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TÍTOL DEL TFG: Assessing the status of Airport Collaborative Decision Making (A-CDM) concept at European airports

TITULACIÓ: Grau en Enginyeria de Sistemes Aeroespacials

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Títol: Avaluació de l'estat del concepte de presa de decisions col·laborativa en aeroports (A-CDM) als aeroports europeus
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Resum

En les últimes dècades, el transport aeri s'ha tornat més accessible i la demanda està creixent cada cop més amb els anys. Els aeroports i l'espai aeri estan cada vegada més concorreguts i han de gestionar un volum de vols molt elevat, per tant, s'enfronten a la necessitat d'augmentar la seva capacitat i millorar constantment el seu sistema operatiu.
El principal repte per a les parts interessades de l'aeroport en aquestes situacions properes a la saturació és aconseguir la màxima eficiència i predictibilitat operativa, així com una millora de la utilització de la capacitat i l'eficiència de costos. No obstant, els *stakeholders* aeroportuaris sovint treballen de manera dividida i aïllada, operant sistemes independents, i aquesta manca de consciència de la situació comuna pot provocar disfuncions i ineficiències generalitzades.
Airport Collaborative Decision Making (A-CDM) és una solució dins del programa SESAR (Single European Sky ATM Research), promogut per EUROCONTROL, ACI-Europe, IATA i CANSO, que té com a objectiu millorar l'eficiència operativa i la predictibilitat dels aeroports, així com millorar la gestió del flux del tràfic aeri i reduir la congestió fent un ús més eficient de la capacitat i els recursos existents. Aquests objectius s'aconsegueixen animant les diferents parts de l'aeroport a treballar de manera conjunta, transparent i col·laborativa, mitjançant l'intercanvi d'informació oportuna i precisa.
Aquest projecte té com a objectiu explicar el concepte A-CDM i el seu procés d'implementació complet en un aeroport. A més, s'ha desenvolupat una avaluació de l'estat actual de l'A-CDM als aeroports de Zuric i Amsterdam-Schiphol i una anàlisi del procés d'implementació. Així mateix, per avaluar la possibilitat d'ampliar el concepte a aeroports no europeus, també s'ha analitzat el cas de l'aeroport de la Ciutat de Mèxic, on l'intent d'implementació no va tenir èxit. Finalment, s'han estudiat els sistemes existents i futurs que complementen o són la continuació de l'A-CDM.
Aquest estudi s'ha realitzat a partir de la informació proporcionada pel cap d'operacions aèries de l'aeroport de Zuric, una entrevista amb el responsable de processos A-CDM d'Amsterdam-Schiphol i una sèrie d'entrevistes amb un consultor que va estar a càrrec de la implementació de l'A-CDM a l'Aeroport de la ciutat Mèxic.
Les principals conclusions a les que s'ha arribat és que l'A-CDM porta molts beneficis tant quantitatius com qualitatius a la gestió del turnaround process, predictibilitat, reducció de taxi time, emissions i reducció de delays, entre molts altres. No obstant, és un procés complex i que requereix molta col·laboració i coneixement dels procediments, i en alguns casos, bastant de temps i inversions. Per això és molt important valorar la decisió tenint en compte els nivells de congestió i capacitat de l'aeroport. També s'ha conclòs que els aeroports europeus tenen avantatges tant tecnològics com culturals per a la seva implementació, per tant en el present són els més favorables per ser aeroports A-CDM. A més, s'ha vist que l'A-CDM, tot i ser un procés estandaritzat d'EUROCONTROL, té un gran factor local i s'adapta a les condicions i necessitats de cada aeroport.

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Overview

In the last decades, air transport has become more accessible and the demand is increasingly growing over the years. Airports and airspace are becoming congested and have to handle a very high volume of flights, therefore facing the need to increase their capacity and constantly improve their operational system.
The major challenge for airport stakeholders in those situations close to saturation is to achieve maximum operational efficiency and predictability, together with improved capacity and cost efficiencies. Nevertheless, airport partners often work in a divided and isolated manner, operating independent systems, and this lack of common situational awareness can lead to widespread dysfunctions and inefficiencies.
Airport Collaborative Decision Making (A-CDM) is a solution within the SESAR (Single European Sky ATM Research) programme, promoted by EUROCONTROL, ACI-Europe, IATA and CANSO, that aims to improve the operational efficiency and predictability of airports, enhance traffic flow management and reduce congestion by making more efficient use of existing capacity and resources. These objectives are achieved by encouraging airport stakeholders to work together in a transparent and collaborative manner, through the exchange of timely and accurate information.
This project aims to explain the A-CDM concept and its complete implementation process at an airport. Further, an assessment of the current status of A-CDM at Zurich and Amsterdam-Schiphol airports and an analysis of the implementation process has been conducted. Moreover, in order to evaluate the possibility of expanding the concept to non-European airports, the case of Mexico City airport, where the implementation attempt was not successful, has been also analysed. Finally, the existing and future systems that complement or continue the implementation of the A-CDM has been studied.
This study has been conducted on the basis of information provided by the Head of Flight OPS at Zurich airport, an interview with the A-CDM Process Manager at Amsterdam-Schiphol, and a series of interviews with a consultant who was in charge of the implementation at Mexico airport.
The main conclusions drawn are that A-CDM brings many quantitative and qualitative benefits in managing the turnaround process, predictability, reduction of taxi time, emissions and delay reduction, among many others. Nevertheless, it is a complex process that requires a lot of collaboration and knowledge in procedures, and in some cases, a lot of time and investments. It is therefore very important to evaluate the decision of implementation taking into account the congestion and capacity levels of the airport. It has also been concluded that European airports have both technological and cultural advantages for CDM implementation, therefore, at present, they are the most favourable to be A-CDM airports. Furthermore, it was found that A-CDM, despite being a standardised Eurocontrol process, has a strong local factor and adapts to the conditions and needs of each particular airport.

Thanks to my tutor, Jovana, for her involvement and dedication and for guiding me through the whole process. To my sub-tutor, Jordi, for giving me his point of view and advice. Also, many thanks to Yiannis Alexopoulos, Jann Döbelin and Andrés Torrecillas, for providing me with first-hand information and knowledge about the A-CDM at Zurich, Amsterdam and Mexico City airports. And special thanks to my family for their support during all the years of my career and all my life.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

A-CDM: Airport - Collaborative Decision Making
A-CDM CG: Airport - Collaborative Decision Making Coordination Group
A-DPI: ATC Departure Planning Information Messages
A-SMGCS: Advanced Surface Movement Guidance and Control System
ACI: Airports Council International
ADIP: Assigned De-icing Position
AIBT: Actual In-Block Time
AICM: Aeropuerto Internacional de la Ciudad de México (IATA)
AIMS: Airport Information and Management System
ALDT: Actual Landing Time
AMAN: Arrival Manager
AMS: Amsterdam Airport Schiphol (IATA)
ANSP: Air Navigation Service Provider
AO: Aircraft Operator
AOBT: Actual Off-Block Time
AODB: Airport Operations Database
AOP: Airport Operations Plan
APOC: Airport Operations Center
ARDT: Actual Ready Time (for Movement)
ASRT: Actual Start-Up Request Time
ATC: Air Traffic Control
ATFCM: Air Traffic Flow and Capacity Management
ATFM: Air Traffic Flow Management
ATM: Air Traffic Management
ATS: Air Traffic Services
AXIT:Actual Taxi-In Time
AXOT:Actual Taxi-Out Time
C-DPI: Cancel – Departure Planning Information message
CANSO: Civil Air Navigation Services Organisation
CARATS: Collaborative Action for Renovation of Air Transport Systems
CBA: Cost-Benefit Analysis
CFMU: Network operations (EUROCONTROL)
CPDSP: Collaborative Pre-Departure Sequence Planning
CTOT: Calculated Take-off Time (NMOC)
DGAC: Directorate General of Civil Aviation
DICS: De-icing Cancelled Status
DIWT: De-icing Waiting Time
DMAN: Departure Management System
DMEAN: e Dynamic Management of the European Airspace Network
DPI: Departure Planning Information Messages
E-DPI: Early-Departure Planning Information Messages
ECAC: Transport Ministers of the European Civil Aviation Conference
EDIT: Estimated De-icing Time
EIBT: Estimated In-Block Time
EOBT: Estimated Off-Blocks Time

ETFMS: Enhanced Tactical Flow Management System
ETO: Estimated Time Over
ETOT: Estimated Take Off Time
ETTT: Estimated Turn-round Time
EXIT: Estimated Taxi-In Time
EXOT: Estimated Taxi-Out Time
FANS: Future Air Navigation Systems
FIDS: Flight Information Display System
FIR: Flight Information Region
FUM: Flight Update Message
GH: Ground Handler
IATA: International Air Transport Association
ICAO: International Civil Aviation Organization
IT: Information Technology
KLM: Royal Dutch Airlines
LLCs: Limited Liability Companies
LVNL: Air Traffic Control the Netherlands
MTTT: Minimum Turn-round Time
NAIM: New Mexico City Airport
NMOC: Network Management Operations Centre
NOP: Network Operations Plan
OPS: Operations
PMP: Project Management Plan
SAOC: Schiphol Airline Operators Committee
SENEAM: Servicios a la Navegación en el Espacio Aéreo Mexicano
SES: Single European Sky
SESAR: Single European Sky ATM Research
SID: Standard Instrument Departure
SITA: Society of International Telecommunication and Aeronauticals
SOBT: Scheduled Off-Block Time
T-DPI: Target - Departure Planning Information message
T-DPI-s: Target DPI-sequenced
T-DPI-t: Target DPI-target
TAM: Total Airport Management
TLDT: Target Landing Time
TOBT: Target Off-Block Time
TSAT: Target Start Up Approval Time
TTOT: Target Take Off Time
TWR: Aerodrome Control Tower
VTT: Variable Taxi Time
ZRH: Zürich Airport (IATA)

INTRODUCTION

In the last two decades, factors such as the advent of low-cost airlines (LLCs) and the affinity of new generations for global experiences have contributed to making air travel more accessible. Due to the rising air travel demand, airports and airspace are becoming congested, being increasingly forced to handle a very high volume of flights. Although it is true that this growth in the market implies an improvement in the activity and productivity of air navigation service providers, airlines and airport operators, it is also creating the need for an expansion of airport capacity and constant improvement of the system.

During the daily activity of airports, various setbacks can occur, such as shortage of free parking stands, late or erroneous communication of information to passengers, situations of adverse operating conditions where capacity is insufficiently utilised, and prolonged periods of time are taken to recover normal operation. In these situations close to saturation, the slightest deviation from the planned traffic can cause large disruptions resulting in high costs. The biggest challenge for airport stakeholders is to achieve maximum operational efficiency and predictability, along with improved capacity and cost efficiencies.

Nevertheless, airport stakeholders often work in a divided and isolated manner operating independent systems, and that lack of common situational awareness can cause widespread dysfunctions and inefficiencies. Enabling this fast-growing market scenario to be sustainable without generating a higher number of flight delays, collaboration between the airport partners is of utmost importance. For this reason, the implementation of Airport-Collaborative Decision Making has become a key process in the recent years.

A-CDM is a joint European initiative and its part of the SESAR (Single European Sky ATM Research) program. A-CDM is promoted by Eurocontrol, ACI-Europe (Airports Council International), CANSO (Civil Air Navigation Services Organisation) and IATA (International Air Transport Association) and aims to improve airport operational efficiency, predictability and therefore event punctuality by the optimisation of the use of existing capacity and resources, both material and human. Through the A-CDM implementation, all parties at the airport benefit in terms of their individual interests, yet the A-CDM is a partnership process with common objectives for all actors. The principal ones are to improve predictability and on-time performance, flexible pre-departure planning, to optimise airport operations and the use of infrastructure and ground handling resources, stands, gates and terminals, to reduce ground movement and associated fuel burn costs, thus producing environmental benefits, and to reduce ATFM slot wastage and apron taxiway and holding point congestion.

These series of objectives are achieved by encouraging airport stakeholders to work together in a transparent and collaborative manner, through the exchange of relevant, accurate and timely information regarding priorities and limitations in a given situation. It focuses specifically on the efficient handling aircraft turn-around and pre-departure processes, covering the period of time between the three hours prior to the estimated off-block time (EOBT) and take-off.

This project is structured in five main chapters. The first chapter consists of the explanation of the methodology followed to develop the project. The second chapter introduces the A-CDM concept in the context of the Single European Sky, followed by a detailed description of the implementation process and key concepts, including the human and the technical part with all the steps to be followed from the moment the decision to implement A-CDM is made at a specific airport, until the airport receives the A-CDM Airport Status. The aim of this initial chapter is to explain the concept of A-CDM and its implementation in a comprehensive way so that everyone who reads the report can become familiar with its main elements.

The third chapter assesses the implementation of A-CDM at two European airports, Zurich Airport and Amsterdam-Schiphol. The main and local characteristics of A-CDM at each airport will be introduced in order to identify the differences between A-CDM at the two different airports, as well as to provide a concrete exemplification of the general process explained in the second chapter. In addition, through information provided by the Head of Flight OPS Engineering at Zurich Airport and an interview with the A-CDM Process Manager at Amsterdam-Schiphol, the A-CDM implementation process will be analysed and compared.

In the fourth chapter, in order to observe and analyse what kind of problems can arise during the implementation process and to be able to assess it in a non-European airport, the case of Mexico City International Airport will be studied. This analysis is based on a series of interviews with a consultant who was present throughout the whole A-CDM implementation process at the given airport.

Finally, in the fifth chapter, other existing initiatives that complement or continue the implementation of A-CDM will be introduced, in order to see systems that further improve the A-CDM benefits and future systems under development.

CHAPTER 1. METHODOLOGICAL FRAMEWORK

The second chapter of the project, which contains the detailed description of the general process of implementation of the A-CDM and of all the key elements that are part of it, has been written through the collection, analysis, comparison and contrasting of information from different sources, mainly implementation manuals of the international aviation organisations involved in A-CDM as EUROCONTROL, IATA and CANSO. The information has been selected and written in a relevant and clear manner, in order to be able to present the A-CDM process and its main elements in a fully comprehensive way.

The third chapter, which contains the assessment of the A-CDM at the two European airports, has been developed as described as follows: The first part, concerning the introduction and the A-CDM procedures at each airport, has been written using the same methodology as in the second chapter, based on the different A-CDM operations manuals of the airports of Zurich and Amsterdam. Afterwards, the analysis of the implementation process has been based on the information obtained from the representatives of each airport, with whom it has been possible to establish contact: the Head of Flight OPS Engineering at Zurich Airport and the A-CDM Process Manager at Amsterdam-Schiphol. The analysis process has consisted of, firstly, studying the A-CDM process in detail for each airport, trying to identify the most important and distinctive points, as well as the main factors affecting the A-CDM process at each airport. Subsequently, to elaborate a series of questions on its implementation and on issues where it was interesting to get an insider's perspective, and in this way, to also obtain information that could only be obtained from first-hand experience. After that, the interview with the survey was conducted in the case of Schiphol, and the feedback was obtained from the representative of Zurich Airport. From there, the sections on implementation have been developed adding also a personal point of view to analyse the strengths and weaknesses of A-CDM at each airport and the differences between them, as well as other aspects including future improvements and systems, benefits achieved and a final comparative analysis between the two airports.

The same methodology has been followed for the elaboration of the fourth chapter, conducting the study and the questions on the possible factors that could have caused the failure of the implementation of the A-CDM at Mexico City Airport, and then contrasting the information through the survey interview with the representative partner of the airport: a consultant from ALG who was in charge of the A-CDM implementation at the airport. Subsequently, an analysis of the possible implementation of A-CDM at non-European airports was conducted on the basis of the information obtained and, after having analysed the existing influencing factors, adding also a personal point of view.

Finally, the fifth chapter has also been based on the information obtained throughout the study of the three different airports, where future trends and updates of the A-CDM have been identified. In this manner, each of the complementary or enhancement systems has been described in the chapter in an comprehensive way, and building on what has been learnt from the current A-CDM system, comparing and identifying the main differences and improvements with respect to it.

CHAPTER 2. INTRODUCTION OF A-CDM AND KEY CONCEPTS

2.1. Single European Sky and A-CDM

The idea of the Single European Sky (SES) originated in 1999, stemming from the inefficiency and congestion of European airspace and the general discontent of airlines and passengers with delays, along with high emissions and costs. The European initiative was launched in 2004 by the European Commission with the aim of reform, reorganise and improve the structure of European ATM as a function of air traffic flow, rather than conforming to national borders; hence reducing the fragmentation of European airspace. The main objectives of the initiative are to improve the efficiency and safety of the air traffic management system, increase capacity and reduce aircraft emissions and lower flight costs, in order to satisfy future airspace capacity and security demands.

Within the Single European Sky initiative resides the SESAR (Single European Sky ATM Research) programme. This programme is the technological component of the SES, being the European system that originated in order to solve the need for technological reform in ATM, since the current technology was outdated and did not allow air traffic to be managed in an optimal way. Its purpose is to modernise european air traffic management and to ensure a high-performance air traffic management infrastructure for the safe, efficient and sustainable operation and development of air transport.

In the first phase of the SESAR project, the Dynamic Management of the European Airspace Network (DMEAN) programme was launched, aimed at increasing ATM system capacity and meeting short-term demand while operational improvements to SESAR solutions materialised [20]. This programme aims to streamline demand and capacity situations in the European ATM Network by improving information exchange processes and introducing new concepts of operational planning and traffic management, based on maximum operational cooperation between European airspace users. One of the priorities of the DMEAN is the improvement of the co-ordination between the airport and traffic management process, whereby aircraft ground operations are one of the key components to achieve these objectives.

Airport-Collaborative Decision Making (A-CDM) is one of the solutions of the DMEAN programme, which is part of the ATM 2000+ Strategy, developed at the request of the ECAC (European Civil Aviation Conference) Transport Ministers in order to meet the future needs of the growing European air traffic, and in this way, the demand for an increased of air traffic management and air services.

The idea of implementing A-CDM at European airports first emerged in 2000. It was based on the American Collaborative Decision Making concept that had been introduced in 1998, in order to deal with the decrease in capacity due to bad weather conditions during the en-route phase or at the airport, and which had had favourable results in terms of delays in its trial period. Therefore, the project was started under the name A-CDM EUROCONTROL, and initially many tests were performed at different European airports in order to be able to establish a European CDM concept.

2.2. A-CDM Concept and objectives

The A-CDM concept consists of the timely and accurate exchange of data between the different stakeholders of the airport system, as well as the implementation of a set of automated procedures and operational processes for the better functioning of airport operations, both in general and for each individual partner.

As many airports and airspaces are currently operating at the edge of their capacity, very close to saturation, A-CDM is born with the objective of improving predictability, improving the process of managing traffic flows, reduce the number of unutilised ATFM slots; thereby reducing congestion and making more efficient use of existing capacity and resources. A-CDM aims at reducing airport and en-route delays and optimising airport operations. It reduces congestion on aprons, taxiways and holding points and improves gate management. By the exchange of information between the airport terminal and the air traffic management system, stakeholders can monitor demand, capacity and constraints, and make decisions based on more accurate information in a very fast varying operational circumstances.

For this reason, A-CDM is an important element in achieving the objectives of the Single European Sky, as it contributes to increasing airspace capacity and hence the efficiency of the whole air traffic system. It is therefore of great importance for other elements of the SESAR project as it represents an improvement of the air transport system. It should be noted that in this exchange of information between all actors, the information has the same meaning for all of them and contributes to the creation of common situational awareness. It also brings a significant improvement in reducing fuel consumption and other operations in other segments, including passenger operations.

Airport CDM is now acknowledged worldwide. A-CDM is fully deployed in 33 airports all over Europe: Amsterdam, Barcelona, Bergamo, Berlin Brandenburg, Brussels, Copenhagen, Düsseldorf, Frankfurt, Geneva, Hamburg, Helsinki, Lisbon, London Heathrow, Lyon, Madrid, Malaga, Milan Linate, Milan Malpensa, Munich, Naples, Nice, Oslo, Palma de Mallorca, Paris CDG, Paris Orly, Prague, Riga, Rome Fiumicino, Stuttgart, Venice, Vienna, Warsaw and Zurich [1]. Figure 2.1 shows the distribution of A-CDM airports in Europe and the current status of their implementation.

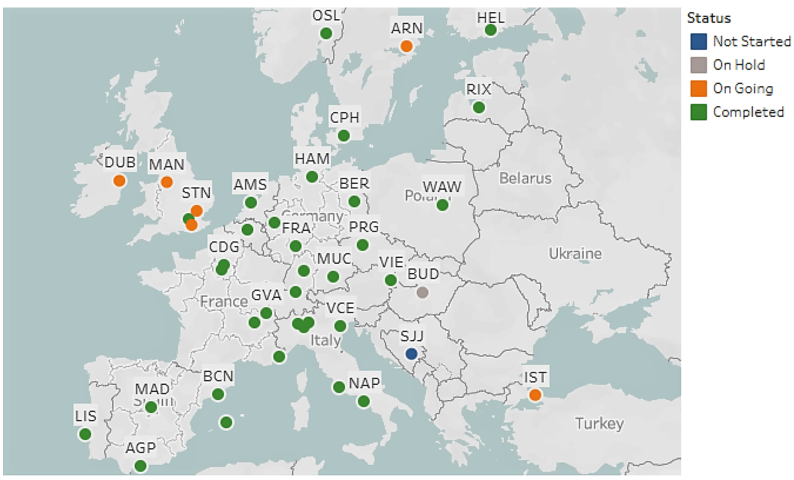


Figure 2.1: Map of A-CDM Airports in Europe and current status (Source: [1])

2.3. International aviation organizations in the introduction of the A-CDM

The European Commission and the European Organisation for the Safety of Air Traffic (EUROCONTROL) have assumed the primary role in the building of the forthcoming air traffic management system in Europe. Other international aviation organisations, including the International Civil Aviation Organisation (ICAO), the Civil Air Navigation Services Organisation (CANSO), Airports Council International (ACI) and the International Air Transport Association (IATA), support the application of the A-CDM implementation programme.

At present, ATM modernisation programmes dealing with Future Air Navigation Systems (FANS) in addition to SESAR, such as the US Next Generation Air Transportation System (NextGen) and Japan's Collaborative Actions for the Renewal of Air Traffic Systems (CARATS), are already implementing several variations of A-CDM. Each of these organisations and projects have developed a vision according to their specific needs and context [21].

Due to some delay in the first phase of the SESAR project, and consequently in the implementation of A-CDM, the Airport Collaborative Decision Making Coordination Group (A-CDM CG) was formed, consisting of several representatives from different stakeholder organisations; airlines, air traffic control service providers (ANSP), international organisations, etc. with the purpose of influencing the short and medium term harmonisation and implementation of A-CDM and accelerating the process, influencing policies and strategies for its development.

EUROCONTROL published an A-CDM implementation manual with the objective of providing detailed guidance from the decision to implement it at an airport to the end, including guidelines for assessing the performance once implemented and risk mitigation, to all entities interested in implementing it.

Additionally, EUROCONTROL counts on the cooperation of ACI and CANSO, who by signing a joint agreement in 2012 agreed on common tasks and objectives, in the dissemination of the advantages of A-CDM and in the technical support in communication and coordination with airports. Also in cooperation with ACI and IATA, EUROCONTROL is in charge of deciding the priority of A-CDM implementation, taking into account the level of airport congestion, infrastructure and demand.

2.4. Stakeholders

A-CDM allows all users involved to work together and make decisions based on accurate and better-quality information. As a result, erroneous decision-making or directly not being able to make decisions scenarios can be avoided.

The optimisation of airport capacity implies cooperation among all airport parties operating as a team. Each partner needs to coordinate its actions and decisions by the exchange of information and resources to reach common goals.

An A-CDM Partner is a stakeholder of an airport CDM, who takes part in the CDM process. The main partners are:

- Airport operators
- Airlines
- Handling agents
- Ground handling agents
- Air Navigation Service providers (ANSP)
- European Air Traffic Flow Management (CFMU)

One of the main focuses of the A-CDM in terms of stakeholders is to achieve a ”no-blame” culture. It is very important to establish a culture that ensures that information will be disclosed and used to reduce problems and learn from them, or otherwise provide a clear and unbiased picture of achievements. The objective is to put aside the partners’ tendency to hold other parties responsible for any inaccuracies or disruptions that may occur during the course of airport processes.

2.5. The process of implementation of A-CDM

A-CDM is primarily about people, not technology. When it comes to implementing A-CDM, the two processes that are often the most novel and challenging for the airport community to consider are the culture change and the new procedures. A-CDM requires a switch of mindset, as it involves a different attitude and behavioural change based on working together and breaking down barriers between different partners. That is why it is of utmost importance to demonstrate and justify the benefits that A-CDM brings to all partners. In addition, it also involves a series of new procedures that are a consequence of this new way of working, and which require a phase of training and understanding of their necessity and impact.

Therefore, the task of educating and convincing all partners is essential. Some of the problems that often arise at the beginning of this phase are related to partners being sceptical about the process, the need to demonstrate the credibility of the project, conflicts of interest, data ownership, among others. In this step, EUROCONTROL is in charge of the training programmes for the partners, showing all the benefits that the A-CDM entails. Another aspect that the A-CDM addresses is the setting of common objectives for all users, which in any case must involve the maintenance of an efficient transport service. After all partners have been convinced and educated and the objectives have been set, the Organisation Structure has to be established, which represents the most crucial part of the process. At this stage there are often disagreements and long periods of decision making to define who will be in charge of the project, who will finance it and how it will be organised. The Organisation Structure consists of the Strategic Steering Board, the Operational Advisory Group, the Project Manager, Sub-Project Managers and Supporting Staff. Once the functionality of all partners involved has been decided and agreed upon, a Project Management Plan (PMP) is created, agreed and signed by all, where all the activities and planning are defined. An A-CDM Program Manager is defined, who has to control the daily coordination and other organisational tasks.

From an airport's initial interest in implementing A-CDM to its full implementation, there are a number of steps in between that have to be undertaken by the different interested parties. Four phases of development can be distinguished in which numerous decisions take place. These phases are usually: The Information Phase, the Analysis Phase, the Implementation Phase of the A-CDM Concepts and last but essential, the validation of the A-CDM Concepts and the subsequent evaluative tests by NMOC. Finally, once these four stages have been successfully completed, the airport receives the A-CDM Airport Status.

- Information Phase: In this phase, a series of meetings are held between all actors in order to get a clearer understanding of the A-CDM concept with all its details, together with an explanation of the whole implementation process and potential enhancements. This is the phase in which the partners reach an agreement and the airport management approves the implementation. Further analysis is usually needed.

- Analysis Phase: Before starting the implementation, it is necessary that a compatibility analysis of existing airport infrastructures and procedures with the requirements of the A-CDM concept is performed. This analysis is called the GAP Analysis. It is performed either by EUROCONTROL or by an independent consultancy company, and defines the operational and technical requirements that must be met for further implementation. After conducting the GAP, if it turns out that a lot needs to be done for the implementation of the A-CDM, the stakeholders may decide to conduct a CBA (Cost Benefit Analysis) to determine the profitability of the project at the airport in question. Based on the CBA, the final decision on whether or not to implement A-CDM at that airport is made.

- Implementation Phase: If after obtaining the results of the CBA it is decided that it will be implemented, the implementation phase of the Concept Elements begins.

The following section 2.6. explains the implementation phase of the A-CDM concepts, which requires further deepening as it is the basis for understanding the functioning of the A-CDM process.

2.6. Key concept elements of A-CDM

The Airport CDM concept is divided into six essential elements:

1. A-CDM Information Sharing;
2. The Milestones Approach;
3. Variable Taxi Times;
4. Collaborative Pre-departure Sequencing;
5. A-CDM in Adverse Conditions; and
6. Collaborative Management of Flight Updates;

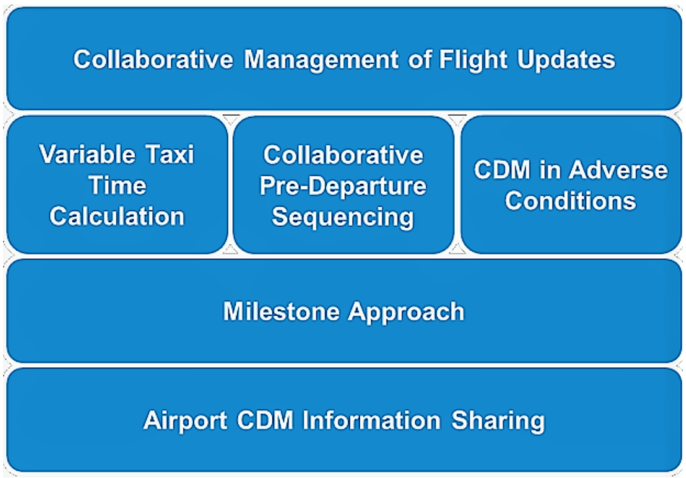


Figure 2.2: Scheme of the key concept elements of A-CDM (Source: [2])

A staggered procedure is proposed, with each step representing an additional benefit which will become even more important as the conceptual components of A-CDM develop.

Some of the elements also help to build the environment that the other ones require to function. Hence, the operational concept assumes that some elements are based upon each other and so they need to be sequentially implemented, as will be described in the following subsections.

2.6.1. A-CDM Information Sharing

Information Sharing is the most important basic element and should be implemented before all others, as it underlies all the following steps. Through the exchange of information, common situational awareness is ensured by providing a single, common set of data. It links all partners and therefore forms the basis for the other A-CDM elements, facilitating their implementation.

The information exchange aims to improve the efficiency and decision-making of all stakeholders through better coordination among them, and is based on a series of procedures and actions.

The key concept and basis for implementing this first element of the A-CDM is the creation of the A-CDM Platform. This platform connects the individual data processing systems of the different stakeholders and unites them into a common system, making all necessary flight status information available to all partners. Through the A-CDM Platform, information is acquired from ATFM, ATS, Aircraft Operators and Airport Operators about flight plans and flight progress. This data is then processed in a single place and subsequently distributed to the concerned parties. The system also gathers information on event predictions, status messages, weather information and on the status of the airport's technical systems. It also distributes recommendations and alert notices. All these data is centralised, and can be recorded and archived for statistical and other purposes.

Another important factor, already mentioned above, to make the creation of such a system possible is the use of standardised data. Considering that there are often inconsistencies between the data of different users, in order to avoid data recognition problems, the data format must be adapted to all of them. Therefore, a series of standards must be defined that meet the requirements of safety, security and reliability of the information, and that have been established by an agreement between all partners.

The A-CDM partners are the responsibles for providing this information. A summary of the information typically provided by each is shown in Figure 2.3. It is important to mention that some of the elements and timings that appear will be defined and explained in the following sections.

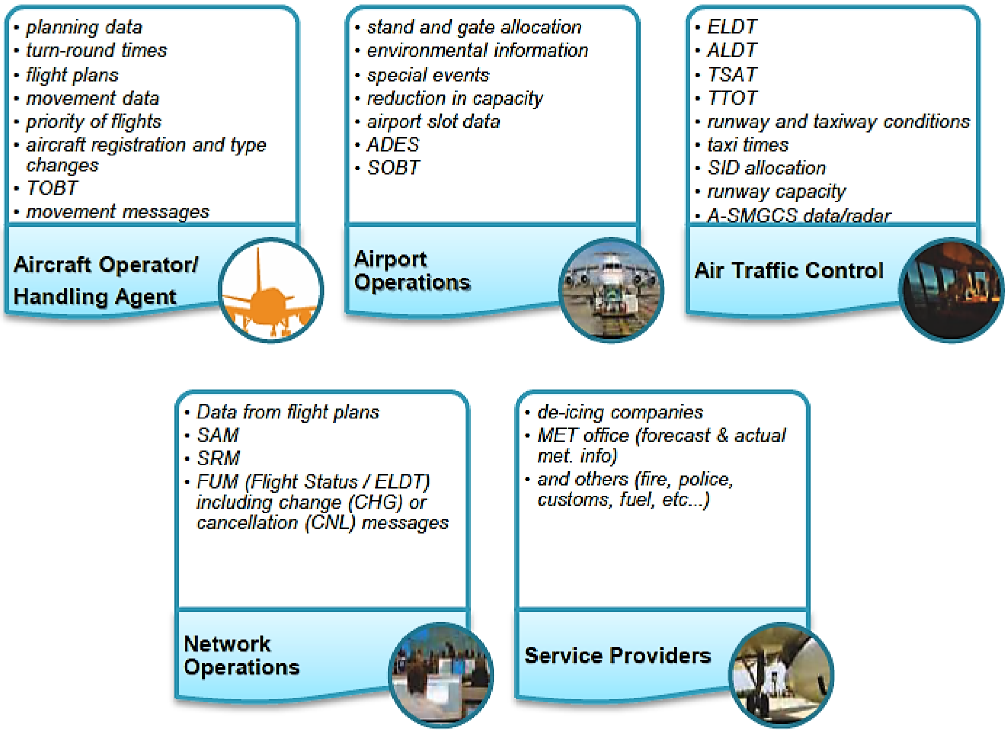


Figure 2.3: Sources and types of data within the Information Sharing element (Source: [3])

2.6.2. A-CDM Turnaround process: The Milestones Approach

Having successfully established the information exchange environment between the partners, it is possible to move on to the next step, the Milestones Approach.

The A-CDM turnaround process is defined by a set of milestones that allow a close tracking of significant events from the initial planning to take-off, enabling all partners to identify possible changes to the planned schedule and all potentially affected stakeholders to have information about the changes available to them. There are a total of 16 basic milestones defined by EUROCONTROL, shown in Figure 2.4.

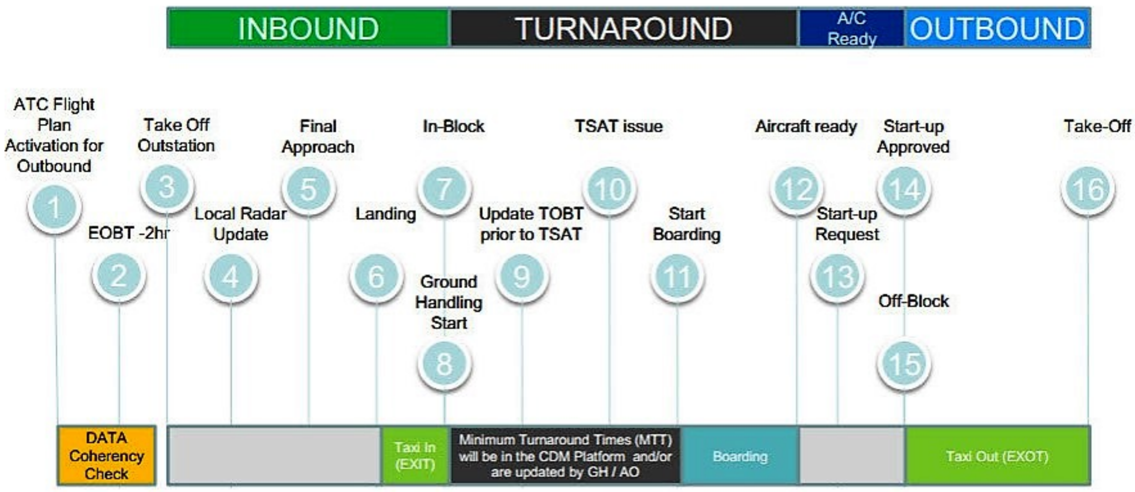


Figure 2.4: Milestones of the A-CDM turnaround process (Source: [3])

The key elements within the Milestones Approach are the implementation of TOBT (Target Off-Blocks Time) and TSAT (Target Start-up Approval Time).

The TOBT is defined as the time at which an aircraft is ready for departure. That is, the time at which the ground handling process is completed: all gates are closed, the boarding bridge is removed, the push-back vehicle is available and ready for push-back/taxi immediately after receiving Tower approval. This is a monitored point in time and must be confirmed by an Aircraft Operator (AO) or Ground Handler (GH), who will inform the airport community. [4]

TSAT, 'in reply' to TOBT, is the time that ATC is expected to clear the aircraft for engine start-up and push back, being the moment when an aircraft leaves the parking position. It takes into account the TOBT, CTOT (if regulated) and/or the traffic situation and ATFCM restrictions and determines the airport's pre-departure sequence. [4]

Therefore, based on an accurate TOBT prediction from Milestones tracking, ATC can design the pre-departure sequence, and the TSAT at which aircraft will depart from their parking stands can be calculated.

TOBT is the most important timing of the turnaround process and crucial for the prediction of target take-off times, start-up times and taxi times.

Nevertheless, the quality and accuracy of the TOBT and TSAT depends on the other milestones. As the process proceeds, each milestone provides new information and introduces changes to existing information, so when more accuracy is needed in these time indicators, it will be important to be able to identify which milestones should be improved.

Another important timings to emphasise are the Minimum Turnaround Times (MTTTs), which help to estimate/calculate TOBT more accurately (TOBT = ELDT/ALDT + EXIT + MTTT or TOBT = AIBT + MTTT). MTTTs depend on different elements, including the type of aircraft and stand, airlines' procedures, etc. They must be obtained through collaboration and agreement with the Airline Operators, in order to be as accurate as possible. MTTT values have to be determined for each aircraft type and stored in the airport database. They will later be replaced by ETTT (Estimated Turn-Round Time).

A brief summary of the 16 main milestones is in the Annex A, containing the purpose of each one, the information it provides, the changes it introduces and the time reference of implementation and release of information. It should be noted that the 16 are not always rigidly required, sometimes more are necessary and sometimes fewer due to the need for more or less information. An example is the case of having to perfome de-icing operations, then more time indicators and extra information are required.

2.6.3. Variable Taxi Times

Taxi time is the time, before or after flight, that an aircraft spends in motion or held on the airport surface, using its own means of power. It can refer to inbound or outbound flights, therefore for A-CDM purposes, two types of Taxi Times are differentiated:

- For inbound flights, EXIT (Estimated Taxi-in Time): The estimated taxi time between landing and in-block [22].
- For outbound flights, EXOT (Estimated Taxi-out Time): The estimated taxi time between off-block and take off [22].

While the use of standard taxi time values at small airports meets planning needs, at complex airports the layout of runways and parking stands make these values very different and more precise taxi time data is required. The time an aircraft spends taxiing depends on many aspects, some of them are: the configuration of the airport, the layout of parking positions, the number of runways and number of runways in use, the weather conditions, the type and weight of aircraft, the traffic density, airport particular operating procedures and many others.

Another improvement brought by the A-CDM concept is related to the accuracy of the taxi time information. Instead of using a standard default value ("NMOC default taxi times"), the calculation of values based on operational experience and historical data is introduced (VTT, Variable taxi time), providing increased predictability for both arriving and departing aircraft [23]. It enables a more accurate determination of take-off time, which is a significant improvement in the traffic planning process by the NMOC. Additionally, more accurate taxi time information allows optimisation of aircraft operations.

The calculation of taxi times is made taking into account the following factors:

- Standard/current default taxi times
- Type and category of the aircraft
- Average taxiing time obtained on the basis of historical data
- Taxiing time in case of specific operating conditions
- Operational expertise contribution (ATC, local operators, Ground Handlers, Aircraft Operators etc.,), These partners are involved in traffic flow on a regular basis and should be implicated in the evaluation of operational limitations and considerations regarding taxi times.
- Taxiing route determined depending on the runway in use

More accurate taxi time data plays a significant role in the calculation of the time related to the significant events defined within the Milestone Approach: EIBT (Estimated In-Block Time), ETOT/TTOT (Estimated/Target Take-Off Time) and CTOT (Calculated Take-Off Time).

Table 2.1 shows the times that VTTs allow to calculate with better precision for both landings and departures, together with the benefits they bring.

Table 2.1: Times calculated with VTT (Source: [3])

Landings	Departures
EXIT + ELDT = EIBT EXIT: Estimated Taxi-In Time ELDT: Estimated/Actual Landing Time EIBT: Estimated In-Block Time	**EXOT** + EOBT/TSAT= ETOT/TTOT EXOT: Estimated Taxi-Out Time EOBT: Estimated Off-Blocks Time TSAT: Target Start Up Approval Time ETOT/TTOT: Estimated/Target Take off Time
Benefits: • Stand and gate planning • Pre-departure sequencing • Ground handling resource management	**Benefits:** • Calculation of more accurate CTOT times • Optimization of the capacity management process and traffic flows at the European level

2.6.4. Collaborative Pre-departure Sequencing

The fourth A-CDM element is the Pre-departure Sequencing. This phase requires the use of data from the previous phases, therefore before moving on to it is necessary that Information Sharing, the Milestones Approach and the Variable Taxi Time calculation have been satisfactorily implemented. Pre-departure sequencing is, according to EUROCONTROL, defined as the order that aircraft are planned to depart from their stands (push off-blocks), as opposed to conventional air traffic management, taking into account partners' preferences. Therefore, the "first in, first served" criterion is replaced by the application of the "best planned, best served" criterion, which is one of the most significant features of A-CDM.

For this element, communication between partners on flight departure preferences and TOBT is very important, as AO, Ground Handlers and Airport Operators can express them via the A-CDM platform for ATC to take it into account. For this reason, it is recommended that the method of determining priorities is defined in advance (at the beginning of the A-CDM implementation) and locally with the participation of all partners, in order to avoid misunderstandings.

First, an initial sequence is established, based on the list of TOBTs provided by the A-CDM Platform to ATC and other partners. ATC is responsible for confirming these TOBTs by assigning a TSAT to each flight, which determines the order in which the flights will depart from their stands. This initial sequence is modified according to the parameters that may affect it, such as regulations (CTOT) and other operational constraints. Based on this TSAT, the TOBT and TTOT are updated, also taking into account taxiing times and other possible factors such as de-icing. This TTOT is sent to Network Operations (via T-DPI messages) in order to update the slots. The next step includes the preferences that have been communicated via the A-CDM platform, whereby ATC modifies this initial sequence as far as possible taking them into account.

Pre-departure sequencing means many advantages related to transparency, predictability and timeliness. It allows for better planning of runway availability, as well as platform usage, parking positions, better efficiency in ground handling activities and in stand and gate management, etc. In addition, a pre-determined flight schedule, made accessible to all parties involved, contributes to reducing taxiing time and aircraft waiting time before take-off.

Moreover, software tools have been developed that provide information and help to calculate the timings concerning TSAT and TTOT/TLDT. These are the Arrival Management System (AMAN) and Departure Management System (DMAN), as well as the Surface Movement Guidance System (A-SMGCS). AMAN and DMAN are automated enablers, which output is TLDT for arrivals and TTOT for departures. The use of information from these programmes facilitates the process of deciding priorities and optimises airport planning. They are usually described as Advanced Concept Elements.

2.6.5. A-CDM in Adverse Conditions

There are a wide variety of events and occurrences that can cause the normal operation of an airport to be disrupted and reduce its capacity to significantly lower operational levels. Some of these are predictable to a greater or lesser extent, such as weather forecasts or planned maintenance, and some are not, such as an aircraft accident.

That is why the fifth main element is the A-CDM in Adverse Conditions, which aims to enable optimal reduced capacity management and to allow a smooth return to normal capacity once adverse conditions are no longer present. This element substantially improves predictability. In addition, another objective is to ensure that de-icing is part of the flight handling process, with the de-icing time being available to partners and hence considered in the calculation of the target times for which it is relevant. It should be noted that, again, since the A-CDM elements are applied sequentially, it is necessary that the previous elements have been implemented successfully beforehand.

In the absence of A-CDM, different procedures are applied in adverse conditions that do not differentiate the type of adversity, but how much the adversity affects the airport's capacity. This results in a system that is not robust. The A-CDM implements a number of procedures, which, since airports are not the same, are not applied in the same way at each airport, but they share a common basis:

- Developing a plan of procedures under adverse conditions.
- Ensure that procedures are straightforward and, as far as possible, the same as under standard conditions.
- Ensure that all partners are aware of the procedures.
- Designating a CDM coordinator to manage all activities.

As mentioned above, adverse conditions can arise from predictable or unpredictable events. The main predictable events are the weather (especially the wind, which conditions the runway and tawixay configuration and therefore the capacity), the level and need for de-icing, maintenance/construction works (although they do not always affect the capacity), if the necessary technical resources are available, technical problems in the actors, etc. Alarm levels are associated with these events, which are at the same time associated with the necessary procedures. Therefore, partners will receive both information about the event and the appropriate alarm.

On the other hand, there are unpredictable outages, which are divided into two categories: Those that are similar to the predictable ones, where existing procedures can be used, and those that are not, where improvisation is required in an organised way following a predefined basic structure for this type of case, so that it is not a total and uncontrolled improvisation. Alarm levels can also be applied in these cases.

In some cases, an A-CDM Coordinator, who can be a single person or a group, is required. The A-CDM Coordinator must have the necessary qualifications and knowledge of the airport operations and the A-CDM process at the airport in question. Some of its main functions include monitoring and modifying alert levels if necessary, coordinating the initiation of locally accorded special procedures, checking that all partners follow the established procedures correctly, triggering de A-CDM Cell if appropiate, and so on.

In many cases, it is also recommended that the A-CDM Coordinator manages the A-CDM Cell. The A-CDM Cell is composed of representatives from each part of the airport who are allowed to make decisions and define the order of priority in which disruptions will be handled. They are also responsible for confirming the procedures to be used in each case, which, although predefined, need to be approved. During adverse conditions, its main duties will be: to compile information on the adverse condition that is occurring and how it affects capacity, to study what factors most affect the airport's capacity during adverse conditions, to assess and report the global capacity of the airport, to inform concerned stakeholders of the current local situation, among others.

Both the A-CDM Coordinator and the A-CDM Cell are very important in situations where capacity is reduced or expected to be reduced, as they contribute to inform Network Operations of the situation.

2.6.6. Collaborative Management of Flight Updates

The essence of the A-CDM concept is to be able to monitor flight information from initial flight plan to take-off. The exchange of timely information increases the predictability of aircraft operations, taking into account that many of them take place at the airport. In addition, the accuracy of this information on important events improves the efficiency of the utilisation and management of the airport capacity, which is the main objective of ATFCM along with flight punctuality. In particular, the quality of flight plan data is crucial to the tactical decisions made by ATFCM.

The final A-CDM element, Collaborative Management of Flight Updates, represents the A-CDM's contribution to ATFCM, integrating A-CDM into the flow and capacity management process. It consists of the exchange of information between airports and Network Operations, which is made through a series of pre-determined messages. These messages can be of two types:

- Sending Departure Planning Information Messages (DPI): Messages that the airport sends to Network Operations. A DPI message contains updated departure flight information, including accurate estimated take-off time, taxi-time (EXOT), TOBT, TSAT and the SID.
- Sending Flight Update Messages (FUM): These are messages sent from Network Operations to the CDM airport, and their main objective is to inform the destination airport of the Estimated Landing Time (ELDT) of a flight.

This element provides numerous benefits, as the combination of information on the in-route phase of flights and airport operations allows for better management of capacity and traffic flows, making it possible to increase capacity. In addition, it also allows for an improved slot allocation process and increased predictability for ground operations. On top of that, this results in significant savings for the airlines.

There are usually discrepancies between ETOT (Estimated Take-off Time) and ATOT (Actual Take Off Time). With Collaborative Management Of Flight Updates, the A-CDM platform provides information about the TTOT, which enables Network Operations to calculate CTOT and inform all stakeholders, which greatly helps traffic planning.

It should also be pointed out that this element can only be introduced if the other elements are properly implemented and after many tests over long periods of time. That is why it is not implemented in all CDM airports, only some of them count with it. Then, it is usual that, due to this necessary verification phase, the A-CDM has to be implemented in two phases at some airports.

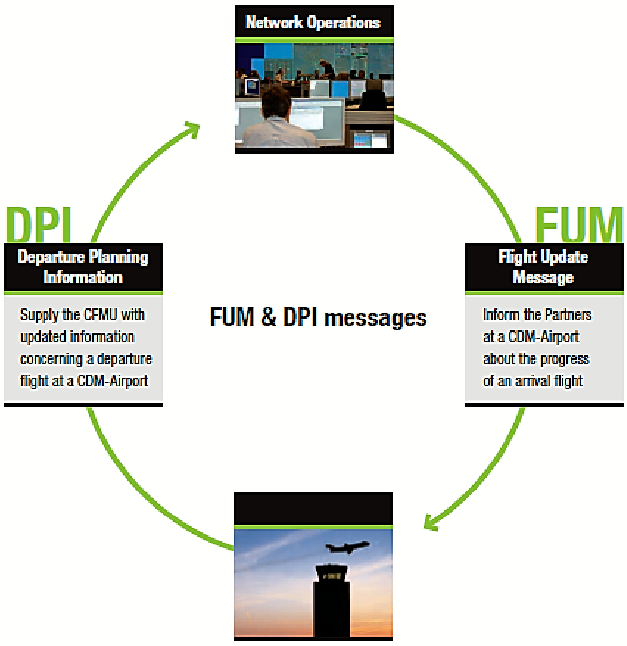


Figure 2.5: Scheme of the DPI and FUM messages exchange (Source: [4])

2.6.6.1. ***DPI Messages***

The more Milestones are achieved, the more accurate the information becomes. That is why there are five types of of DPI messages that are sent at different points in the process, as discussed in the Milestones description. Each type of message provides more rigorous information about the flight, which means that each new message is an update of the information sent in the previous one.

DPI messages are individual, i.e. they refer to a single flight, and are transmitted automatically as Milestones Approach events are reached.

The different types of DPI messages are:

1. E-DPI – Early DPI: This message is sent 2-3 hours before the aircraft leaves the parking position, i.e. 2-3 h before EOBT. For this message to be transmitted, it is essential that the EOBT consistency of the flight plan data and the airport slot has been verified. Therefore, its purpose is to confirm that the flight is going to take place. In case there is no airport slot, the E-DPI shall not be sent. It contains information on the ETOT time.

2. T-DPI-t – Target DPI-target: This message is sent from 2 hours before EOBT and before the ATC time of the pre-departure sequencing. The information it transmits is an updated ETOT time, i.e. the earliest possible TOBT time confirmed by the airline and the ground handling service provider.

3. T-DPI-s – Target DPI-sequenced: This message is sent 2 hours before the aircraft leaves the parking position. It is sent when the TSAT is established, and provides updated TTOT information. Based on this, Network Operations calculates the CTOT, and sends the enhanced calculated information if required.

4. A-DPI (ATC-DPI): This message is sent after off-blocks and before take-off. It contains very precise TTOT information based on the established take-off sequence.

5. C-DPI – Cancel DPI: This message cancels previously sent ETOT and TTOT information. It suspends the flight within the Enhanced Tactical Flow Management System (ETFS) tactical unit. Typically, this type of message appears when there is a technical problem with the aircraft after take-off clearance has been received.

When these messages are sent, Network Operations sends a response message, confirming that the message has been received or notifying if there are any errors or inconsistencies in the flight data. Figure 2.6 shows the DPI messages at the corresponding timings and Milestones.

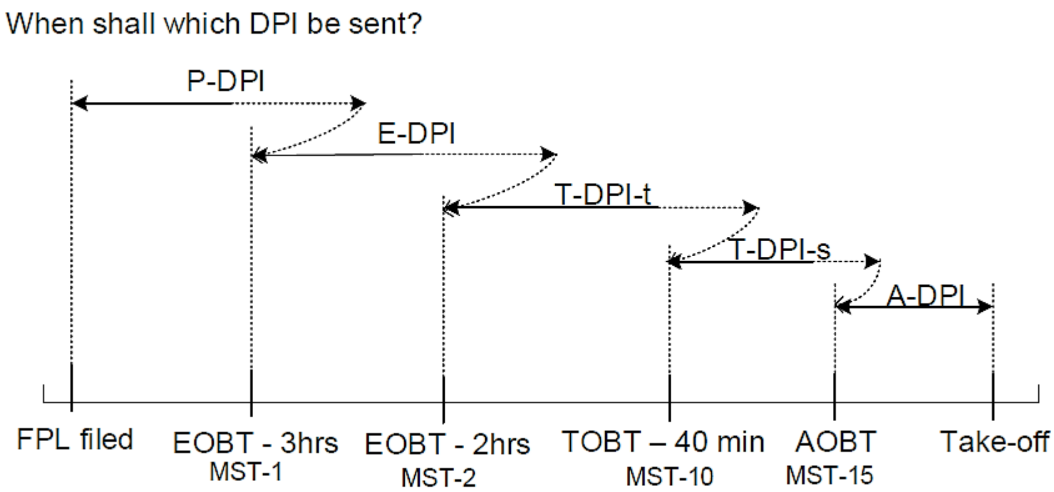


Figure 2.6: DPI Messages and timing (Source: [5])

*2.6.6.2. **FUM Messages***

Flight Updates Messages (FUM) are messages sent by Network Operations to the destination airport. These messages contain information on the Estimated Time of Arrival (ELDT) and are also individual messages, referring to a single flight. Apart from ELDT, the FUM also contains the ETO (Estimated Time Over) of the last point on the flight plan route (estimated time at which the aircraft will pass that point) and the flight status in ETFMS.

The first FUM is sent 3 hours before the estimated landing time, while subsequent messages are sent when ELDT varies by 5 minutes or more, or when the flight status changes.

The message content consists of flight information obtained from flight profile calculations and radar data collected from air traffic control service providers (if the aircraft is in flight), or from DPI messages (if the aircraft has not yet taken off).

2.7. A-CDM Airport Status

Having seen the six A-CDM Concept Elements, the next step is the recognition of the airport as a CDM Airport. In this final stage, the operation of the CDM elements must be validated: An airport is considered to be a CDM Airport when the Elements of Information Exchange, Milestones Approach, Variable Taxi Times, Pre-Departure Sequencing, Adverse Conditions and Collaborative Management of Flight Updates are successfully implemented [4]. Therefore, once these concepts have been validated, operational evaluation tests will be carried out by NMOC, followed by live operations with DPI transmission. If the tests are successful, finally the CDM Airport status will be received [4].

The entire process can be visualised schematically and clearly in the diagram in Figure 2.7., where all steps explained of a successful implementation up to the CDM Status can be followed.

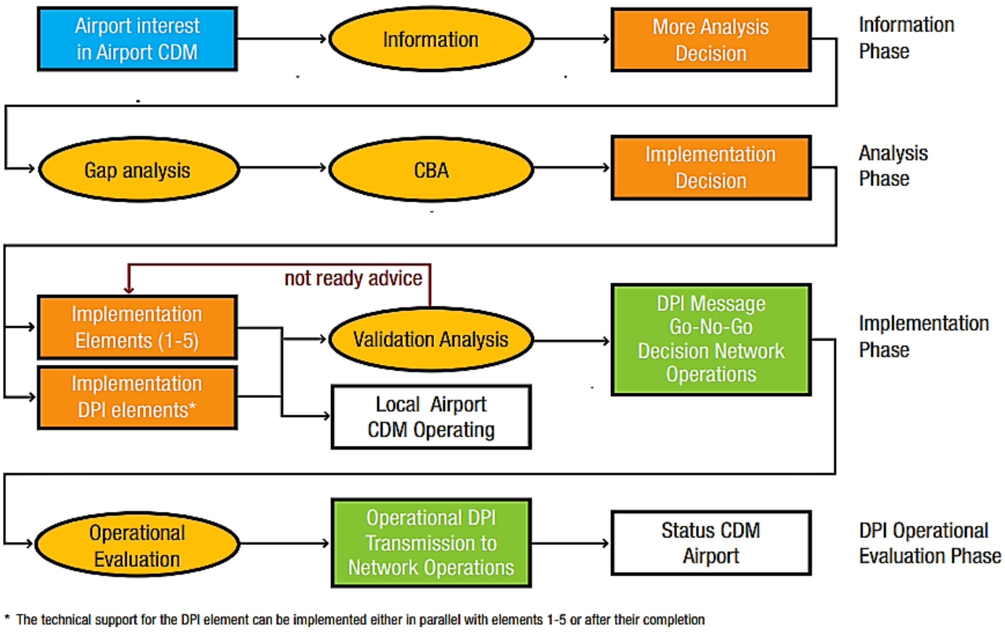


Figure 2.7: General process for Airport CDM Implementation (Source:[4])

CHAPTER 3. ANALYSIS OF THE IMPLEMENTATION AT EUROPEAN AIRPORTS

In this chapter, the implementation of A-CDM at two European airports, Zurich Airport and Amsterdam Schiphol, will be analysed. First, for both cases, a brief explanation of the respective airport's main characteristics will be presented, focusing on the configuration and the factors affecting the airport's performance and capacity. Afterwards, the main concepts of the A-CDM process will be explained for each of them. The objective is to study the process and adaptation of A-CDM at different airports, pointing out the particularities and distinctive parts that may exist at each of them. Therefore, the aim is also to see if there are any differences in the implementation and processes of each airport, thereby identifying where A-CDM may differ from one airport to another. In addition, thanks to information provided by the Head of Flight OPS Engineering at Zurich Airport, and an interview with the Process Manager of A-CDM at Amsterdam-Schiphol airport, the A-CDM implementation process will be analysed in terms of culture change, stakeholders and improvements that have been achieved, among other aspects, in order to analyse the factors that can influence the A-CDM process and to understand the complexity of the implementation process.

3.1. Zurich Airport (ZRH)

Zurich Airport (ZRH) is located at the foothills of the Swiss Alps, in Kloten, 13 kilometres north of central Zurich. It is Switzerland's largest and main international airport, and it is one of the 20 busiest airports in Europe. In 2019, a total of 31.507.692 passengers passed through ZRH [24]. It is also the principal hub of Swiss International Air Lines.

Due to its location in the heart of Europe, it represents an excellent transfer point for global destinations, providing access to international and national transportation networks, and also being a gateway for Swiss regional transport. In 2022, 22.561.132 travellers transited the airport, and almost 30% of them were transfer passengers [24].

Air navigation services are provided by Skyguide, the leading ANSP that manages and monitors the airspace in Switzerland, and apron control services are provided by Zurich Airport (Apron Control), being Flughafen Zürich AG the owner and operator of the airport. ZRH frequently receives recognition for various quality indicators, such as short transfer distances, reliability of their processes and generally very good services. Flughafen Zürich AG is committed to the aspects of profitability, environment and social responsibility, working constantly to find a compromise between capacity, complexity and noisiness.

3.1.1. Regulations governing flight operations

The traffic at ZRH is accommodated on three runways (16/34, 14/32 and 10/28), which are generally operated in segregated mode. In the daytime, runway 14 is normally used for landings and runways 16 and 28 are used for take-offs. Runway 16 is also used for long-haul departures, as runway 28 is not long enough. On the other hand, in the mornings, runway 32 is for take-offs and runway 34 for take-offs and landings, and in the afternoon runways 32 and 34 are used for take-offs and runway 28 for landings.

Figure 3.1.1. shows the configuration of the runways.

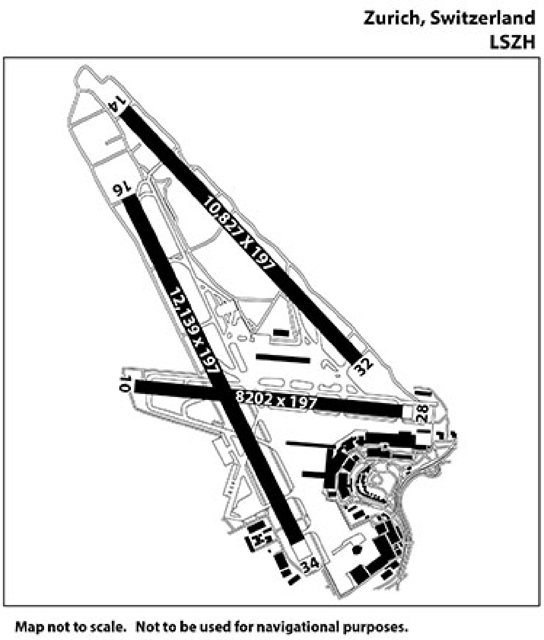


Figure 3.1: Zurich Airport diagram (Source:[6])

Nevertheless, for safety reasons, ZRH has three standard runway configurations and one non-standard configuration, which are selected depending on the wind direction and wind speed, that is, their selection depends on the weather forecast. The three standard configurations are North, East and South, named after the direction the wind is coming from, and the non-standard one is called Bise, which is the name of the wind type.

Besides the weather limitations, there are also other factors that influence the runway configuration, such as emergency landings, accidents, runway modifications, etc. In addition, because of its location, the airport is affected by German airspace restrictions.

Flight operations have to be preferably as regular as possible, therefore the different configurations are generally used on a fairly regular schedule, as can be seen in Figure 3.2, which summarises the time slots for each configuration. (The departures are shown in red, arrivals in blue and go-arounds in dashed red).

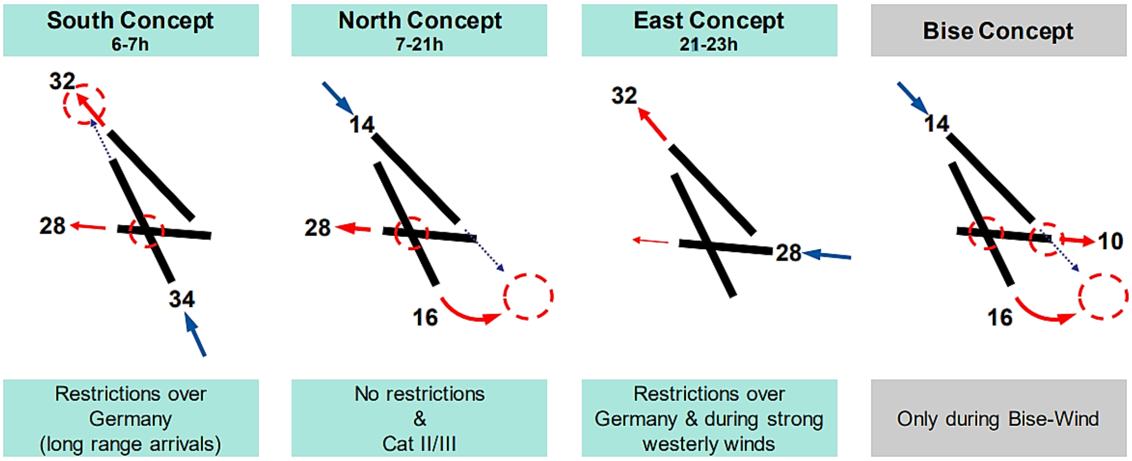


Figure 3.2: Zurich Airport runway configurations (Source: [7])

3.1.2. Capacity

As discussed in the previous sub-section, wind conditions among other factors affect the selection of the runway configuration, and consequently, they directly have an effect on capacity and delays, as some configurations are more favourable than others.

Therefore, evidently, the configuration of the runways determines the capacity during the time period in which it is used, as show in Table 3.1.

Table 3.1: Zurich Airport capacity for each runway configuration [17]

Runway configuration	Arrival RWY	Departure RWY	ARR/h	Dep/h
North	14	**28**, 16	40	40
South	34	28, **32**	32	30
East	28	28, **32**, (34)	30	30
Bise	14	**10**, 16	28	30

3.1.3. A-CDM at Zurich Airport

The A-CDM implementation process at Zurich Airport was conducted in two stages.

Firstly, in May 2012 it was partially established: implementation of selected Milestones, CDM Alerting for Ground Handling via AIMS (Airport Information and Management System) Alarm Window and for Aircraft Operators via SITA Messages, as well as the introduction of CDM terminology (TOBT, TSAT and TTOT) in different systems and screens [8].

On 19th August 2013, the Collaborative Management of Flight Updates (Departure Planning Information (DPI) exchange with NMOC) was introduced, completing then all the steps of the A-CDM implementation manual, so that it finally received the A-CDM Status granting it the title of CDM Airport.

As will be seen in the following sections, the A-CDM process is adapted to Zurich Airport according to existing resources and particular needs and requirements. Therefore, the procedures that ZRH undertakes in order to comply with the A-CDM standard will be presented, that have been developed and approved by a team of experts including Air Traffic Control, Ground Handlers, Airlines and Zurich Airport.

3.1.4. Information Sharing at ZRH

As explained in the second chapter, the exchange of information is a fundamental step and the basis for the effective implementation of all the following A-CDM principles. In order for all partners involved to be able to share the latest and most important data for the turnaround process in a timely manner, this is conducted via an A-CDM platform (IT-Tool, interface). At ZRH, this platform is the AIMS, which includes the FIDS (Flight Information Display System).

3.1.5. Milestones Approach at ZRH

In order to monitor the progress of flights during the inbound, turnaround and outbound phases, the Milestones Approach is implemented, with each significant event being a Milestone. Therefore, the TOBT is obtained. According to the EUROCONTROL A-CDM implementation manual, there are 16 Milestones. However, not all of them are implemented at ZRH airport for different reasons. In Figure 3.3, the active and inactive Milestones at Zurich Airport are shown.

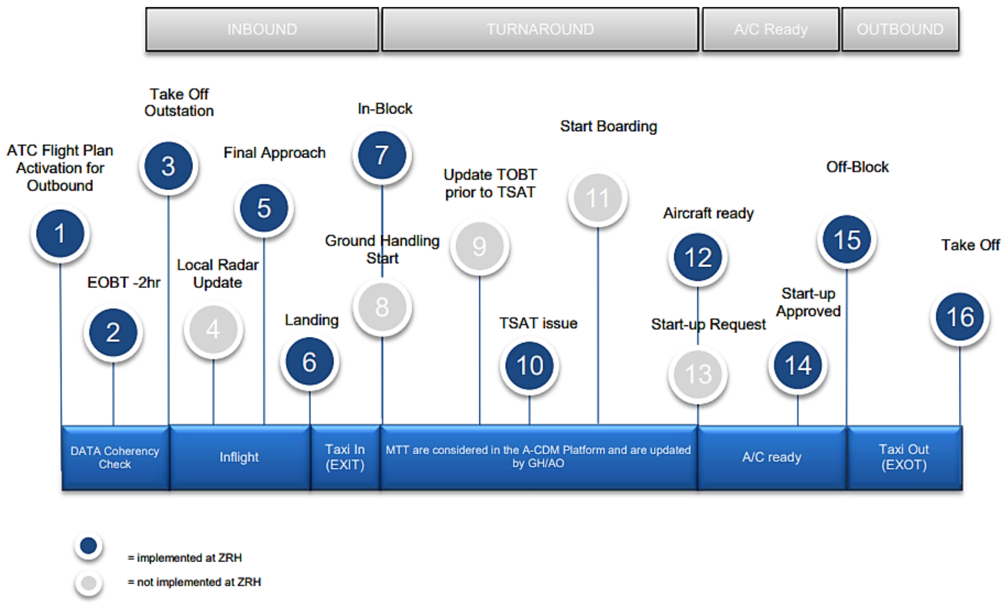


Figure 3.3: Diagram of the Milestones implemented in ZRH (Source:[8])

The reasons why Milestones 4, 8, 9, 11 and 13 are not currently implemented are the following:

- **Milestone 4 (Local Radar Update):** This Milestone corresponds to the entry of the aircraft into the Switzerland FIR, but, although the data would be available, it is not implemented as it does not provide useful information for the CDM process.

- **Milestone 8 (Ground Handling Start):** Corresponds to the start of Ground Handling, it is not implemented as it does not provide any extra information, as in Milestone 7 already informs about the moment when the aircraft is on-block, which is when ground handling will start.
- **Milestone 9 (Update TOBT prior to TSAT):** Not implemented because all TOBTs are accepted.
- **Milestone 11 (Start Boarding):** The boarding start, although available in AIMS, does not appear in ZRH as a Milestone per se, as it is not a reliable indicator of possible delays and therefore does not really provide relevant information.
- **Milestone 13 (Start-up Request):** It is not implemented in ZRH as its purpose is already fulfilled by Milestone 12 (Aircraft Ready).

3.1.6. A-CDM Alerts at ZRH

Although it is not strictly mandatory in the implementation of A-CDM, but it is highly recommended, several airports have a CDM Alert system, including Zurich Airport. This is a series of alerts defined in the EUROCONTROL manual, the function of which is to warn of unforeseen events or discrepancies during the progress of the Milestones Approach so that they can be addressed in time. There are 14 alerts defined in the Manual. In ZRH the alerts are sent via SITA-Telex Message, by email or displayed in the AIMS alarm window.

It is important to note that after receiving the alert message, it is the responsibility of the involved partners to react to them by resolving the problems.

Table 3.2 shows the different alarms, in bold the ones that are active at the ZRH airport.

Table 3.2: Zurich Airport CDM Alarms [8]

CDM Alert	**Description**	**Milestone**	**@ZRH**
CDM01	No airport slot available or slot already correlated	1	Not active
CDM02	SOBT vs EOBT discrepancy	1	**Active**
CDM03	Aircraft type discrepancy	1-14	On hold
CDM04	Aircraft registration discrepancy	1-14	Not active
CDM05	Destination discrepancy	1	**Active**
CDM06	None-airborne alert	3	**Active**
CDM07	EIBT + MTTT discrepancy with EOBT	2-5	**Active**
CDM08	EOBT compliance alert	5-12	**Active**
CDM09	Boarding not started	11	Not active
CDM10	TOBT rejected or deleted/Advise Time set	9 or later	**Partly active**
CDM11	Flight not compliant with TOBT/TSAT	12 and 13	On hold
CDM12	TSAT not respected by ATC	13	On hold
CDM13	No ATC flight plan available	1-16	**Active**
CDM14	Automatic TOBT Generation not possible	4-9	Not active

A visual diagram with the Milestones, CDM Alerts and DPI messages at ZRH can be found in Annex B for a further view of the timing and the overall process.

3.1.7. Adverse conditions at ZRH

An adverse condition is any condition on the ground or in the air that causes a decrease in capacity to levels much lower than normal. Therefore, a planned operating procedure is required for the adverse conditions that may arise, so that the airport is affected as little as possible by this decrease in capacity. In the case of ZRH, de-icing is very important, as it impacts heavily on airport capacity and is treated as an adverse condition, because it can restrict the runways during some periods during the day and create bottlenecks depending on the demand for it. This implies that the process needs to be very transparent by making the scheduled and actual times of the de-icing process available through the CDM platform to all parties concerned. De-icing can be on-stand or remote.

At Zurich Airport there are three different statuses for de-icing:

- From normally 1 October until 30 April, **"De-icing on request"** is implemented, as less than 50% of the traffic is expected to need it. That means that the Flight Crew decides whether it is necessary or not, and if it is required, it must be requested at the appropriate time, according to the AIP, to the de-icing coordination unit. Here, the role of the Flight Crew in communicating it in time for the most optimised allocation of de-icing recourses is crucial. At that time, a DPI message is sent with the status and the de-icing time.
- On the other hand, the **"General de-icing"** status is activated when more than 50% of the traffic needs it. It is published in the AIMS, and it has to be requested by the Flight Crew as well. For this status and for the prior one, the ATC slot adherence must be complied with, as in principle the de-icing time should not be very long.
- Finally, the status **"General de-icing with extended Slot Tolerance Window"** is also requested by the Flight Crew and displayed in AIMS. In this case, the ATC Slot adherence is no longer met as the de-icing time is longer.

The A-CDM, through accurate de-icing times and progress milestones, has strongly contributed in the improvement of resource and asset utilisation during winter operations at Zurich Airport, as de-icing had previously meant an "operational black hole" for ZRH operators [25].

3.1.8. Provision of TTOT and TSAT at ZRH

The process of determining TTOT and TSAT, as well as TOBT, the fundamental timings of the A-CDM process, is conducted in a specific manner:

- Before or during the turnaround process, the SOBT in case of non-delay (SOBT = TOBT) or the ETDs in case of delay to the AODB (AIMS) are entered by the AO/GH and used to update the TOBTs, the times at which ground handling activities have been completed. The TOBT has a tolerance of 5 minutes, so the Flight Crew must notify ATC that the aircraft is ready between that interval.
- The GH are in charge for adhering to the TOBT, and in case the TOBT is inaccurate, this will negatively influence the calculation of CTOT and therefore TSAT, causing the

runway capacity not to be completely utilised. Once the aircraft has been notified as ready, no changes to the TOBT will be taken into account for the determination of the departure sequence.

- The TOBTs are then sent to the DMAN (darts, Departure Manager), which uses them, in combination with the local constraints at the airport, to calculate the TTOT and generate the departure sequence with the TSAT calculation.
- The TSAT is sent to AIMS 40 minutes before the corresponding TOBT and then displayed. Later than 5 minutes before TOBT, the TSAT cannot be changed.
- As for the EOBT, which is in the Flight Plan, it should not differ by more than 15 minutes from the TOBT. If it does, the AO must notify it.

Figure 3.4 shows the process in a summarised and schematic form.

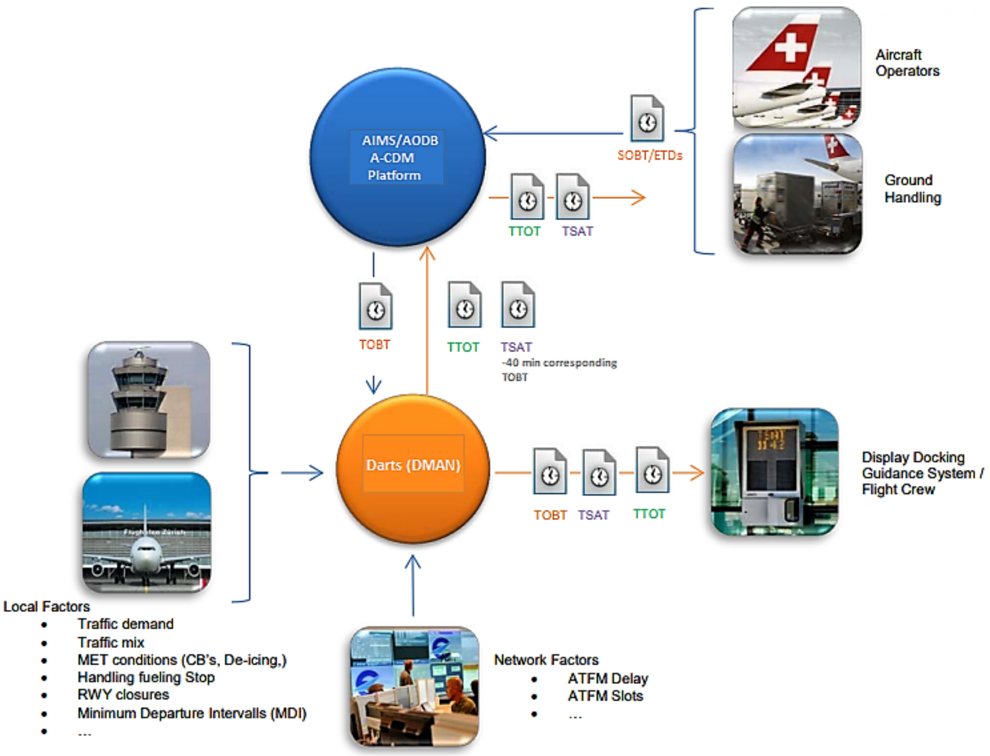


Figure 3.4: Process of obtention of TOBT, TSAT and TTOT in ZRH using DMAN (Source: Manual adaptation of a diagram from [8])

Nevertheless, some deviations may occur, which are dealt with as described below:

- If EOBT and TOBT differ by more than 15 minutes, an alert message is sent from AIMS to the Ground Handler to adjust them, and vice versa.
- If the aircraft ready message is not notified within 5 minutes before or after TOBT, it will not be cleared by ATC. If not reported before TOBT + 6 minutes, the aircraft is excluded from the departure sequence and receives a TSAT penalty, which means that 10 minutes are added to its TSAT. If the aircraft is not reported as ready later than 15 minutes after TOBT, a C-DPI is automatically generated to NMOC, which

means that the flight is cancelled. In this case, EOBT and TOBT must be updated so that the flight can be re-entered into the sequence.

- It may be that TOBT is updated even after TSAT has been calculated. In that case, a specific criterion will be followed to determine whether or not to recalculate TSAT. In case the new TOBT is later than the previous TOBT, it is not recalculated as long as the new TOBT is before or at the same time as TSAT. In case the new TOBT is later than TSAT, or in cases where de-icing or CTOT is required, it is recalculated. However, within the 5 minutes prior to TOBT, as mentioned above, TSAT shall not be recalculated.
- Departures that have an assigned CTOT have to be ready in the interval between 5 minutes before and after TOBT. That is why an inaccurate TOBT or a TOBT readjustment that goes out of limits (later than TSAT) has a negative influence on the CTOT. In that case, with NMOC approval, the tolerance can be adjusted.

3.1.9. Benefits at ZRH

At Zurich Airport, significant improvements have been noted in the years following the implementation of A-CDM. Firstly, the management of winter operations has greatly improved, which prior to A-CDM were not handled in an optimal way. In fact, the de-icing was referred to as an ”operational black hole” at the airport, as mentioned above. The sharing and inclusion of de-icing information in the turnaround process, allowing accurate estimation of de-icing times, has helped to significantly improve the predictability and transparency of the entire process, and optimising capacity and resource utilisation.

With DMAN and its calculation of TSAT and TTOT, the predictability and optimisation of the departure sequence has increased, improving the utilisation of runway capacity.

There has also been a reduction in last minute stand changes due to increased predictability of incoming flights. Another notable improvement has also been in the accuracy of scheduled departure times, and in the reduction of workload for the TWR, by managing communication with NMOC through DPI messages.

On the other hand, it is also estimated to have contributed significantly to environmental benefits. It was recorded that from 2012 to 2014 there was a reduction in taxi time of 40 seconds on average per flight, which meant a fuel saving of 2300 tonnes of fuel burn in total in just one year since full implementation, combined with the contribution of DMAN (2004) [25].

In terms of delays, ATFM slot adherence was increased by 5% in that year, reducing the delay index and resulting in 20,500 fewer ATFM delay minutes and a tactical delay saving of almost €2 million in 2015. The accuracy of the take-off time also decreased from 6 minutes to 20 seconds in that year [25].

3.1.10. Further improvements at ZRH

While the benefits of the A-CDM implementation have been already great, Zurich Airport is planning an even further improvement with the introduction of the AOP (Airport operations plan) and the APOC (Airport Operations Centre). AOP Control Center is a new approach through technology, which will allow to visualise the A-CDM and more processes, increasing the common situational awareness of stakeholders. Furthermore, just as the A-CDM process starts 3 hours prior to EOBT, the AOP will allow predictive information about bottlenecks and is a rolling plan up to 180 days in advance. Therefore, it allows for more and better information in the pre-tactical phase. Both the AOP and the APOC, are explained in detail in Chapter 5.

From information provided by Zurich Airport's representative partner, it appears that the imminent plans for ZRH's airport steering are to combine AOP, A-CDM and APOC. Additionally, on the other hand, with these innovations Zurich Airport will also evolve to data-based Airport Operations, with the aim of improving integration in the European Aviation Network (EUROCONTROL), establish a visualisation of operations on a common platform, extend the operational control time horizon to up to 72 hours and establish proactive operations control with partners and define common KPI's.

This will be based on the ZRH Bridge Data Platform technology, with the objective of contribute to the exchange of relevant data with stakeholders, and in this way leverage the data to collaboratively develop advanced insights to optimise the operational efficiency of all partners.

Expert local operational knowledge and a deep understanding of the semantics of the data are key to developing analytical capabilities and more advanced insights.

Figure 3.5 shows the process from the information to the optimisation of operations, which will be performed using advanced technologies: cloud components, machine learning forecast models, predictive waiting times, etc. and will enable descriptive, diagnostic, predictive and prescriptive data analysis.

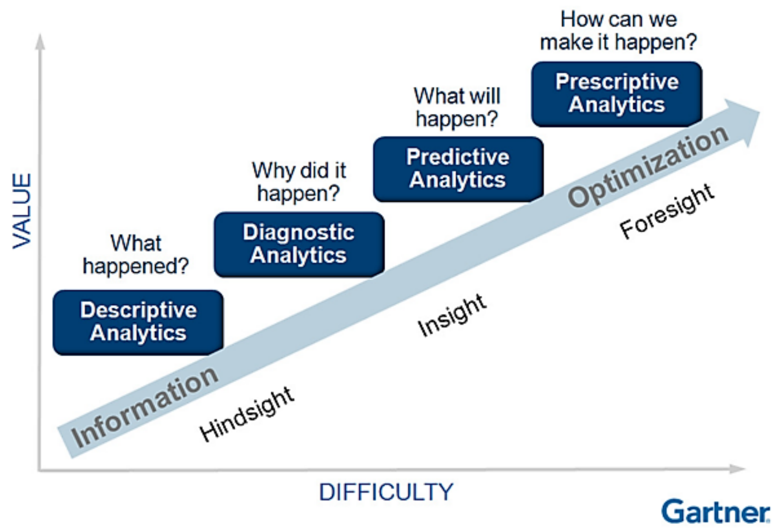


Figure 3.5: ZRH evolution from basic to advanced analytics capabilities (Source: Provided by ZRH representative, from Gartner).

3.2. Amsterdam-Schiphol Airport (AMS)

Amsterdam-Schiphol Airport (IATA: AMS), or simply Schiphol, is the main airport of the Netherlands, and it is situated 9 kilometres from Amsterdam, in Haarlemmermeer. Schiphol is the busiest airport in Europe in terms of aircraft operations, and the third busiest airport in the world in terms of passenger traffic. In 2019, prior to the pandemic, it recorded 71.7 million passengers [26].

The airport offers direct flights to a total of more than 330 destinations worldwide, 296 of them international destinations, in almost 100 countries. With 52.000 transfer connections [27], it is considered one of the world's best-connected airports, and the world's second most important hub. The airport is a hub for KLM Airlines, KLM Cityhopper, Martinair and Transavia.

The operator and owner of Schiphol is the Royal Schiphol Group, a Dutch airport management company that is strongly committed to the achievement of fully sustainable and high quality airports, with plans to achieve zero emissions and zero waste in its airports in the coming years.

3.2.1. Runway configuration and capacity

Schiphol Airport disposes of a total of five runways for take-offs and landings (18L-36R, 09-27, 06-24, 18R-36L, 18C-36C) for international flights and an extra shorter runway (04-22) for general aviation, private jets and helicopters. The configuration and runways used at any given time are determined by weather and runway conditions, as well as environmental rules. Two runways are used at all times, one for take-offs and one for landings, however, at AMS, being such a strong connection point, at peak times it is necessary to open a third runway or even a fourth between peak times.

Figure 3.6: Amsterdam-Schiphol Runway Layout (Source:[9])

Since it is a hub, there are times of the day when inbound flights predominate and times of the day when outbound flights predominate. For these peak hours, there are two configurations: Departure peak mode (Two runways for take-off and one for landing) or Arrival peak mode (Two runways for landing and one for take-off). In terms of capacity, for the summer of 2022 the capacity for each configuration is summarised in the table 3.3.

Table 3.3: Schiphol Airport capacity for each runway configuration, Summer 2022 (Source: [18])

ATM Mode	From - to (UTC)	IFR Arrivals/h	IFR Departures/h
Day; departure peak mode (S)	05:00 – 19:39	36	74
Day; arrival peak mode (L)	05:00 – 19:39	68	38
Day; off peak mode (O)	04:00 - 04:39	24	30
Day; off peak mode (O)	04:40 - 04:59	24	40
Day; off peak mode (O)	05:00 - 20:39	36	34
Day; off peak mode (O)	20:40 – 20:59	36	25
Night Mode (N)	21:00 - 03:59	24	25

3.2.2. A-CDM at AMS

At Schiphol, the implementation of A-CDM was done in two phases and achieved by a programme involving Amsterdam Airport Schiphol, KLM, Air Traffic Control the Netherlands (LVNL), Ground Handlers and the Schiphol Airline Operators Committee (SAOC), all of them collaborative partners of A-CDM at AMS [28].

The first phase was concluded on 18 November 2015, and consisted of the implementation of the A-CDM method for local operations, i.e. of all the A-CDM concepts, except for the connection to EUROCONTROL NMOC. It was not until 16 May 2018 that the airport incorporated into its operations the exchange of information with EUROCONTROL, and therefore the connection with the European Network, contributing to the predictability of European airspace. This last step allowed AMS to become a full CDM Airport, the 27th in Europe to obtain this title.

3.2.3. Information Sharing at AMS

In Schiphol Airport, the Airport Central Information System Schiphol (CISS) is used to facilitate information sharing. The system collects all available flight information, and also sorts the information in such a way that the best time elements are identified according to the source of the data. In this way, a common situational awareness for all stakeholders is achieved. Also, apart from the CISS, data can also be provided by ground handlers, airlines or LVNL.

3.2.4. Milestones Approach and CDM Alarms at AMS

In Amsterdam all milestones are implemented except: Milestone 3 (Take-off Outstation), Milestone 12 (Aircraft Ready) and Milestone 14 (Start-up Approved) as they are redundant in the process and do not provide extra information. Nevertheless, all of them are planned to be implemented in the near future to further increase the accuracy of the whole process. There are also a number of CDM Alarms implemented at Schiphol, shown in Table 3.4.

Table 3.4: Zurich Airport CDM Alarms [8]

CDM Alert	Description
(SIBT)	Delay indication: Orange collored SIBT field
CDM03	Aircraft Type discrepancy
CDM04	Aircraft Registration discrepancy
CDM09	Boarding Not Started
CDM11	Flight not Compliant with TOBT/TSAT
CDM101	Diversion Alert: Provide new estimate landing time
CDM102	Indefinite Holding Alert: prepare for diversion
CDM103	Non-Inblock Alert: Update Outdated In-Block Time
CDM104	EOBT/TOBT discrepancy Alert
CDM105	TSAT before TOBT, check validity CTOT and Flightplan

3.2.5. Adverse conditions and de-icing at AMS

To report and address adverse conditions that may emerge, at Schiphol there is a system for reporting the Airport Status which is updated at the end of a period through an agreement between A-CDM partners. The status is provided by the AAS Flow Manager Aircraft (FMA) and displayed in the CDM portal, and consists of a colour classification. Green means that the airport is in normal operations, orange indicates disruptions and red indicates severe disruptions and emergency status.

Regarding de-icing operations, which also alter the A-CDM process and are treated as adverse conditions, extra timings are added to the CDM chain. The de-icing parameters are provided by the de-icing companies, and are integrated into the CPDSP (Collaborative Pre-Departure Sequence Planning system), for the re-calculation of TSAT and TTOT. The parameters utilised are the following:

- Where de-icing will take place (ADIP)
- How long the de-icing process will take (EDIT)
- If there is a delay because of insufficient de-icing capacity (DIWT)
- If a de-icing request is cancelled (DICS) [10]

A more detailed and visual explanation of the de-icing processes, both on-stand and remote at Schiphol airport, can be found in Annex C.

3.2.6. Provision of TTOT and TSAT at AMS

At Schiphol, the process of obtaining TOBT, TSAT and TTOT is also conducted in a defined manner:

- Initially, the TOBT is based on the SOBT of the flight plan. During the course of the process, the CDM system recalculates the value based on EIBT + MTT, until the aircraft is at AIBT. From then on, at Schiphol, the TOBT is updated by the Main Ground Handler Agent (MGHA), assigned by the Airline Operator for each flight. The TOBT shall be updated if and when it differs from the previous calculation. If the TOBT varies by +- 5 minutes, the AO must communicate it to the CDM system via the MGHA of the flight.

- Schiphol uses the Collaborative Pre-Departure Sequence Planning System (CPDSP) to calculate the TTOT and consequently the pre-departure sequence (TSAT). The CPDSP first calculates the earliest TTOT, and continues to refine the calculation by means of its algorithm. From the calculated take-off sequence, it calculates the pre-departure sequence by subtracting the EXOT time. Figure 3.7 depicts this process. Then, the ATC communicates TSAT and TTOT to each flight.

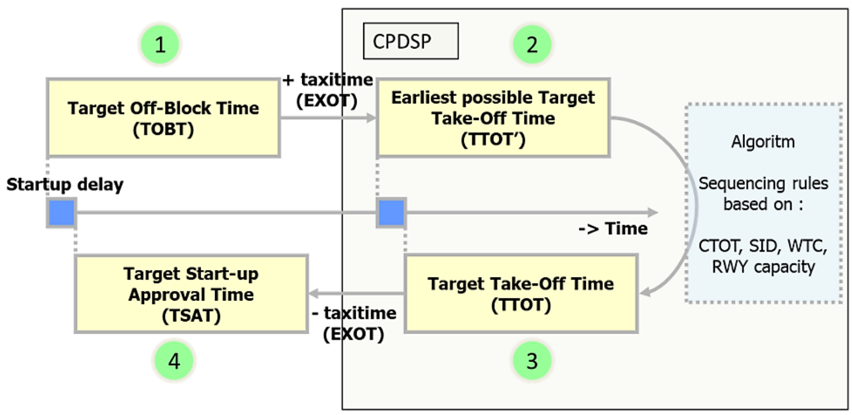


Figure 3.7: CPDSP calculation of pre-departure and take-off sequences (Source: [10]).

- Events that will trigger a recalculation of the TSAT may be: an update of the TOBT where the new TOBT is before the previous one or after the TSAT, a new CTOT for the flight, a change in current capacity or runway usage and changes in taxi or take-off traffic.

Some deviations may occur, which are dealt with as described below:

- Depending on the rate of change of TOBT with respect to the current TOBT and the TSAT, a specific criterion will be used to determine whether or not to recalculate the current TSAT: If the new TOBT is before the current TOBT, the TSAT shall be recalculated from the new data. If the new TOBT is is between the current and the TSAT, it shall not be recalculated. And if the new TOBT is equal to or later than the TSAT, the TSAT shall be

- There may be cases, especially in congested airport conditions, where a departure flight is blocking a stand for an inbound flight. These situations are classified into two types: If the inbound aircraft has to wait more than 20 minutes, when it is ready but not in the TSAT interval, the departure aircraft is sent to a different temporary parking position, but is still ready for TTOT/CTOT updates. If it has to wait less time, the departure flight remains within the take-off sequence and is also sent to a temporary parking position, but is no longer subject to TTOT/CTTOT updates.

3.2.7. Analysis of the A-CDM implementation process at AMS

The analysis in the following subsections has been developed on the basis of the survey interview with the A-CDM process manager at Schiphol, hence the most important and decisive issues of the A-CDM at the airport have been possible to discuss.

3.2.8. Main reasons for implementation decision

The first point to discuss is the reason for the decision to implement A-CDM. In the case of Amsterdam-Schiphol, there were two main reasons for this determination: the first one was the regulatory requirement, as all major European airports were under the obligation to become CDM airports. The second one was the clear benefits that A-CDM would bring to the airport. Schiphol, as has been seen, is a very congested airport and this often causes capacity problems: very high demand and operating at peak hours, which means that there is an inbound peak followed by an outbound peak. This happens about 8 times a day. Therefore, these conditions, prior to A-CDM, used to create a problem of excessive demand for the available capacity, and consequently the capacity was not utilised at 100%, but only around 80%. Moreover, no reliable information was available during the aircraft turnaround process, all planning was based on the flight plan, provided by the airline. This information was not accurate at all, so planning based on it was not accurate either. With A-CDM, this predictability and higher accuracy of timings would be enabled, so that flight planning would become much more reliable, as this information on flight status would be available in real time.

3.2.9. Main constraints during the process and stakeholders adaptation

The implementation process in its entirety was quite challenging. Schiphol was one of the first European airports to start the implementation and one of the last to complete it, taking a total of 12 years. Considering that other European airports achieve it within 2 years, this is a very long period of time. The main reasons for this prolongation were, on the one hand, the technical difficulties and, on the other hand, the Dutch culture.

Regarding technical issues, the main problem was the complexity of connecting the overall system, which required a lot of interactions with the airport system, the database, the air traffic control system, the airline system and the ground handling system. On the other hand, concerning stakeholders, interestingly there was no resistance to sharing information, but problems of a different nature emerged. The Dutch culture was another

”inconvenience” during implementation (in the Netherlands they even have a term for it, ”Gezelligheid”). The Dutch tend to have a pleasant personality, and this human factor caused a prolongation of the process due to the need for all stakeholders (Airport, ATC, Airlines, Handlers, etc.) to agree on each procedure to be performed, and for everyone to be satisfied with the solution.

Furthermore, another reason that hindered the process as a CDM community was that, as a whole sector, the same CDM objectives/vision were held, but the path that needs be followed to reach those objectives is different for each type of stakeholder. In other words, different types of stakeholders are guided by different factors. An example is ATC and airlines: ATC's objectives are guided by safety, and those of the airlines by economic benefits. In the case of Amsterdam, this was the part that is considered the most difficult in terms of the stakeholders; the agreement of procedures that would satisfy all parties, rather than the willingness to share information which was not a problem at all. Therefore, in this aspect, a straight airport authority was missing, which would impose the procedures without the extreme need to please all parties in all their preferences.

Moreover, to date, it cannot yet be said that Schiphol has achieved a ”no-blame” culture. This has to do with the economic interests of the different stakeholders. Stakeholders use the IATA delay codes, which are standardised IATA codes that are used to report flight delays and attribute cause and responsibility for the delay. In this way, situations continue to occur in which different stakeholders report delays with codes that hold others responsible for them. The most commonly reported is code 89 (AM), referring to ATC, by ground handling. In this case ground handling usually blames ATC for delays as they are not interested in losing their customers, which are the airlines.

The main ”learning” that stakeholders have taken away during the implementation of the A-CDM is that the theory is easier than the practice, as in reality each organisation has different targets. Therefore, the more stakeholders are involved, the more difficult the process becomes.

3.2.10. Infrastructure and additional staff

Another important consideration for A-CDM is the needed infrastructure, as one of the advantages of A-CDM is the fact that mainly existing resources are ideally utilised. In the case of Schiphol, only one asset had to be invested in, the installation of CDM displays to the gate, placed in front of the pilot so that provide the information about the TOBT and TSAT, and the same for the handlers.

On the other hand, the human resources used must also be considered. At Schiphol, the A-CDM started as a project, and had a project leader among other experts with different roles. Now it is brought into the normal organisation without a project, and no extra department has been opened for its development. A-CDM is actually embedded in all the processes as they were, therefore, the most efficient way to manage it is to divide the necessary tasks in the current organisation, so that there are not two separate communities: a small one of A-CDM experts, and the rest who don't know anything about it. Obviously, one person is needed to act as CDM Advisor. In the past, Amsterdam experienced this exact situation where only a few people had full knowledge of A-CDM, hence much work had to be done into sharing that knowledge across the different airport departments and also dividing up the tasks.

3.2.11. Influence of the runway configurations

The runway configuration at Schiphol has two main impacts on the A-CDM. The first is related to the operation at peak hours, since when there is an inbound peak (two landing runways and one departure runway), there is less take-off capacity, affecting the departure sequence of the aircrafts. Besides, different runways have different taxi times, some are around 15 minutes, others around 2-5 minutes taxi time. Therefore, the runway utilised determines the taxi time, and hence the CDM planning.

Further, the A-CDM process is also impacted in circumstances such as restrictive weather conditions or other factors including airfield maintenance, where only one runway can be accommodated for take-offs and one for landings. That means that the capacity will be reduced for the day, and there will be inbound regulations and outbound delays on the outbound process. Delays in the outbound process cause outbound flights to be at the gate for a longer time, and then inbound flights cannot be accommodated because the apron capacity is fully utilised. The inbound flow will then be regulated to prevent flights arriving in Amsterdam too early.

3.2.12. Procedures to be improved

Winter operations, specially de-icing, are still a very destructive process even with A-CDM. The reason is that A-CDM tries to create predictability by sharing information, thereby the more processes are added to the whole chain, the more complex it gets. For the core CDM process without de-icing, the main input is the TOBT, and that already is a big challenge for the ground handlers. When the de-icing operations have to take place, the handler has to provide the TOBT, the de-icing waiting time and the de-icing time, hence two additional components, i.e. two additional risks. Then, the planning may become less predictable, because especially in de-icing operations it gets very hectic and the back office does not prioritise the CDM process. When CDM is not taken into account, the timings are not updated and the planning becomes unrealistic and creates even more unpredictability. A kind of vicious circle is created and it's not easy for the partners to get out of it in those situations.

Other operations that remain challenging are terminal operations, since there is no information available regarding the location of the passengers. It is not known until the last moment whether all passengers are at the boarding gate or not, as they are not monitored. This means that, until the last moment, when all passengers have boarded, it is not possible to know if there are passengers missing, and it is even more difficult to know how many of them are missing and whether to wait or leave without them. That also determines the TOBT and therefore the CDM. Therefore, the issue of passenger monitoring is still a gap to be solved in the coming years. Some initiatives are emerging today and are discussed in Chapter 5.

3.2.13. A-CDM further improvements at AMS

At Schiphol, in the near future, there are plans to further improve the A-CDM processes through what will be the next phase, the AOP or APOC. The APOC is a centre where all stakeholders work together to create the airport operations plan, which actually is the CDM process but with a wider scope. The AOP also integrates the arrival process, the passenger process and the landside processes, therefore widening the range of time A-CDM. In this way, the whole processes are planned in advance, moving from strategic to tactical to operational. In addition, it solves the existing problem of uncertainty of the passenger situation. This contributes to Total Airport Management (TAM), and the basic idea is supply chain management in all airport processes. Both AOP-APOC and TAM are explained in Chapter 5 in more detail.

In addition, Amsterdam is currently implementing Smart Cameras, consisting of the installation of cameras outside the gate that monitor all ground handling activities. It is an artificial intelligence system capable of informing about possible delays when a certain process has started or finished. This information is used to validate the TOBT and to check whether a flight is ready or not to start the push-back. Section 5.5., included in the following chapter, explains the implementation of Smart Cameras in more detail.

Therefore, the next phase that the airport is entering is that of data-driven automation, in order to have objective data. This will help to avoid subjective perspectives driven by the interests of different types of stakeholders in situations where neutral data is needed, and also avoid possible misunderstandings and inaccuracies.

3.3. Comparative analysis of A-CDM between Zurich Airport and Schiphol Airport

Having studied two European airports, Zurich Airport and Schiphol, it is interesting to note some differences and similarities between them in terms of the A-CDM process.

First of all, it should be noted that in Zurich, A-CDM started to be first discussed between the airport partners 20 years ago (information provided by the ZRH airport representative), but it was not until 2012 and 2013 that it was implemented, although over a period of two years. At Schiphol, implementation took longer than usual due to problems encountered in reaching agreements between all airports. This shows that the theory was much easier than the practice when it came to implementation. Also, in this regard, the importance of culture and stakeholder involvement becomes evident. Still, the exchange of information between the airport partners has been achieved succesfully at both airports.

On the other hand, looking at the Milestones and CDM Alarms implemented at each airport, it can be seen that each of them have set aside and implemented different Milestones and alarms, hence highlighting the idea that although A-CDM is a process established and standarized by EUROCONTROL, each airport adapts it to its local conditions and needs.

The local component can also be noted in the management of adverse conditions and de-icing operations, where each airport has its own developed management system. Regarding de-icing operations, at Zurich Airport, A-CDM has been a turning point in its management. There has been a noticeable improvement compared to pre-A-CDM de-icing procedures, as they represented very complex and challenging situations to handle. Nonetheless, at Amsterdam, although they have also improved considerably, they still represent a rather hectic situation in which it is difficult for the back office to prioritise A-CDM and in which predictability is lost, therefore it represents an area for further improvement. The management procedures for TOBT, TSAT and TTOT are conducted in a similar manner, with a different system (Advanced concept element) used to calculate the pre-departure and take-off sequences; the DMAN for Zurich Airport and the CPDSP for Schiphol. Moreover, some tasks concerning the provision of the timings are distributed among different actors at each airport, even in the case of Amsterdam they have a person specifically assigned to the provision of the TOBT, the Main Ground Handler Agent (MGHA).

The other key concept elements of the A-CDM, such as the variable taxi times and the collaborative management of flight updates, have not been mentioned as they are implemented in the same way at the two airports.

At both airports, there have been many benefits from the implementation of A-CDM, particularly in terms of reduced taxi times, emissions and pollution, as well as improved capacity utilisation and runway utilisation. Also, both Zurich Airport and Schiphol are in the process of implementing APOC and AOP to further enhance the benefits already brought by A-CDM, and to be able to include passenger and terminal related processes in the monitoring of activities. Both airports intend to and are also working to bring in an artificial intelligence component, as although it has been achieved good collaboration between stakeholders, it is desirable to have objective and more accurate data to increase the predictability and optimisation of the processes.

CHAPTER 4. ANALYSIS OF THE IMPLEMENTATION AT THE MEXICO CITY INTERNATIONAL AIRPORT

In this chapter, the implementation and current status of A-CDM at Mexico City International Airport will be discussed and analysed. As in the previous chapter, the characteristics of the airport will first be introduced. Next, the context surrounding the airport in terms of capacity and saturation problems will be introduced in order to understand the reasons why it was decided to implement A-CDM at this airport. Subsequently, it will be explained how the A-CDM implementation process was carried out and the difficulties encountered during it. Finally, the current situation of the airport and future expectations will be presented, ending with an assessment of the feasibility of extending A-CDM to airports outside Europe. These points have been developed thanks to an interview with a consultant for ALG that was in charge of the implementation of A-CDM at Mexico City International Airport and was present during the whole process. The main objective is to contrast this case with European airports, as A-CDM is a European initiative, and to analyse the reasons why the process was not successful.

4.1. Mexico City International Airport

Mexico City International Airport (AICM), officially Benito Juárez International Airport, was founded in 1931. It is Mexico's first civil airport and the most concurred important airport in Latin America in terms of number of passengers and number of air operations. It is located 5 km (3 miles) east of the centre of Mexico City.

The AICM, in addition to providing services to Mexico City, also serves a large part of the country, as it provides services to important nearby urban centres. Therefore, it is estimated that it handles about 35% - 40% of the country's air operations [29]. It operates domestic flights and international flights to numerous destinations within the Americas, Europe and the Far East, being the major gateway for the country offering flights to more than 100 destinations across the world.

AICM currently operates 30 domestic and international passenger airlines and 17 cargo airlines. It is the main hub for the airlines Aeromar, AeroUnion, Más Air Aeroméxico Connect and Aeroméxico, the latter being the airline with more number of flights at the airport. It is also a focus city for Air France Cargo, Volaris and Viva Aerobús.

4.1.1. AICM Governing Organisations

Mexico City International Airport is a public/military airport and it is entirely dependent of the Federal Government. It is owned by the Ministry of Infrastructure, Communications and Transport. The Federal Civil Aviation Agency (AFAC), an administrative body of the ministry, is in charge of the airport's air transport services, and SENEAM (Navigation Services in the Mexican Airspace) is responsible for the provision of Air Traffic Control, Radio Aids to Air Navigation, Telecommunications, Meteorology and Aeronautical Information services [30].

This is, in fact, a disadvantage in terms of its management, because since everything depends on the government of the given moment, when there is a change of government, the decisions and plans are subject to it.

4.1.2. Runways of AICM

The AICM currently has two runways in operation, 5L/23R (3963 metres long) and 5R/23L (3985 metres long). Nevertheless, despite having two runways, it is not possible to operate them both simultaneously, due to the fact that safety standards are not met, as the distance between them is only 305 metres. The regulatory minimum to be able to do so is 1100 metres distance, so it is as if there were only one runway. This represents a huge reduction in capacity.

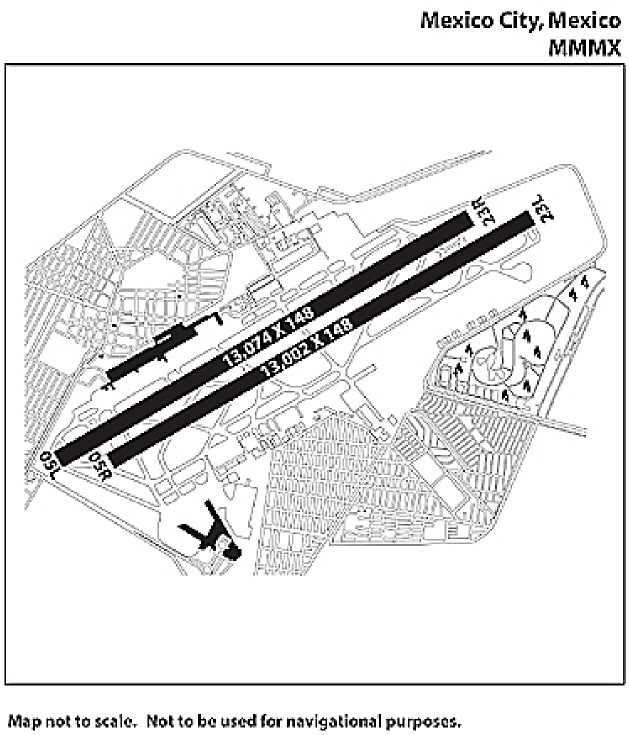
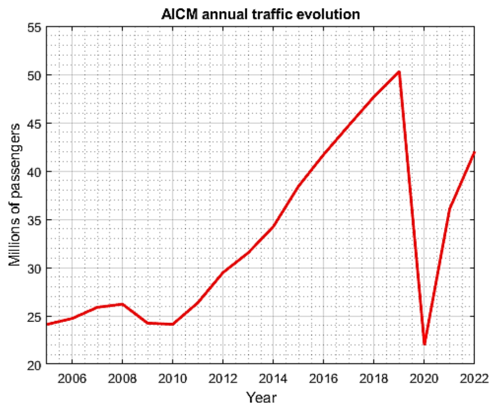


Figure 4.1: AICM Runways layout (Source: [11])

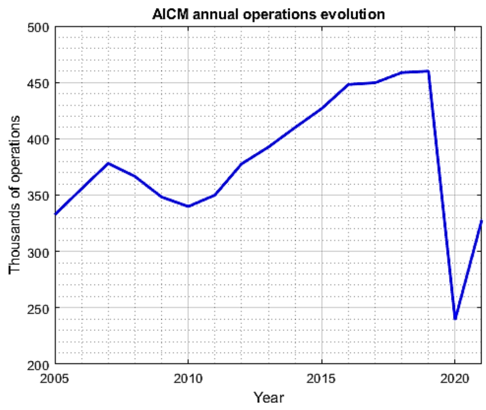
4.1.3. Traffic statistics of AICM

Mexico City International Airport is and has been the busiest airport in Latin America in recent years, ahead of São Paulo-Guarulhos International Airport, El Dorado International Airport and Cancún International Airport.

The evolution of the number of passengers and number of operations per year has been represented in two graphs, taking the data from the annual statistics of the official website of the AICM airport [31].



(a) AICM annual traffic evolution in recent years



(b) AICM annual operations evolution in recent years

Figure 4.2: AICM anual traffic and operations evolution in recent years (Source: Compilation based on [12])

It can be seen that between 2010 and 2019 there was a huge growth of number of passengers and operations. In 2019 alone, the airport accumulated a total of of 459.987 air operations and more than 50 million passengers, breaking extraordinary limits that reflected the airport's hypersaturation [32].

That growth plummeted in 2020 due to the pandemic, but is rising again to very high levels. In 2021, it increased its passenger numbers by 64% and its number of operations by 37% compared to 2020, with a total of 36.056.614 passengers and 327.889 operations [33].

It is quite evident that the airport handles a very high level of passengers and operations, leading to a very high rate of congestion which, together with other factors studied in this chapter, leads to situations where the capacity limit is exceeded and has an impact on the quality of airport services and the punctuality of operations.

4.1.4. Lack of capacity: a historical problem at AICM

Benito Juárez Airport has suffered from a lack of capacity for at least 35 years, approximately since the early 1990s. When the terminal opened in 1952, the number of operations it would have today was unimaginable, and the demand has continued to grow over the years.

This lack of capacity is due to multiple causes. One of the main ones, which has been pointed out in a previous section, is the fact that it only has two runways that cannot operate simultaneously, which reduces the airport's capacity to one operation per runway.

This generates congestion both in the air and on the ground, as SENEAM places the arriving flights in a holding pattern while the take-off flights are being attended to. Another reason is the lack of national strategic planning: 20% of the passengers passing through the AICM are connecting to another flight, as there is a lack of direct flights at the national airports. This contributes to the fact that 40% of the operations carried out at the country level are done at the AICM, with this concentration of operations at the AICM being a further cause of congestion [29].

Throughout these years of congestion, multiple attempts have been made to solve the problem, such as the expansion of Terminal 1 (the original) on numerous occasions, the construction of a new terminal (Terminal 2) in 2007, the attempt to open a third terminal which was cancelled due to the pandemic, the development of new taxiways and aprons, and even the planning and start of construction of a new airport, the New Mexico City Airport (NAIM), which was cancelled in 2013 by the government following a referendum decision. It can be said that as demand has grown, attempts have been made to address the problem by patching up the infrastructure.

Nonetheless, despite all the measures taken, the Directorate General of Civil Aviation (DGAC) declared the airport as saturated in 2013, reducing it from a capacity of 61 operations per hour to 58 operations per hour at peak times, due to the fact that during the previous year the capacity limits were exceeded on more than 50 occasions. In 2014, the DGAC declared it saturated again, as the same pattern was repeated during that year, establishing a maximum capacity of 61 operations per hour (40 departures for 20 arrivals). It determined that air operations from this point onwards were no longer safe, as such congestion implies a risk to the safety of passengers, flight crews, airport personnel and residents of the nearby areas.

4.1.5. Implementation of the A-CDM at AICM

In this context of capacity constraints and numerous failed attempts to fix them, AICM was a "perfect" candidate to implement the A-CDM. At the beginning of 2018, its implementation was announced. This would provide operators with accurate, real-time information that would help improve take-off times and reduce flight delays. In addition to many other benefits such as aircraft localisation, improved operating conditions and reduced fuel use and environmental impact through less runway operation and a more controlled traffic flow. With the introduction of A-CDM, airlines would also benefit from lower operating costs, as boarding and disembarkation would be streamlined and therefore fuel costs would be reduced.

The implementation process was planned to be completed in 18 months, i.e. in 2020. However, during the process, some setbacks emerged. Firstly, there was a lack of the necessary technology and operational systems, as AICM did not have a modern AODB (Airport Operational Database), which is the main database where all operations and milestones, from landing to blocks, are stored at an airport, i.e. where all operations and milestones are recorded and concentrated. As most airports in Europe have AODBs that capture the milestones automatically. In this aspect, the starting point was already lower than in Europe.

Therefore, quite a large investment was needed to implement this basic system, which was indeed carried out. Nevertheless, the most decisive problem was the resistance to the change of culture, as this modernisation of the database already generated resistance, but also the change in the way of operating generated even more.

During the first year an openness to change on the part of the airlines was achieved, together with them being able to share information and report milestones information (Blocks-In, Blocks-Out, Landing, Take-off, Taxi times, etc.), i.e. information that only airlines have, and integrate them into a dashboard. This was the main focus during the first year along with the previously mentioned modernisation of the systems. It was also achieved the construction of an Airport Management Centre, where representatives of airline operators, ground operators, air traffic controllers and the AICM itself would be physically concentrated in order to achieve a global and unique vision of what happens at the airport, and hence make joint decisions to improve the use of airspace and infrastructure, such as runways, aprons, parking gates, taxiways and terminals, hence replacing the current Operational Control Centre, located in the old control tower in Terminal [34]. The writing of the A-CDM operational procedures manual for the airport agreed by all airlines was also achieved: The Milestones Approach with the respective departure sequences and the variable taxi times.

Nevertheless, due to the fact that, as explained above, Mexico Airport is coordinated by the Federal Government, following the change of government, the implementation was halted.

These facts do not only apply to Mexico's airport, but in most Latin American airports there is a similar problem in terms of available technologies and therefore, it is not that A-CDM cannot be applied, but that if it is done, it requires more investment, more changes and therefore more time than in European airports in general. To date, the only Latin American airport that has A-CDM in operation is Sao Paulo International Airport (Guarulhos). Furthermore, it is clear that the willingness of stakeholders to cooperate is of paramount importance for a successful implementation.

4.1.6. A-CDM situation at AICM today

Currently, the AICM is still in a very delicate situation, as in recent months it has been at the centre of incidents and controversies that cast doubt on the safety of its operations. Moreover, all these problems have increased since March 2022, after the inauguration of a new airport in Mexico, the Aeropuerto Internacional Felipe Ángeles (AIFA), with the aim of reducing congestion at the AICM, and which aims to reduce its activity by 30% [35] by absorbing part of the airport's traffic. In addition, it is also intended to transfer much of the activity to Toluca International Airport.

The efforts are currently being made to move cargo and mail flights to AIFA, and it is estimated that this will reduce congestion at AICM by 3% [36]. In addition, this measure will also be taken in order to give visibility to the new airport. Even so, all this migration to the new airport also implies a large investment on the part of the cargo permit holders, as they will have to relocate equipment, hire new staff and change their concession permits to be able to operate at the new airport. However, it is insisted that the benefits will be greater over time.

In short, the AICM is currently in a very critical situation that is being resolved in a chaotic and hopeless way. The airport is still fully congested and cannot handle the number of operations it should, and is forced to restrict capacity, still generating many delays and poor service.

The implementation of A-CDM at MEX would have been a real decongestant for the airport, and would have solved much of this major problem. However, if this current situation can be alleviated, A-CDM is still a very good option for this airport that could bring a lot of benefits because it is a clear example of an airport that needs to increase and better manage capacity.

4.2. Implementation of A-CDM at non-European airports

The case of Mexico illustrates a good example of an attempted implementation at a non-European airport. Having seen this example, some conclusions can be drawn about the feasibility of implementing A-CDM at airports outside Europe.

The main difference between Europe and the other continents is that Europe is a very small continent with many countries. That is why collaboration within all of them is needed for the airspace planning. In contrast, in other continents, such as America, which are much larger, there is no such coordination cell like EUROCONTROL. The question would be, in this case, who would play the role of EUROCONTROL in these continents. If A-CDM is to be implemented, there is also a need for a centric ATM network as EUROCONTROL to coordinate the slots, and because countries do not have legal authority over each other (e.g. a flight from JFK to AICM, different countries). Therefore, implementation outside Europe turns to be a challenging issue when it comes to this cooperation within countries.

In addition, for A-CDM to work properly, all airport partners must be familiar with it and be knowledgeable about the procedures. For this reason, as the A-CDM is rooted in Europe, there may also be a lack of information that impedes the implementation at other airports. It is noticeable that A-CDM is a very complex and tedious concept, especially at the beginning of the implementation, and sometimes if there are setbacks it can take a long time to implement. Therefore, experts and skilled people are needed to be able to conduct it. Moreover, as has been seen with the example of Mexico City, many airports do not have the technology or infrastructure base for A-CDM, so that CBA is not successful, or they have to make a greater financial investment than most European airports, which is another reason to discard A-CDM.

In some continents like Asia, some turnaround process optimisation systems have been developed, which in some cases may have some similarities with A-CDM. While it is true that some Asian airports claim to be CDM airports, the only feature of A-CDM that they implement is the dashboard with some timings available, but as of today there are actually no fully CDM airports in Asia. In conclusion, it is clear that European airports have a number of advantages when converting/becoming CDM airports, but, for hyper-saturated airports such as AICM, the implementation of A-CDM or even a similar system would be entirely positive for decongestion, even taking into account higher investments and implementation difficulties than in Europe.

CHAPTER 5. BEYOND A-CDM

During the project it has been emphasised that A-CDM is focused on the optimization of the turnaround process, and hence on the tactical part of the ATM process. In this chapter, Beyond A-CDM, initiatives and solutions that are emerging at present are presented, that focus on the integration of airside and landside, expanding the time horizon to a pre-tactical range of several hours. Such initiatives and concepts are complementary to the A-CDM or the natural continuation of the correct and complete implementation of the A-CDM, with the aim to further improve the process and flow of data and operations at the airport.

5.1. Airport Logistics Concept

While it is true that delays can be generated for a variety of reasons and can originate from both air and ground sources, most delays are usually initiated at the airport, whether they originate from the gate, taxi departure or taxi entry. The objective of the airport logistics concept is to be able to efficiently manage the logistics activities and processes that take place in and around an airport, therefore including all logistics activities and sub-processes that intervene and influence the air transport process. The aim is to develop a complete picture of all airport processes and activities, thereby creating an overview and real-time controllability of all resources.

Resources cover everything from airspace and runway capacity to available boarding gates, the baggage system, fuel and food vehicles and all other infrastructure, equipment and personnel necessary for the air transport system (ATS) to function properly. Resource management is the term that encapsulates the use of resources in the ”smartest” way possible to achieve the best utilisation and performance of the system [13].

Resource management in airline operations includes planning at all levels: schedule design, fleet allocation, maintenance planning, crew pairing and assignment, and revenue management. Relevant elements of resource management on the airside of an airport include runway capacity, runway and taxiway sequencing, slot allocation and gate allocation and scheduling [13].

In the A-CDM context, the purpose of airport logistics is to use and process the information available through the A-CDM to achieve efficient resource management. With this information available, planning and utilisation of all resources can be optimised at the tactical level, and at the operational level, it is possible to reschedule due to system disruptions.In this way this concept makes it possible to capture the interaction between processes, and the interaction between these processes and the ATM. The most significant ATM process is air traffic flow management, which includes rerouting, metering and ground holding measures.

Figure 5.1 depicts the main tasks performed by the ATS actors, where it can be seen that various tasks are performed jointly between them.

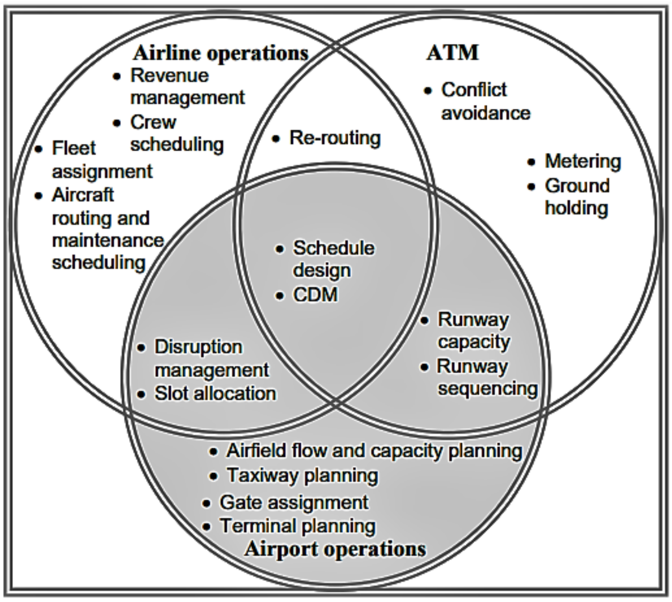


Figure 5.1: Task diagram of ATS actors (Source: [13])

5.2. META-CDM

META-CDM (Multimodal, Efficient Transportation in Airports - Collaborative Decision Making) is a project that aims at a future A-CDM where the focus of information exchange is on passengers and their door-to-door journey.

A-CDM helps to reduce ATFM slot non-compliance caused by delays, thus facilitating airlines, airports and ground handlers to manage their resources more efficiently. However, it is not focused on the ground side, and does not include the passenger in the process.

Based on A-CDM, the project aims to be a unified concept of airside-CDM, which focuses on airline delays, and landside-CDM, which focuses on delays generated during the interval between the passenger arriving at the airport and entering the aircraft. In this way, it aims to mitigate the impact of severe disruptions and unify the management of the two types of delays. The idea is to incorporate into the process the exchange of information on the passenger's door-to-door travel status, both in normal situations and day-to-day operations as well as during adverse events. This allows this information to be incorporated into the planning of the transport service so that passengers can travel stress-free, facilitate and streamline procedures by reducing door-to-door journey times, provide earlier and more accurate information on flight updates to passengers and generally improve their experience.

Like the A-CDM, the META-CDM also consists of the implementation of milestones to monitor the passenger's journey in the door-to-door interval, and thus also to make a forecast of the estimated elapsed times and estimated arrival times for the critical points of the process. From this data, defined times are created that allow passengers to have better information about the times and therefore to better plan when to go to the airport and how long the process will take them to board, so that by being better informed about it, they help to reduce congestion at airports. More importantly, they can plan better especially in situations where disruptions occur, knowing whether they need to go to the airport or not and alternative ways to proceed with their journey in the event of disruptive events. It also helps airlines, as they can make better decisions by knowing the situation of passengers at critical times.

However, Meta-CDM is still in its very early stages and more research is required to design the concept and implementation, as well as the need for further benefit studies.

Table 5.1: Functional Groups of A-CDM and equivalents in MetaCDM (Source: [19])

Nº	A-CDM Functional Group	MetaCDM Functional Group
1	Information Sharing	Information Sharing
2	Collaborative Turn-Round Process	Passenger Travel Milestones
3	Variable Taxi Time Calculation	Variable Process and Transfer Time Prediction
4	Col. Management of Flight Updates	Collaborative Management of Travel Updates
5	Col. Pre-Departure Sequence	Performance Based Travel Management
6	CDM in Adverse Conditions	MetaCDM in Adverse Conditions

5.3. AOP and APOC

"Airport operations plan (AOP) and seamless integration with the network operations plan (NOP)" is one of the SESAR solutions being implemented in order to develop the concepts of the European ATM Masterplan, which is the main planning instrument for ATM modernisation across Europe. The ATM Masterplan defines the priorities and development activities to achieve the Single European Sky vision, and is constantly being updated by ATM stakeholders in line with the evolving aviation scenario.

In order to achieve the digitalisation necessary to cope with the expected traffic growth and future ATM challenges, and to fully integrate airports into the ATM network to optimise air operations, this SESAR solution introduces the additional resources for the collaborative management of airport operations: the AOP and APOC.

The AOP is an airport operations plan that contains the necessary information, data and KPIs from different partners (airlines, ground handlers, ATC, security, emergency services, etc.) and aims to coordinate the activities of all actors on-site and enable collaborative decision-making. It is available to all airport stakeholders, allowing them to access changes in scheduling and operational conditions and circumstances, contributing to improved management and efficiency of operations. It is prepared several months in advance of the flight, taking into account all known information, traffic schedules, works and planned events, among others. Later on, more precise data is added to it, so that it is constantly being refined. In the short term, very detailed and accurate information on traffic demand, runway configuration, weather forecasts and links between arriving and departing flights is available and added to the AOP.

The AOP is managed and supervised by the APOC, which is either a physical installation or a remote collaboration among partners. The APOC manages the day-to-day operations of the airport. The consistency between planned and actual performed operations is being continuously monitored and the needed changes are made to the AOP. As explained above, the AOP is perfected as stakeholders update their intentions or as more precise information on the progress of flights is reported. In case the follow-up of the AOP generates an alert, the APOC facilitates both the definition and the implementation of the solution [37].

In this way, the airport is able to track the development and performance of the plan and to mitigate the impact of any deviations that might arise, making the airport more resilient to disruptions by having a common situational awareness for all stakeholders. The purpose of this SESAR solution is to provide the tools to maintain airport operations in all types of operational conditions and share information with the wider network.

This solution is strongly connected to A-CDM, in fact, it is the natural next step after a successful A-CDM implementation.

The NOP (Network Operations Plan), on the other hand, is a global plan that links the AOPs of all airports in the network, ensuring a common network-wide situational awareness. The NOP has as its main source of information the AOPs of the airports, but it also collects data from other sources. The different network stakeholders (the airports, ground handlers, airlines, air navigation service providers, etc.), coordinate their activities through SESAR's System Wide Information Management (SWIM) [37].

Therefore, the combination of AOPs and NOP enhances predictability across the entire network as well as at individual airports, thereby reducing delays, unnecessary fuel burn and thus pollution and costs for airlines, and helps to optimise resource utilisation and passenger services.

SESAR carried out several real-time simulations and tests focusing on landside-airside integration. The complete SESAR APOC and AOP/NOP solutions are already industrially operational and are part of a synchronised European deployment.

In fact, the AOP has already been applied at Brussels Airport with very satisfactory results [38]:

- 5% increase in sales per pax
- 4% reduction in airport delay
- 25% performance increase
- Payback in less than 4 years
- Passenger forecast accuracy in COVID of 86%
- More than 500 active users in 2021

The APOC of Nice Côte d'Azur Airport is shown in Figure 5.2.

Figure 5.2: Airport Operations Center of Nice Côte d'Azur Airport (Source: [14])

5.4. Total Airport Management (TAM) and SESAR Project PJ.04

As it has been seen, A-CDM focuses on the optimisation of airside airport processes, and therefore stakeholders are only involved in the tactical phase. Total Airport Management (TAM) is a further development of A-CDM, which in addition to the airside, incorporates the landside and the terminal, so that it covers the tactical, pre-tactical and strategic phases of the process. It then also integrates the processes related to passengers, baggage, etc. and the interaction and synchronisation between them, thus providing an overall view of the airport processes.

The SESAR PJ04- TAM project provided two SESAR solutions with the objective of increasing the predictability, timeliness and efficiency of airport operations, as well as resilience through faster recovery of normal operations and enhance the passenger's experience [39].

The first one, Solution PJ.04-01 'Enhanced Collaborative Airport Performance Planning and Monitoring', is based on the already mentioned SESAR Solution #21 ('Airport Operations Plan and AOP-NOP Seamless Integration') and on the basis of the A-CDM, and aims to increase the quality of the AOP by including more data from the extra airport processes included in the TAM, as it incorporates the ground and terminal side and therefore more information to be added to it. Therefore, it adds information on processes such as baggage and passenger-related processes, and studies how they impact on airside processes. In addition, it also provides tools for data registry and post-operational analysis.

The second one, Solution PJ.04-02 'Enhanced Collaborative Airport Performance Management', is an extension of A-CDM that provides a dashboard on which information is recorded on what has happened, what is happening and forecast of what is going to happen, providing 'What-if' information and solutions to problems as they arise. It also includes the identification of trends and potential performance deviations [40].

In addition, information on weather forecasts and environmental parameters is added to the AOP, improving common situational awareness. Therefore, the main objective of this solution is to enable stakeholders to make more efficient collaborative decision-making and to efficiently carry out comprehensive impact assessments using the most updated data available, forecasting possible future scenarios.

Figure 5.3 shows the scope TAM comprises compared to the A-CDM scope.

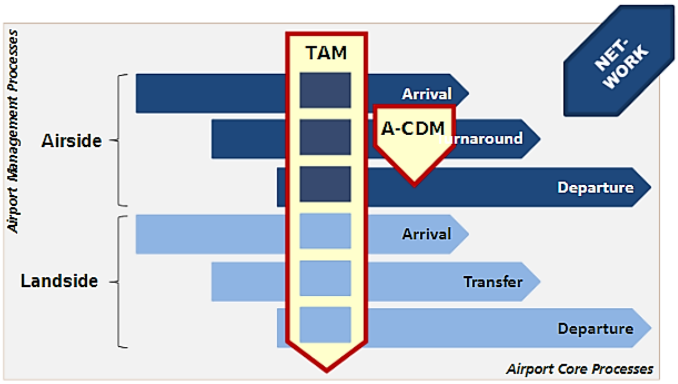


Figure 5.3: TAM vs A-CDM scope (Source: [15])

5.5. Smart Cameras at Amsterdam-Schiphol

Schiphol Airport aims to become a leading digital airport and is a pioneer in the introduction of artificial intelligence at airports. To achieve that goal, the airport is working on innovations to make the airport more efficient, smarter, safer and more automated. One of the designs being developed in collaboration with Bosch (who have been Schiphol's partner for more than a decade in the airport security sector and systems integrator for complex IT projects) are the Smart Cameras.

These cameras are intended to provide information on the waiting times and timestamps of the turnaround process, in order to predict and avoid delays and to streamline the process. They are located on the outside of the gates and collect snapshots for an advanced deep learning technology algorithm to convert them into usable data, recognising specific elements of the turnaround. This allows the start and end time of each activity to be identified and the time taken for each process to be calculated. By analysing all the processes that take place in the parking position, it also improves the determination and prediction of the time when the aircraft is ready for take-off.

Moreover, in 2019, also in collaboration with Bosch, a state-of-the-art APOC was installed, initiating the Airport Operations Centre programme at the airport. The plan is to build further on the alignment between airport stakeholders regarding their involvement/role in the APOC to improve the initial decision-making model. Figure 5.4 shows the state-of-the-art APOC at Schiphol.

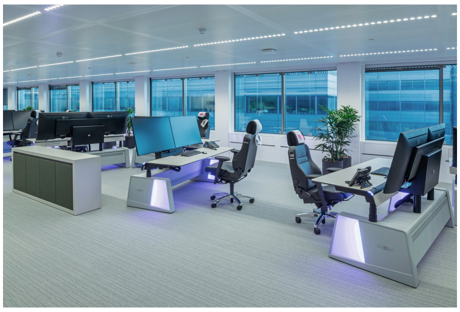


Figure 5.4: State-of-the-art APOC at Schiphol (Source: [16])

CONCLUSIONS

One of the main and first objectives of this work has been to disaggregate and understand the whole A-CDM process, from the very first moment when the idea of implementation is raised, to the achievement of CDM Status by an airport. During the study, it has become clear that it is a rather complex and tedious process, especially the first steps, and that the understanding of the concept by all airport partners and the willingness and collaboration to get involved and share information is crucial. Nevertheless, it is a system that brings many benefits to any airport that implements it, both qualitative and quantitative, and furthermore, it is also designed to take into account most of the inconveniences that may occur, and it is backed up by very elaborate procedures for each type of situation or adversity that may arise, which provides a great deal of robustness.

On the other hand, the current status of A-CDM has been assessed at Zurich Airport and Amsterdam - Schiphol, two leading European airports that have provided a great example to better understand A-CDM in practice, and, in particular, the obtainment of TOBT, TSAT and TTOT, the pillars of A-CDM. The study of two different airports has allowed to observe that despite being a standardised process, the A-CDM has a strong local factor, which means that it is adapted at each airport according to existing resources, local needs and preferences. Hence, some procedures may differ or be assigned to different partners, although this tends to be for specific rather than general issues.

In addition, it has been possible to compare the implementation process, another of the main objectives of the project. Once again, the importance of stakeholder cooperation has been corroborated, seeing how a factor such as the partners' attitude has affected the implementation at Schiphol to the point of prolonging it by many years. In this respect, the need for a strong airport authority has become evident.

Furthermore, during the study, it has been possible to understand various factors that can affect and decrease the capacity and efficiency of the airport procedures, and how the A-CDM is adapted in order to minimise the effect. It has been observed that one of the most important factors for the A-CDM process is the runway configuration, which in this case depends on the weather and wind factor for Zurich Airport, and the peak hour factor for Schiphol, a very busy airport as it is a major hub. Runway configuration conditions both capacity and taxi time, thereby making it a determinant for CDM planning.

Another factor to highlight is the importance of the inclusion of de-icing operations in the process and the benefits it entails in its management, but also the complications that can develop, which remain a point for further improvement, especially at Schiphol.

From the analysis of the two airports, it can be seen that the focus of future A-CDM improvements for both of them is the inclusion of passenger and terminal processes monitoring in the A-CDM chain, as they also influence turnaround process timings, and in order to have a better picture of the overall airport functioning. In addition, there is a trend for both airports to include an artificial intelligence factor in order to digitalise and automate airport processes and hence further improve the accuracy of information. Even so, the process as it is currently designed greatly increases accuracy, and the AI component will continue to be a potentiation of these human knowledge and methods.

Another objective of the project was to study the feasibility of extending the A-CDM concept to non-European airports. With the example of Mexico City airport, a case of unsuccessful implementation has been analysed and some general conclusions have been drawn. The main reasons for its hypersaturation, including political aspects, have been made clear, and have helped to increase the knowledge of aspects that can affect saturation. In addition, it has been shown that there are certain pre-requisites to be met in terms of airport technology in order to avoid delays and many complications during implementation, and that there is a need for partners to be very knowledgeable about A-CDM in order to implement it. It is evident that currently the most ideal airports for the smoothest and least costly possible implementation are European airports. It is also evident that in Europe it is much easier for reasons such as the greater understanding of the whole process, and the fact that there are already many european CDM airports with proven benefits. In addition to a very important factor, which is the great advantage of the role played by EUROCONTROL in Europe, and that in other continents there is no organisation of this type to coordinate the slots and the continent's airspace network.

For this reason, some airports outside Europe do have similar systems in place, but it is more challenging for them to have a full A-CDM. The implementation of full A-CDM can be difficult, which is why some airports implement only certain features or involve fewer stakeholders, so that they implement it partially and in a shorter period of time. In any case, including in Europe, what has been proven is that the theory is often easier than the practice when it comes to A-CDM, as in reality there can be bottlenecks that hinder its development.

Finally, meeting another of the objectives of the project, the last chapter has provided an insight into upcoming systems that further enhance the benefits of A-CDM and allow it to extend the time scope. AOP and APOC are two very promising SESAR solutions that are already in the process of implementation as a natural continuation of A-CDM in Europe.

In the end, it is clear that A-CDM in the great majority of cases brings many benefits in terms of better capacity utilisation, better management of runways, gates and slot utilisation, and smoothing of the turnaround process and information, as well as reduction of taxi time and therefore emissions and costs, among many others. While it is true that for EUROCONTROL it will always be positive for a European airport to become CDM, as this will contribute to the predictability of European airspace and network capacity planning, for an airport itself it will not in all cases be totally necessary. It is of utmost importance to take capacity and saturation levels into account when considering A-CDM at an airport and to study thoroughly whether the benefits will be of great importance and will solve many airport problems, as A-CDM, as it have been seen, requires a great effort from all parties, and in many cases time and investment.

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APÈNDIXS

APPENDIX A. DESCRIPTION OF THE MILESTONES

Milestones Approach section: 2.6.2..

Milestone 1: ATC Flight Plan Activation

Time reference: Normally 3 hours before EOBT (The ATC Flight Plan is submitted)

Description:

- Milestone at which the A-CDM process begins for a flight. It is initiated when the AO uploads the ATC Flight Plan, and is used to check the consistency of data between the FPL, Airport Slot Programme and Airport Flight Data (SOBT/STD (Schedule Off-Block Time/Scheduled Time of Departure) vs EOBT (Estimated Off-Block Time) check).
- Once it has been confirmed that there are no inconsistencies: Start the DPI process to communicate the information via an E-DPI to Network Operations.
- A-CDM Actions: Update ELDT and EIBT for an arrival and EOBT and ETOT for a departure.
- Start of the DPI process.

Milestone 2: EOBT -2 hrs CTOT Allocation

Time reference: Normally 2 hours before EOBT (If regulated flight).

Description:

- At EOBT-2 hours, all flights, regulated and unregulated, are known to the A-CDM platform. Regulated flights will be issued a CTOT from Network Operations.
- ELDT update for inbound flights and EOBTs
- First estimate of TTOT (take into consideration EIBT+MTTT+EXOT, if later than EOBT+EXOT).
- A T-DPI message is sent to inform Network Operations of updated take off time estimate.
- ETOT/TTOT/CTOT indicate the corresponding fields as REGULATED.

Milestone 3: Take-off from Outstation

Time reference: The information is immediately released once the milestone has been achieved.

Description:

- Aircraft take-off from the airport of origin.
- The outstation provides the ATOT (Actual take-off time) to the Network Operator and the AO. Using the ATOT, an ELDT can be computed using the Estimated Elapsed Time of the FPL.
- ELDT, EIBT, TOBT and TTOT updated.

Milestone 4: FIR Entry

Time reference: It depends on the destination airport by the position relative to the boundary of its FIR.

Description:

- In this milestone, the flight enters the FIR (Flight Information Region) of the destination airport.
- ELDT is updated and TOBT calculated by the A-CDM Platform.
- The precision of the ELDT is of high importance as it is used to manage stands, gates, preparing the arrival sequence and ground handling operations, among other procedures.
- ELDT, EIBT, TOBT and TTOT updated.

Milestone 5: Final Approach

Time reference: Depends on the parameters defined by ATC of the concerned airport.

Description:

- In this Milestone the flight enters the Final Approach phase at the destination airport. ELDT is updated, TOBT is redetermined and checked for consistency with the ATC Flight Plan.
- Normally the Final Approach starts between 2 and 5 minutes before landing, and this is the moment when ground handling and parking services start to be prepared.
- ELDT, EIBT, TOBT and TTOT updated.

Milestone 6: Aircraft Landed

Time reference: The information is immediately released once the milestone has been achieved.

Description:

- This is the moment when the aircraft touches down the runway of the destination airport. The ELDT becomes ALDT (Actual Landing Time), which is used to calculate EIBT (ALDT + EXIT). Therefore, TOBT and TTOT are updated.

Milestone 7: Aircraft In-Blocks

Time reference: The information is immediately released once the milestone has been achieved.

Description:

- At this Milestone the Aircraft arrives at the parking stand, hence EIBT becomes AIBT (Actual In-Block Time). TOBT and TTOT are updated.

Milestone 8: Ground Handling Starts

Time reference: The information is immediately released once the milestone has been achieved.

Description:

- This Milestone marks the start of turnaround activities (Actual Commence of Ground Handling: ACGT) It is dedicated to flights that are the first operation of the day or that have been parked for a prolonged period of time. For the rest, GH activities are initiated in the AIBT.
- ETTT/TOBT and TTOT are updated.

Milestone 9: Final Confirmation of the TOBT

Time reference: Information issued t minutes before EOBT (t is a locally commonly decided time value).

Description:

- In this crucial Milestone the AO or GH provides the most accurate and definitive TOBT based on the actual operating situation, which is a requirement to enter the flight in push back/pre-departure sequence and have a TSAT assigned to it.
- ATC calculates EXOT (Estimated Taxi-Out Time).
- ETTT/TOBT and TTOT are updated.

- ETTT/TOBT and TTOT are updated.

Milestone 10: TSAT Issued

Time reference: Information issued t minutes before EOBT (t is a locally commonly decided time value).

Description:

- Once the TOBT is confirmed, this Milestone defines the moment at which a TSAT is assigned to the flight and stabilises in the pre-departure sequence.
- Network Operations is informed by a T-DPI-s (for unregulated flights).
- Update of TTOT.

Milestone 11: Boarding Starts

Time reference: The information is immediately released once the milestone has been achieved.

Description:

- The gate is open for passengers to start boarding (ASBT: Actual Start Boarding Time).
- This time is indicative for A-CDM Partners of whether the TOBT and TSAT are met. The ASBT must be reported.

Milestone 12: Aircraft Ready

Time reference: The information is immediately released once the milestone has been achieved.

Description:

- ARDT (Actual Ready Time): Closing of aircraft gates, removal of boarding bridge and disconnection of handling vehicles.
- ARDT has to be reported to the A-CDM partners concerned confirming that the flight complies with the indicated TOBT.

Milestone 13: Start up Requested

Time reference: The information is immediately released once the milestone has been achieved.

Description:

- The pilots of the aircraft request clearance from ATC to turn on the aircraft's engines and to commence taxiing back to the runway.
- ASRT (Actual Start-Up Requested Time).
- The concerned A-CDM Partners of the ASRT must be informed of the ASRT.

Milestone 14: Start up Approved

Time reference: The information is immediately released once the milestone has been achieved.

Description:

- The time at which the aircraft receives the start up approval, ASAT (Actual Start Up Approval Time), and can push back and start to taxi.
- The concerned A-CDM Partners have to be informed about the ASAT and that the aircraft has received TSAT clearance.

Milestone 15: Off-Block

Time reference: The information is immediately released once the milestone has been achieved.

Description:

- EOBT becomes AOBT (Actual Off-Block Time), aircraft commences taxi to runway.
- Update of TTOT taking into account the EXOT.

Milestone 16: Take-off

Time reference: The information is immediately released once the milestone has been achieved.

Description:

- TTOT becomes ATOT (Actual Take Off Time), in which the aircraft takes off from the runway.
- The A-CDM partners concerned must be informed of ATOT, an airborne message is generated and the flight is dropped from the departure sequence.
- ATOT recorded.

APPENDIX B. ZURICH AIRPORT

A-CDM Alerts at Zurich Airport section: 3.1.6..

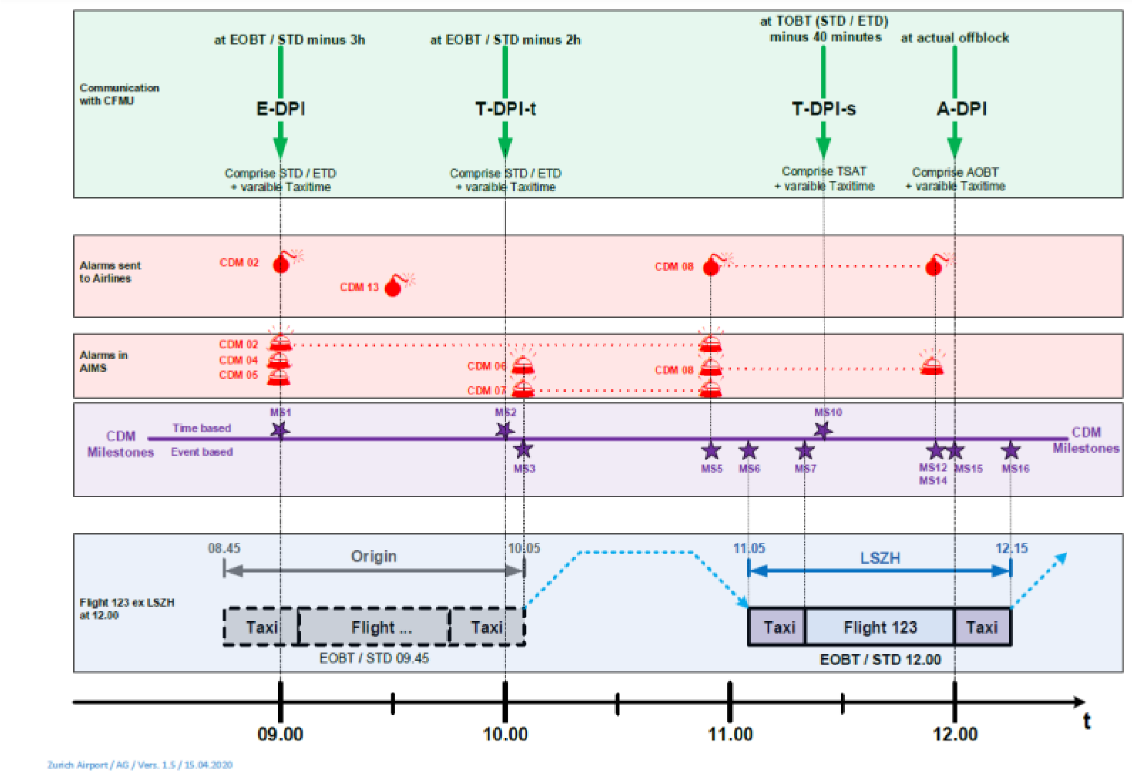

Figure B.1: Diagram of Milestones, CDM Alarms and DPI at ZRH [8]

APPENDIX C. SCHIPHOL AIRPORT

Adverse conditions at Schiphol Airport: 3.2.5..

C.1. Gate de-icing

The gate de-icing is based on the TOBT of the flight. The EDIT is added to this TOBT, and in the event that there is a need to wait for de-icing due to limited aircraft capacity for de-icing, the DIWS is added.

Figure C.1: Gate de-icing process in AMS[10]

C.2. Remote de-icing

In this case, the CDPSP will recalculate TSAT and TTOT but using a new TOBT: TOBT = TOBT + DIWT. TTOT shall be calculated by adding EDIT to EXOT.

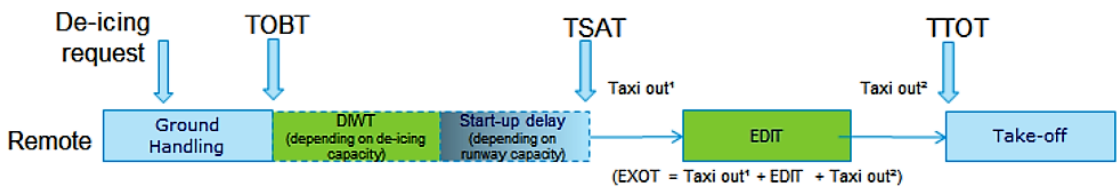

Figure C.2: Remote de-icing process in AMS[10]