a timeframe to 2035 and describes areas where operational improvements, supported by technical enablers, bring the expected performance gains to deliver the overall performance benefits in the Single European Sky High-Level Goals (Eurocontrol, 2018) set out in the European ATM Master Plan (SESAR JU, 2020 edition).

Optimized ATM Network Services aim to meet SESAR goals of increasing ATM capacity and providing greater opportunities for stakeholders to optimize their operations - in terms of operational efficiency and environmental gains. This sees full integration of Dynamic Airspace Configurations (DAC) with Demand Capacity Balancing (DCB) and dynamic DCB with ATC planning, alongside Queue Management. This new operation can support optimized trajectories in an environment that includes Free Route, Flight and/or Flow-Centric operations, and use of Collaborative Control. One of the DCB solutions is the integration of a MAS to manage the air capacity.

Improved airport performance and access utilize solutions to allow airports to operate efficiently during periods of high traffic density, extending capability to operate at maximum capacity, even during periods of adverse weather conditions. This is achieved by implementing enhanced runway throughput capabilities, safety nets and more accurate navigation and routing tools. New approach procedures improve operational flexibility and accessibility to airports - even with limited ground navigation infrastructure. Solutions for remote tower services that enable operational coverage to be extended at low and medium-traffic airports also provide safety and operational efficiency benefits to the tower operations.

2.3 MAS through the eyes of R. de Neufville

This section contains a summary of the work (Neufville, Management of multi-airport systems, 1995) in which the MAS through the eyes of R. de Neufville is explained. A multi-airport system is the set of airports that serve the airline traffic of a metropolitan area. The multi-airport system for London, for example, includes among others its major airports: London/Heathrow, London/Gatwick, London/Luton, London/Swanswick, London/City and London/Stansted.

'' It is a set of significant airports, serving commercial transportation in metropolitan area, without regard to ownership or political control. ''

Important points here are that the focus is on airports serving the commercial market, military bases are not included. Fields intended for shows or aircraft production are also excluded. General aviation fields are also excluded. A MAS relates more to a metropolis (an urban area), rather than a single city.

The focus is on the market and does not consider who owns the field. The MAS focuses on significant airports with more than one million passengers per year or 100,000 tons of cargo traffic. Airports within a single MAS often have significantly different numbers of movements. Often there is one primary field, and one or two fields that count 10-50% of the movements of the primary field.

From the perspective of the users, a multi-airport system properly includes all the airports that effectively serve the region. For example, the Baltimore airport is effectively part of the multi-airport system serving the Baltimore-Washington region, even though it is in a different state and under different ownership than the Washington/National and Washington/Dulles airports. It is even called the Baltimore/Washington International Airport. The fact that airports associated with different cities and jurisdictions can be part of the same multi-airport system needs to be stressed. This concept is a definite shift from past thinking, when airport served 'catchment areas', that the Baltimore airports only served Baltimore, the Washington airports only served Washington and so on. This concept is a definite shift from past thinking, when airport planners generally assumed that airports served ‘catchment areas’, that the Baltimore airport only served Baltimore, the Washington airports only served Washington, and so on.

The change to a functional, geographic definition of a metropolitan airport system results from world-wide changes in urban structure. The combined effect of population growth and the spread of rapid modes of transport such as expressways and high-speed rail systems has been to extend cities over much wider areas, merge cities into each other, and create metropolitan regions that function as a unit despite traditional boundaries. Thus, as a practical matter Baltimore and Washington merge as a market for air transport, even though their centers are 60 km apart. Many Washington suburbanites find it more attractive to use the Baltimore airport than either Washington/National or Washington/Dulles.

Airline airports can be considered part of a multi-airport system if they are either: as close as one of the existing major airports for a significant fraction of the metropolitan region, in particular the suburban centers of traffic; or officially so designated by local authorities. time to Bostonians along the ring road than the main airport (Boston/Logan), although two of these airports serve the capitals of different states.

Military facilities, general aviation airfields without substantial airline service and private airports closed to the public, are not part of multi-airport systems for air transport. They must be considered in the context of air traffic control. They can be excluded, however, when considering how to develop airport capacity to serve airlines, passengers, and cargo.

2.4 MAS through the eyes of SEO

This section contains a summary of the work (Wit, Luchthavensystemen, 2007) in which the key features are explained through the eyes of SEO.

“A set of two or more airports that show a substantial share in the airport choice of travelers coming from or having their destination in each metropolitan conurbation. Those airports do not necessarily have to be in or close to the metropolitan area in question.”

Airports that are part of a MAS are not necessarily located in the same metropolitan area. However, MAS airports do have a shared service function for the same metropolitan area. Which airports have a serving function for the same metropolitan area, and thus are a substantial part of passenger choice, depends primarily on pre-trip time, service supply and frequency, and ticket price.

It also follows from the above that a MAS is not a fixed spatial entity. If passenger choice changes, the role of airports in the system can also change. Moreover, if the landside accessibility of airports is improved, new airports can become part of the multi-airport system because they will play a substantial role in the passenger choice process. But also, at the same time we can distinguish several multi-airport systems for one metropolitan area. A distinction can be made, for example, according to type of passenger or type of destination.

In summary, a MAS as a special form of airport system has the following characteristics:

- Two or more airports
- That (can) have a substantial share in the airport choice of travelers from the metropolitan area in question
- That are not necessarily located in the same metropolitan area
- Where it does not matter whether the multi-airport system has regulatory status or is owned by the same owner or operator.

2.5 Application of a system

The two literature reviews did not discuss airport-to-airport cooperation to create a system of airports. The characteristics of a MAS do not address airport-to-airport cooperation to create a system of airports. But via which manner can that airport-to-airport cooperation be established?

2.5.1 What is a system

In science, a system is a coherent entity on which a scientist's attention is focused. A system is an entity composed of several smaller, interrelated, or interacting components, and which exhibits some degree of cohesion, order, and complexity through the relationships among the components. A system can be of any size, from a single atom to the universe. All systems, no matter how different they are, have one commonality: everything is interconnected and interdependent. Any change in one of the parts affects the others. In other words, a system is more than the sum of its parts.

2.5.2 Airport cooperation (system)

As described earlier, in the literature, the phenomenon of the "multi-airport system" is characterized differently from the way the multi-airport system is used in this report. According to the literature, the Netherlands, through its multiple airports, is already characterized as a "multi-airport system", however, the part "system" is not used according to the operation of a "system" as described in Subchapter 2.1.1. Here the definition of a " system " reads:

“A system is an entity composed of several smaller, interrelated, or interacting components, and which exhibits some degree of cohesion, order, and complexity through the relationships among the components.”

For the Dutch airports including Schiphol Airport, The Hague Airport, Eindhoven Airport and Lelystad airport to work together as a "system" to solve the identified capacity problem in sectors 2 and 3, several studies need to be conducted to which this research contributes.

2.6 Operational context

In this chapter an overview is provided of the airports concerned in the study, along with the Air Traffic Control (ATC) sectors and ATFCM toolset of the three service providers: ATC the Netherlands (Luchtverkeersleiding Nederland, LVNL), Dutch Air Force (Commando Luchtstrijdkrachten, CLSK) and Maastricht Upper Area Control (MUAC).

All four Dutch airports studied are part of the Schiphol Group, or N.V. Luchthaven Schiphol. This N.V. has as shareholders the Dutch State (75.8%), the municipality of Amsterdam (21.8%) and the municipality of Rotterdam (2.4%). Schiphol Group manages and operates Schiphol Airport, Rotterdam Airport and Lelystad Airport, and has a 51% share in Eindhoven Airport N.V., which manages and operates the civil part of Eindhoven Airport. Of Eindhoven Airport N.V., the rest of the shares are owned by the municipality of Eindhoven and the province of Noord-Brabant, each owning 24.5%.

The land ownership of the four airports considered is as follows:

- Schiphol's land is owned by N.V. Luchthaven Schiphol, including through its real estate subsidiary Schiphol Real Estate.
- The land of Rotterdam Airport is owned by the municipality of Rotterdam;
- The land ownership of Eindhoven Airport is divided between the Ministry of Defense (including the runway) and Eindhoven Airport N.V. (the passenger area);
- The land of Lelystad Airport is owned by N.V. Luchthaven Lelystad, of which N.V. Luchthaven Schiphol owns 100% of the shares.

2.6.1 Characterizing the airports

This study focuses on four airports (EHAM, EHEH, EHRD and EHLE) in the Netherlands closely located to each other. Their locations are displayed in Figure 4. Schiphol is the international airport, and the other three airports are regional airports. The three regional airports have a single runway with a southwest-northeast orientation. Schiphol has six runways in three different orientations. Schiphol typically uses three of its runways during an inbound or outbound peak and four runways while switching between these peaks. Off-peak two runways are normally used. The complexity of route design is to a great extend caused by many runway configurations that can be applied at Schiphol. (Verboon, et al., 2020)

Figure 4: Four airports within the scope of the project

2.6.2 Schiphol Airport

In 2018, the number of aircraft movements at Schiphol was 499,444 and 12,584 for general aviation. The number of passengers was 70.9 million. Therefore, the average number of passengers per passenger aircraft movement was 142.

Schiphol Airport has six runways of which three are parallel to each other: 18L/36R, 18C/36C and 18R/36L and three other runways which are all in different directions: 06/24, 09/27 and 04/22.

The actual capacity of Schiphol is a derivative of the limit values included in the Schiphol Airport Traffic Decision, whereby the applicable noise restrictions are normative. These restrictions mean that the maximum number of annual flight movements is limited to approximately 500,000. This is a global estimate that is highly dependent on the type of aircraft, flight procedures, runway use and the way in which noise impact is measured and allocated.

Incidentally, for the functioning of Schiphol as a hub, the runway capacity per hour is particularly important. Currently, the peak capacity is approximately 110 aircraft movements per hour. This is higher than Heathrow (about 90), but slightly lower than Charles de Gaulle (about 120), Frankfurt (about 126). Clearly, the construction of additional runways will increase Schiphol's peak hour capacity and thus its reliability to handle the busy flight schedules, thus improving Schiphol's functioning as a hub. (Wit, Luchthavensystemen, 2007)

2.6.3 Rotterdam The Hague Airport

In 2018, the number of aircraft movements at Rotterdam Airport was 53,322, including 14,637 for passenger aircraft, 13 for cargo aircraft and 38,672 for general aviation and other aircraft. Passenger flights are mainly scheduled flights and to a lesser extent charter flights. The number of passengers in 2018 was 1.9 million. The average number of passengers per aircraft was therefore 122. (Rotterdam The Hague Airport, 2021)

Rotterdam Airport has one runway with a length of 2200 m and a width of 45 m. The runway length is therefore relatively small, and extension is impossible given the fact that the airport is sandwiched between provincial and national roads. The direction of this runway is 06/24.

Rotterdam Airport is slot-coordinated and operational 24 hours a day. A few restrictions apply during the evening and night hours, during the night the airport is not in commercial use, with a few exceptions:

- Between 18:00 and 08:00 there is a ban on noisy, large aircraft;
- Between 23:00 and 07:00, the airport is only open for aircraft with technical failures, rescue flights, emergency medical flights (e.g. for organ donations), diversions (aircraft that cannot land at their destination airport due to weather conditions, for example), business passenger flights with smaller aircraft, police and coastguard;
- Between 23:00 and 00:00, takeoffs and landings of delayed large aircraft are allowed (under certain conditions) as well as landings of large aircraft of the quietest category;
- Between 00:00 and 01:00, delayed silent large aircraft are allowed to land;
- From 06:00, landing position flights are allowed (aircraft coming in without passengers to start service after 07:00);
- The state (the Minister of Transport and Public Works) can grant exemption in other (special) cases.

2.6.4 Eindhoven airport

Eindhoven Airport has traditionally been a military airport that is also used for civil aviation. In 2018, the number of civil aircraft movements was 38,642. The number of passengers was 6.2 million in 2018. Eindhoven has direct scheduled services to European business destinations, low-cost carrier flights and charter flights, both for business and vacation traffic. The average number of passengers per passenger aircraft was therefore 160. Eindhoven Airport has one runway with a length of 3000 m and a width of 45 m. (Eindhoven Airport, 2018). The direction of this runway is 04/22.

Like Schiphol and Rotterdam, the capacity of Eindhoven Airport is determined by noise restrictions. These noise restrictions are based on the exemption from the (military) designation under the “Wet Luchtvaart”, whereby the noise consumption of civil aviation is deducted from the noise allowance for the military airport. However, in practice, this military noise space is not flown full, which theoretically creates the possibility that the exemption for civilian traffic could be increased.

2.6.5 Lelystad Airport

Lelystad Airport was opened in 1973. Until 1988 it rapidly developed into the Netherlands largest airport for small aviation, operated by the regional and local authorities of that time. In 1988 the airport became an independent NV, whose shares were transferred to Schiphol Group in 1993.

The current traffic at Lelystad Airport involves approximately 150,000 aircraft movements per year, consisting mainly of recreational and training flights. There are also many business flights, advertising flights, agricultural flights, and helicopter flights. Part of the air traffic at Lelystad Airport is general aviation that was relocated from Schiphol in the 1990s. So far, no commercial passenger flights have been carried out at Lelystad. There is also no commercial cargo traffic.

The current runway is 1250m long and 30 m wide. The direction of the runway is 05/23. Since November 7, 2019, air traffic control has been introduced at Lelystad Airport. LVNL and CLSK (Commando Luchtstrijdkrachten) are jointly responsible for handling air traffic. The departure and arrival routes for Instrument Flight Rules (IFR) traffic are not available for commercial traffic until the political decision on the opening for commercial traffic.

The development of Lelystad Airport aims to accommodate scheduled and charter flights to European destinations with appropriate passenger aircraft of limited size, including Boeing 737 and Airbus A320 (ICAO code C). To this end, the runway will be extended to 2100 m and reinforced to accommodate heavier traffic. The current width of 30 m will be maintained. Also, a parallel taxiway will be constructed, and a new passenger area will be developed on the north side of the runway. In 2004 the Key Planning Decision for airports Maastricht and Lelystad was adopted. This KPD assumes for Lelystad approximately 140,000 aircraft movements for "small" aviation in 2015 and 60,000 movements for "large" aviation, of which 30,000 for helicopters and 30,000 for aircraft. Of these, approximately 14,000 movements involve aircraft of the type Boeing 737 and Airbus A320, with which low-cost carriers usually fly. (Wit, Luchthavensystemen, 2007)

2.6.6 Characteristics airports

Schiphol Airport has six runways of which three are parallel and three other runways which are all in different directions, Rotterdam airport has one runway, Eindhoven airport also has one runway, Lelystad airport. Table 4 shows the characteristics of the four airports within the scope. Schiphol is currently the largest airport in terms of aircraft movements in The Netherlands. To put Rotterdam and Eindhoven Airport in perspective: they both have around 10% of that number of movements. Schiphol has reached its capacity of 500.000 commercial flights before COVID. This is an environmental ceiling, not an operational ceiling. From 2021 there is potential for growth up to 540.000 commercial flights, this growth has yet to be earned with noise reduction measures. Both Rotterdam and Eindhoven are reaching their environmental capacity limits, there is currently no plan for further growth. Lelystad has no commercial flights now. A cap of 45,000 commercial flights (Lelystad Airport) is currently set for the period until the airspace redesign has been accomplished.

	Aircraft movements	Main runways	Distance from Schiphol
Amsterdam Airport Schiphol	512,028	18R/36R, 18C/36C, 18L/36L, 09/27, 06/24, 04/22	-
Rotterdam The Hague Airport	28,947	06/24	25 NM
Eindhoven Airport	38,645	03/21	55 NM
Lelystad Airport		05/23	30 NM

Table 4: Characteristics of the airports within the scope

2.6.7 Airspace regulator

Annex 11 to the Chicago Convention (ICAO, 2001) states that the State must determine in which parts of the airspace and airports over which it has jurisdiction air traffic services must be provided. Subsequently, the State must designate an air traffic service provider for this purpose.

The ''Wet Luchtvaart'' regulates in article 5.13 that air traffic services by the Dutch state are deposited with Air Traffic Control the Netherlands (LVNL) and the Ministry of Defense. Section 5.14 of the same law also designates the Eurocontrol organization to provide air traffic services in parts of Dutch airspace (namely above FL245) and makes provision for special situations where other organizations may also provide air traffic control.

These situations tend to involve areas where it is more operationally practical to delegate airspace (permanently or otherwise) to an adjacent air traffic services organization (such as parts of the lower airspace over the North Sea in connection with helicopter operations). (Ministerie van Infrastructuur en Milieu en Ministerie van Defensie, 2012)

2.6.8 Airspace classification

The Dutch civil airspace is divided into several air traffic control areas, namely (from lower to higher airspace) the Control Zones, the Terminal Manoeuvring Areas, the Amsterdam Control Areas, and the Upper Control Areas.

Eindhoven Airport differs from the other airports in this study as it accommodates military traffic. For this reason, Eindhoven Airport has military tower (TWR) and approach (APP) control that handles both the civil and military traffic. In the future concept, civil ATC only is assumed. This will standardize operational procedures and information sharing among units.

Lelystad Airport differs from the other airports in this study as it currently only handles general aviation (GA) traffic. The Dutch government has decided Lelystad will be opened for commercial flights; it is not yet known when the first commercial flights will be scheduled. In the future concept, commercial flights will be assumed to take place.

2.6.9 Control zones (CTR)

Control zones (Platform Nederlandse Luchtvaart, 2013) are in the immediate vicinity of an airport, the Control zones (CTR), LVNL's Tower Control, is responsible for air traffic services. Because of the Instrument Landing System (ILS), rectangular protrusions have been created at Amsterdam Airport Schiphol and Rotterdam The Hague Airport to allow the final approach procedure to fall completely within the CTR. At Amsterdam Schiphol Airport, these two rectangular protrusions became separate CTRs, namely CTR 2 and CTR 3, due to different vertical boundaries. The CTRs and TMAs of the Dutch airports within the scope are shown in figure 5. The vertical ranges of the various CTRs are shown in Table 5.

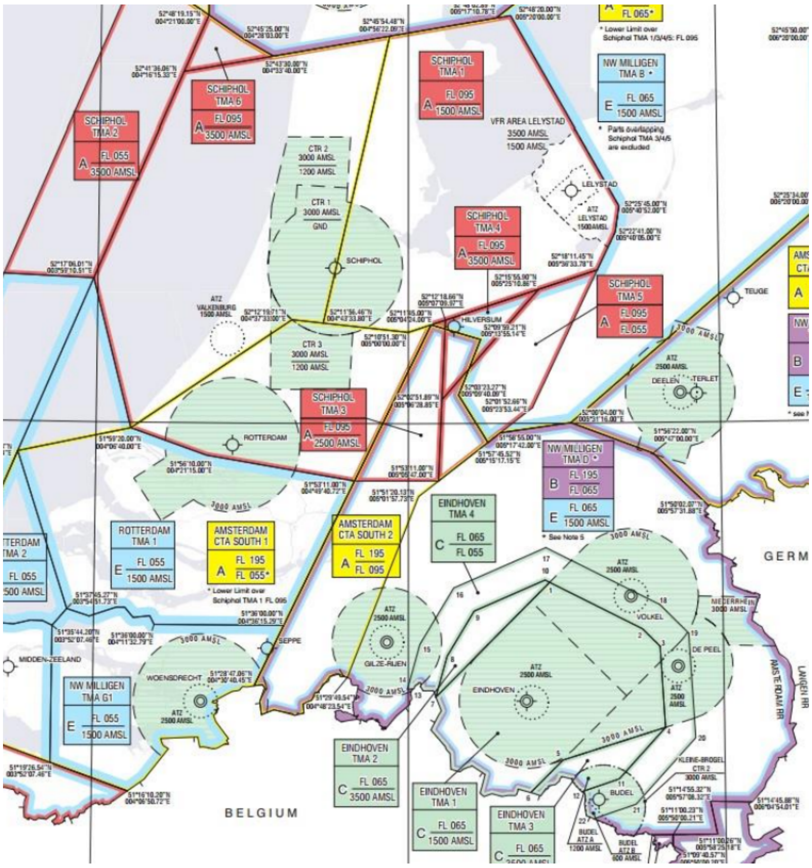

Figure 5: CTRs and TMAs of airports within scope

CTR	Vertical range under	Vertical range above	Airspace classification
Schiphol 1	Ground	3000 ft	C
Schiphol 2	1200 ft	3000 ft	C
Schiphol 3	1200 ft	3000 ft	C
Rotterdam	Ground	3000 ft	C
Eindhoven (military)	Ground	3000 ft	C

Table 5: Vertical ranges and airspace classification CTR

2.6.10 Terminal Manoeuvring Areas (TMA)

The Terminal Maneuvering Areas (TMA) (Platform Nederlandse Luchtvaart, 2013) delineate the work area of Approach Control (APP). This ATC is responsible for approaching, controlled traffic from the handover by the higher (or adjacent) ATC until the final approach, and any traffic that crosses the relevant airspace. In addition, they are responsible for departing, controlled air traffic from the airport via the departure routes. In the Netherlands, civil TMAs have been established for Schiphol, Rotterdam, Maastricht and Eelde airports. In contrast to CTRs which in higher airspaces, altitude is calculated with reference to the standard pressure of the International Standard Atmosphere. This standard pressure usually does not correspond to the real air pressure and therefore in the lower airspaces the barometric pressure at sea level is used. Unlike CTRs which all have airspace classification C, no standard class applies to TMAs in the Netherlands. The vertical boundaries are also less unambiguous than for CTRs. Table 6 shows the specifications for civil TMAs within the Netherlands. Eindhoven airport is an airport where both military and civil activities take place. Like the Eindhoven CTR (Gordijn), the TMAs used by air traffic are also military in nature.

TMA	Vertical range under	Vertical range above	Airspace classification
Schiphol TMA 1	1500 ft AMSL	FL 095	C
Schiphol TMA 2	3500 ft AMSL	FL 055	C
Schiphol TMA 3	2500 ft AMSL	FL 095	C
Schiphol TMA 4	2500 ft AMSL	FL 095	C
Schiphol TMA 5	FL 055	FL 095	C
Schiphol TMA 6	3500 ft AMSL	FL 095	C
Rotterdam TMA 1	1500 ft AMSL	FL 055	E
Rotterdam TMA 2	2500 ft AMSL	FL 055	E
Rotterdam TMA 3	3500 ft AMSL	FL 055	E
Eindhoven TMA 1	1500 ft AMSL	FL 065	C
Eindhoven TMA 2	1500 ft AMSL	FL 065	C
Eindhoven TMA 3	3500 ft AMSL	FL 065	C
Eindhoven TMA 4	3500 ft AMSL	FL 065	C

Table 6: Vertical ranges and airspace classification TMA

2.6.11 Control Area's (CTA)

The Control Areas (CTA) delineate the working area of Area Control Center (ACC) which is responsible for handling air traffic in the en-route phase of flight along the air traffic routes. In addition to the air traffic routes, the arrival routes of various Dutch airports are also located in the CTAs. For Schiphol Airport there is also a holding area in the CTAs, at the point where the approach procedure begins. For the other airports this point, and the holding areas lie within the TMA. Table 7 shows the vertical range specifications for civil CTAs within the Netherlands.

TMA	Vertical range under	Vertical range above	Airspace classification
CTA West	FL 055 (Above Schiphol TMAs FL 195)	FL 195	A
CTA South 1	FL 055	FL 195	A
CTA South 2	FL 095	FL 195	A
CTA East 1	FL 065 (Above Schiphol TMAs FL 095)	FL 195	A
CTA East 2	FL 095	FL 195	A

Table 7: Vertical ranges and airspace classification CTA

2.6.12 ATC-sectors

In the Amsterdam Flight Information Region (FIR) (Verboon, et al., 2020), ATC is provided by three service providers: LVNL, CLSK and MUAC. Each service provider manages their designated parts of airspace. Provision of ATC is divided into different sectors, so the resulting tasks have a manageable workload for Air Traffic Controllers (ATCO). ATC sectors usually have a declared capacity. The declared capacity is expressed as the maximum number of aircraft entering a specified portion of airspace per hour, taking due account of weather, ATC unit configuration, staff, and equipment available, and any other factors that may affect the workload of the controller responsible for the airspace.

Generally, an increased demand is met by the provision of more sectors so that the traffic (and workload) is divided over more controllers. Usually, this demand is calculated as short-term operational predictions based on planned flights. Opening/closing of sectors should closely monitor the demand to achieve efficient use of all available resources. The opening of new sector does not guarantee the sum of the capacities of the elementary sectors – the combined capacity is a combination of factors such as traffic flow direction, coordination procedures, in-sector flight times, etc. Therefore, a specific capacity figure is calculated for every sector configuration.

The four airports concerned in the study are each enclosed by their specific Control Zone (CTR) and Terminal Control Area (TMA). The concept of ATC sectors generally applies to en-route airspace specifically, in Dutch lower airspace serviced by the ATC units of Amsterdam Area Control Centre (ACC) at LVNL and Military Air Traffic Control Centre (MilATCC) Area (CLSK) and in upper airspace by MUAC.

2.7 Departure scheduling in a MAS

This section contains a summary of the work (Wang, Hu, & Yong, 2009) in which the departure scheduling study is explained. The first one is the scheduling of aircraft for departure and the second is merging departure flights onto their filed routes in a congested airspace environment.

The purpose of departure scheduling in this study in a MAS is to determine an optimal sequence and takeoff times under different objectives. These objectives include maximizing the runway throughput, minimizing the total delay, and ensuring airlines or airports equities in the departure sequence.

The proposed model and algorithm are performed on a real case study of Shanghai Terminal Area with departure flights from Shanghai HongQiao International Airport and Shanghai PuDong International Airport. The model can be applied to any case study with a MAS.

Shanghai has two airports, Hongqiao to the west and Pudong to the east of the city. Since Hongqiao is only used for domestic flights and some short connections to Korea and Japan, if you are flying from Europe, you will always arrive at Pudong. This is Shanghai's largest and newest airport. In table 8 the Shanghai airport characteristics over the two airports in the region are shown. Figure 6 shows how the airports are stationed relative to the region. PuDong International airport has two pairs of parallel runways. Of each runway pair, one runway is designed for departures and the other one for arrivals. HongQiao International airport only has one runway which is used for arrivals and departures.

	Aircraft movements	Main runways	Distance from PuDong
Shanghai PuDong International Airport	146,000	35L/17R, 34R/16L, 35R/17L, 34L/16R	-
Shanghai HonqQiao International Airport	109,500	18/36	28NM

Table 8: Shanghai airport characteristics

Figure 6: Airports within Shanghai region

There will be developed a new model and an efficient algorithm for computing an optimal departure sequence in a MAS terminal area. The efficient algorithm is a tabu search algorithm which is developed and implemented to obtain reasonable solutions within acceptable computation times.

The most common way of sequencing departure flights has been to maintain the First-Come-First-Served (FCFS) order. AFCFS schedule is easy to implement, and it also maintains a sense of fairness. Obviously, a drawback of the FCFS schedule is that it may limit the throughput of runway due to large spacing requirement.

A departure time window will be assigned to a particular aircraft, to which the aircraft must adhere. These time windows impose an earliest and latest departure time for an aircraft. If any aircraft missed its time window, it will be delayed for another chance of allocating time window. To comply with the separation rules a scheduling modeling for MAS departure sequence and departure times for a given set of flights is made. When scheduling flights in a MAS, the sequences of flights passing intersection points have great impact on the entire terminal area operating effectively and efficiently.

During the research, there will be made a new model for solving departure scheduling problems in a MAS. The fairness among airliners was guaranteed by the CPS (Constrain Position Shifting). In the CPS framework, there has a certain degree of flexibility to shift an aircraft in the FCFS sequence by a small number of positions. The Maximum Position Shifting (MPS) as an important parameter is introduced to specify the maximum number of positions an aircraft can shift from its FCFS order. Consequently, CPS may increase runway throughput while ensuring some degree of fairness.

Via this algorithm the shared departure fixes will result in an enhancement of terminal capacity. Departure traffic interaction between airports can bring the unfairness among airports. Fortunately, this can be eliminated by a reasonable departure control strategy. Some improvement to the departure scheduling may be including the airliners preferences in the model.

The algorithm only focuses on departure flights and not on arrival flights.

Additionally, a tabu search algorithm has been built and realized to get a global optimal solution of the problem. Via this algorithm the shared departure fixes will result in an enhancement of terminal capacity. Departure traffic interaction between airports can bring the unfairness among airports. Fortunately, this can be eliminated by a reasonable departure control strategy. Some improvement to the departure scheduling may be including the airliners preferences in the model. Integral scheduling departure and arrival flow in terminal area will be another challenging aspect in ATFM field.

2.8 A metroplex-wide route planning and airport scheduling tool

This section contains a summary of the work (Frederick Wieland, 2014) in which the airport scheduling tool is explained. Metrosim is targeted at the solution to a full integrated arrival- departure and surface (IADS) problem at a Metroplex, including all surface as well as Metroplex airspace constraints and dependencies within the Metroplex. The goal is to optimize the sequencing, runway assignment, and route allocation to maximize throughput, increase safety, and minimize the environmental footprint. This paper presents a promising approach with an initial feasibility study using data from the New York Metroplex.

New York has three large airports, and millions of people use them each year. The three major airports are the John F. Kennedy International Airport (JFK) which is in Queens and offers mainly international flights. LaGuardia Airport (LGA) is also located in Queens and primarily domestic flights land and depart there, so if you are flying to New York from anywhere in the United States, chances are you are flying into this airport. The third major airport is Newark International Airport (EWR). This airport is in New Jersey and there are both domestic and international flights. In table 9 the New York airport characteristics over the three airports in the region are shown. Figure 7 shows how the airports are stationed relative to the region. JFK has two runways, two pairs of parallel runways. LaGuardia has two runways in different directions. Newark does have three runways of which two are parallel and one is in a different direction.

Airport	Air Traffic Movements	Main runways	Distance from JFK
JFK International Airport	455,529	4L/22R, 4R/22L, 13L/31R, 13R/31L	-
LaGuardia Airport	372,025	4/22, 13/31	10NM
Newark International Airport	458,674	4L/22R, 4R/22L, 11/29	21NM

Table 9: New York airports characteristics

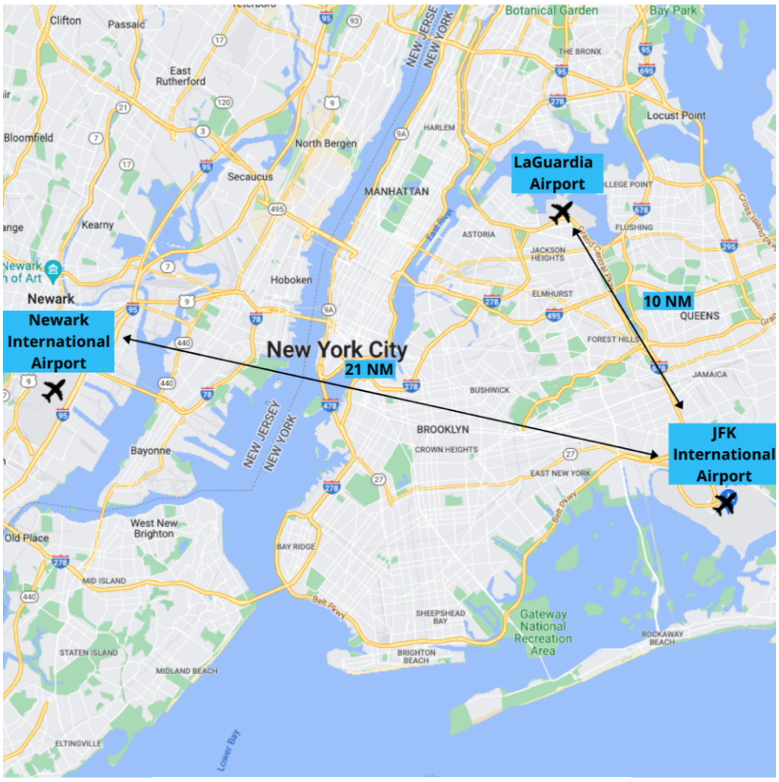

Figure 7: Airports within New York region

Researchers have devised a solution, called Metrosim, that solves the IADS problem not only for a single airport with multiple parallel and intersecting runways, but also for a group of airports in a Metroplex, including the sometimes-complex interactions among them and the structure of the airspace within the Metroplex. Metrosim is designed and implemented in prototype form and have run tests using recorded data at the New York TRACON (N90) to get a quick look as to whether Metrosim meets the requirements. The design of Metrosim will be showed and how it is meeting the requirements, at a high level, and provide the results of the initial feasibility tests.

Integrated arrival, departure, and surface scheduling (IADS) is currently an active area of ongoing Air Traffic Management (ATM) research. Seamlessly integrating the flows into and out of an airport without building expensive infrastructure and allowing a diversity of aircraft types to be efficiently controlled. Metrosim solves the IADS problem not only for a single airport with multiple parallel and intersecting runways, but also for a group of airports in a Metroplex, including the sometimes-complex interactions among them and the structure of the airspace within the Metroplex.

The basic requirement is that a IADS tool needs to consider arrival, departure, and surface operations simultaneously. Merely optimizing departure operations while assuming that the arrival stream is fixed by the enroute system ignores the reality that the airport’s throughput can sometimes be increased by managing both streams simultaneously. This requirement begs the question as to how the tool might interact with enroute control tools, such as Time-Based Flow Management (TBFM) or the Terminal Sequencing and Spacing (TSS) tools.

The requirements are that a Metroplex-wide IADS tool maximize the Metroplex throughput, minimize airborne travel time and distance, minimize departure queues, minimize surface congestion, maintain the current or produce greater levels of safety, as well as minimize fuel burn, emissions, and noise. Finally, there is a requirement that an IADS tool that is used in an operational environment as a decision support system must run in real time and connect to the relevant control systems.

Optimizing the Metroplex flows and adhering to operational realities can sometimes be conflicting and recognizing that the run time of Metrosim must be fast enough for implementation as a decision support tool for controllers, the design relies on a distributed two-phased approach. In phase one each airport individually optimizes its own operations (arrival, departure, and surface), passing the results to a second phase which considers constraints in the Metroplex airspace and other operational realities to adjust the local airport’s plan to reach an operationally feasible solution.

To do so, Metrosim is divided into two major components: an Airport Planner (AP) and a Metroplex Planner (MP). The Airport Planner is, itself, divided into two closely coordinated modules, a Combined Arrival Departure Scheduler (CADS) and an Airport Surface Manager (ASM). There is one instance of the Airport Planner (CADS and ASM) resident at each airport in the Metroplex. In figure 8 the architecture diagram of Metrosim is shown.

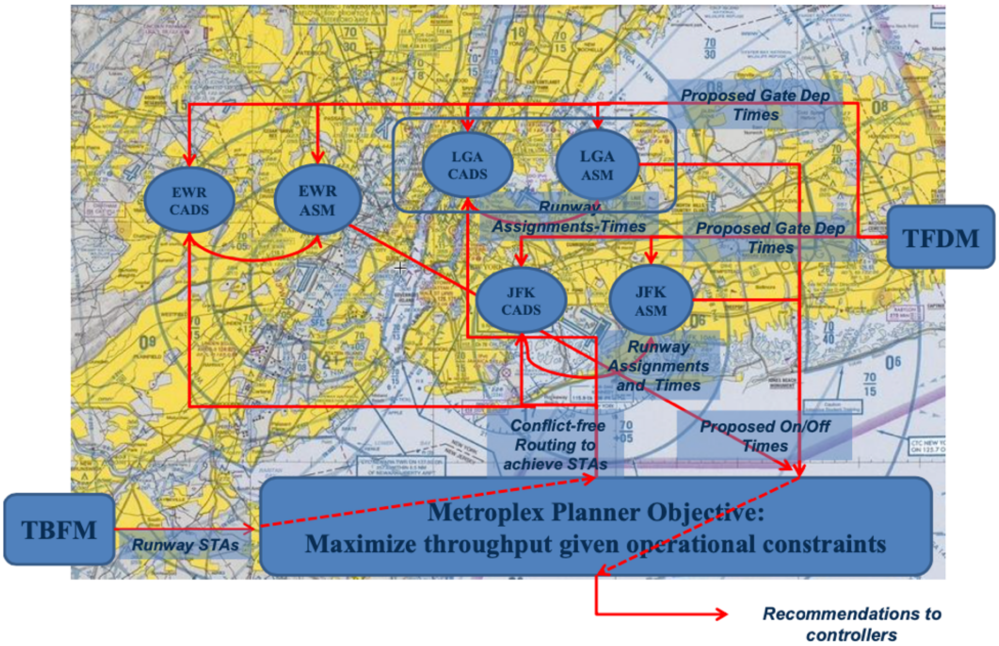

Figure 8: Architecture diagram of Metrosim

Metrosim can be loaded with an entirely different airspace design and routing structure, or with different types of aircraft, or with a mix of conventional and remotely controlled aircraft, or with additional runways and taxi paths. In such a research mode, Metrosim acts like an exploratory tool that can be used to assess the utility of experimental Metroplex designs. A system like Metrosim as a series of communicating sequential programs appears to be the right strategy for developing a full IADS solution, at least the initial results indicate that the architecture is promising.

The feasibility experiment, as limited as it is, shows that Metrosim has potential to realize its goal of increasing the efficiency of Metroplex operations. These results presented, however, are unconvincing to a skeptic. Extensions to the feasibility experiment and more robust testing are underway to fully evaluate this idea.

The main result is that Metrosim is able to successfully schedule 97 minutes of recorded departures in only 75 minutes. On other words, the set of departures that require 97 minutes to exit the Metroplex boundary in the recorded data require only 75 minutes if the Metrosim gate departure times, taxi paths, and departure routes are used instead. This compression of departure times increases the Metroplex throughput considerably. On average, in each 15 minute time bin, Metrosim increased departure throughput by about 15%. A system like Metrosim as a series of communicating sequential programs appears to be the right strategy for developing a full IADS solution, at least the initial results indicate the architecture is promising.

Finally, we have learned that air traffic controllers prefer predictable, repeatable patterns in the airspace. Metrosim is architected to work with the airspace design and to improve its performance. The design which Metrosim uses is input to the tool. For a real-time decision support system that controllers would use, the current airspace design for a Metroplex such as N90 would be used. Preferred routes, both in the air and on the ground, can be considered first so that repeatable patterns of traffic are produced for the controllers.

2.9 Traffic flow patterns in multi-airport systems

Efficient planning of airport capacity is key for the successful accomplishment of traffic flow management. Yet, the dynamic and uncertain behavior of capacity determining factors makes it difficult to estimate flow rates precisely, especially for strategic planning horizons. MAS impose additional challenges in this decision-making process because of relevant operational interdependencies between the closely located airports. By presenting a data-driven framework to identify, characterize, and predict traffic flow patterns in the terminal area of MAS an improved capacity planning decision tool will be established in a complex airspace. Through the identification and characterization of patterns in the terminal area traffic flows, there will be obtained recurrent utilization patterns of runways and airspace as well as relevant decision factors and use that knowledge to develop descriptive models for MAS configuration prediction and capacity estimation.

The features/characteristics of the New York region is already explained in subchapter 1.12.

The data-driven approach for identification, characterization and prediction of traffic flow patterns is based on a modular framework for sequential application of machine learning techniques. Figure 9 provides a high-level description of the framework. In a first step, a multi-layer clustering analysis is performed to identify and characterize traffic flow patterns from historical flight tracks. For this, flight tracks are first clustered at the spatial dimension to identify spatial trajectory patterns, which define the as-flown route structure. Based on this knowledge, a trajectory classification scheme is developed to match new flight trajectories with the learned airspace structure. Once trajectories are classified, flows are identified as temporally associated flight trajectories conforming to the same standard route. Finally, clustering is performed at the temporal dimension to identify patterns in air traffic flows. Based on the knowledge generated by the multi-layer clustering process, classification techniques are used to predict traffic flow patterns over time. The knowledge generated is used to develop a classification scheme for prediction of traffic flow patterns.

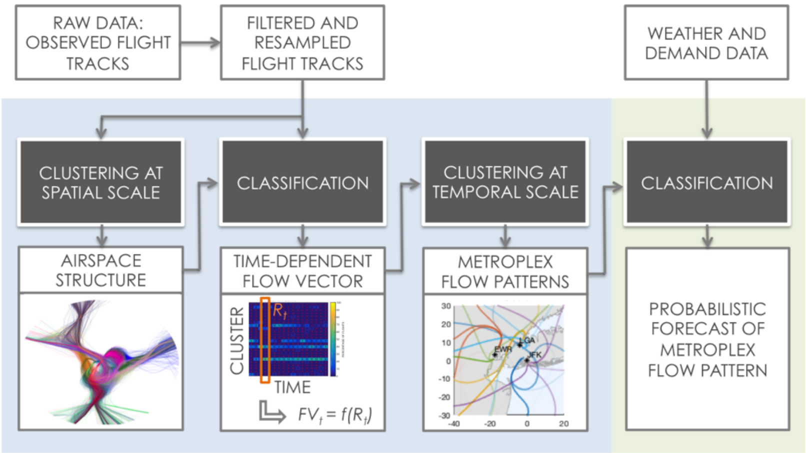

Figure 9: Schematic overview of machine learning framework

Airport capacity planning is a challenging aspect of TFM. Flow rate predictions are required to determine the need of Traffic Management Initiatives (TMI) (e.g., Ground Delay Programs) and plan the regulation of the traffic, but they depend on several factors/decisions that are uncertain, especially for long time horizons. Because airports are closely located and the terminal airspace is shared, runway and terminal airspace configuration decisions must be coordinated to de-conflict the arrival and departure flows and minimize interferences. Because of the existence of constraining inter-airport flow interactions, the capacity of individual airports becomes highly dependent on the global MAS configuration. Currently, the planning of runway/airspace configurations and capacity in the NAS is typically done based on experience and through the use of rules-of-thumb.

As the observed patterns in the terminal area traffic flow reveal recurrent utilization patterns of runways and airspace, a "reverse-engineering" approach is taken to identify the major configurations in which the MAS collectively operates as well as key intervening factors. The knowledge generated by the characterization of metroplex flow patterns is then used to develop descriptive models for metroplex configuration prediction and flow rate estimation.

The selection of the runway configuration in which an airport will operate is a subjective human-based decision-making process, which is per se affected by various factors such as meteorological conditions (wind, speed, direction, ceiling, and visibility), demand, noise and workload related restrictions and terminal airspace constraints.

Through the identification and characterization of patterns in the terminal area traffic flows, there will be learned recurrent utilization patterns of runways and airspace as well as relevant decision factors and use that knowledge to develop descriptive models for metroplex configuration prediction and capacity estimation.

The observed variability in throughput and terminal area delay performance emphasizes the importance of metroplex configuration predictability toward improved flow rate planning and ultimately better traffic regulation. The knowledge generated by the characterization of metroplex flow patterns is then used to develop descriptive models for metroplex configuration prediction and flow rate estimation.

This research is only focusing on the Identification, Characterization, and Prediction of Traffic Flow Patterns and not on a MAS solution.

A multi-way classification model is developed using machine learning (random forests) to generate probabilistic forecasts of the MAS flow pattern for an eight-hour planning horizon. For the New York multi-airport system, the classification model showed an average prediction accuracy of 83% for a short-term 1-hour forecast, 63% for a 3-hour forecast, and 52% for longer look-ahead times. Future research goes along this direction by exploring the development of higher-fidelity models for airport capacity prediction that take as input detailed weather information and metroplex configuration forecasts to deliver probabilistic capacity forecasts for strategic TMI planning.

2.10 CAP: Collaborative Advanced Planning

This section contains a summary of the work (Christophe Hurter, 2016) in which the CAP project is explained and how it is integrated for the Paris region. European Air Traffic Management (ATM) mostly relies on strategic, pre-tactical and tactical traffic flow procedures based on post-operation analysis. The Collaborative Advanced Planning (CAP) process was designed using walkthrough methods and ecological interface design. As traffic demand increases, some air traffic control sectors are becoming real bottlenecks for which the implementation of daily regulations can no longer be the sole solution to address airspace congestion and induced critical delays for airlines and passengers. With an estimated price of $81 per minute of delay alongside with the recent evolution of European air passenger rights, most of airlines top concern is flight on-time performance. DSNA, the French ANSP designed a new approach to better distribute the traffic demand according to the control sector capacities available: The Collaborative Advanced Planning (CAP) process. This collaborative approach introduces a new pre-tactical flow-centric method for Demand and Capacity Balancing in the European Network.

The Paris region consists of two major airports: Paris CDG and Paris Orly. Orly airport accommodates the domestic flights by Air France and is also the main hub for Transavia France, whereas CDG airport is the main hub for international Air France flights and is served by members from the alliances Star Alliance, OneWorld and SkyTeam. Almost all traffic at Orly is point-to-point traffic. Additionally, Le Bourget serves general aviation traffic. CDG has two pairs of parallel runways. Of each runway pair, one runway is designed for departures and the other one for arrivals. This efficient design led to a programming capacity in 2017 of 120 movements per hour. Orly and Le Bourget have converging and crossing runways. Details of the Paris airports characteristics can be found in table 10. In terms of air traffic movements, CDG is the biggest airport and Orly comes in second. Together they serve around 700,000 flights. In figure 10 the airports stationed relative to the region are shown.

Airport	Aircraft movements	Main runways	Distance from CDG
Paris - CDG	480,945	08L/26R, 08R/26L, 09L/27R, 09/27L	-
Paris - Orly	229,052	06/24, 08/26, 02/20	20 NM
Paris – Le Bourget	60,325	03/21, 07/25, 09/27	5 NM

Table 10: Paris airports characteristics

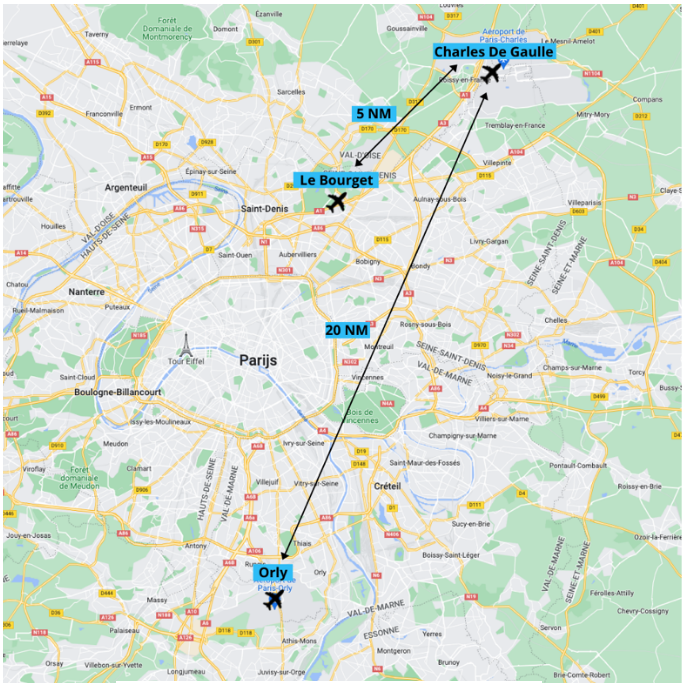

Figure 10: Airports within Paris region

Once the modelling of the CAP was built, the next step consisted in testing and calibration. A first set of flight planning scenarios in the French airspace was defined: cruising level capping, early descent towards a set of destinations and free requests.

High demand of flights on elementary air traffic control sectors results in high delays, extra-fuel burn and CO2 emissions, and may also lead to safety issues due to the destabilization of the aviation network. Flow management positions in Area Control Centers suggest to airline operations centers delay-free routes for the most capacity impeding flights within the French airspace. Instead of spreading flight demand over time, this innovative approach aims at spreading the demand in space, relying on local expertise and enhanced collaboration.

In the airline operation control centers, the organization of the tasks related to flight planning changes from one airline to the others. Depending on who oversees making the decision to change a flight plan, traffic managers, senior flight planners, flight planners and chief of operations were met during these walkthroughs in their premises in London, Manchester, Dublin, and Amsterdam.

For each flight, the first flight plan (FPL) is filed and distributed to every ANSP at least six hours before the estimated time of departure (distribution is ensured by the NM, part of Eurocontrol). If updates on a FPL are communicated later than two hours before departure, the flight is tagged as late updater and subject to more impeding measures. When a flight is delayed because of its flight plan, its route can be modified by the airline operations to try avoiding the congested (and regulated) sectors based on their knowledge of the overall environment.

The global design of the CAP process relies on mutual understanding of front-line operators from ACCs and from OCCs. Constraints of both parties are explained to each party and a presentation of possible exchange timing is extracted: this drives to Collaborative Decision Making in En-Route airspace management. To meet ACCs requirements in terms of flight distribution in the available airspace, the initial flight plan demand must be known. This demand is available when all flight plans have been first filed, for the shortest flights between 6 and 4 hours before their estimated time of departure. Changes on these flight plans may be achieved between 4 hours and 2 hours before the estimated take off time. These requirements defined the timings of figure 11.

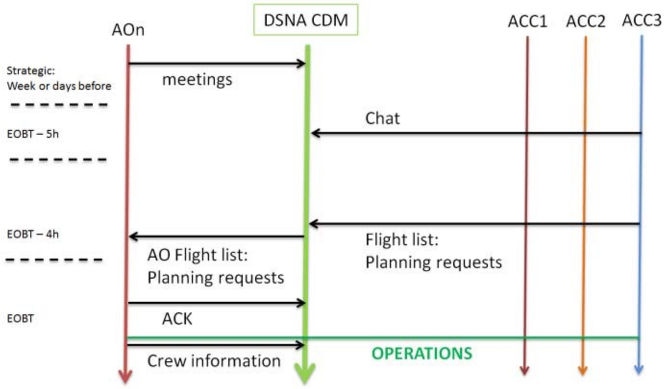

Figure 11: CAP timing. The process involves strategic meetings and daily collaboration between the stakeholders that starts 5 hours before the potentially impacted flights leave their parking stand (Estimated Off Block Time – EOBT).

Fruitful collaboration relies on data that are tactically extracted from operational systems: flight name (A/C ID), airports of departure and arrival (ADEP and ADES), Estimated Off Block Time (EOBT) and current filed route.

The first live trial enabled to save 5,481 minutes of initial delay over three days by amending 23 flight plans in a flow of more than 200 daily flights. The flight plan demand is now streamlined in the French busiest sectors by acting on less than five FPL for each peak (figure 12) rather than delaying hundreds of flights and generating thousands of minutes of delay.

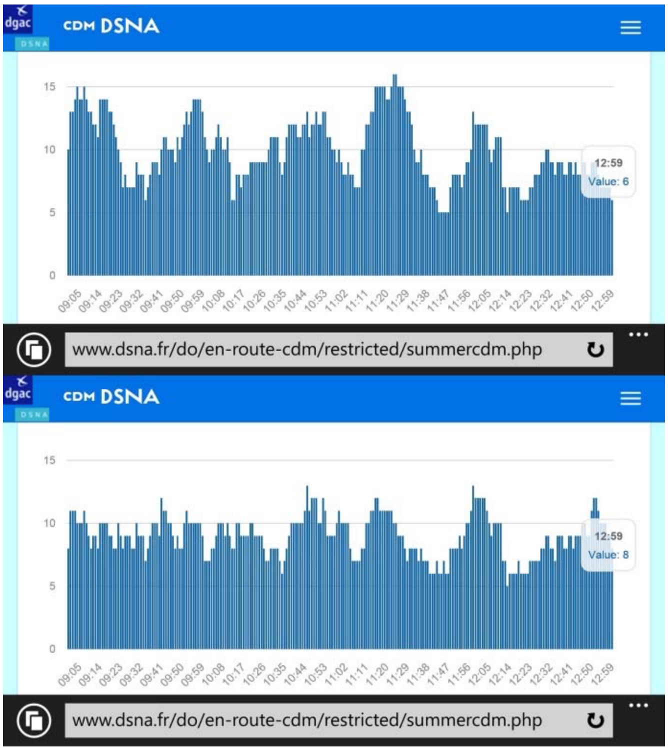

Figure 12: Evolution of the flight plan demand in HYR sector while the CAP process is run between all stakeholders. The first graph demand represents the initial flight plan demand over time when operators started the process. The second one depicts the demand after flight plans where balanced between upper and lower sectors: traffic peaks are mitigated.

Benefits of this process is that it allows ATC flow management units to suggest delay-free flight trajectories and/or cruising levels to airlines operations with the objective to prevent control sectors from congestion and induced delays.

Follow-up research should show whether this process can also be implemented for the Netherlands and whether it is enough to solve the entire problem.

From July 7th to September 13th 2015, the CAP process was run 62 days over 69. 628 flight plan changes were suggested to the airline's operations. 92% of these requests were implemented by the airline OCCs. The traffic in the considered sectors (5R) increased by 6% during summer 2015 compared to summer 2014 while the delay was reduced by 52% during the summer 2015. ATC is really pleased with this collaboration, showing that the French ANSP can work closely with the airspace users to improve the global performance through innovative and collaborative ATFCM (Air Traffic Flow and Capacity Management) methods.

2.11 Impact analysis of demand management on runway configuration in metroplex airports

This section contains a summary of the work (Yin, Yuanyuan, Tia, Chen, & Hu, 2020) in which runway configuration management based on a MAS is explained. Growing air traffic congestion in airports and metroplexes is a major concern in the global air transport system due to the imbalance between increasing demand and insufficient capacity. The resulting low performance, such as conflict, queue, and delay, experienced at high density traffic airports, poses significant costs to relevant stakeholders including air navigation service providers, airports, airlines, and passengers. Congestion in airports and metroplexes is increasingly becoming a key bottleneck in the global air transport system. It is largely due to inefficient utilization of runway resources and its consequences of imbalance between demand and capacity. Existing studies mainly focus on runway configuration in a single airport system, and little consideration is given to the impact of demand management on runway configuration in metroplexes. The objective is to propose a methodology and assessment framework for runway configuration with a focus on the exploitation of multiple active runways in metroplex airports.

The features/characteristics of the Shanghai region is already explained in subchapter 1.11.

A multi-objective runway configuration model will be formulated to enhance the performance of integrated runway operations in metroplex airports, considering a series of Runway Configuration Capacity Envelope (RCCE)-based Air traffic Demand Management (ATDM) options. The ATDM options reflect the priority settings for arrivals and departures based on different cases of demand and capacity imbalance. In other words, for a certain runway configuration with a known RCCE, the selection of ATDM options defines the nature of flight adjustment which in turn has a significant impact on runway configuration. The model will not only be applied for managing runway configuration, but also to evaluate the impact of ATDM options on runway configuration.

A novel framework will be designed to optimize the dynamic runway configuration in metroplex airports and assess the impact of ATDM options on runway configuration. The methodology improves the flexibility of ATDM and Runway Configuration Management (RCM), and performance of runway operations in different assessment scenarios. The proposed framework allows for the application of a set of priority coefficients for arrival and departure movements to obtain expected computational results of flight adjustments. The contributions of the research are summarized as follows:

- The framework focuses on dynamic and integrated runway configuration in the Shanghai metroplex system with 2 high-density traffic airports ZSPD and ZSSS, and analyzes the impact of ATDM options on runway configuration by establishing in detail 4 cases / 6 sub- cases of demand-capacity imbalance and 3 options of RCCE-based ATDM
- The formulated dynamic RCM (DRCM) and static RCM (SRCM) models optimize 3 objectives of cost, total number, and maximum number of flight adjustment, subject to a variety of constraints. There are designed 3 assessment scenarios with 11 priority settings for arrival and departure movements and establish the relationship between assessment scenarios and ATDM options.
- Computational results show that the DRCM model has a significant advantage over the baseline SRCM, and the minimum total number configuration is the best choice to make satisfactory tradeoffs among cost, total number, and maximum number. A higher priority for departures is suggested to reduce the number of adjusted flights.

Most of the existing studies of RCM optimization mainly focus on a single-objective optimization in a single airport system. The RCM problem in metroplex airports involves different concerns from air transport stakeholders such as minimizing flight delay, maximizing the rate of flight punctuality, and maximizing airport slot utilization in multiple airports. The framework can provide some significant references about multi-runway operations (configuration, sequencing and scheduling) in a metroplex system or a single airport system, which brings significant benefits to air traffic demand management and runway capacity utilization in hub-airports and metroplex systems at the pre-tactical (i.e. one-day planning) and tactical (i.e. several-hour rolling horizon) levels. The framework can be used for both arrivals and departures.

The selection of runway configurations will change based on the needs of the MAS this may bring drawbacks such as noise and other environmental considerations. Also, there should be little wind to adjust the configuration to the favorable MAS configuration. The proposed framework does not have the same problem statement as the problem of why runway configuration management would be chosen in a MAS system in the Netherlands, but this study can be well used for further research on the framework.

The framework proposed a methodology to assess the impact of ATDM options on runway configuration in metroplex airports. From the results the DRCM model can reduce the total number of adjusted flights in metroplex airports by 42.2%, 29.0% and 37.2%.

2.12 Towards a more harmonized and wider use of short-term ATFCM measures (STAM)

This section contains a summary of the work (Choroba & Van der Hoorn, 2016) in the STAM concept is explained. STAM is a demand and capacity balancing (DCB) procedure which allows flight management positions (FMPs) to identify pre- regulation hotspots and apply short term air traffic flow and capacity management (ATFCM) measures. It is a collaborative (CDM) process involving all partners to ensure that equity is maintained. The STAMs such as ground delays, flight level capping and horizontal re-routings are applied to a limited number of flights helping to avoid a considerable amount of the (sometimes unnecessary) ATFCM ground regulations and delays. The objective is to summarize the results of one of the three validation exercises that were carried out in SESAR R&D program under the P13.02.03 project (SESARju, 2019).

The report focuses on single airports and not on multi-airports within a certain region. The parts within the trial are Brest, Reims (DSNA); Zürich, Geneva (SkyGuide); Swanwick (NATS UK); Maastricht (MUAC); Karlsruhe, München, Langen, Bremen (DFS); Roma (ENAV). For the purposes of this report the features/characteristics of Zürich, Geneva will be outlined during this section.

Zürich Airport also known as Flughaven Zürich is the largest international airport of Switzerland and the principal hub of Swiss International Airlines. The airport is located 13 kilometres north of central Zürich. In table 11 the Zürich airport characteristics are given. Figure 13 shows how the airports are stationed relative to the region. Flughaven Zürich has 3 runways, all three of them are in different directions.

Airport	Air Traffic Movements	Main runways	Distance from Zürich
Flughaven Zürich	132,600	10/28, 14/32, 16/34	-

Table 11: Zürich airport characteristics

Figure 13: Airports within Zürich region

Current network performance and flight operations are impacted by ATFCM measures imposed on individual flights to prevent situations that traffic demand exceeds available ATC and Airport capacity. In the European system the short-term ATFCM planning is taking place the day before and day of operations to adjust the

Demand Capacity Balancing (DCB) plan, i.e. to detect residual overloads and to apply mainly a ground delay regulation plan at the airport departure to smooth the overloaded traffic.

The first STAM live trial took place over 3 days in November 2011. The STAM concept was successfully demonstrated with very limited tool support, but the low number of participating airlines and Air Navigation Service Providers (ANSPs) did not enable to collect representative enough data of acceptable quality. A recommendation was made to organize a large-scale live trial covering most of the core-European airspace.

In the SESAR program framework, the main improvement is to provide a new dynamic DCB process based on procedures and technics aiming at bridging the gap between the short-term ATFCM planning and the ATC execution phase (Gawinowski, 2014). It allows local flow manager (FMPs) in ACCs to play a key role in the reduction of traffic peaks by applying STAM Measures such as minor ground delay, flight level capping or small re-routings.

To resolve declared hotspots, STAM solutions are investigated seeking minimum impacts on Airspace Users, such as Cherry-picking actions based on the identification of the flights creating the complexity, using enhanced flight list attributes providing FMPs with an accurate flight status and aircraft attitude. Possible measures included the allocation of minor ground delays to specific flights, flight level reassignments or route changes negotiated with Airspace Users and, in the last resort, interventions on airborne flights coordinated with adjacent FMPs where needed. A simplified what-if (simulated Occupancy Count) allows the FMPs to analyze whether the planned STAM measures resolve properly the hotspot.

The STAM Measures allow ACCs to play a key role in the reduction of traffic peaks by applying measures such as minor ground delay, flight level capping or small re-routings. Rather than applying a penalizing regulation to a group of flights, an FMP may target individual flights with STAM Measures while accommodating Airspace User preferred solutions.

The use of STAM Measures versus ground delay regulations reduces drastically the number of impacted flights, reduces the average delay, and increases the flight efficiency. It releases a certain part of ATC capacity “frozen” with the regulation mechanism.

A limitation in the use and the assessment of the STAM concept and tool was the number of aircraft operator participants. Even if 8 airlines were involved in the live trial, more airlines would be required to facilitate the choice of most appropriate flights for STAM and the coordination between the actors involved in the Collaborative Decision Management (CDM) process.

There was an occasional issue reported, when a single flight was caught by both the STAM and Civil Aviation Safety Authority (CASA) regulation. A rule was created as a follow on to avoid these cases to happen again (to avoid double penalty and increased workload).

Because the test was conducted for multiple airports that are not located in a multi-airport region, this study will not be included in the comparative analysis.

(Workflow and coordination states shall be tailored to the needs of the individual STAM measures. The Role and Responsibility of FMPs in the CDM process and workflow were clear, but roles should be fine-tuned according to the defined STAM scenarios. Despite some positive subjective assessments, the overall result was that FMPs were not confident with the use of prototype STAM support tools in operational conditions. Main issues were around the interaction time consumed by measure creation and coordination tasks. It was suggested that development of local tools and predefined scenarios could probably solve 90% of the problems in an adequate timeframe.)

The STAM concept has progressed well in the SESAR 1 R&D program towards the end of V3 maturity phase, although it still made a few important recommendations for the pre- industrialization phase – to be tackled in the context of the SESAR2020 R&D.

3. Multi-Airport Systems across the globe

3.1 Paris Region

The Paris region consists of two major airports: Paris CDG and Paris Orly. Orly airport accommodates the domestic flights by Air France and is also the main hub for Transavia France, whereas CDG airport is the main hub for international Air France flights and is served by members from the alliances Star Alliance, OneWorld and SkyTeam. Almost all traffic at Orly is point-to-point traffic. Additionally, Le Bourget serves general aviation traffic.

The characteristics of the airports within the Paris region have already been given during the explanation of the CAP project during chapter 1.14.

3.1.1 Dual Multi Airport System

Paris has a dual Multi Airport System. The airports in northern part of the TMA - these are Charles de Gaulle, le Bourget, Creil (military field) and Pontoise - form their own Multi Airport System for which Charles de Gaulle controls the traffic. For the TMA south, Orly controls traffic for Toussus le Noble, Villacoublay (military) and Bretigny. Paris has created a system with SIDs and STARs (although the last part is fighter controlled) that are strategically interwoven. If the wind changes and Charles de Gaulle changes the runway configuration, the configuration for le Bourget, Creil and Pontoise (TMA north) also changes with it. The same is true for Orly and the TMA south. The south TMA and the north TMA are not obliged to adapt to each other, but through good coordination with each other they often use the same configuration. It is only difficult to coordinate during thunderstorms and strong westerly winds, about 2% of the time. Still, it results in using the same configuration 99% of the time.

3.1.2 ATC sectors

Paris ACC provides air traffic services within certain parts of the TMA at flight level 115 and above. Paris CDG APP and Paris Orly APP provide air traffic services within the other parts of the TMA. The northeast sector of the TMA is controlled by De Gaulle APP, the southwest sector by Orly APP. There is permanent radar service for all sectors. Paris CDG, Le Bourget, Paris Orly and Villacoublay (military airbase) are all located in the Paris CTR which is class D airspace. Pontoise and Melun have a dedicated CTR with a TMA with class D airspace, where also flights operating under VFR are allowed.

3.1.3 Route design and procedures

The route design for Paris CDG and Orly is separated by design to reduce dependencies and optimize capacity. Both airports use a similar four corner posts methodology. Paris CDG has four entry TMA entry points and Orly has three for their arrivals. These points are in the corners of the TMA, departure route will use exit points in between. At each entry point there is a dedicated holding pattern for Paris CDG /Le Bourget and Orly. Route design is based on RNAV1 principles.

Paris CDG and Le Bourget use two main runway configurations: west and east. Normally, if Paris CDG changes the runway configuration, Le Bourget will adapt theirs, due to operational dependencies. It only rarely happens that the two airports operate oppositely, because this will have operational constraints. Figure 14 and Figure 15 show the main runway configurations and the indicators of the associated standard instrument departure routes.

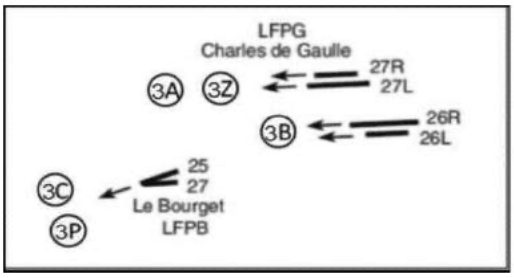

Figure 14: Runway configuration west

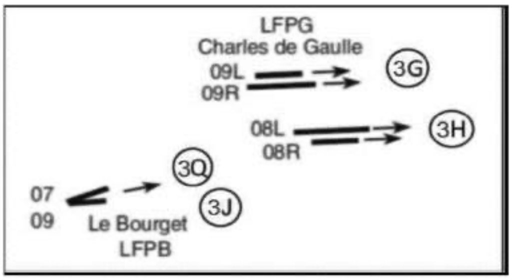

Figure 15: Runway configuration east

3.1.4 Point-merge concept

In 2013, the point-merge concept was introduced in Paris ACC. It is used to sequence arrivals at the four IAFs of Paris ACC. Figure 16 shows a specific route design for Paris CDG arrivals using point merge and Figure 17 depicts the resulting tracks during an inbound peak.

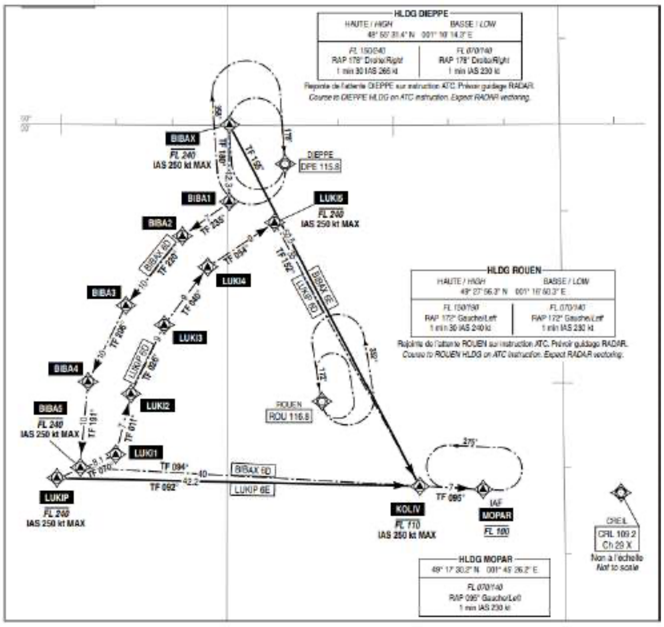

Figure 16: Point merge route for Paris CDG

Due to its systematic character, point merge allows for maximization of inbound capacity at an IAF while allowing the merge of multiple arrival flows. Point merge increases predictability while preserving track miles and flight time (SESAR JU, 2012). When considering point merge, or any other path stretching technique, in a multi-airport concept within Dutch airspace, it is important that it will be used in a planned way or working and not in a tactical way. The background is that with 3D separated trajectories in the TMA, delay absorption in the TMA will not be possible any longer. Consequently, arriving flights will have to be delivered accurately at the TMA entry point, and a planned way of working that combines speed adjustments and path stretching/shortening is deemed necessary to achieve a high precision at the TMA entry point in accordance with the AMAN planning.

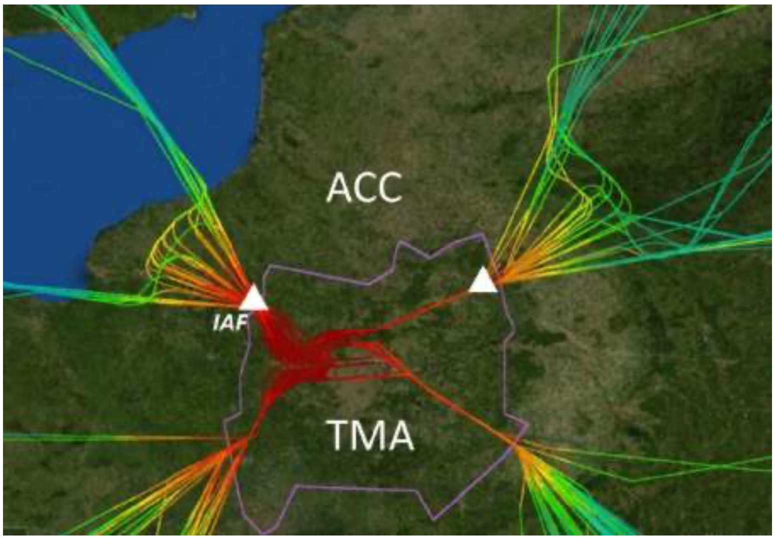

Figure 17: Point merge in Paris ACC to Paris CDG

3.1.5 ATFCM Collaborative Measures

DSNA has taken several ATFCM collaborative measures (which they refer to as “the MAC project”) for Paris ACC and adjacent Upper Area Control (UAC). The various levels of measures are described in the following paragraphs.

3.1.6 Pre-tactical: Target Time of Arrival trials (2017 - present)

During the summer of 2017, Target Time of Arrival (TTA) trials were performed in Paris ACC to optimize arrival times at Paris-Orly airport. From May to October 2018 this was repeated for Paris CDG. DSNA developed their own experimental tool and interface for Cross Border Arrivals Management (XMAN) within the Paris region called iAMAN. Using Mode Control Panel (MCP), the FMP can assign a TTA to a flight. This is then fed to the (Network Manager) NM, which calculates the corresponding Calculated Take Off Time (CTOT).

From January until June 2019, a new Orly trial phase was initiated. During this trial phase, 81% of the 102 flights with a priority request were adjusted. The trial was during many days not active due to lack of ATFCM regulations (which is a prerequisite), and technical or meteorological issues. Furthermore, not all requests could be granted due to too late or incorrect requests or other technical reasons. From August until September 2019, the Orly trial was expanded with an interface called AFLEX, allowing airlines to set priorities of their flights via a web portal. AFLEX is basically an improved slot-swap procedure, but with a lot of added value in terms of directly involving both NM and local ATC. During this trial, only one swap with another flight and four arrival time improvements were requested. 60% of those requests were fully or partially accepted.

3.1.7 (Pre-)tactical: Collaborative Advanced Planning (CAP)

Collaborative Advanced Planning (CAP) by DSNA aims to have aircraft operators refile their flight plans when hotspots are predicted. The CAP web portal is currently used by KLM, Easyjet, British Airways, Ryanair, Air France, Air Lingus, Vueling, Transavia and others. Besides the AO, German ANSP DFS and Spanish ANSP ENAIRE are also involved.

In the case of a predicted overload, the flight is listed and highlighted to the FMP. The FMP can provide route suggestions to the AO directly or via chat functionality. An example suggestion is shown in Figure 18. When the system detects a flight plan is refiled and the foreseen conflict is resolved, the flight will move to the green table. By encouraging the aircraft operators to proactively refile their flight plans, regulations by the ANSP may be prevented.

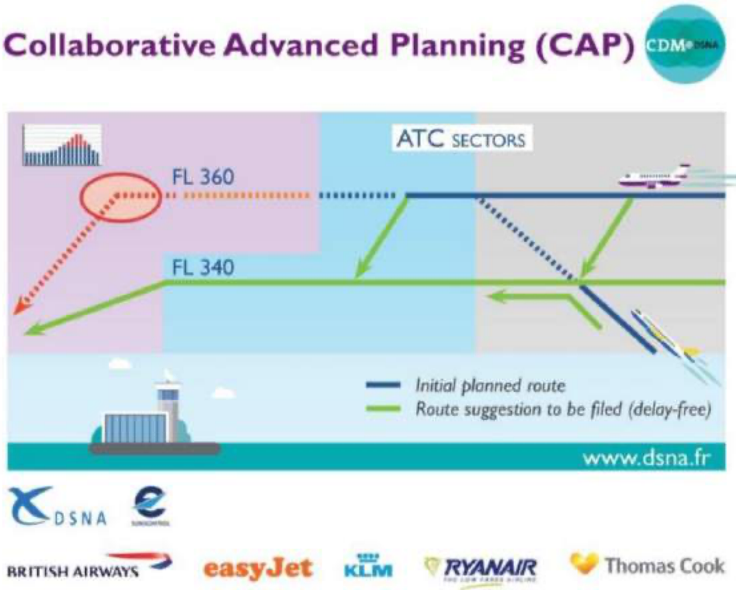

Figure 18: Collaborative Advanced Planning DSNA

3.1.8 Airspace structure

The entire Paris area is covered by the Paris TMA. The TMA structure is indicated in Figure 19. A schematic of the vertical profile can be seen in Figure 20. The vertical structure of the TMA is sometimes referred to as an upside-down wedding cake. This TMA shows nine different levels on top of the airport's control zone that ends at 2.000 ft. The airspace classification is exclusively A; therefore, no traffic operating under Visual Flight Rules (VFR) is allowed.

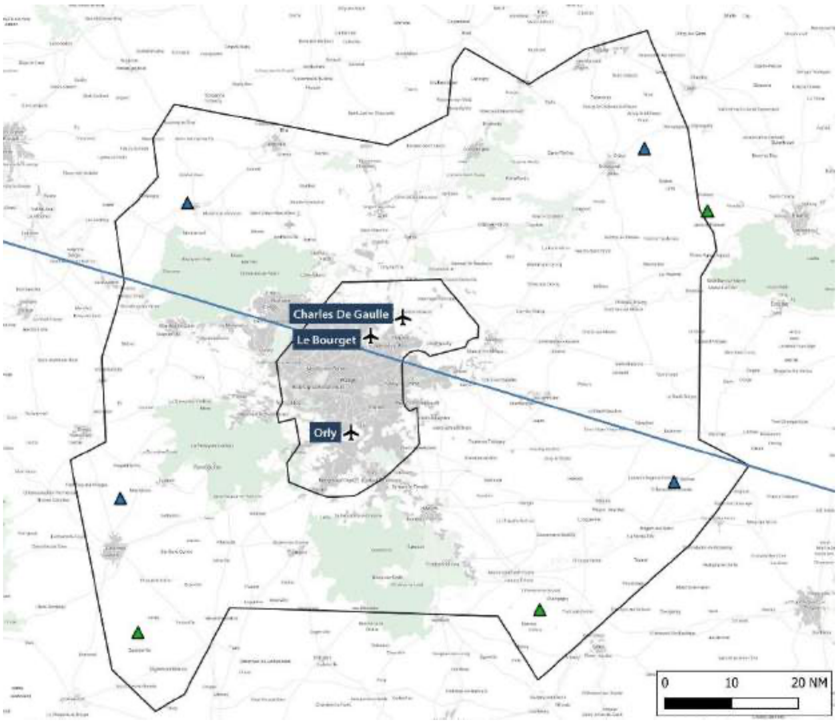

Figure 19: Paris CTR, TMA 7 and IAFs for Paris CDG, Le Bourget and Orly Airport

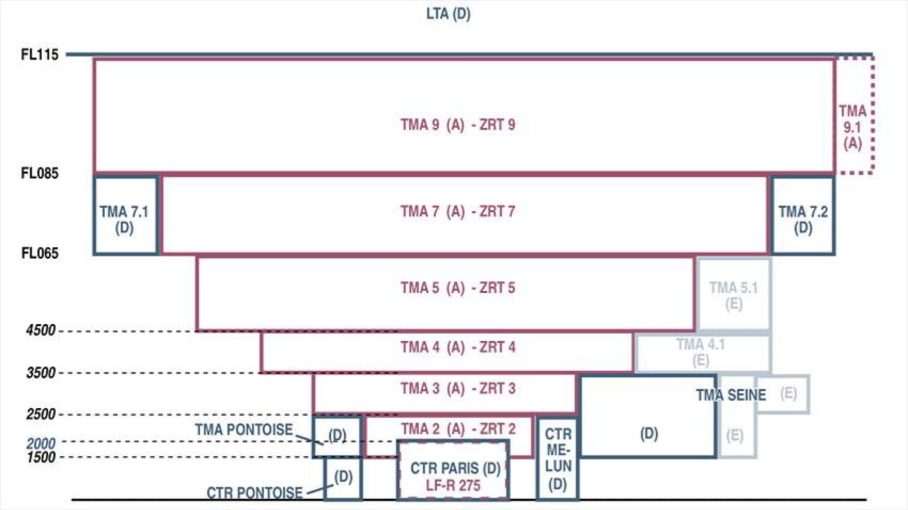

Figure 20: Schematic airspace structure of the Paris region

3.2 London Region

The London region consists of six main international airports: Heathrow, City, Gatwick, Luton, Stansted and Southend. Heathrow and Gatwick can be regarded as the main hubs. Combined they account for more than half of the total 1,213,033 movements carried out by the six main airports in the London area in 2018. To put these movements into perspective, the smallest airport in the London area: Southend, has a comparable number of movements as the second largest airport in The Netherlands: Eindhoven Airport. Heathrow and Gatwick are the only airports with multiple runways, both airports are having two runways which are parallel to each other. In table 12 the characteristics of all the airports within the London region are given. Figure 21 shows how the airports are stationed relative to the region.

Under the Traffic Distribution Rules 1991 whole plane cargo services or general or business aviation cannot be operated at Heathrow or Gatwick airports during periods of peak congestion declared for each scheduling season, without permission from the airport operator.

Airport	Air Traffic Movements	Main runways	Distance from London City
London City	80,854	09/27	-
London Heathrow	477,604	09L/27R, 09R/27L	10NM
London Gatwick	283,919	08L/26R, 08R/26L	26NM
London Luton	136,511	08/26	31NM
London Stansted	201,614	04/22	27NM
London Southend	32,531	05/23	29NM

Table 12: London region airport characteristics

Figure 21: Airports within London region

3.2.1 Airspace structure

NATS controls the airspace above the London area. This airspace is divided into London Terminal Control (TC, surface to FL245) and London Area Control (AC, FL245 to FL660). Both are controlled from the London Terminal Control Centre (LTCC) and London Area Control Centre (LACC) in Swanwick. Contrary to The Netherlands, tower control in the Aerodrome Control Zone (CTR) is a commercial service not reserved for NATS. After take-off the flight leaves the CTR and is handed over to NATS before entering the TMA (Figure 22).

Figure 22: London airport Air Traffic Movements

London Heathrow, City and Gatwick are co-located within LTMA 1 (2500ft – FL195), with Luton, Stansted and Southend co-located in the adjacent LTMA 3 (3500ft – FL195).

3.2.2 ATC sectors

The London Terminal Control Area (TMA) is split into two groups or banks, TC North and TC South, which not only relates to the position of the airspace sector relative to London Heathrow, but also the direction in the Terminal Control Room in which that sector's controllers face when at their radar consoles. TC North is further split into North East, North West. TC South is further split into South East and South West. There can be a total of 10 subsectors configured. At its busiest, each sector will have an individual radar controller. When it is quieter sectors are "band boxed" with one controller operating multiple sectors, until at night there may only be one controller operating the whole bank.

Aircraft departing Heathrow, Gatwick, Luton (to the north or west only), and Stansted mostly depart on a free-flow principle: the radar controllers do not release each individual flight for departure, they just receive an indication on their radar screen that a flight is pending. In this case the tower controller can decide on the most efficient departure order. In many cases the departure route does not conflict with the approach sequence of aircraft arriving at the airport, so the airport's approach control does not need to handle the aircraft and it is transferred straight to the TMA controller on departure. The TMA controllers then climb the departures through the arrivals to the airports that they are also working.

Arrivals to the London airports usually follow standard arrival routes and are descended against the departing traffic, sorted out into different levels, and routed to various holds (generally at the end of STARs), where they will hold until the approach control units are ready to position them into an approach sequence to land. Dedicated approach control units for the five major London airports are also controlled from TC, plus the radar approach services for Biggin Hill. Each approach unit has more than one sector. Most of the work for the approach units is controlling the sequence of aircraft making an approach at an airport from the holds until established on final approach about four miles away from the airport. The approach units also handle some aircraft departing from the airport, when that aircraft's departure conflicts with the approach sequence.

Slightly unusual to the approach sectors at TC is that some of them can be staffed by two controllers at a time, making transmissions on the same frequency.

3.2.3 Route design and procedures

In the UK, Basic Area Navigation (B-RNAV or RNAV5) is mandated to the base of the airway structure on all existing routes. Current CAA guidance requires all new ATS routes to be designed in line with RNAV1. specification which requires a higher degree of navigation accuracy resulting in concentration of aircraft on route centerlines with the potential to increase airspace capacity.

The route design into the five major London airports is largely laterally and vertically separated which allows the airports to operate independently to a certain degree. There is no clear policy set in case routes do overlap, radar controllers solve this tactically.

˝ B-RNAV or RNAV5 is an equipment specification which permits aircraft to navigate without the use of point source navigation aids. To meet the specification, aircraft track keeping accuracy must be within +/- 5 nautical miles of the route for at least 95% of the time.
RNAV1 is a performance requirement of +/- 1 nautical mile for at least 95% of the time’’

3.2.4 Airspace Capacity Management

Airspace Capacity Management (ACM) activities at NATS are organized in four planning phases: of strategic, pre-tactical, tactical, and post-operations. Fundamental to these activities are partnership agreements between NATS and various stakeholders which enable a transparent collaboration while maintaining confidentiality.

3.2.5 Strategic: Strategic Team

Strategic ACM is carried out by the strategic team which comprises of office staff with an operational background. Its main activity is carrying out operational evaluations on a seasonal and monthly basis. These evaluations commence a year to a week before actual day of operation. The work mainly consists of collecting data on flight schedules and special events. In collaboration with an ACC supervisor, ATCO or other relevant experts the Strategic ACM team carries out impact analyses to create an estimation of the impact of future events and the consequences for the operation. These analyses provide a forecast of the available airspace and required ATCO staff related to a future actual day of operation.

Analyses carried out by the Strategic ACM team are supported by NATS analytics. This department is responsible for data collection, warehousing and development of performance metrics used for dashboarding purposes. Examples of data used in the dashboard are:

- Regulations
- Available capacity
- Deployed ATCO

Three months to a week before the actual day of operation the forecast is more fine-tuned and serves as the basis for ACM activities in the pre-tactical phase (D-7 to D-1).

3.2.6 Pre-tactical phase: D-1 planning

Based on the D-7 forecast carried out by the Strategic ACM team, the FMP team works towards creating a D-1 planning. Terminal airspace planning becomes quite stable from approximately D-5 days. An ACC Supervisor is involved in the D-1 process which reduces the amounts of adjustments on the actual day of operation.

A tool used by the team is NEST (Network Strategic Modelling Tool) from Eurocontrol which can load traffic predictions from PREDICT data directly from the NM. With this tool the team simulates ‘scenarios’ which are based on bilateral agreements with adjacent ANSPs before being shared with the Network Manager. It serves as an instrument to reduce regulations in the tactical phase.

Alignment between civil and military users is enabled through an airspace booking process using the airspace booking tool LARA (Local and Sub-Regional Airspace Management Support System) from Eurocontrol. Based on the bookings, in which military missions are leading, NATS analyses the effects on airline efficiency. To ensure optimal functioning of Flexible Use of Airspace (FUA), NATS actively monitors Key Performance Indicators (KPIs) such as the availability and use of Conditional Routes.

The final D-1 planning is published at 16:00LT before the day before operations. Where relevant, it contains agreements with customers of NATS related to the actual day of operation. These agreements are made in consultation with the ACC supervisor. The D-1 planning is also incorporated in a UK/Irish Functional Airspace Block (FAB) D-1 report in a reduced form.

3.2.7 Tactical: Extended Arrival Management

The priority for airlines flying into London Heathrow is to maximize the runway capacity. In support of this priority, holding stacks are applied to ensure a continuous demand. An average 'holding delay' of six minutes was deemed acceptable between NATS and the airlines. However, reality showed this average to be nine minutes. The three minutes of delay attributed by NATS had to be addressed somehow.

As part of a broader strategy to reduce holding times for London Heathrow, the UK/Ireland FAB, MUAC and Direction des Services de la Navigation Aérienne (DSNA) collaborate in extending the arrival management systems to better absorb delay in the en-route phase of flights, reducing the need for excessive holding. In a running trial, NATS can request MUAC or DSNA to have flights under their control to reduce their speed (e.g. 'reduce speed by 0.02 Mach'). It is still regarded as a delicate process to both avoid overstacking as well as understacking. In figure 23 the Extended AMAN and speed reduction horizon is shown for the London region.

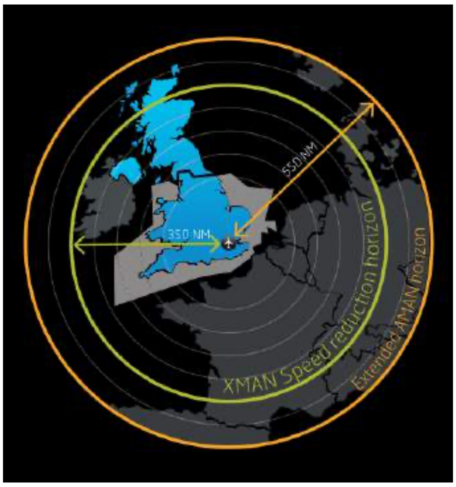

Figure 23: Extended AMAN and speed reduction horizon

3.2.8 Tactical phase: Flow Management Position

The UK has established a single FMP to act as liaison between NATS and the Network Manager. The position is manned in shifts by a team of eight persons located in the Swanwick Centre. The FMP is responsible for utilising the ACC capacity within the London, Scottish and Swanwick Oceanic FIRs to the maximum possible extent.

The FMP and ACC supervisor both monitor workload using the Traffic Load Prediction Device (TLPD). In the addition to the TLPD, the FMP also uses the Collaborative Human-Machine Interface (CHMI) provided by the NM and the local meteorological conditions at the various airports potentially affecting capacity.

In case of a predicted over-demand, the FMP approaches Aircraft Operators and provides them with the opportunity to avoid a tactical regulation by adjusting their flight plans accordingly.

In case flow and capacity interventions cannot be avoided, NATS has a set of STAMs applicable which includes Mandatory Cherry Picking (MCP), MIT and MDI for the purpose of peak spreading and de- bunching of outbound traffic.

Responsibilities in tactical air traffic regulations are strongly divided between NATS and the airports in the London area. In case an airport is not able to handle the declared capacity, such as in case of runway or taxiway maintenance or severe weather, the airport will communicate this constraint to the FMP. NATS only takes the initiative to regulate ATC sectors, which by design may contain traffic destined for more than a single airport. There is no mechanism to prioritize traffic flows with NATS. In this structure, they aim to maintain a level playing field and allows the NM to regulate in an indiscriminatory way.

3.3 Milan Region

The information regarding the Milan MAS was provided by Mr. Roberto Ghidini in 2007, he is an air traffic controller who is now mainly working on routes and procedures. As the information was provided in 2007 some parts may not be up to date anymore.

3.3.1 Multi-Airport System

In the Milan TMA, Malpensa, Linate, and Bergamo airports form a MAS. The airports are spaced 30-40 NM apart from each other. Traffic for the three airports use the same TMA entry and exit points, holdings, and fixes. The airspace around the fields CTRs is divided into four approach sectors. One sector per runway is in use. If Malpensa has two runways in use, there are also two approach sectors in use. If there is less traffic for Malpensa the sectors are combined. Linate and Bergamo each have their own approach sectors, these sectors are also combined when it is not busy.

Above these four approach sectors, which run from ground 1500 ft to FL 100, are four feeder sectors from FL100 to FL200, here a presequence is built after which the arrival controller takes over the traffic on FL100, also the departures are transferred to en-route via the feeder sector. In total, the TMA is subdivided into 4 approach sectors and 4 feeder sectors. In Table 13 the characteristics of the airports within the Milan region are given. In figure 24 the Milan flight information region is shown.

Airport	Air Traffic Movements	Main runways	Distance from Malpensa
Milan Malpensa Airport	118,341	17L/35R, 17R/35L	-
Milan Linate Airport	118,543	17/35, 18/36	30NM
Milan Bergamo Airport	38,668	10/28, 12/30	48NM

Table 13: Milan region airport characteristics

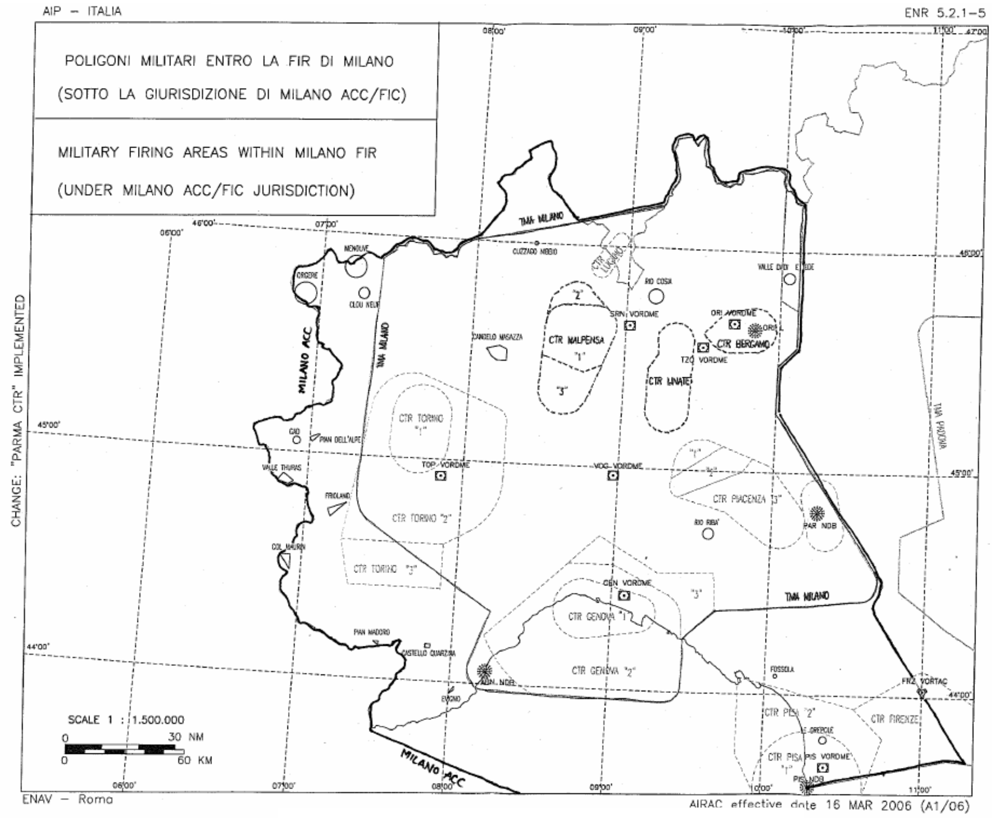

Figure 24: Milan flight information region

The feeder sectors connect to 3 en-route sectors, in addition a separate en-route sector has recently been opened exclusively for the inbound and outbound to the Rome TMA (>FL100). The CTR of Genoa and Torino

are in the Milan TMA but are not part of the MAS. They are respectively FL100 and FL120 high, traffic can be offered to the Feeder at FL100 but only after prior coordination.
The airports in the multi airport system have their TMA entry and exit points in common. From the TMA entry point, the STARs are different for the three airports though. The SIDs are also different within the TMA but lead to a common TMA exit point. The inbound and outbound flows are separated as much as possible.

The runway configurations of the different fields are not explicitly dependent on each other. But since the runways are oriented in almost the same direction anyway, depending on the wind, the same take-off and landing direction is almost always chosen. Traffic taking off from Malpensa and Linate must immediately make a turn because of the mountains nearby.

3.3.2 Task distribution

When it is busy, Malpensa has two runways in use and each runway has its own approach sector. Two arrival controllers and two departure controllers will be active. When it is less busy, the approach sectors are combined with one arrival controller and one departure controller. A special feature of this configuration is that the second departure controller is mainly used to distribute noise. When taking off from Malpensa, a sharp (low) left or right turn must be made to avoid the mountains; this nuisance must be spread fairly over the region.

Linate and Bergamo each have an approach sector where each also works an arrival controller, when it is not busy the sectors are combined and only one arrival controller works. Linate and Bergamo share their departure controller, which merges the traffic flows from the airports and transfers them to the Merge sector. So, at any given time in the approach sectors there are 2-4 arrival controllers active and 2-3 Departure controllers.

Traffic to and from the approach sectors comes and goes via the feeder sectors. There are 4 feeder sectors between FL100 and FL200, these sectors can be combined depending on crowds. There are 1-3 Feeder controllers working at any given time.

The traffic approaches the Milan TMA or departs from Milan through one of the three ACC sectors above FL200 or via the Rome sector >FL100. The ACC controller makes a first sequence before the traffic has passed the TMA Entry (Exit) point. Then the Feeder takes over and guides the traffic towards one of the approach sectors depending on the destination airport.

There are two coordinators at work who monitor planning and any restrictions. The supervisor (first coordinator) coordinates between the feeder sectors and the approach sectors. The second coordinator coordinates between the three towers.

3.3.3 VFR

The Milan TMA runs from 1500 ft to FL200 and has a diameter of approximately 220 km. The TMA has airspace class A. VFR flights are therefore only allowed under the TMA. These aircraft can reach Linate and Bergamo (Airspace Class C and D) by flying under the TMA, both airports accept VFR traffic for several hours of the day. This traffic must be coordinated in advance. Malpensa is always closed to VFR traffic.

3.3.4 Traffic management

The Flow Management Unit is connected to CFMU and is part of the Milan ACC sector. No distinction is made between airports in terms of priority. The traffic for each airport is equally important. The method is: first come, first serve. It is anticipated that the SESARE project will set rules for prioritization.

There are no ATM related capacity problems in the Milan area, if flow restrictions are issued it is always due to weather. In addition, the airport has insufficient handling capacity every morning in the first peak, this also leads to restrictions.

3.3.5 Flexible use of airspace

Airspace Management at the tactical level is easily organized in the Milan TMA, civilian and military controllers work side by side in the same Area Control Centre. At the strategic level, FUA phase 3 has been implemented and many CTR3s have been published. The military has reserved airspace, if that airspace is not in use, then it can be used for civilian traffic. The CTR3 allows planning to consider the availability of military airspace. This makes it possible to always have a route to and from the CTR, without having to fly through military airspace.

3.3.6 Training

Malpensa opened in 2000, which is also when the MAS was developed. For the transition to the MAS no special training was required, of course routes and procedures change but air traffic controllers did not need to learn any new skills. All controllers are first trained for ACC when they have enough experience and/or aptitude they are trained for the transition to APP. The training consists of one week of theory, two weeks of simulator training and then an average of 200 hours of on the job training with an instructor. So, there is an ACC/APP group and not a TWR/APP group like at LVNL.

3.3.7 CDM

A CDM cell was developed for Malpensa in collaboration with Eurocontrol in 2003. The participants in the CDM cell are all the actors at Malpensa airport, in addition to ENAV thus, the handling company/companies, the airlines, the supervisor/regulator, police, security, maintenance services, etc. So, this is already an extensive Local CDM cell. The CDM cell is in a testing phase, errors are being resolved and procedures written.

4. Analysis & highlights literature

In this section, the analysis and highlights of the literature are described, then this information is put into a table to make a comparison between the literature and the Dutch MAS characteristics.

4.1 Analysis

4.1.1 Departure scheduling in a MAS

Objective

The purpose of departure scheduling in a MAS is to determine an optimal sequence and takeoff times under different objectives. These objectives include maximizing the runway throughput, minimizing the total delay, and ensuring airlines or airports equities in the departure sequence.

Features/characteristics

- Real case study
- Two airports
- PuDong International airport handles international flights and HongQiao international airport handles domestic flights.
- Total amount of aircraft movements 255,500
- PuDong International airport does have two pairs of parallel runways. HongQiao International airport only has one runway.
- The distance between the two airports is 28 NM (51.83 kilometres)

Methodology

There will be developed a new model and an efficient algorithm for computing an optimal departure sequence in a MAS terminal area.

Advantages

- Shared departure fixes will result in an enhancement of terminal capacity.
- Airlines preferences can be included in the model.

Disadvantages

- The algorithm only focuses on departure flights and not on arrival flights.

Conclusion

- Via this algorithm the shared departure fixes will result in an enhancement of terminal capacity.
- Integral scheduling departure and arrival flow in terminal area will be another challenging aspect in ATFM field.

4.1.2 A metroplex-wide route planning and airport scheduling tool

Objective

The objective is to optimize the sequencing, runway assignment, and route allocation to maximize throughput, increase safety, and minimize the environmental footprint.

Features/characteristics

- Real case study
- Three airports
- JFK International airport handles mostly international flights, Newark International airport handles international and domestic flights and LaGuardia airport primarily handles domestic flights.
- Total amount of aircraft movements 1,286,228
- JFK International airport does have two runways which are parallel runways, Newark International airport does have three runways of which two are parallel and one is in a different direction, and LaGuardia airport does have two runways in different directions.
- The distance between JFK International airport and Newark International airport is 21NM (38.9 kilometres). The distance between JFK International airport and LaGuardia airport is 10NM (18.5 kilometres).

Methodology

There is devised a tool which is called Metrosim, this tool solves the IADS problem not only for a single airport with multiple parallel and intersecting runways, but also for a group of airports in a Metroplex, including the sometimes-complex interactions among them and the structure of the airspace within the Metroplex.

Advantages

- Metrosim can be loaded with an entirely different airspace design and routing structure, or with different types of aircraft, or with a mix of conventional and remotely controlled aircraft, or with additional runways and taxi paths.
- Metrosim appears to be the right strategy for developing a full IADS solution, at least the initial results indicate that the architecture is promising.

Disadvantages

- Metrosim has the potential to realize its goal of increasing the efficiency of metroplex operations but now there should be more feasibility experiments and more robust testing to fully evaluate this idea.

Conclusion

Metrosim is able to successfully schedule 97 minutes of recorded departures in only 75 minutes. This compression of departure times increases the Metroplex throughput considerably. On average, in each 15 minute time bin, Metrosim increased departure throughput by about 15%. A system like Metrosim as a series of communicating sequential programs appears to be the right strategy for developing a full IADS solution, at least the initial results indicate the architecture is promising.

4.1.3 Traffic flow patterns in multi-airport systems

Objective

Developing a data-driven framework to identify, characterize, and predict traffic flow patterns in the terminal area of MAS an improved capacity planning decision tool will be established in a complex airspace.

Features/characteristics

The features and characteristics of New York has already been discussed in subchapter 4.1.2.

Methodology

A trajectory classification scheme is developed to match new flight trajectories with the learned airspace structure. Once trajectories are classified, flows are identified as temporally associated flight trajectories conforming to the same standard route.

Finally, clustering is performed at the temporal dimension to identify patterns in air traffic flows. Based on the knowledge generated by the multi-layer clustering process, classification techniques are used to predict traffic flow patterns over time. The knowledge generated is used to develop a classification scheme for prediction of traffic flow patterns.

Advantages

- There will be learned recurrent utilization patterns of runways and airspace as well as relevant decision factor by having that knowledge there can be developed descriptive models for metroplex configuration prediction and capacity estimation.

Disadvantages

- This research is only focusing on the Identification, Characterization, and Prediction of Traffic Flow Patterns and not on a MAS solution.

Conclusion

For the New York multi-airport system, the classification model showed an average prediction accuracy of 83% for a short-term 1-hour forecast, 63% for a 3-hour forecast, and 52% for longer look-ahead times.

4.1.4 CAP: Collaborative Advanced Planning

Objective

DSNA, the French ANSP designed a new approach to better distribute the traffic demand according to the control sector capacities available: The Collaborative Advanced Planning (CAP) process. This collaborative approach introduces a new pre-tactical flow-centric method for Demand and Capacity Balancing in the European Network.

Features/characteristics

- Real case study
- Three airports
- Paris Charles de Gaulle (CDG) is the main hub for international flights, Orly airport accommodates domestic flights, and Le Bourget serves general aviation traffic
- Total amount of aircraft movements 770,322
- Paris CDG has two pairs of parallel runways, Paris Orly has have three runways in different directions, and Paris Le Bourget does also have three runways in different directions.
- The distance between Paris CDG and Paris Orly is 20NM (37 kilometres), and the distance between Paris CDG and Paris Le Bourget is 5NM (9.3 kilometres).

Methodology

The first step was to build the collaboration system, the next step consisted in testing and the calibration of the system. A first set of flight planning scenarios in the French airspace were defined: cruising level capping, early descent towards a set of destinations and free requests. During the test feedback has been given to the system, this feedback has been used to create new scenarios and implement them two months later with five airlines in the loop.

Advantages

- Benefits of this process is that it allows ATC flow management units to suggest delay-free flight trajectories and/or cruising levels to airlines operations with the objective to prevent control sectors from congestion and induced delays.

Disadvantages

- Follow-up research should show whether this process can also be implemented for the Netherlands and whether it is enough to solve the entire problem.

Conclusion

From July 7th to September 13th 2015, the CAP process was run 62 days over 69. 628 flight plan changes were suggested to the airline's operations. 92% of these requests were implemented by the airline OCCs. The traffic in the considered sectors (5R) increased by 6% during summer 2015 compared to summer 2014 while the delay was reduced by 52% during the summer 2015. ATC is really pleased with this collaboration, showing that the French ANSP can work closely with the airspace users to improve the global performance through innovative and collaborative ATFCM (Air Traffic Flow and Capacity Management) methods.

4.1.5 Impact analysis of demand management on runway configuration in metroplex airports

Objective

Existing studies mainly focus on runway configuration in a single airport system, and little consideration is given to the impact of demand management on runway configuration in metroplexes. The objective is to propose a methodology and assessment framework for runway configuration with a focus on the exploitation of multiple active runways in metroplex airports.

Features/characteristics

The features/characteristics of the Shanghai region is already explained in subchapter 4.1.1.

Methodology

A multi-objective runway configuration model will be formulated to enhance the performance of integrated runway operations in metroplex airports, considering a series of Runway Configuration Capacity Envelope (RCCE)-based Air traffic Demand Management (ATDM) options.

Advantages

- Most of the existing studies of RCM optimization mainly focus on a single-objective optimization in a single airport system this research focuses on metroplex airports.
- The framework can provide some significant references about multi-runway operations (configuration, sequencing, and scheduling) in a metroplex system or a single airport system.
- The framework can be used for both arrivals and departures.

Disadvantages

- The selection of runway configurations will change based on the needs of the MAS this may bring drawbacks such as noise and other environmental considerations.
- There should be little wind to adjust the configuration to the favorable MAS configuration.
- The proposed framework does not have the same problem statement as the problem of why runway configuration management would be chosen in a MAS system in the Netherlands, but this study can be well used for further research on the framework.

Conclusion

- The framework proposed a methodology to assess the impact of ATDM options on runway configuration in metroplex airports. From the results the DRCM model can reduce the total number of adjusted flights in metroplex airports by 42.2%, 29.0% and 37.2%.

4.1.6 Towards a more harmonized and wider use of short-term ATFCM measures (STAM)

Objective

STAM is a demand and capacity balancing (DCB) procedure which allows flight management positions (FMPs) to identify pre- regulation hotspots and apply short term air traffic flow and capacity management (ATFCM) measures.

The objective is to summarize the results of one of the three validation exercises that were carried out in SESAR R&D program under the P13.02.03 project (SESARju, 2019).

Features/characteristics

- Real case study
- One airport
- Zürich Airport also known as Flughaven Zürich is the largest international airport of Switzerland and the principal hub of Swiss International Airlines.
- Total amount of aircraft movements 132,600
- Flughaven Zürich has 3 runways, all three of them are in different directions.

Methodology

Current network performance and flight operations are impacted by ATFCM measures imposed on individual flights to prevent situations that traffic demand exceeds available ATC and Airport capacity. In the European system the short-term ATFCM planning is taking place the day before and day of operations to adjust the Demand Capacity Balancing (DCB) plan, i.e. to detect residual overloads and to apply mainly a ground delay regulation plan at the airport departure to smooth the overloaded traffic.

Advantages

- The STAM Measures allow ACCs to play a key role in the reduction of traffic peaks by applying measures such as minor ground delay, flight level capping or small re-routings.
- The use of STAM Measures versus ground delay regulations reduces drastically the number of impacted flights, reduces the average delay, and increases the flight efficiency.

Disadvantages

- A limitation in the use and the assessment of the STAM concept and tool was the number of aircraft operator participants. Even if 8 airlines were involved in the live trial, more airlines would be required to facilitate the choice of most appropriate flights for STAM and the coordination between the actors involved in the CDM process.
- There was an occasional issue reported during the test, when a single flight was caught by both the STAM and Civil Aviation Safety Authority (CASA) regulation.
- Because the test was conducted for multiple airports that are not located in a multi-airport region, this study will not be included in the comparative analysis.

Conclusion

Despite some positive subjective assessments, the overall result was that FMPs were not confident with the use of prototype STAM support tools in operational conditions. Main issues were around the interaction time consumed by measure creation and coordination tasks. It was suggested that development of local tools and predefined scenarios could probably solve 90% of the problems in an adequate timeframe.

4.2 Additional MAS solutions

During the study (Verboon, et al., 2020), several MAS TMA solutions were described. Some of these solutions were further investigated during the literature review. Regarding the solutions described in this subchapter, little additional online literature is available. Therefore, no further analysis can be given at this time.

4.2.1 Coordinated slot allocation

In The Netherlands airport slot allocation is currently a local process, this means there is no coordination of declared capacity (for example peak hours) between the slot-coordinated airports. By managing the capacity declarations between the airport involved in the multi-airport concept, as part of the slot coordination process, the root cause of congestion could be addressed. An example that could be better managed is the structural congestion of Amsterdam sector 3 between 7:00 and 8:00 LT due to the large number of departures from Rotterdam, Eindhoven, and Schiphol Airport, see Figure XX in section XX.

The slot coordination process could be further optimized by restricting the number of flights to specific airways at specific timeframes to strategically relieve certain ATC sectors. Local planning and operational restrictions are already part of the current capacity declarations to ACNL and could be expanded with restrictions that are derived on a national level.

All stakeholders have an interest into balanced air traffic demand and capacity, on the ground and in air traffic flows, in order to create stable traffic flows, resilient and robust against disruptions. Stable and predictable traffic flows eventually allow ANSPs to reduce their buffer capacity, leading to a small increase of capacity and accommodation for future growth.

Another reason of the traffic imbalance is that monitoring of airport slot utilization is not actively performed by the slot coordinator. Whilst airlines will not consequently structurally deviate from their allocated airport slots, this lack of monitoring could result in increased traffic during peaks. Hence, to enlarge the effect of coordinated slot allocation, slot monitoring should be improved as well.

4.2.2 Strategic flight scheduling

Strategic flight scheduling is a technique that schedules flights in such a way that the interference of flights is reduced. In a far-fetched scenario, flights to the south may be scheduled from a southerly airport and flights to the north from a northerly airport. In this scenario it could mean that traffic to (from) the south will mostly depart from (arrive at) Eindhoven and Rotterdam-The Hague airports, whereas traffic to (from) the north or north-east will mostly depart from (arrive at) Lelystad airport. This scenario will result in conflicting interests. Airlines business strategies will most likely not support it.

A less far-fetched scenario, as proposed for this measure in this document, is to redistribute the traffic over the various sectors, therewith reducing the load on specific sectors. For example, flights to (from) South America or the Canary Islands could always be planned and executed via sector 4, thereby alleviating sector 3 to a certain extent.

The scheduling of flights via sectors with less or no hotspots could in principle be used in all phases (strategic, pre-tactical, tactical), though most impact could be anticipated when applied at a strategic level. This occurs already on European network level in the strategic phase.

4.2.3 National daily ATFCM entity and plan

The current ATFCM plan prepared by LVNL at D-1 aims first and only at Schiphol. A national ATFCM entity and daily plan is considered a potential evolution where the center of attention would shift from Schiphol to at least all four airports involved in the multi-airport system.

A national air traffic flow and capacity management (ATFCM) entity could support in the balancing of demand and capacity in the timeframe from a week up to hours before actual operations. An ATFCM entity could anticipate predictable and unpredictable disruptions by preparing decision information for its stakeholders. Such ATFCM entity could also coordinate with adjacent ANSP's and Eurocontrol Network Manager on situations and conditions. On request it can support airports, airline operators and ATC, whilst reporting to the Eurocontrol NM and the Civil Aviation Authority.

The national ATFCM entity could also be responsible to establish a national daily ATFCM plan. This plan can provide a clear overview of the latest information on demand (scheduled flights) and capacity (weather conditions, special events in airspace, airport availability, planned runway configurations). When the demand exceeds the available capacity, the entity can decide on pre-tactical regulations. An initial plan could be prepared from D-7 until D-1 after which it will be officially published.

A fully operating ATFCM entity and daily plan will enhance optimized use of airspace and airport capacity in the pre-tactical timeframe, especially when predicted or ad hoc disruptions require attention of all stakeholders. It strongly relies on increased information sharing between the ANSPs handling air traffic at or over the airports involved. LVNL and the military ANSP will be integrated into a single ANSP by 2023. This would already allow for better sharing of information on airport operations and airspace booking.

4.2.4 Runway configuration management

Currently, the runway configuration at Schiphol frequently changes. At Schiphol, bound to environmental regulations, an average daily number of sixteen runway configuration changes significantly reduces the predictability of traffic flows, both inbound and outbound. The runway configurations must adhere to environmental rules such as a preferential runway selection system. Next to this a maximum number of simultaneous used runways is established by the *New Standards and Enforcement System*. Also, the other airports involved in the multi-airport concept decide on their runway configuration independently. This leads to unpredictability of the foreseen multi-airport concept.

The runway configurations of the airports could in the future be coordinated such that the arrival and departures routes to the airports in the multi-airport concept are more aligned. Rotterdam, Eindhoven and Lelystad are single runway airports. They decide on their runway configuration based on actual wind conditions. If wind speed is limited, the interests of the multi-airport environment could influence the runway configuration selected. This asks for coordination and sharing of information at a pre-tactical and tactical level between the airports and as a prerequisite an increased planning horizon for the runway configuration at Schiphol.

Runway configuration management can be made more predictable by shifting to more schedule-based runway configuration changes rather than a change based on tactical conditions. For AOs, a schedule- based runway configuration changes at Schiphol compared to current situation where tactical conditions determine the moment of change, would mean a more predictable and possibly fixed route through the TMA and hence a more reliable landing time on the runway, and in-block time at the gate.

Runway configuration management is positioned as a pre-tactical measure. Improved coordination and predictability of the runway configurations would make arrival and departure trajectories more predictable, both lateral and vertical; also enabling other measures establishing a multi-airport environment.

4.2.5 STAM

STAM is a demand and capacity balancing procedure which allows FMPs to identify regulation hotspots and apply measures smoothing sector workload by reducing traffic peaks (SESAR, European ATM Master Plan: Edition 2015, 2015). It is a collaborative process that aims to involve all stakeholders in order to ensure that equity is maintained. Normally ATFCM regulations result in a systematic allocation of departure slots to all flights through the congested area, regardless of how they contribute to the expected overload. This process is no longer favorable when the demand does not significantly exceed the available capacity and when traffic can be predicted in a more refined way. FMPs can play a key role in the reduction of traffic peaks by applying measures such as assigning minor ground delay, flight level capping or small re-routings.

MUAC FMP has advanced STAM procedures in place for Dutch upper airspace. In lower airspace, LVNL FMP could develop measures having minimum impacts on airspace users, such as cherry-picking of the flights causing the complexity, based on expanded information including weather, airport operations, runway occupancy and traffic complexity. Today already some measures are used by approach air traffic controllers by coordination with adjacent airports. An example is the Rotterdam runway 06 departures, which could be held near the runway to avoid interference with Schiphol traffic.

This measure is applied tactically. NM tooling can provide support for STAM. The tooling allows for hotspot detection, a “what-if” function to assess potential measures and effecting measures.

4.2.6 Traffic synchronization

ATCO workload is often not only a function of the amount of traffic, but also traffic complexity like crossing traffic, crossing a busy stream of other traffic. Sometimes, a small adjustment to the departure time of a single crossing flight may reduce workload below levels where regulations would be required. An example of such a case is a departure from Eindhoven (EHEH) to the west. A delay of 5 or 10 minutes for this flight may avoid crossing a group of outbound flights from Schiphol.

To minimize interference, departing traffic can, under certain circumstances, be synchronized with other traffic flows in the multi-airport environment. This is especially an option for aerodromes where there is limited outbound demand. Traffic can be designated to take-off within a certain time window, before or after a certain time. Due to the nature of the departure operation, this would not be possible for Schiphol as this would affect the required high departure capacity, but would be more suitable for Rotterdam, Eindhoven and Lelystad. A technological enabler is the Departure Metering project for the London TMA and the Departure Spacing program in New York-Boston Northeast corridor. This measure for departure at multiple airports in proximity is also known as DMET.

Arriving traffic flows into the multi-airport can likewise be synchronized in such a way that flows into different airports do not conflict in the sectors but also not compromise the throughput at the largest airport Schiphol. Well in advance of entering Dutch airspace, potentially even before take-off, aircraft are assigned a TTA at the destination airport or a TTO an entry point, ensuring a distributed traffic rate into the airports. TTA/TTO strongly relies on the available arrival management concepts and tooling for multi- airports. These techniques can be used in the tactical phase to prevent workload limits to be exceeded. Having this tactical measure could also be used to allow for a greater design margin when choosing capacity limits on a strategic level. For instance, the available capacity in a traffic stream is measured in a percentage at which a certain capacity can be guaranteed. Applying this method could permit choosing a less stringent percentage at which a competing traffic stream needs to be deconflicted, thereby increasing capacity levels.

To facilitate this concept element, certain systems support is likely to be required. Accurate trajectory information on conflicting traffic profiles needs to be available. Also, a conflict detection and resolution capability could assist the controller/planner in deriving an appropriate time constraint for a departure from one of the departure restricted airports.

	Specific case study	**W1**	**W2**	**W3**	**W4**	**W5**
Objective	Capacity bottleneck solution for departing and arriving traffic in the TMA through a MAS	Strategic departure scheduling to optimize runway throughput and minimize the total delay.	Strategically optimize the sequence of runway allocation and route assignment to maximize throughput	Strategically identify, characterize, and predict traffic flow patterns in TMA airspace	Pre- tactically and tactically allocate demand for departing and arriving traffic according to control sector capacity	Pre- tactical and tactical runway configuration management for departing and arriving flights
Features/characteristics	• Real case study • Four airports • 579,620 aircraft movements of the four airports combined • EHAM has six runways of which three are parallel and three other runways which are all in different directions, EHRD has one runway, EHEH also has one runway, EHLE • The distance between EHAM and the other airports is 25, 55 and 30 NM respectively	• Real case study • Two airports • 255,500 aircraft movements of the two airports combined • ZSPD has two pairs of parallel runways. ZSSS only has one runway • Distance between the airports is 28NM	• Real case study • Three airports • 1,286,228 aircraft movements of the three airports combined • KJFK has two runways which are parallel runways, KEWR does have three runways of which two are parallel and one is in a different direction, and KLGA has two runways in different directions. • The distance between KJFK and KEWR is 21NM. The distance between KJFK and KLGA is 10NM	Features and characteristics have already been given in W2	• Real case study • Three airports • 770,322 aircraft movements of the three airports combined • LFPG has two pairs of parallel runways, LFPO has three runways in different directions, and LFPB does also have three runways in different directions • The distance between LFPG and LFPO is 20NM, and the distance between LFPG and LFPB is 5NM	Features and characteristics have already been given in W1
Methodology	Develop a MAS solution for the capacity problem in sectors 2 and 3 for both departures and arrivals	Developing a tabu search algorithm for computing departure sequence	Developing a commercial software (Metrosim) to solve Integrated Arrival and Departure Surface problems at airports	Developing a data-driven framework to match new flight trajectories with the learned airspace structure	A software has been developed which is called CAP, the software will be used to adjust FPL's	A multi-objective runway configuration software will be developed to enhance the performance of integrated runway operations
Advantages	• Introducing a MAS could potentially lead to an improvement in the capacity problem • Opportunity for more efficient flight operations	• Shared departure fixes will result in an enhancement of terminal capacity. • Airlines preferences can be included in the model.	• The software can be loaded with an entirely different airspace design and routing structure, or with different types of aircraft, or with a mix of conventional and remotely controlled aircraft, or with additional runways and taxi paths. • The software appears to be the right strategy for developing a full IADS solution, at least the initial results indicate that the architecture is promising.	There will be learned recurrent utilization patterns of runways and airspace as well as relevant decision factor by having that knowledge there can be developed descriptive models for metroplex configuration prediction and capacity estimation.	Benefits of this process is that it allows ATC flow management units to suggest delay-free flight trajectories and/or cruising levels to airlines operations with the objective to prevent control sectors from congestion and induced delays.	• Most of the existing studies of RCM optimization mainly focus on a single-objective optimization in a single airport system this research focuses on metroplex airports. • The framework can provide some significant references about multi-runway operations (configuration, sequencing, and scheduling) in a metroplex system or a single airport system. • The framework can be used for both arrivals and departures.
Disadvantages	Implementing a MAS will have an impact on stakeholders requiring	The algorithm only focuses on departure flights and not on arrival flights.	The software has the potential to realize its goal of increasing the efficiency of metroplex operations but now there should be more	This research is only focusing on the Identification, Characterization, and Prediction of Traffic Flow Patterns and not on a MAS solution.	Follow-up research should show whether this process can also be implemented for the Netherlands and	• Selection of runway configurations changes based on the MAS brings drawbacks such as noise and other environmental considerations.

	training and facilities to be provided		feasibility experiments and more robust testing to fully evaluate this idea.		whether it is enough to solve the entire problem.	- There should be little to no wind to adjust the configuration to the favorable MAS configuration. - Proposed framework does not have the same problem statement as the problem of why runway configuration management would be chosen in a MAS system in the Netherlands
Conclusion		Shared departure fixes will enhance the terminal capacity, but the integral scheduling and arrival flow will be a challenging aspect	The software managed to increase the departure throughput by about 15%	Average prediction accuracy of 83% for a short-term 1-hour forecast, 63% for a 3-hour forecast, and 52% for longer look-ahead times	CAP process was run 62 days over 69. 628 flight plan changes were suggested to the airline's operations. 92% of these requests were implemented by the airline OCCs	DRCM model can reduce the total number of adjusted flights in metroplex airports by 42.2%, 29.0% and 37.2%.

4.3 Findings and recommendations

This chapter describes the findings of the literature reviewed and recommendations for follow-up research.

4.3.1 W1 (Departure scheduling in a MAS)

Findings

It is noted that a tabu search algorithm for strategic purposes works very well only that in this study it is limited to the scheduled departures and not on the arrivals. This algorithm makes it possible to set up an optimal departure sequence in a MAS TMA.

Recommendations

- Review the advantages and disadvantages of a tabu search algorithm for merging and sequencing
- Use the tabu search algorithm technique to see if arrival and departures could be merged for strategic purposes
- Further investigate whether the same similar solution as in this study can be used for the Dutch MAS and whether this solution contributes to the problem.

4.3.2 W2 (A metroplex-wide route planning and airport scheduling tool)

Findings

It is noted that the tool Metrosim solves the Integrated Arrival and Departure Surface problem not only for a single airport, but also for a group of airports in a Metroplex. The tool has also the potential to realize its goal of increasing the efficiency in a metroplex but there should be performed more feasibility experiments and testing to fully evaluate the idea.

Recommendations

- Further research into the development of Metrosim and the elaboration of the Integrated Arrival and Departure Surface problem.
- Continue to develop the tool to make it operational and conduct more testing to flesh out the idea.

4.3.3 W3 (Traffic flow patterns in multi-airport systems)

Findings

This research is focused on the mapping of flight trajectories. Air traffic flow patterns are identified, and data is collected. With this data classification schemes can then be made to predict future traffic flow patterns. The mapping of the traffic flow patterns has no relationship with the capacity problems that arise in Dutch airspace. Therefore, this study does not need to be further investigated in a follow-up study.

4.3.4 W4 (CAP: Collaborative Advanced Planning)

Findings

The collaborative approach introduces a new pre-tactical flow-centric method for Demand and Capacity Balancing. Opgemerkt kan worden is dat ATC flow management units suggesties kunnen doen om een vertragingsvrije vlucht uit te kunnen voeren. It can also be noted that during 62 days in 2015, more like 69,628 flight plans were submitted to be modified and 92% of these requests were eventually modified by the airlines OCCs. This resulted in 52% fewer delays in the summer of 2015 compared to the summer of 2014.

Recommendations

- Follow-up research should show whether this process can also be implemented for the Netherlands and whether it is enough to solve the entire problem.
- Research on the tool and how it is specifically working for the DSNA.
- Drawbacks of the system should be examined

4.3.5 W5 (Impact analysis of demand management on runway configuration in metroplex airports)

Findings

The multi-objective runway configuration model enhances the performances of the integrated runway runway operations in a MAS. The benefit of the framework is that it can provide some significant references about multi-runway operations in a MAS and the framework can be used for both arrivals and departures. But with there are some drawbacks like the selection of runway configurations will change based on the needs of MAS TMA operations which can bring noise and other environmental problems.

Recommendations

- Conduct additional research on the feasibility of implementing a runway configuration change based on the requirements from a MAS.
- Conduct additional research on the effects of noise and other environmental considerations.

4.3.6 W6 (Towards a more harmonized and wider use of short-term ATFCM measures)

Findings

By using STAM, tactical balancing of supply and demand can be done. If pre-regulation hotspots are identified STAMs can be used to resolve the hotspots. STAM was not tested in a MAS during this study so no comparison could be made with MAS in the Netherlands.

Recommendations

- Additional research is needed if STAM measures offer sufficient reduction in traffic peaks.
- The limitations to the STAM measures should be further investigated, is it at all possible to have ACC controllers take on this tactical task additionally.
- During a test, an occasional issue was reported, research should find out to what extent this was a serious issue and what the impact of this was on the operation.
- Additional research should reveal whether STAM measures are also relevant for a MAS solution.

4.3.7 Coordinated slot allocation from (Verboon T. v., 2020)

Findings

There is no coordination of declared capacity (for example peak hours) between the slot-coordinated airports (EHAM, EHRD, EHEH & EHLE). By managing the capacity declarations between the airport involved in the multi-airport concept, as part of the slot coordination process, the root cause of congestion could be addressed.

Recommendations

- Follow-up research will have to show whether this solution is sufficient to solve the problem and whether it is possible to integrate this solution successfully.

4.3.8 Strategic flight scheduling from (Verboon T. v., 2020)

Findings

Strategic flights scheduling basically schedules flights in such a way that the interference of flights is reduced. In a far-fetched scenario, flights to the south may be scheduled from a southerly airport and flights to the north from a northerly airport. In this scenario it could mean that traffic to (from) the south will mostly depart from (arrive at) Eindhoven and Rotterdam-The Hague airports, whereas traffic to (from) the north or north-east will mostly depart from (arrive at) Lelystad airport. This scenario will result in conflicting interests. Airlines business strategies will most likely not support it.

Recommendations

- This strategy has such a large impact on airlines, airports, and other stakeholders that it may be deemed that this option should be disregarded for follow-up research.

4.3.9 National daily ATFCM entity and plan from (Verboon T. v., 2020)

Findings

The current ATFCM plan prepared by LVNL at D-1 aims first and only at Schiphol. A national ATFCM entity and daily plan is considered a potential evolution where the center of attention would shift from Schiphol to at least all four airports involved in the multi-airport system.

Recommendations

- Follow-up research will have to show whether this solution is sufficient to solve the problem and whether it is possible to integrate this solution successfully.

4.3.10 Traffic synchronization from (Verboon T. v., 2020)

Findings

To minimize interference, departing traffic can, under certain circumstances, be synchronized with other traffic flows in the multi-airport environment. This is especially an option for aerodromes where there is limited outbound demand. Traffic can be designated to take-off within a certain time window, before or after a certain time. Due to the nature of the departure operation, this would not be possible for Schiphol as this would affect the required high departure capacity, but would be more suitable for Rotterdam, Eindhoven and Lelystad.

Recommendations

- Further research into the departure metering project which has been done for the London TMA because during this project access couldn’t have been provided
- Further research into the Departure Spacing program which has been done for the New York-Boston Northeast corridor because during this project access couldn’t have been provided
- Follow-up research will have to show whether this solution is sufficient to solve the problem and whether it is possible to integrate this solution successfully.

4.3.11 MAS Paris Region

Findings

The Paris region consists of two major airports: Paris CDG and Paris Orly. Additionally, Le Bourget serves general aviation traffic. Several systems have been designed in Paris to balance demand and capacity in the TMA. These include CAP, TTA, and several merge points that connect to route procedures.

Recommendations

- Because this is a commercial real case example there isn't much literature written about these systems unleash the CAP project.
- Further research should be done on the Paris region MAS and the systems which are established, this could be done by doing interviews.

4.3.12 MAS London Region

Findings

The London region consists of six main international airports: Heathrow, City, Gatwick, Luton, Stansted and Southend. Heathrow and Gatwick can be regarded as the main hubs. In terms of MAS systems little information has been made available by the NATS.

Recommendations

- Because this is a commercial real case example there isn't much literature written about the system.
- Further research should be done on the London region MAS and the systems which are established, this could be done by doing interviews.

4.3.13 MAS Berlin Region

Findings

The information regarding the Milan MAS was provided by Mr. Roberto Ghidini in 2007, he is an air traffic controller who is now mainly working on routes and procedures. As the information was provided in 2007 some parts may not be up to date anymore.

Recommendations

- The available information is outdated and therefore may the quality of the information also be doubted. It is recommended to update the information.
- Further research should be done on the London region MAS and the systems which are established, this could be done by doing interviews.

5. Conclusion

The objective of the research is to find out what aeronautical studies are necessary/beneficiary to further implement MAS in the Netherlands. The following MAS studies should be conducted to further integrate the MAS into the Netherlands.

- Departure scheduling in a MAS
- Metroplex-wide route planning and airport scheduling tool
- CAP: Collaborative Advanced Planning
- Runway configuration management depending on a MAS
- Usage of short-term ATFCM measures
- Coordinated slot allocation
- Strategic flight scheduling
- National daily ATFCM entity and plan
- Traffic synchronization

Also, the MAS of Paris, London, and Berlin, among others, should be further investigated to discover which MAS system is successful at them and which can also be integrated in the Netherlands.

6. Further work

To further integrate the MAS into the Netherlands, the following studies need to be conducted. After these studies have taken place, follow-up studies can be conducted again.

- Departure scheduling in a MAS
- Metroplex-wide route planning and airport scheduling tool
- CAP: Collaborative Advanced Planning
- Runway configuration management depending on a MAS
- Usage of short-term ATFCM measures
- Coordinated slot allocation
- Strategic flight scheduling
- National daily ATFCM entity and plan
- Traffic synchronization

Also, the MAS of Paris, London, and Berlin, among others, should be further investigated to discover which MAS system is successful at them and which can also be integrated in the Netherlands.

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