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IMHOTEP

INTEGRATED MULTIMODAL AIRPORT OPERATIONS FOR EFFICIENT PASSENGER FLOW MANAGEMENT

This document is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 891287 under European Union's Horizon 2020 research and innovation programme.

Abstract

This document is the Concept of Operations (CONOPs) of the IMHOTEP project. The CONOPs describes the characteristics of the proposed system and services from the user perspective, and will be used to communicate the quantitative and qualitative characteristics of such system and services to all stakeholders in the project.

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List of Acronyms

Acronym	Meaning
AAT	Actual Arrival Time
A-SMGCS	Advance Surface Movement Guidance and Control System
A-CDM	Airport Collaborative Decision Making
ACI	Airport Council International
ACIS	Airport CDM Information Sharing
ACISP	Airport CDM Information Sharing Platform
ADES	Aerodrome of Destination
ALDT	Actual Landing Time
ANSP	Air Navigation Service Provider
AO	Airport Operator
AOBT	Actual Off-Block Time
AODB	Airport Operations Data Base
AOP	Airport Operations Plan
APOC	Airport Operation Centre
ATC	Air Traffic Control
ATFCM	Air Traffic Flow and Capacity Management
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
AU	Airspace User
AWT	Actual Waiting Time
CDM	Collaborative Decision Making
CHG	Change Message

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Acronym	Meaning
CNL	Cancelation Message
CONOPs	Concept of Operations
CTRP	CDM Turn-Round Process
EAT	Estimated Arrival Time
EC	European Commission
EFPS	Electronic Flight Progress Strip
ELDT	Estimated Landing Time
ER	Exploratory Research
EWT	Estimated Waiting Time
FUM	Flight Update Messages
GA	Grant Agreement
GDPR	General Data Protection Regulation
GH	Ground Handler
HLOR	High-Level Operational Requirements
HPR	Human Performance Requirements
ICAO	International Civil Aviation Organization
IMHOTEP	Integrated Multimodal Airport Operations for Efficient Passenger Flow Management
INTEROP	Interoperability Requirements
IR	Industrial Research
KPI	Key Performance Indicator
MaaS	Mobility as a Service
MCDM	Multimodal Collaborative Decision Making
MET	Meteorological Service

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Acronym	Meaning
NM	Network Manager
NTK	Noise and Track Keeping Systems
OD	Origin-Destination
PAX	Passengers
POC	Proof of Concept
PT	Public Transport
SAM	Slot Allocation Message
SCR	System Capacity Requirements
SIBT	Scheduled In-Block Time
SID	Standard Instrument Departure
SJU	SESAR Joint Undertaking
SMR	Surface Movement Radar
SOBT	Scheduled Off-Block Time
SPR	System Performance Requirements
SRM	Slot Revision Message
SSR	Safety and Security Requirements
TAM	Total Airport Management
TOBT	Target Off-Block Time
TSAT	Target Start Up Approval Time
TTOT	Target Take Off Time
UAAR	User Access and Administration Requirements
VTTC	Variable Taxi Time Calculation

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Executive summary

IMHOTEP's vision is that of a multimodal European transport system where the different modes are seamlessly integrated, so that passengers travel from door to door in an efficient, sustainable and resilient manner. Within this vision, airports will become multimodal connection nodes. A set of interconnected platforms and services will enable common situational awareness and real-time coordinated decision-making between airports and ground transport modes, allowing a more efficient passenger flow management and providing travellers with accurate information and recommendations for the planning and reconfiguration of their journeys in real time.

IMHOTEP's goal is to increase the efficiency of the overall transport chain by improving the interoperability of different modes of transport, addressing the contribution of airports to multimodality. The project results are expected to

- increase environmental sustainability, by facilitating the use of more sustainable ground access modes;
- make more efficient use of the existing infrastructure, through better monitoring and prediction of passenger flows;
- and improve the passenger's experience, by enhancing intermodal processes with respect to time efficiency, predictability, seamlessness, resilience, convenience and accessibility.

The technologies developed by IMHOTEP will serve as an enabler for establishing coordination processes between airports and other public transportation modes, including dynamic schedule synchronisation (e.g., to manage disruptions).

Enhanced situational awareness achieved by extending the monitoring of passenger flows beyond the airport boundaries will help improve aircraft wait/no-wait rules so that airlines can make better use of last-minute capacities and pax re-accommodation, and will facilitate the identification of airborne pax connectivity requirements in terms of links to ground services.

The aim of the IMHOTEP CONOPs is to specify the standards, information flows and data management technologies required to support the proposed concept.

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1 Introduction

1.1 Purpose of the document

The purpose of this document is to present the CONOPs of the IMHOTEP Project. The concept of operations is the document where the functionalities and specifications of future IMHOTEP Solution are defined, constituting the baseline and reference guide for the rest of the Project

1.2 Scope

The document proposes a concept of operations for the extension of airport collaborative decision-making to ground transport stakeholders. The CONOPs is complemented by deliverable 'D2.2 Specification of Case Studies' which define a set of use cases based on information sharing and real-time decision-making situations between air and ground transport modes.

IMHOTEP focuses on passenger transport; freight transport is out of the scope of the document.

1.3 Intended readership

As identified in the Project Management Plan, the target audience for the project includes:

- SESAR JU
- European Commission
- Airports
- AUs
- ANSPs
- Network Manager
- Ground transport stakeholders
- Relevant SESAR IR projects (e.g., PJ04 TAM)
- Relevant SESAR ER projects (e.g., TRANSIT, MODUS, X-TEAM D2D projects)
- Scientific Community

The intended readership of the CONOPs is expected to be similar

1.4 Structure of the document

The document is structured as follows:

- Section 1 describes the scope and background of the IMHOTEP CONOPs and explains the organisation of the rest of the document.
- Section 2 provides a general overview on airport operations, Airport Collaborative Decision Making (A-CDM) and airport intermodal concepts.
- Section 3 contains the description of the main elements and functions that constitute the proposed Multimodal Collaborative Decision Making Operational Concept, including the high-level operational requirements for its implementation.
- Section 4 describes the Multimodal Collaborative Decision Making implementation approach.

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- Section 5 defines the KPIs that will be used to validate and measure the effectiveness of the IMHOTEP platform.
- Section 6 deals with Safety, Performance and Interoperability Requirements (SPR-INTEROP).
- Section 7 includes the references and applicable documents used to produce this document.
- Appendix A provides a Cost-Benefit Analysis that considers the stakeholders' expectations and the benefits and costs mechanism for the project.

1.5 Glossary of terms

Table 1. Glossary of terms

Term	Definition
Airport Collaborative Decision Making (A-CDM)	Airport Collaborative Decision Making (A-CDM) is a concept which aims at improving Air Traffic Flow and Capacity Management (ATFCM) at airports by reducing delays, improving the predictability of events and optimising the utilisation of resources. The implementation of A-CDM allows each A-CDM Partner to optimise its decisions in collaboration with other A- CDM Partners, knowing their preferences and constraints and the actual and predicted situation. Decision making by the Airport CDM Partners is facilitated by the sharing of accurate and timely information and by adapted procedures, mechanisms and tools. The A-CDM concept comprises the following Elements: • Airport CDM Information Sharing • CDM Turn-Round Process – Milestones Approach • Variable Taxi Time Calculation • Collaborative Management of Flight Updates • Collaborative Pre-departure Sequence • CDM in Adverse Conditions Advanced CDM
Multimodal Collaborative Decision Making (MCDM)	The solution proposed for the implementation of the IMHOTEP Concept, which consists of the extension of the airport collaborative decision-making processes to the ground transport modes necessary for airport access and egress.
Airport CDM Information Sharing Concept Element (ACIS)	The Airport CDM Information Sharing Element defines the sharing of accurate and timely information between the Airport CDM Partners in order to achieve common situational awareness and improve traffic predictability. The Airport CDM Information Sharing Platform (ACISP), together with defined procedures agreed by the partners, is the means used to reach these aims. The Airport CDM Information Sharing is the core Airport CDM Element and the foundation for the other Airport CDM Elements.

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Term	Definition
Airport CDM Information Sharing Platform (ACISP)	The Airport CDM Information Sharing Platform (ACISP) is a generic term used to describe the platform used by CDM airports to allow Information Sharing between the Airport CDM Stakeholders. The ACISP can comprise systems, tools and user interfaces.
Airport CDM Stakeholders	An Airport CDM Stakeholder is a stakeholder that participates in the CDM process. The main Airport CDM Partners are: • The Airport Operator • Aircraft Operators • Ground Handlers • De-icing companies • The Air Navigation Service Provider (ATC) • The Network Manager Support services (Police, Customs and Immigration, etc.)
Alarm	A system generated signal or warning which alerts the MCDM Partners of an irregularity and which normally requires one or more MCDM Partners to make an intervention to resolve the irregularity.
CDM Airport (CDM-A)	An airport is considered as a CDM-A when the Airport CDM Information Sharing, Turn-Round Process (Milestones Approach) and Variable Taxi Time Calculation Elements are applied at the airport.
CDM Turn-Round Process Concept Element (CTRP)	The CDM Turn-Round Process Element (Milestones Approach) describes the progress of a flight from the initial planning to the take-off from a CDM-A by defining Milestones to enable close monitoring of significant events. The aim is to achieve common situational awareness and to predict the forthcoming events for each flight. The CDM Turn-Round Process combined with the Airport CDM Information Sharing Element is the foundation for the other Airport CDM Elements.
Event	An Event is a distinct occurrence in the planning or operations of a flight or in surface transport services that a person or system perceives and responds to in a specific way.
Ground Handling	Ground Handling covers a complex series of processes that are required to separate an aircraft from its load (passengers, baggage, cargo and mail) on arrival and combine it with its load prior to departure.
Ground Handler / Ground Handling Agent	A Ground Handler or Ground Handling Agent is the company or person(s) that performs Ground Handling.

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Term	Definition
Milestone	A significant event that occurs during the planning or progress of a trip. A successfully completed Milestone will trigger the decision-making process for downstream events and influence both the further progress of the flight and the accuracy with which the progress can be predicted.
Passenger Activity-Travel Diary	A Passenger Activity-Travel Diary is the unit of work for the MCDM system. It aims to provide a comprehensive picture of the full door to-door passenger journey. A Passenger Activity-Travel Diary is composed by the sequence of activities and trip stages performed by the passengers during the door-to door trip.
Variable Taxi Time	Taxi Time is the duration of time that an aircraft spends taxiing between its parking stand and the runway or vice versa. It includes some time spent on the runway when lining up and vacating. At complex airports the layout of runways and parking stands can result in a large difference in taxi time. Instead of using a standard default value, a calculation of the different permutations based upon historical data, operational experience and/or an integrated tool will provide a set of more realistic individual taxi times.
Variable Taxi Time Calculation Concept Element (VTTC)	The Variable Taxi Time Calculation Element consists of calculating and distributing to the Airport CDM Partners accurate estimates of taxi-in and taxi-out times to improve the estimates of in-block and take off times. The complexity of the calculation may vary according to the needs and constraints at the CDM-A. The aim is to improve the traffic predictability. At least the Airport CDM Information Sharing Element needs to be applied at the CDM-A to implement the Variable Taxi Time Calculation.

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2 State of the art

2.1 Airport operations

2.1.1 The airport of the future

IMHOTEP addresses the development of an **innovative concept for airport operations aimed at achieving an enhanced coordination with other transportation modes.**

The project tackles the specific challenge of developing the role of airports as intermodal nodes in a larger multimodal transportation network. IMHOTEP will contribute to this goal by developing an operational concept and a set of enabling technologies for information sharing and collaborative decision-making between the airport and other transport modes, acknowledging that "the transformation of the airport into an interchange node within a wider network imposes […] challenges which differ from those of a single-mode node" and calls for coordinated management decisions across modes. This enhanced coordination will contribute to the efficiency of airport operations, notably in capacity-constrained airports, where a more accurate forecast of the passenger flows is expected to enable a better dimensioning of resources.

IMHOTEP will also contribute to airports' environmental sustainability, especially regarding local air quality: considering that landside access accounts for around 50% of airport emissions (Community Observatory on Airport Capacity, 2013), the passenger shift from private car, taxi and Uber-like ride-hailing services towards more sustainable modes is crucial for improving local air quality; the technologies developed by IMHOTEP can contribute to this goal by increasing the attractiveness of collective public transport (e.g., through dynamic adjustment of public transport services based on the predicted passenger flows) as well as by enabling the development of innovative mobility services, such as on-demand ride-sharing systems.

The proposed research is in line with the "vision for the digital transformation of airports" put forward by ACI (Airport Council International, 2017). IMHOTEP will contribute to delivering a better experience to all passengers and customers, by adopting and implementing new technologies (e.g., new data analytics methods) and integrating them with existing ones (e.g., geolocation technologies). The project shares ACI's vision that processes such as collaborative decision-making is grounded on trusted, accurate, real-time information exchange". The proposed research involves several of the key enabling technologies identified in the ACI document, such as geolocation, Internet of Things (IoT), mobile applications and data analytics.

Finally, the project will also incorporate ACI's recommendations and best practices about the conditions and barriers for the effective adoption of new digital solutions from the initial stages of the research, in order to facilitate the future transition to industrial research and ultimately to deployment.

2.1.2 Airport Collaborative Decision-Making Solutions

Collaboration between stakeholders to improve performance is not a new concept in aviation. ICAO (2018) defines collaborative decision-making as an explicit supporting process focused on deciding on a course of action between two or more community members. Through this process, ATM stakeholders affected by a certain decision share information and agree on a decision-making

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approach with the aim of improving ATM performance, while balancing against their individual performance needs. The concept of A-CDM responds to this philosophy. A-CDM is primarily focused on aircraft turnaround and pre-departure sequencing and is based on 6 main elements: information sharing, a milestone approach, variable taxi time, pre-departure sequencing, adverse conditions, and collaborative management of flight updates. All necessary data, contextual information and KPIs are consolidated into the Airport Operations Plan (AOP), a common and collaboratively agreed rolling plan available to all airport stakeholders (EUROCONTROL, 2018a).

A-CDM has delivered a variety of benefits, including taxi-out time savings, fuel burnt savings, increased schedule adherence, reduction in push-back delays after start-up approval, increased ATFM slot adherence, improved ground handling resource utilisation, reduction in the number of late stand and gate changes, improved management of and recovery from adverse conditions, and improved take-off time predictability (EUROCONTROL, 2016).

The Airport CDM Implementation Manual (EUROCONTROL, 2017) was designed to facilitate the harmonised implementation of Airport CDM at European airports. The Implementation Manual guides the user through all the steps required for successful implementation and operation. Guidance is given from the time a management decision has been taken to organise an Airport CDM project through to implementation. The measurement of success and planning for operational use are included in the manual as a basis for analysis and evaluation after implementation.

2.1.3 SESAR Research beyond A-CDM

To further evolve A-CDM, SESAR has proposed the concept of Airport Operation Centre (APOC), which brings together different stakeholders in a physical or virtual room in order to monitor the alignment between planned and executed operations, with changes being made to the AOP as required. The goal is to advance towards the so-called Total Airport Management (TAM), which aims to provide closer integration of landside and airside processes by combining data-derived trends on meteorological conditions, flight prioritisation, runway traffic loads and aircraft turnaround times with data on baggage and passenger operations. However, airport landside access is still missing from the picture. In this context, several European research projects, such as the FP7 project META-CDM (www.meta-cdm.org/), have suggested that the extension of the TAM CDM process to encompass other transport modes would deliver a number of benefits for the passenger, for example in terms of disruption management (Marzuoli et al., 2014).

The ‘first’ PJ04 project kicked off at the end of 2016 and closed at the end of 2019. This SESAR 2020 IR Wave 1 project worked on two SESAR Solutions:

- PJ04-01 - Enhanced Collaborative Airport Performance Planning and Monitoring. This solution reached an E-OCVM ‘V3 ongoing’ maturity level, i.e., V2 maturity level was achieved during the project lifecycle and some V3 validation activities took place, but the project did not have the time and resources to perform all the activities required to achieve full V3 maturity. The most relevant deliverables associated to this solution are the V2 data pack and the V3 validation report (VALR). The data pack is publicly available on CORDIS. The VALR was not a contractual deliverable of the project.
- PJ04-02 - Enhanced Collaborative Airport Performance Management. This solution reached V2 maturity level.

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At the end of the project, the team recognised that the grouping of the operational improvement steps (the 'fundamental' elements describing the concepts covered by a solution in the ATM Master Plan) was not optimal. They suggested reorganising the whole TAM concept into six solutions. This, and the work performed in PJ04 as a whole, is explained and summarised in PJ04 final project report.

These six solutions are now under the responsibility of Wave 2 project PJ04-W2 that kicked off in December 2019 as a follow up of Wave 1 PJ04:

- PJ04-W2-28.1 – Regional network integrated airports. This solution is targeting V3 by mid-2023.
- PJ04-W2-28.2 – Regional Airport(s) Collaborative management. This solution is targeting 'V2 ongoing' by mid-2023.
- PJ04-W2-28.3 – Connected large airports. This solution is targeting V3 by mid-2023.
- PJ04-W2-29.1 – Airside/Landside performance management. This solution is targeting 'V3 ongoing' by mid-2023.
- PJ04-W2-29.2 has been split up into PJ.04-W2-29.2a 'Management of airport performance under MET conditions at very-large/large and medium-hub airports' and PJ.04-W2-29.2b 'Monitoring of airport performance under MET conditions at medium/small airports', both targeting V3 by mid-2023.
- PJ04-W2-29.3 – ENV performance management. This solution is targeting V2 by mid-2023.

2.2 Intermodality at airports

2.2.1 Introduction of the concept

The European Commission's 2011 White Paper on Transport (European Commission, 2011a) highlights intermodality as one of the pillars of the future European transport system. **Intermodality** can be defined as the coordinated use of more than one transport mode in one trip. When applied to passengers using air transport, the term intermodality is equally used for airport landside access and for the integration of air transport in the regional or national transport network (Rebello et al., 2005). In the case of airport landside access, intermodality refers to the integration of the airport with the access modes that connect the airport with its catchment area. Landside access is a crucial factor for attracting passengers (De Neufville and Odoni, 2013), it can account for a significant part of the total door-to-door travel time (García Albertos et al., 2017), and it is therefore a vital part of the competitive position of airports and airlines. Another reason to improve landside access is to increase the choice of residence for airport workers. Finally, landside access is also important from the point of view of environmental sustainability, as ground access modes account for a significant portion of airport-related emissions.

The planning of landside access must take into account the needs of different types of passengers, including the fact that transfer passengers require no landside access at all. In the case of the **integration of the airport in the regional or national network**, the focus in Europe is mostly on air-rail intermodality. In a context in which the lack of airport capacity is expected to lead to increasing levels of unaccommodated air transport demand, air-rail intermodality is seen as an opportunity to offer more options to the passengers, improve the connectivity between European cities and regions, and replace short-haul flights by rail services, releasing airport capacity that can be used for long-haul flights (EUROCONTROL, 2018b).

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The European transport policy includes a variety of measures aimed at facilitating intermodality, including financial support for multimodal infrastructure through the Connecting Europe Facility (CEF) programme, the development of a legislation to protect passenger rights in multimodal journeys, and the creation of framework conditions that promote the development and use of intelligent systems for interoperable and multimodal scheduling, information, online reservation systems and smart ticketing. Recent EU policy documents put an increasing emphasis on **digitalisation as a key enabler of intermodality** (European Commission, 2017, 2018), not only to develop multimodal travel information and ticketing, but also to put in place the so-called 'digital corridor information systems', which shall facilitate **information sharing and coordinated decision-making across all stakeholders along the transport chain**.

Air transport is, in practice, virtually impossible without intermodality. Even with technological advances in vertical take-off and landing capabilities, door-to-door will remain an elusive characteristic for the vast majority of air trips. Hence surface access and egress is a key challenge for airport planners and operators (De Neufville, 2013, p. 613). Indeed, airport accessibility plays a key role in airport catchment areas and in the competitive position of airports and airlines (Bao et al., 2016). Yet efforts to deliver infrastructure are not enough, as intermodality requires a conscious organisation to integrate and coordinate the different transport systems beyond the physical level, including operational (scheduling) and commercial (ticketing, marketing) integration (Community Observatory on airport capacity, 2013.

2.2.2 Latest trends in airport multimodal connectivity

In the European context, priorities at the strategic level are set out in the European Commission white papers on transport and have been evolving. The guiding principle of the 1992 policy document was opening-up the transport markets, which resulted in spectacular growth for aviation but proved difficult for railways. The 2001 paper focused on shifting the balance between transport modes, with a clear intention to favour rail transport, decrease dependency on road traffic and harmonise growth in air travel with environmental concerns. In a sense, the 2001 paper understood intermodality as favouring competition between modes and identified the overfragmentation of ATM systems as a source of inefficiencies that affect air travel competitiveness (European Commission, 2001).

The 2011 paper recognised important achievements, particularly in the implementation of high-speed rail (HSR) lines and the launch of the Single European Sky, as well as important limitations in developing a sustainable transport system. In fact, the challenge of reducing oil-dependency and increasing sustainability is more pressing than ever. Crucially, by explicitly stating that "curbing mobility is not an option", this white paper changed the focus towards co-modality and the need to use "the most efficient (combination of) modes" in "three major transport segments: medium distances, long distances and urban transport" (European Commission, 2011).

In the past decades, the airport access paradigm has progressively changed from the encouragement of the use of private car, based on building parking facilities and links with the main road system, to the integration of airports with the public transport system (Budd et al., 2016). More recently, the integration of airports with the high-speed rail (HSR) network has gained importance. In this context, HSR is seen as way of complementing air transport by absorbing part of the demand for short-haul flights, releasing airport capacity that can be used for long-haul flights (Givoni and Banister, 2006). Examples of this integration are the German AIRail service, born from the collaboration between Lufthansa, Fraport and Deustche Bahn, and the Air France-SNCF cooperation for guaranteeing air-rail connections in case of delays. A number of European projects, such as INTER-PASS

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(https://interpass.adrioninterreg.eu), have also addressed the improvement of the connectivity between ports and airports. However, despite all these efforts, taxi and private car still play a dominant role in airport access (DLR, 2010). Another relevant aspect of airport intermodality is the overhead in terms of travel times and **buffer times that access and egress legs add to air travel**. García-Albertos et al. (2016) explored the competition between air transport and HSR, showing the important role played by the accessibility to airports and HSR stations in the modal share of the Madrid-Barcelona corridor.

EUROCONTROL has developed an online tool to assess the connectivity between European regions (https://ext-test.eurocontrol.int/connectivity_web/from) and similar work has also been conducted by the H2020 project DATASET2050 (https://dataset2050.eu/), showing that the current European transport system is far from the Flightpath 2050 4-hour door-to-door target (European Commission, 2011). This was also the conclusion of García-Albertos et al. (2018), where door-to-door travel times for the passengers of the Spanish airport network were measured using anonymised mobile phone records.

In terms of information sharing with passengers, some airports provide onward travel facilities or information desks and monitors, usually located at arrivals or baggage reclaim halls. This, combined with wayfinding, aids passengers in making their decisions about the best alternative for surface egress. However, when ground services are too frequent, information about next departures can create anxiety for passengers.

In addition, airports have extensively used their websites as the point of contact with passengers to provide information about surface transport alternatives. Most recently, some airports have resorted to embed third-party applications within their websites to allow passengers to plan their journeys to or from the airport. Information available through such applications normally depends on the provision of local authorities or transport operators and may not be complete, particularly regarding public transport options; which leads to individual transport alternatives (private car, car hire, taxi and ride-hailing, for instance) being more prominently presented in many cases.

2.2.3 Key challenges and opportunities for modal integration with air transport

2.2.3.1 Intermodality and sustainable transport

Limiting the effects of climate change must be a priority (IPCC, 2007). Surface access and egress is responsible for 50% of the local impact at airports (Community Observatory on airport capacity, 2013, p. 17), thus intermodality provides an interesting opportunity to tackle sustainability in aviation by reducing the use of private vehicles and increasing the share of public-transport to and from airports.

In Europe, research on intermodality for aviation focuses on air-rail integration or substitution, particularly for HSR (Givoni & Banister, 2007; International Transport Forum, 2009). The degree of modal competition depends on the segments, as defined above, and the 2011 white paper aims for the majority of medium-distance passenger transport to go by rail by 2050. However, replacing flights with HSR services frees slots to accommodate more, usually long distance, flights. Moreover, rail connectivity is normally available at major hubs but secondary and regional airports with more point-to-point traffic rely more heavily on other modes for complementarity, highlighting opportunities for more research (de Neufville, 2006).

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Typically, one third of all access journeys to an airport are done by employees who are more reliant on private cars than passengers, which may be due to traveling at unsociable hours or working in parts of the airport away from passenger terminals (Budd, 2011). Accommodating the needs of airport staff may play a significant role in sustainable surface access development.

2.2.3.2 Effect of uncertainty for intermodal choices

In order to ensure efficient modal choices, transport networks need to improve integration, particularly at transfer nodes such as airports. Information systems and data availability and interoperability are crucial to facilitate multimodal travel, especially from the perspective of the passengers. The rise in mobility solutions provided by multiple operators hinders seamless coordination along the entire journey, and increases uncertainty about the distribution of responsibilities in disruptions. This affects the resilience provided by the transport systems and decreases the likelihood of passengers preferring intermodal alternatives.

The Community Observatory on Airport Capacity (2013) recommends accurate and timely communication with passengers, “including prompt information on delays and rerouting options of all modes”. This is something that current access to mobile devices and the data they generate facilitate but still needs to be implemented and tested at a large-scale, considering aspects like liability and differences in passenger rights, taxation and verification of travel across modes.

2.2.3.3 Airport capacity constraints

Ever increasing growth in aviation poses a significant strain on airport capacity, particularly at the largest hubs (Boosten, 2017), and schedule disruptions and delays result in operational bottlenecks and congestion at airports (Shed, 2016). However, there is also latent capacity in secondary and regional airports where surface access and egress are more limited by the lack of alternatives to private cars (Community Observatory on airport capacity, 2013). Indeed, EUROCONTROL (2013) identified the use of local alternatives (in terms of runway capacity) around major cities as the measure that is more likely to contribute to mitigating airport congestion. The second-best alternative is schedule smoothing, using quieter times at the airports. Both alternatives require a better understanding of challenges and opportunities for intermodality, as well as a solid integration between air traffic management and ground connectivity, with the ultimate aim of improving the quality, efficiency and resilience of the door-to-door passenger journey. Finally, through improved information sharing with passengers and local transport authorities, we can explore dynamic management practices and their effectiveness in reducing congestion for both airports and surface modes.

2.2.3.4 Response to the COVID-19 pandemic in 2020

As a result of the COVID-19 pandemic and new guidelines, airports were functioning at a reduced capacity. Passengers tended to carry more baggage, arrive earlier and, due to health questions, the check-in process took longer (EUROCONTROL, 2020). This called for ground handlers to react and adjust opening times based on demand which can benefit from improved information sharing with local transport authorities. As Europe emerges from the restrictions on travelling and air transport demand recovers, airports, ground handlers and airlines have suffered from a lack of human talent to undertake essential tasks. This has resulted in passengers being asked to arrive far longer in advance than normal to the airport, extended queues and extreme waiting times, as human resources limit the extent to which capacity may be utilised or strain resources given the large number of passengers arriving too early for their flights and the number of flights suffering severe delays or cancellations, to the extent that some major airports imposed artificial caps on capacity during summer 2022 to

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maintain acceptable levels of passenger experience. Perhaps more importantly for the IMHOTEP project, the extent of disruptions has affected surface transport providers too, albeit to a lesser degree. As a consequence, passengers have their entire door-to-door experience affected, which call for alternative means to communicate timely information about all steps in the process.

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3 Operational service and environment definition

3.1 Overview of IMHOTEP solution: extended A-CDM/TAM concept

The new IMHOTEP concept aims to enhance the current A-CDM and TAM concepts by changing the current vision of the air transport system, from a flight-centric approach to a passenger-centric view that goes beyond the airport to also integrate ground transport modes. In this context, the passenger becomes the main element of the whole transport network, which includes both the airport leg and the surface transport legs, enabling a more comprehensive understanding on the impact of different operational management measures on the passenger based on a holistic view of the door-to-gate and gate-to-door passenger flows.

Data from different sources are used to create a so-called Passenger Activity-Travel Diary, i.e., a sequence of activities and trip stages performed by each passenger, which becomes the backbone of the new system. This information will be made available, in real time, to the agents involved in the provision of services throughout the entire trip. The intention is to expand the capacities and efficiency of the system, in such a way that the collection, aggregation and management of passenger-centric information enables the dynamic adaptation of the different services and means of transportation taking into account the evolution of the different flows of passengers.

Additionally, this holistic view of the entire passenger journey, including the ground transport modes and the terminal processes, will enable the provision of updated information to the passenger for the entire trip, including recommendations in the case of incidents or disruptions both inside and outside the airport.

3.2 Detailed operational environment

3.2.1 Operational characteristics

The IMHOTEP CONOPs has been developed with the aim to extend A-CDM to ground transport stakeholders, including local transport authorities, traffic agencies, transport operators and mobility service providers.

The main characteristics of the IMHOTEP approach are the following:

- It considers airport passenger processes and the ground transport system in an integrated manner.
- It is focused on the passenger journey, considering different stages of the door-to-door trip depending on whether the passenger is departing, arriving or in connection:
    - For departing passengers: from the starting point of the trip to the flight take-off.
    - For arriving passengers: from landing until they reach their final destination.
    - For connection passengers: from the gate of the arriving flight to the gate of the departing flight.

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The new concept materialises in the Multimodal Collaborative Decision Making (MCDM) system. The MCDM system collects information on the status of the transport system provided by the involved stakeholders as well as personal mobile devices and digital sensors, and uses this information to feed predictive models that forecast the itinerary of these passengers during its journey.

By aggregating the information of all the passengers, it will be possible to optimise ground transport and airport operations based on real-time demand information. Additionally, the system will allow the passenger to obtain information on estimated times for each of the trip stages.

The system will also create alerts to inform stakeholders about incidents and disruptions, so that they can re-plan their operations and provide alternatives to the passenger to minimise the impact on the planned trip (different route alternatives, means of transport, itineraries within the terminal, etc.

3.2.2 Roles and responsibilities

The proposed concept requires the commitment of the different stakeholders participating in the new MCDM system to provide the required information. The stakeholders involved in the concept at this stage are:

- Airport Operators
- Ground Transport Operators and/or mobility service providers

The project has focused on the requirements, benefits and roles of the stakeholders involved in the project (Airport and Ground Transport operators). However, as explained in further sections, the concept may also bring performance benefits to other stakeholders such as AUs and ANSPs. Additionally, the concept may benefit from the inclusion of these stakeholders in the process, due to the additional information these stakeholders may provide.

Finally, it is worth noting that, in the case of implementation in an A-CDM airport, the stakeholders already involved in the A-CDM solution (Aircraft Operators/Ground Handlers, ANSPs, NM and other services providers) will also be involved in the MCDM system

3.2.3 Applicable standards and regulations

The IMHOTEP CONOPs is based on the extension of the current A-CDM concept. As such, standards and regulations that are applicable to the A-CDM Concept are also applicable to this CONOPs. There is currently no implementing rule for A-CDM (yet), but there is a European Standard (ETSI EN 303 212) “Airport Collaborative Decision Making (A-CDM); Community Specification for application under the Single European Sky Interoperability Regulation EC 552/2004”. In addition, several EUROCAE documents (European Standards) have been developed to ensure interoperability between technical system enablers:

- ED-141 System Requirements Document
- ED-145 Interface Definition Document
- ED-146 Test and Validation Document

The identification of needs for new standards may start at V2 level of maturity of the IMHOTEP Solution. It must be highlighted that the feasibility assessment of the proposed CONOPs shall address “the impact of multimodal pax rights” and “personal data security”. The latter includes aspects such as data anonymisation in order to comply with the General Data Protection Regulation (GDPR).

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3.3 Detailed operating method

3.3.1 Previous operating method

ICAO (2018) defines collaborative decision-making as an explicit supporting process focused on deciding on a course of action between two or more community members. Through this process, ATM stakeholders affected by a certain decision share information and agree on a decision-making approach with the aim of improving ATM performance, while balancing against their individual performance needs. The concept of A-CDM responds to this philosophy. A-CDM is enhancing the efficiency of airport operations thanks to information sharing and common situational awareness between airports, airspace users (AUs), ground handlers and air navigation service providers (ANSPs). The concept has so far focused on aircraft turnaround and pre-departure sequencing, and is based on 6 main elements: information sharing, a milestone approach, variable taxi time, pre-departure sequencing, adverse conditions, and collaborative management of flight updates. All necessary data, contextual information and KPIs are consolidated into the Airport Operations Plan (AOP), a common and collaboratively agreed rolling plan available to all airport stakeholders (EUROCONTROL, 2018a). A-CDM has delivered a variety of benefits, including taxi-out time savings, fuel burnt savings, increased schedule adherence, reduction in push-back delays after start-up approval, increased ATFM slot adherence, improved ground handling resource utilisation, reduction in the number of late stand and gate changes, improved management of and recovery from adverse conditions, and improved take-off time predictability (EUROCONTROL, 2016).

Building on A-CDM, SESAR developed the concept of Airport Operation Centre (APOC) as a physical or virtual room where relevant stakeholders can change the AOP if a misalignment between planned and executed operations is found. Ultimately, this will contribute to the development of Total Airport Management (TAM) as a means to better integrate landside and airside processes by combining data-derived trends on meteorological conditions, flight prioritisation, runway traffic loads and aircraft turnaround times with data on baggage and passenger operations. TAM is a more holistic concept that foresees closer integration of landside and airside processes, but the passenger access and egress legs are still absent from the picture and that is where the IMHOTEP CONOPs will add value.

3.3.2 New IMHOTEP operating method : Multimodal Collaborative Decision Making

The inclusion of ground transport into the TAM collaborative decision-making process has been suggested as a future extension that could enable a better integration between the airport and the ground transport system, especially in situations of disruptions. A key enabler for this enhanced integration is the development of information platforms and services that provide airports and ground transport stakeholders with a common and comprehensive picture of the passenger flows. In recent years, the pervasive use of personal mobile devices has opened new opportunities for the collection of high-resolution passenger trajectory data with an unprecedented level of accuracy. These data can in turn be blended with the information available from different stakeholders (e.g., flight departure and arrival information, schedules and travel times of ground access modes, terminal processing times, etc.) not only to monitor passenger flows in real-time, but also to build short-term predictive models and develop look-ahead strategies. This shared, permanently updated picture of the actual and future status of passenger flows would facilitate coordination between transport modes, as well as the development of passenger information services for the planning and reconfiguration of the door-to-

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gate and gate-to-door journey, enhancing the passenger experience and rendering the transport system more resilient against disruptive events.

The new MCDM concept aims to seize these opportunities by developing a set of enabling technologies able to provide a holistic view of the airport processes, the ground transport system and the passenger flows, with the ultimate purpose of improving the quality, efficiency and resilience of the door-to-gate and gate-to-door passenger journey. The implementation of mechanisms for collaborative decision-making between airports and ground transport modes requires a common understanding on the impact of operational decisions on the passenger. This naturally leads to the need for a passenger-centric view, where the passenger journey becomes the backbone of a common and comprehensive situational awareness of the status of the airport processes, the ground transport system and the passenger flows. Such common situational awareness would not only enable a more efficient management of the different transportation modes, but also the timely provision of relevant information to the passengers, empowering them to plan and reconfigure their journey in real time (e.g., to manage disruptions).

This extension of the A-CDM concept must be coordinated with current research towards the implementation of TAM (PJ04-W2), in particular Solution 29-1 - Airside/Landside Performance Management (PJ04-W2-29.1). The new operating method proposed in IMHOTEP provides the mechanisms that enable information sharing between the airport and ground transport stakeholders. Sharing this information automatically in real-time contributes to identifying potential issues related to surface access that may eventually lead to a degradation in airport services or affect the punctuality of landside and airside operations.

Airside and landside processes in an airport have traditionally been managed in isolation, but in fact, there is significant degree of coupling between both of them, with the performance of one process having the potential to significantly impact the other. Solution 29.1 focuses on this issue and aims to enhance information sharing and collaborative decision making between the airside and the landside processes in an airport by means of a dashboard containing key performance indicators, decision support tools and enhanced predictions. The concept and tools envisioned in IMHOTEP could be seen as a potential expansion of this Solution, aimed at extending even more the scope of the CDM process by including, not only terminal landside processes, but also the surface access and egress legs of passengers by involving ground transport stakeholders in the process

3.3.3 Differences between new and previous operating methods

The main differences between the current and the proposed operating methods are the following:

- **The inclusion of ground transport stakeholders into the airport collaborative decision-making processes**. The A-CDM concept focuses mainly on the airside, mostly on the turnround and pre-departure sequencing. TAM is a more holistic concept which includes a set of processes from landside, such as certain passenger processes and baggage processes. However, the access and egress legs are left out of the concept, despite of being an important part of the passenger journey. The proposed concept aims to fill this gap by including the ground transport system into the collaborative decision-making processes.
- **The passenger-centric view**. Currently, both the A-CDM and TAM concepts are more focused on airport processes than on the passenger itself, which can lead to an incomplete understanding of the impact that operational decisions have on the passenger. The proposed approach aims to change this vision by developing a passenger-centric view where the passenger journey

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becomes the main pillar of a common and comprehensive situational awareness of the status of the airport processes, the ground transport system and the door-to-gate and gate-to-door passenger flows.

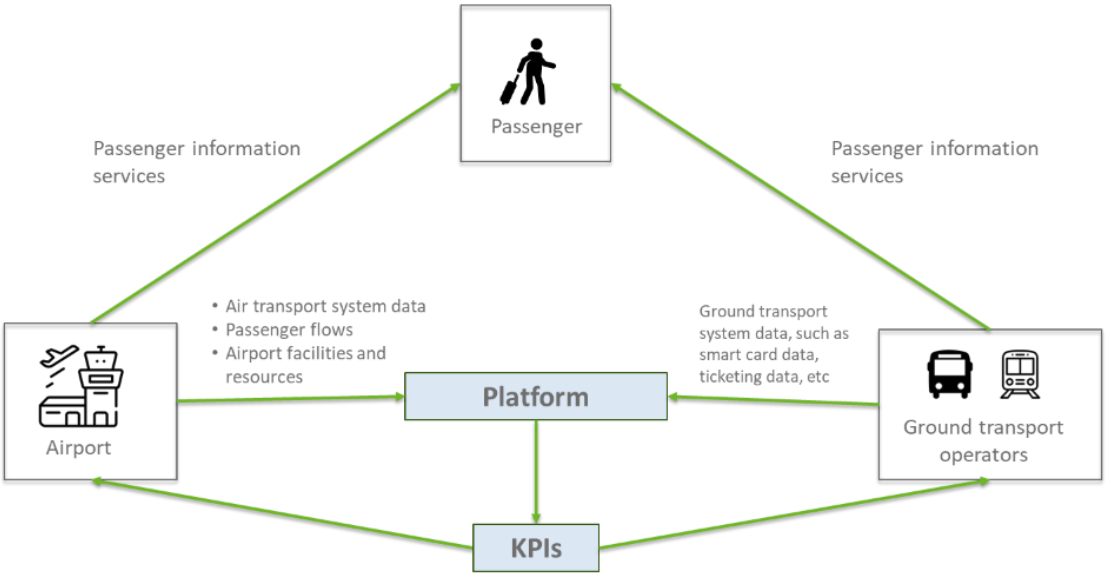

Figure 1. Proposed system

Figure 1 illustrates the relation and the different flows of information between the main stakeholders of the proposed concept. Airport stakeholders and ground transport operators will feed the platform with information and, in exchange, they will receive different KPIs assessing the status of the complete transport system (including both the airport terminal and the surface legs), allowing them to better manage its resources as well as to provide information to the passenger about their trip aimed at enhancing the passenger experience.

Differences between the IMHOTEP concept implementation in airports with and without TAM must be taken into account. As it has been mentioned, both IMHOTEP and TAM concepts are being developed in parallel. IMHOTEP will encompass the extension of the airport collaborative decision-making processes from the airside to the landside, including the ground transport modes for the passengers' access and egress. The IMHOTEP system has been developed under the premise that the system could be applied at any airport, regardless of the level of CDM of the airport. Therefore, it has been envisioned as a completely independent platform that may be connected to existing platforms already in place at the implementation airport (e.g., ACISP in case of CDM airports or the APOC in case of airports with TAM implemented)

For CDM airports or airports with TAM implemented, the IMHOTEP solution will enrich the management and information exchange regarding the ground transport stakeholders, shedding light on the passenger access and egress modes. If the TAM solution is in place at the implementation airport, the IMHOTEP platform will be connected to the APOC so both can mutually exchange information therefore providing a comprehensive view of the whole passenger journey; in case the implementation airport is a CDM airport, the IMHOTEP platform will be connected to the ACISP, so similarly both platforms can exchange information.

Apart from airports with TAM implemented and CDM airports, there are many airports which have opted for not developing the full CDM solution as the investment required for its implementation was

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not worthy due to the airport size or level of congestion. Therefore, many airports have chosen to develop a lighter solution of the CDM solution, such as the so-called 'Regional airports'. In these cases, the IMHOTEP solution should be adapted to the pre-existing platforms (if any) already in place at the deployment airport.

3.3.4 Applicability of the new operating method

3.3.4.1 Operational impact

Before describing the technical aspects of the potential solution, it is adequate to introduce the applicability of the new operating method and explain how it would improve decision-making between airports and ground transport modes, allowing a more efficient passenger flow management.

Under the IMHOTEP concept, the idea of flight optimisation is extended to the complete passenger journey and the efficiency of all stages that participate in the complete journey is sought after. The systems that are feeding information during the complete journey cease to be only airports and include ground transport systems and information systems of passenger flows.

This new proposed concept will bring benefits for the complete transport system (including both the airport and the ground transport system), allowing the implementation of valuable solutions not available at this moment for airports, such as:

- **Personalisation of the passengers' door-to-gate and gate-to-door journey** depending on the passengers' profile. Different types of passengers present different types of travel behaviours: for example, a business traveller will usually travel with less/no baggage and may use different types of transport modes for access/egress the airport than a leisure passenger. Gaining insights on passengers' profile and behaviour would constitute a big advantage to the airport, helping take into account aspects such as the passengers' origin and final destination or passengers' sociodemographic profile.
- **Predictive data analytics for collaborative decision making**. A better knowledge on passengers' profile and behavioural patterns, along with better situational awareness and information sharing between the airport and the ground transport operators, will allow, through the use of different predictive tools, to forecast passenger behaviour. This will provide the involved stakeholders with the possibility of anticipating adverse situations and collaboratively deciding on the best course of action.
- **Development of an integrated information system to provide information to the passengers**. The forecast on the transport system status may be made available to the passenger (e.g., information about the airport or ground transport system status so the passenger can decide whether to delay or anticipate its journey to the airport) as well as different aspects of their journey (e.g., available choices to access/egress the airport, schedules, waiting times, etc.).
- **Enable off-airport activities**. Additionally, IMHOTEP predictive models will allow the simulation of different situations and the evaluation of the benefits brought by the implementation of different off-airport activities, such as bag-free travelling or remote check-in. This will entail significant advantages for both airport operators and ground transport stakeholders. In order to better illustrate the benefits provided for the new system and to better understand its impact on airport operations, a set of different use cases have been defined.

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- **Management of flight disruptions**. The new proposed concept will provide both airport and ground transport operators with the possibility to foresee possible adverse situations in the air transport system and minimise the impact on their operations. For example, if one or more arriving flights are delayed, this information will be used by the airport operator to adapt its resources to deal with those passengers arriving late (e.g., more personal resources on baggage claims) and by the ground transport operator to preventive actions (e.g., increase frequencies or, if the delay makes the passengers arrive outside the working hours, to extend them in order to accommodate the incoming passengers). Similarly, in the case of delayed departing flights, the airport operator will need to manage its resources in advance to avoid capacity problems within the airport terminal; additionally, it would be possible to develop an app that warns passengers beforehand in order to recommend them to delay their arrival to the airport. In case, extra staff is required it will be discussed in due course with regional and/or local unions when applicable.
- **Management of surface disruptions**. The proposed concept will provide both airport and ground transport operators with the possibility to foresee possible adverse situations in the ground transport system (e.g., major road/rail incidents affecting a significant proportion of passengers travelling to the airport; surface public transport alternatives forced to close or run a significantly reduced timetable, for instance due to failures or strikes) and minimise the impact on their operations. For example, if departing passengers are arriving late to the airport due to surface disruptions, the airport will have this information in advance and can manage the situation in order to assure that the passengers arrive to their flight on time, for example by increasing human resources on the airport terminal and guiding passengers to the security control or check-in desks, or by increasing human resources in the security control.
- **Optimised normal operation**. The proposed concept is not just applicable in the case of disruptions, but it is also useful in case of normal operation. By providing the airport and ground transport operators with a shared, integrated picture of the whole transport system, they will be able to plan their resources in advance and better adapt to upcoming situation (e.g., set public transport frequencies, determine required human resources, etc.).
- **Management of special events** that may affect the operation of the complete transport system.

From these identified use cases, some have been selected in order to evaluate the proposed concept. The results obtained show that the coordination between the airport and the ground transport modes entails various benefits for the involved stakeholders as well as for the passengers, including:

- **Shortening of passenger waiting times** in both the access and egress legs (waiting time for the public transport and reduction of surface network congestion) and the airport terminal (waiting time at the different airport facilities such as security control or passport control) and overall **travel times** for passengers, which would translate into an enhancement of the passenger experience.
- **Reduction in the number of flights missed** by passengers due to potential airport and access disruptions, which is directly translated into a better passenger experience.
- **Reduction of the congestion** on the access and egress from the airport, which not only leads to an improvement of the passenger experience, but also to the **reduction of the CO_2** emissions, thus improving the airport environmental footprint.
- **Better predictability** of the passenger flows and the overall transport network performance, which gives the involved stakeholders the possibility to better allocate their resources (human

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resources in the case of airport operators, and vehicle fleet in the case of ground transport operators). This is in turn translated into a potential improvement of the **Operational Efficiency**, a reduction of costs (**Cost-Efficiency**), an increase of **Capacity** and, ultimately, an improvement of the service provided to the passengers.

Further information about this can be found in deliverable D7.1 Demonstration and evaluation of IMHOTEP ConOps and decision support tools. A deeper analysis of the benefits brought to the stakeholders involved in the process is included in Appendix A.

The concept may also bring relevant benefits to other ATM stakeholders (i.e., ANSPs, ground handlers, AUs, NM) due to the improved information sharing and higher predictability of the passenger flows, which will allow them to optimise their resources and infrastructure (e.g., AUs may decide to slightly delay a flight if a high number of passengers is going to miss it due to a disruption in the airport access). However, assessing the operational impact of the proposed concept is not straightforward, as the current approach to collaborative decision-making in the ATM ecosystem is centred around airside operations, while the proposed concept is passenger-centric. One of the drawbacks of the current approach is the lack of multimodal and passenger KPIs available in the current Performance Framework, which is based on a flight-centric vision. One of the conclusions of the different meetings and workshops conducted by IMHOTEP is the need to define multimodal and passenger-centric KPIs able to capture relevant aspects of the complete door-to-gate and gate-to-door passenger journey which are not captured by the current Performance Framework.

3.3.4.2 Application to A-CDM and non-CDM airports

As explained in Section 3.3, the proposed system has been envisioned as an independent platform with the objective of allowing its implementation in airports with different levels of automation, including:

- Airports with TAM implemented
- A-CDM with different levels of implementation (such as regional airports or full A-CDM implementation)
- Non-CDM airports with different levels of automation.

The application of the concept in airports with TAM implemented or A-CDM airports will entail benefits for the proposed system as it will allow feeding real-time flight information (crucially, EOBT, as it determines whether a departing flight will be delayed or not, along with the corresponding information from ATFM for arriving flights), as opposed to more “fixed” schedules. The evaluation of the concept of operations performed in the study airports comprised a CDM airport (PMI) and a non-CDM airport (LCY). In both cases the implementation of the proposed concept led to important benefits for both the involved stakeholders and the passengers, thus demonstrating the applicability of the proposed concept in both A-CDM and non-CDM airports.

The already existing systems in the airport of implementation will differ from an A-CDM airport or a TAM implemented airport, which will have an ACISP or APOC already in place in the airport, respectively, to a non-CDM airport. Therefore, the system integration and the interoperability between the proposed system and the systems already in place in the implementation airport will significantly differ from one to another (see Section 6.1). These differences should be further studied in future development stages when the real application of the concept to a real airport environment will be researched. However, the functionalities of the solution will not differ between different implementations: the only internal different between those will be the quality and accuracy of the data

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that is feed to the MCDM system. The concept is expected to provide better performance in A-CDM or TAM airports as the data fed will represent the most up-to-date information on the status of the air transport system.

It is worth noting that, at the current stage, the focus has been set on the assessment of the potential benefits that the IMHOTEP Solution can bring to stakeholders and passengers. The real implementation of the proposed system in an airport is out of the scope and should be researched in further stages of the development of the concept.

3.3.4.3 The use of sensitive data

The project has proven that it is possible to combine different data sources to gain a better picture of the door-to-gate and gate-to-door passenger journey without the need for any stakeholder to actively provide sensitive information, by developing algorithms that turn anonymised mobile phone records and other anonymous data into aggregated information that enables passenger characterisation with regards to surface transport mode and other attributes (e.g., trip purpose). This, along with other information that is already available (such as boarding card readers used throughout the airport terminal processes) provides a level of detail that goes beyond current possibilities.

At this stage of the concept development, all the data used is anonymous and follows the data processing principles defined by GDPR EU regulation; in further stages of the development of the concept, as new potential datasets become available and new stakeholders become involved, methods must be put in place in order to assure that the data processing methodologies and processes follow the existing rules and regulations regarding privacy and personal data protection.

3.4 The Passenger Activity-Travel Diary

The backbone of the concept is the common view of real-time passenger flows and their short-term evolution, considering every passenger who uses the airport during a day. Passenger flows are represented in a disaggregated manner, through the concept of **Passenger Activity-Travel Diary**. A Passenger Activity-Travel Diary is composed by the sequence of activities and trip stages performed by the passenger. Each activity or stage of the journey will have a start time, a start location, an end time, an end location, and a set of additional attributes selected from a list of pre-defined options for each type of activity or stage (e.g., the activity prior to the trip of a departing passenger or the subsequent activity to the trip of an arriving passenger will have a an attribute called ‘activity type’ that may take different possible values: ‘home’, ‘work’, ‘leisure’, etc.; the access and egress legs will have an attribute called ‘transport mode’ that may take the values ‘rail’, ‘metro’, ‘bus’, ‘private car’, ‘taxi’, etc.).

The construction of the Passenger Activity-Travel Diaries is based on two main pillars:

i. **Data integration, analysis and fusion**. Input data will comprise three main types of data sources: passenger-centric data sources able to provide information on the passenger trajectory (e.g., data from personal mobile devices); data on the airport systems and processes (e.g., airport layout, flight schedules, gate allocation); and data on the landside access network available from ground transport stakeholders (e.g., public transport schedules, traffic counts).
ii. **Modelling and forecasting**. Different types of predictive models will be integrated to reproduce and forecast the passenger itinerary both inside the airport and during the access and egress legs.

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For each passenger using the airport, an individual Passenger Activity-Travel Diary will be created at the beginning of the day using a combination of operational data (e.g., flight schedules) and historical data (e.g., behavioural patterns of different types of passengers). This Passenger Activity-Travel Diary will then be successively updated using real time information provided by the involved stakeholders as it becomes available. The Passenger Activity-Travel Diary information will be made available to different stakeholders through a set of web services and an interactive dashboard, which will allow users to filter, visualise and extract the information of their interest to support decision-making (e.g., an airport may allocate more or less resources to one particular terminal process, an airline may decide whether to wait or not for certain passengers, a taxi company may decide to send more or less taxis to the airport, etc.) and/or to develop passenger information systems that provide passengers with relevant information and recommendations about their trip.

3.4.1 Processes and events for each door-to-door travel type

The figure below represents the scheme of a generic Passenger Activity-Travel Diary, showing the segments of the door-to-door journey we are interested in for departing passengers, arriving passengers and connecting passengers.

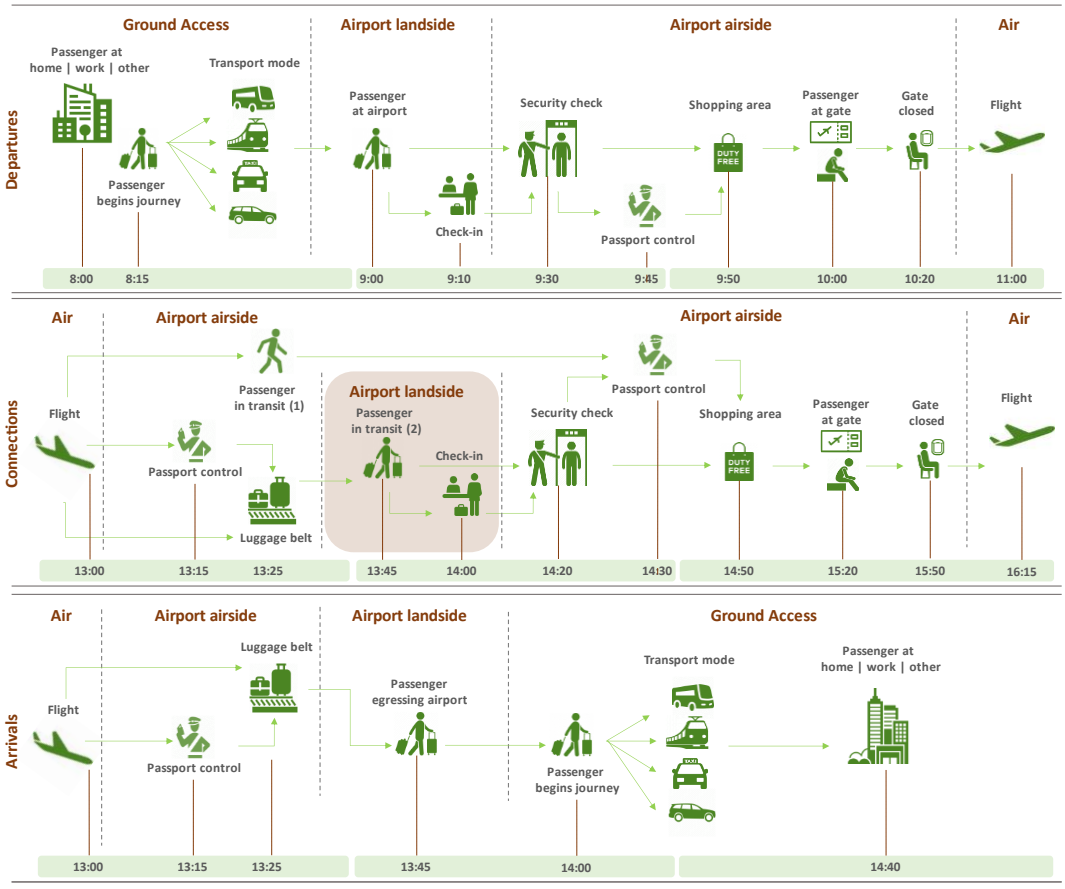

Figure 2. Passenger Activity-Travel Diary

The information that will be collected in each of these trip segments and the stakeholders involved are identified in the following sections.

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3.4.2 Information sharing for access and egress processes

Table 2 shows the main sources of information available on the access and egress legs, together with the stakeholders that could be in a position to provide the data and the main technologies available to collect such data, as well as the main disruptions that cause deviations from normal operations and should trigger an alarm signal. The subset of data used to build the Passenger Travel Diaries will depend on the airport context and the specific implementation of the MCDM concept.

Table 2. Summary of information sources for access and egress processes

Transport mode	Data	Data providers	Data sources	Disruptions/Alarms
Walk	- Pedestrian flows	- Airport operator	- Cameras - Counters	-
Bicycle	- Bicycle flows - Parking locations - Parked bicycles - Rented bicycles	- Bicycle companies - Parking companies - Traffic agencies	- Bicycle counters - Bicycle management system - Parking sensors	-
Private car	- Traffic flows - Occupancy rates - Tolls - Parking occupancy	- Traffic agencies - Parking companies - Users	- Traffic counts - Cameras - Parking sensors - Navigation apps	- Traffic jams - Accidents - Roadworks
Bus	- Bus frequency - Occupancy rate - Luggage	- Bus operators	- Bus management systems - Passenger counters - Bus positioning system - PT payment systems - MaaS apps[1]	- Traffic jams - Accidents - Roadworks - Service breakdowns - Bus capacity exceeded by demand
Taxi	- Taxi traffic flows - Taxi lane status - Number of passengers	- Taxi companies - Users	- Taxi management systems - Taxi GPSs - Taxi apps - MaaS apps[1]	- Lack of taxis - Outnumbered taxi lane - Traffic jams - Accidents - Roadworks
Rail	- Rail frequency - Occupancy rates - Luggage	- Rail operators - Users	- Rail management systems - Passenger counters - Rail positioning system - PT payment systems - MaaS apps[1]	- Accidents - Service breakdowns - Rail capacity exceeded by demand
Metro	- Metro frequency - Occupancy rates - Luggage	- Metro operators - Users	- Metro management systems - Passenger counters - Metro positioning system - PT payment systems - MaaS apps[1]	- Accidents - Service breakdowns - Metro capacity exceeded by demand
Ferry	- Ferry frequency - Occupancy rates - Luggage	- Ferry operators - Users	- Ferry management systems - Passenger counters - Ferry positioning system - PT payment systems - MaaS apps[1]	- Accidents - Service breakdowns - Ferry capacity exceeded by demand

[1] MaaS apps: Mobility as a Service is a type of service that, through a joint digital channel, enables users to plan, book, and pay for multiple types of mobility services (e.g., EMT apps, Moovit, etc.).

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3.4.3 Information sharing for landside/airside terminal processes

Table 3 shows the main sources of information available on the terminal processes, together with the stakeholders that could be in a position to provide the data and the main technologies available to collect such data, as well as the main disruptions that cause deviations from normal operations and should trigger an alarm signal. The subset of data used to build the Passenger Travel Diaries will depend on the airport context and the specific implementation of the MCDM concept.

Table 3. Summary of information sources for terminal processes

Data		Data providers	Data sources	Disruptions/Alarms
DEPARTURES				
Airport Landside	Passengers at airport: number and location	- Airport operator	- Cameras - Counters	- High occupancy rates
	Check-in: number of passengers, location	- Airlines	- Camera - Counters - Airline information systems	- Insufficient number of checked people by flight
Airport Airside	- Security control: number of passengers, location	- Airport operator - Security services	- Cameras - Counters	- Long queues
	- Passport control: number of passengers, location	- National Police	- Cameras - Counters	- Long queues
	- Shopping area: number of passengers, location	- Airport operator	- Cameras - Counters	- High occupancy rates
	- Passengers at gate: number of passengers, location	- Airlines	- Cameras - Counters	- Events related with boarding processes
	- Gate status (open, closed)	- Airport operator	- Airport information systems	-
Air	- Flights: status, number of passengers	- Airport operator - Airlines	- Airport information systems - Airline information systems	- Delayed flights
CONNECTIONS				
Air	- Flights: status, number of passengers	- Airport operator - Airlines	- Airport information systems - Airline information systems	Delayed flights
Airport Airside	- Passport control: number of passengers, location	- National Police	- Cameras - Counters	- Long queues
	- Shopping area: number of passengers, location	- Airport operator	- Direct connection Airport-MCDM - Counter cameras	- Occupancy rates
	- Luggage belt: number of bags, location	- Airport Operator - Handling Services - Customs agents	- Cameras - Counters - Airline information systems	- Bags not picked up
	- Security control: number of passengers, location	- Airport Operator - Security services	- Cameras - Counters	- Long queues
	- Shopping area: number of passengers, location	- Airport Operator	- Cameras - Counters	- High occupancy rates
	- Passengers at gate: number of passengers, location	- Airlines	- Cameras - Counters	- Events related with boarding processes

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Data		Data providers	Data sources	Disruptions/Alarms
	- Gate status (open, closed)	- Airport Operator	- Airport information systems	-
Airport Landside	- Passengers in transit: number and location	- Airport Operator - Security Services	- Cameras - Counters	- Bags not picked up - Belt fault - Transportation fault
	- Check-in: number of passengers, location	- Airlines	- Camera - Counters - Airline information systems	- Insufficient number of checked people by flight
ARRIVALS				
Air	- Flights: status, number of passengers, connecting passengers	- Airport Operator - Airlines	- Airport information systems - Airline information systems	- Delayed flights
Airport Airside	- Passport control: number of passengers, location	- National Police	- Direct connection Airport-MCDM - Counter cameras	- Long queues
	- Luggage belt: number of bags, location	- Airport Operator - Handling Services - Customs agents	- Cameras - Counters - Airline information systems	- Bags not picked up
Airport Landside	- Passengers egressing airport: number and location	- Airport Operator	- Cameras - Counters	- High occupancy rates

3.4.4 Integration with current A-CDM

Classic A-CDM focuses on the pre-departure sequence of a flight and seeks to optimise the resources, systems and services of the airport.

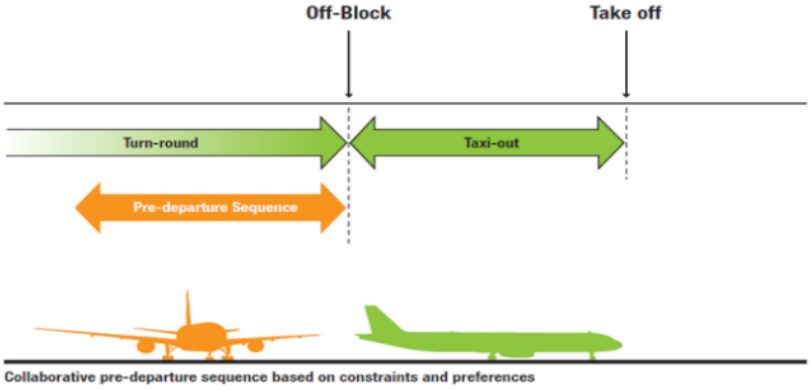

Figure 3. A-CDM stages (Airport CDM Implementation Manual. EUROCONTROL, 2017)

The IMHOTEP CONOPs aims at extending the A-CDM concept to include airport access and egress modes. However, terminal processes still represent an essential part of the concept. In airports in which the CDM concept has been already implemented, the data from the Airport CDM Information Sharing Platform (ACISP) will serve as inputs for the MCDM system, and the data and alarms that the different stakeholders of the MCDM system supply will be inputs to the ACISP.

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Table 4. Summary of the information in a classic A-CDM implementation

CONCEPT Milestone	Stakeholders info providers	Objective	Data shared	OUTPUTS	Mean
ACDM INFORMATION SHARING	**Aircraft Operator** **Ground Handler** **Airport** **Network operations** **Air Traffic Control** **Other service providers**	Airline's schedule Planning information Flight progress information Prediction messages Status messages Operational planning information	_**Aircraft Operator/Handling Agent**:planning data, turn-round times,flight plans,movement data,priority of flights, aircraft registration and type change, TOBT, movement messages _**Air Traffic Control**: ELDT,ALDT, TSAT,TTOT,runway and taxiway conditions,taxi times,SID allocation, runway capacity, A-SMGCS data/radar information. _**Network Operations** _**Service providers:** de icing companies, MET office (forecast&actual met info), and others (fire, police, customs, fuel,etc...) _**Airport Operations:** stand and gate allocation, environmental information, special events, reduction in capacity, airport slot data, ADES,SOBT	Advisories Alerts maintenance of environmental information (aeronautical and meteorological) data recording and archiving	The Airport CDM Platform receives most of its information automatically from the partners' databases. However, certain manual inputs are required to be set locally on the airport, or even individually per person. These include: _System management _Individual display settings _Response to alerts _Change of default values _Change of arrival or departure sequence _Changes to airport configuration and runway capacity
(16) MILESTONES : SEE UNIT	**Aircraft Operator** **Ground Handler** **Airport** **Network operations** **Air Traffic Control** **Other service providers**	The Milestone Approach aims to have an early and accurate prediction by the Aircraft Operator, in order for Air Traffic Control, Airport Operator, and Ground Handlers o anticipate for resources or traffic planning purposes	1 ATC Flight Plan activation 2 EOBT-2hr 3 Take off from outstation 4 Local radar update 5 Final approach 6 Landing 7 In-block 8 Ground handling starts 9 TOBT update prior to TSAT 10 TSAT issue 11 Boarding starts 12 Aircraft ready 13 Start up request 14 Start up approved 15 Off-block 16 Take off	With prediction of TOBT in place, improved prediction of target take off times, start up times, and taxi time will become possible.	The progress of a flight is tracked in the Airport CDM Platform by a continuous sequence of **different events, known as milestones, and rules for updating downstream information** and the target accuracy of the estimates are defined. Different Airport CDM Partners can be responsible for different milestones, with the aim of integrating all of the milestones into a common seamless process for the flight.
VARIABLE TAXI TIME	**Aircraft Operator** **Air Traffic Control** **Airport** **Other service providers**	At complex airports the layout of runways and parking stands can result in a large difference in taxi time. Instead of using a standard default value, a calculation of the different permutations based upon historic data, operational experience and/or an integrated tool will provide a set of more realistic individual taxi times.	_Airport layout and infraestructure _Runway(s)in use (including the distance of the taxi holding positions from the runway) _Number of runway crossings required _Aircraft parking stand location _Meteorological conditions _Aircraft type and operator _Aircraft weight _Push back approval delivery time _Remote de-icing/anti-icing _Traffic density _Local operating procedures	Knowledge of realistic taxi times under changing conditions: _Enables ATC to optimise the push back, taxi and take off sequence and hence reduce queuing and taxiway congestion _Improves CTOT compliance	In order to keep track of the traffic situation taxi time parameters can be adjusted in order to hold or release aircraft at / from the stand, with the purpose to regulate traffic based on actual events. **Surveillance data from radar or routing information from Advanced SMGCS, clearance input from controllers, or manual controller correction of taxi time values are all means** to modify the taxi time estimates into more realistic values

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PRE-DEPARTURE SEQUENCING	**Aircraft Operator** **Ground Handler** **Airport** **Other service providers** **Network operations** **Air Traffic Control**	The main objectives of Pre-departure Sequencing are: _Enhance sequence transparency _Improve event predictability by creating TSAT and TTOT predictability _Improve punctuality (e.g. slot adherence, Airline Operator schedule)	Key parameters sent via ACISP are TOBT and preferences from one airline to prioritise (e.g. flight X before flight Y), and TSAT as output from ATC to all partners. The local implementation will determine the method how such information is made known to ATC.	Pre-departure sequencing allows ATC to handle the Target Off-Block Times (TOBTs) obtained from the turn-round process in a way that flights can depart from their stands in a more efficient and optimal order. Based on aircraft progress by using the TOBT, as well as the operational traffic situation on the aprons, taxiways and near runways, ATC can provide a TSAT which places each aircraft in an efficient predeparture sequence (off-blocks).	ACISP (Airport CDM Information Sharing Platform)
ADVERSE CONDITIONS	**Aircraft Operator** **Ground Handler** **Airport** **Other service providers** **Network operations** **Air Traffic Control** **Airport CDM Coordinator** **Airport CDM Cell**	_Prepare an adverse conditions or crisis plan of procedures and actions _Make sure the procedures are simple and are the same as those used in normal operations, where possible _Ensure that all partners, at all levels, are familiar with the procedures _Appoint an Airport CDM Coordinator who will be responsible for coordinating the activities	**_Need for de-icing** – The need for de-icing is predicted, together with the level of de-icing to be performed. The impact on capacity is determined and the resulting information has to be shared among the Airport CDM Partners. **_Construction and maintenance works** – Planned works of this kind may or may not have an impact on capacity. If they do, the impact is evaluated and the resulting information must be shared between the Airport CDM Partners. **_Technical resource availability** – Every airport needs a minimum set of technical resources to achieve its nominal capacity. The actual and future availability of those resources is monitored and if their availability changes, the impact on capacity is evaluated. The resulting information must be	There are adverse conditions which can be foreseen with more or less accuracy and both their scope and likely effects are predictable.The output of this element is almost exclusively alerts and warnings.The effects of the above and other predictable adverse conditions can be allocated different “alert levels”, while the alert levels in turn have associated procedures and other provisions, as necessary	Setting up a CDM Cell, managed by the CDM Coordinator, is also highly recommended .Airport CDM Cell managed by Airport Coordinator is the focus of activity during adverso conditions.
COLLABORATIVE MANAGEMENT OF FLIGHT UPDATES	**Aircraft Operator** **Ground Handler** **Airport** **Other service providers** **Network operations** **Air Traffic Control** **Airport CDM Coordinator** **Airport CDM Cell** **ATFCM**	Collaborative Management of Flight Updates is the Airport CDM contribution to ATFCM _It ensures the completeness of information between en route and airport operations _It improves predictability of ground operations through enhanced initial information about inbound flights _It improves estimates of take off times, allowing a more accurate and more predictable view of the traffic situation, resulting in improved ATFM slot allocation.	_In Collaborative Management of Flight Updates the exchange of information between the Network Operations and the airport is realised by: _Sending Departure Planning Information Messages (DPI) from the airport concerned to the Network Operations _Sending Flight Update Messages (FUM) from the Network Operations to the airports concerned	The Collaborative Management of Flight Updates integrates Airport CDM into the core of the flow and capacity management process. By establishing Airport CDM information exchange with the Network Operations systems, Collaborative Management of Flight Updates is re-conciliating the network view with Airport operations, closing the loop between en route / arrival constraints and departure planning.	DPI(departure Information Planning) and FUM(Flight Update Messages) are system to system messages, triggered by events and sent automatically.The automated transmission of the DPI messages is triggered by system events derived from the Milestone Approach processes at the airport. Each DPI message relates to a single flight only. The Network Operations processes the DPI messages received and if necessary, the CTOT is re-calculated (improved or deteriorated). A Flight Update Message (FUM) is sent by the Network Operations to the flight’s next destination airport. The Network Operations terminal is an existing flow management tool, widely used by ATC, Aircraft Operators and Ground Handlers. A new Network Operations Interface for TOwers (CITO) is now available for ATC at airports. CITO can also be used by small towers for CTOT monitoring.

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3.5 Multimodal Collaborative Decision Making Functions

The system enabling the proposed concept, the MCDM system, will extend information sharing to the access and egress legs of the trip, as well as to passenger flows inside the terminal.

The system is built using the Passenger Activity-Travel Diary as the fundamental information item. For each passenger using the airport, a diary will be created prior to the day of operations and will then be continuously updated as more information becomes available during the day of operations, so that the latest update is always available from the MCDM system.

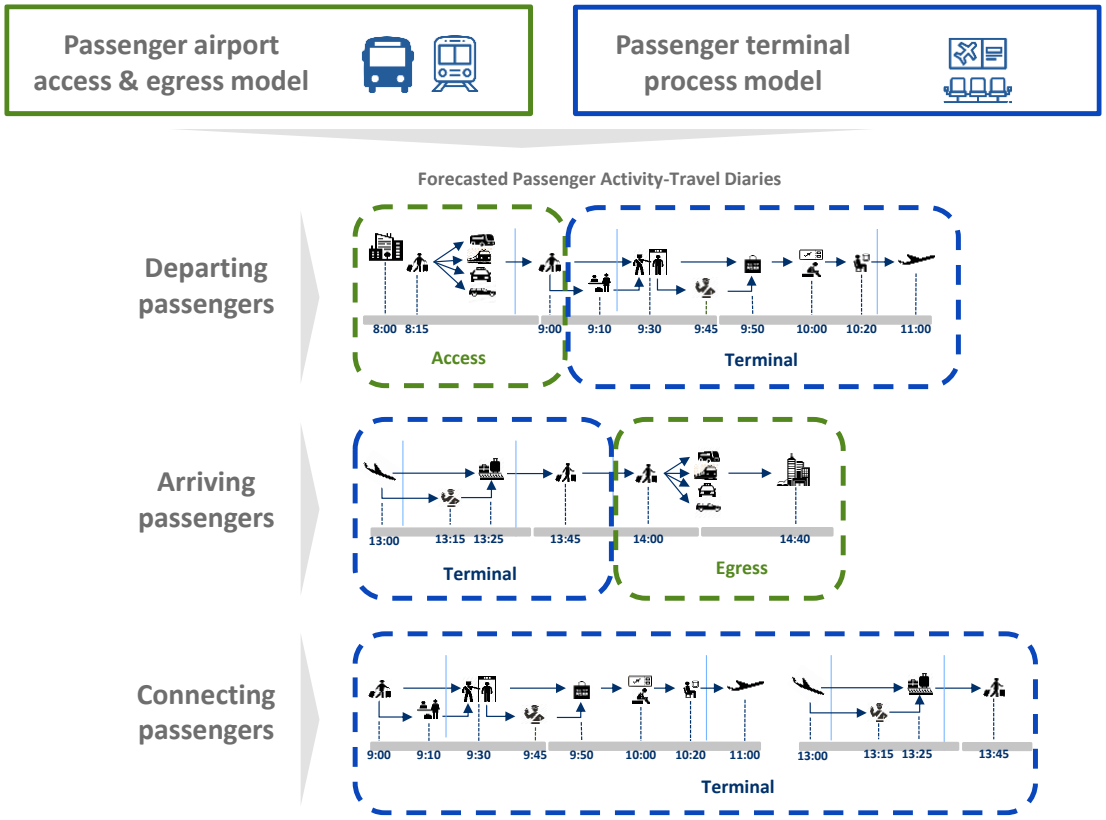

Figure 4: System predictive models

In the system, two predictive models are used to forecast the Passenger Activity-Travel Diaries. As shown in Figure 4, one recreates the access and egress legs of the passengers' trip and the other one recreates passenger flows within the airport terminal, which also takes into account connecting passengers that do not leave the airport.

The system will have a series of functions that define where the data is collected from and how it is used in both models to create and update the diaries for the MCDM system.

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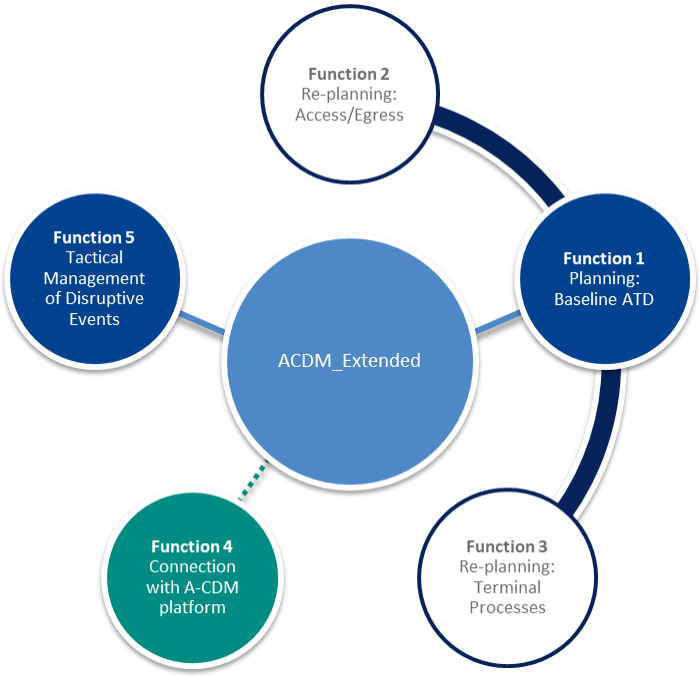

Figure 5: Schematic representation of the Multimodal Collaborative Decision Making functions.

- Function #1 is in charge of creating the baseline scenario for the day of operations. All the information available prior to the day of operations is used to create the Passenger Activity-Travel Diaries for the day of operations and extract relevant indicators on the expected airport and ground transport network performance. This information can then be used by the different stakeholders (e.g., ground transport operators, airport, etc.) to adequately plan and allocate resources thanks to a better understanding of demand and the potential bottlenecks that would have gone unnoticed otherwise.
- During the day of operations, the diaries created by Function #1 are updated with real-time information from the different stakeholders. This re-planning will be broken down into two functions: access/egress to and from the airport (Function #2) and passenger flows in the airport terminal (Function #3). Both are strongly interrelated, as the outputs of one are inputs on the other and vice versa. Additionally, the data collected during the day of operations can be used afterwards for post-ops analysis.
- For CDM airports, Function #4 will also be in place. The updated diaries will be used by the A-CDM platform to obtain additional information on passenger flows arriving and leaving the airport as well as within the terminal. At the same time, the predictive models of the MCDM system will receive data from the A-CDM platform on the state of the system to produce more accurate diaries.
- Normal operations are defined as the situation in which the Passenger Activity-Travel Diaries deviate from the ones produced by Function #1 during the planning phase no more than an initially established threshold. When abnormal situations occur, Function #5 will be triggered in order to support the tactical management of these situations.

More detail on the different functions of the system is provided in the following sections.

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3.5.1 Function #1 Planning: Baseline Activity-Travel Diaries

Objectives

Function #1 Planning provides an initial picture of the flows of departing, connecting and arriving passengers at one particular airport prior to the day of operations, enabling the extraction of relevant indicators estimating the status of the transport network and allowing the different stakeholders (e.g., ground transport operators, airport operators, AUs etc.) to allocate their resources more efficiently.

Description

Function #1 uses the information available prior to the day of operations to create the Passenger Activity-Travel Diaries for the day of operations and extract, using predictive models, relevant indicators on the expected airport and ground transport network performance. This information can then be used by the different stakeholders (e.g., ground transport operators, airport operators, AUs) to adequately plan and allocate their resources more efficiently thanks to a better understanding of the upcoming demand.

The data collected to create the diaries include:

- Data from the ground transport systems: PT routes, schedules and capacity; surface network expected status, historical traffic counts and passenger demand from smart card data, etc.
- Data from the air transport systems: flight schedules, airport layout, number of facilities/resources, airport capacity, passengers expected demand, surveys, historical boarding card reader data, etc.
- Data from personal mobile devices: historical mobile network data, mobile apps data, etc.

3.5.2 Function #2 Re-planning: Access/Egress

Objectives

Function #2 updates the access and egress legs of the Passenger Activity-Travel Diaries with real-time data in order to obtain more accurate indicators on the actual status of the surface access and egress legs to/from the airport.

Description

Function #2 uses more up-to-date information to recalculate the flows of passengers on the airport access and egress. This information may be provided by:

- The different ground transport stakeholders involved such as ground transport operators or transport authorities (e.g., disruptions on the ground transport system or the PT services, real-time demand, surface network status, etc.).
- Function #3. The update of information in Function #3 may result in a modification of the passenger terminal exit times, which are inputs to Function #2 (see Section 3.5.3).

In the case of the access legs, the update of information may result in a modification of the forecasted passenger arrival times to the airport, what entails an alteration on the inputs for the terminal processes, thus triggering Function #3.

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If any of the access/egress legs indicators differ from normal operation more than a previously established threshold (e.g., increasing travel times due to a traffic jam on the airport access, road network capacity reduction due to a temporal shortage of some lines due to road works, public transport demand exceeding capacity, etc.), an alarm will be automatically raised notifying the involved stakeholders of the adverse situation. In this case, Function #5 will be triggered.

3.5.3 Function #3 Re-planning: Terminal Processes

Objectives

Function #3 updates the terminal leg of the Passenger Activity-Travel Diaries using real-time data collected during the day of operations in order to obtain more accurate indicators on the actual status of the airport terminal processes.

Description

Function #3 is also a re-planning function, and therefore works in a similar way as Function #2 but updating the passengers' terminal leg. It uses real time information to update the passenger flows within the airport terminal. This information may be provided by:

- Airport stakeholders such as AO (e.g., changes in gate/stands allocation, reallocation of resources such as opening/closing security lanes, real-time information on the status of some passenger processes such as security control queue times, etc.), AUs (e.g., reallocation of resources such as opening/closing check-in desks, real-time information on the status of some passenger processes such as check-in or boarding, etc.) or ANSPs (e.g., updated flight departure/arrival times)
- Function #2. The update of information in Function #2 may result in a modification of the passenger terminal arrival times, which are inputs to Function #3 (see Section 3.5.2).

In the case of arriving passengers, the update of information may result in a modification of the forecasted passenger exit times from the airport terminal, what entails an alteration on the passenger egress flows, thus triggering Function #3. If any of the airport terminal indicators differ from normal operation more than a previously established threshold (e.g., due to an excess of passengers at certain airport area thus exceeding the capacity, an increase on the passenger waiting times at security/passport control queues, an estimation of a big proportion of passenger missing their flights, etc.), an alarm will be automatically raised notifying the involved stakeholders of the adverse situation. In this case, Function #5 will be triggered.

3.5.4 Function #4 Connection with A-CDM platform

Objectives

One of the premises of the MCDM concept is that it should be possible to implement it in both CDM airports and non-CDM airports. Therefore, instead of envisioning this new platform as an extension of the current Airport CDM Information Sharing Platform (ACISP), it has been defined as an independent platform which can be used by any airport without the need of having an ACISP previously implemented.

In the case of implementing this system in an A-CDM airport, Function #4 will be in charge of connecting the Airport CDM Platform and the MCDM so that both platforms can exchange information.

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Description

At A-CDM airports, the Airport CDM Platform contains the most reliable and up-to-date information on flight schedules, flight status, airport operational data, etc. Feeding the new MCDM Platform with more precise information coming from the Airport CDM Platform will lead to better predictions and estimations on passenger flows. Information sharing will work in both directions:

- Data updates on arriving and departing flights from the Airport CDM Platform will be used by the MCDM to recalculate the Passenger Activity-Travel Diaries accordingly through the re-planning functions #2 and #3. For example, if an arriving flight is delayed, the Airport CDM Platform will exchange this information with the MCDM via Function #4 in order to have a better estimation of the passengers deboarding time. The new information will then be used by Function #3 to update the terminal predictive model, thus providing a more accurate view of the passenger flows within the terminal and updating the passenger exit time from the airport terminal, triggering Function #2.
- The MCDM system can also provide information to the Airport CDM Platform regarding passenger flows. For example, if due to a disruption on the airport access, a high percentage of the passengers from one particular flight are not able to arrive on time, this information can be shared with the Airport CDM Platform so that the airline and the handling operator are aware of the situation and can act accordingly.

3.5.5 Function #5 Tactical Management of Disruptive Events

Objectives

The objective Function #5 is to support the collaborative management of operational adverse situations or disruptions that could appear during the day of operations in order to minimise its impact on the passengers and the involved stakeholders.

Description

A set of warnings or alarms will be defined in order to inform the involved stakeholders that the transport system performance is deviating from normal operation. When such deviation is greater than a certain threshold previously established and agreed by the stakeholders involved in the system (e.g., airport operator, ground transport operator, AUs, etc.), the disruption management process will be initiated.

The workflow of the disruption management process is the following:

- The process is initiated once an alarm is raised by the system, indicating that the performance deviates from the objectives set. An impact assessment is then performed in order to analyse the severity of the problem.
- Then, a suitable solution for the problem is looked for. Usually, there is not a unique solution, therefore, a set of solutions which may mitigate the adverse situation will be selected. This may be done, for example, by using a historical database of previous approaches to similar situations.
- Once the relevant solutions for the problem have been selected, a What-If analysis will be performed for each of them in order to find the most appropriate solution, as the different

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potential solutions may cause unbalances in other areas of the airport or the access and egress legs. This analysis will be performed using the terminal and access/egress predictive models.

- Once all the What-If analyses have been performed, the involved stakeholders will collaboratively select and execute the most suitable solution. Performance will be continuously monitored and, if it deviates from the expected outcomes, measures will be taken accordingly.

Some of the disruption management solutions may include notifying the passengers on the adverse event and providing them with a suitable solution for completing the trip, hence helping them to mitigate the impact on their journey. This information will be available in the system and accessible via an API that can be used to push notifications to passengers through different methods such as mobile apps, SMS, etc. For example, if a disruption takes place on the underground access to the airport, the airport operator may advise the passengers via an app notification to use another transport mode to reach the airport terminal

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4 Implementation approach

The envisioned implementation approach of the new proposed concept is sketched in Figure 6:

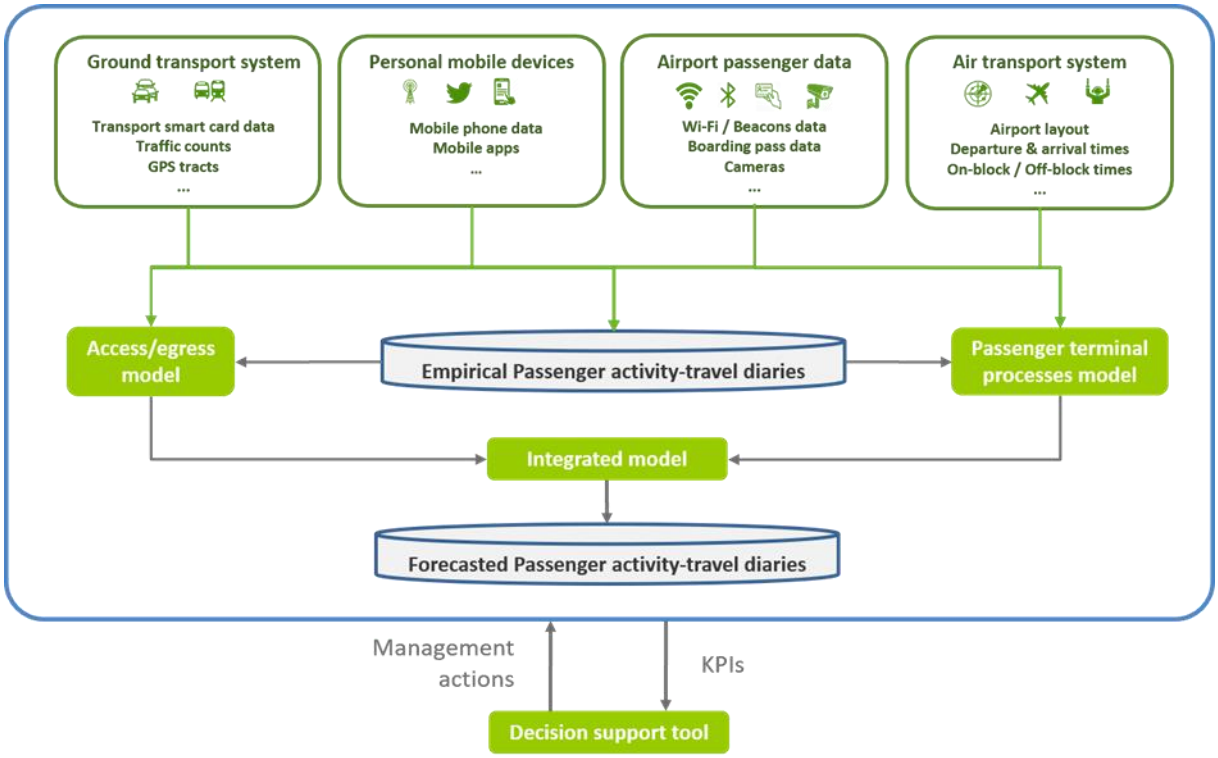

Figure 6 New proposed concept implementation

The proposed implementation approach would entail the following steps:

- First, the empirical Passenger Activity-Travel Diaries will be reconstructed using historical data from relevant data sources during the passenger journey through different data fusion and analysis methods.
- Then, the empirical Passenger Activity-Travel Diaries as well as other available data sources (including those from the airport and ground transport systems) will be used to develop and calibrate predictive models able to short-term forecast the passenger flows.
- Once the models of the passenger terminal flows and of the access and egress legs are developed, they will be integrated in order to provide a comprehensive view of the full Passenger Activity-Travel Diaries. The integration will involve two main activities:
    - the **development of the required interfaces** so that each model can take as inputs some of the outputs produced by the other models. For example, if a flight is delayed, the model of the passenger terminal processes will use the information on the estimated time of arrival and the prediction of the de-boarding, border control, baggage handling and customs to estimate the time at which these passengers will enter into the ground transport system. This information can be used, for example, by a public transport operator or a taxi company to adequately serve that demand. The flow of information can

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also occur in the other direction: for example, the prediction of the arrival times at the airport of different passenger types will be used by the airport simulation model to assess the impact on passenger handling process, decide on the optimal allocation of resources, and update the Passenger Activity-Travel Diaries accordingly;

- the **implementation of the KPIs on which the collaborative decisions will be based**. The information contained in the Passenger Activity-Travel Diaries and other simulation outputs will be used to build the set of KPIs specified in Section 5, with the aim of measuring the quality, sustainability, efficiency and resilience of the passenger journey (e.g., time spent at the different legs of the trip and at the different terminal sub-processes, use of airport resources, travel time reliability, environmental impact of the access modes, etc.). These KPIs will be the ones used by the airport and/or the ground transport stakeholders to perform what-if analyses and collaboratively decide on the best course of action.

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5 Key Performance Indicators (KPIs)

5.1 Introduction

This Concept of Operations has been developed under the initial assumption of being an extension of the current A-CDM system. The advantage of this approach is that part of the information which is already been managed by the A-CDM platform is also useful for the MCDM system. In the same way, it is expected that, for those airports that have already been dealing with an A-CDM platform and are familiar with its procedures, it will be easier to implement this new concept.

To ensure maximum alignment with current A-CDM, the approach that has been followed to define Key Performance Indicators (KPIs) has been the same as in an A-CDM implementation (EUROCONTROL, 2017)[28]. Many of the current A-CDM KPIs already in use can be accepted as part of the MCDM KPIs, and therefore the main effort regarding the definition of new KPIs is related to the passenger journey and the ground transport system.

The methodology followed to define the performance indicators has been as follows. First, the main performance objectives established at European level has been described. The KPIs have been defined as a consequence of these objectives in order to assess the benefits of the proposed concept for the passengers. Some KPIs have also been proposed to evaluate how providing incident warning alerts and proposing alternative choices can help mitigate the impact on the passenger journey and therefore improve the resilience of the whole transport network.

Maximum alignment with the SESAR performance framework was sought. However, said framework refers exclusively to ATM operations and since the proposed concept is characterised by its intermodal nature, additional KPIs had to be considered, which are deemed necessary in the context of IMHOTEP. The following sections present the most relevant identified KPIs at the time of writing this document. After looking for synergies with different SESAR ER4 projects related to intermodality, it has been identified that the TRANSIT project, in its deliverable D3.1 Multimodal Performance Framework, provides an extensive review of different relevant intermodality KPIs, most of them applicable to the needs of this CONOPs. Therefore, some of the KPIs have been directly extracted from SESAR ER4 TRANSIT project, while others have been specifically developed within IMHOTEP.

It is important to note that KPIs must be adapted to the context of application depending on the characteristics of the airports considered, the interactions between air and surface transport stakeholders and the interests of the stakeholders implementing the CONOPs. Deliverable 7.1 of the IMHOTEP Project introduces the process and definition of customised KPIs for the two case studies analysed (Palma de Mallorca and London City airports), the extent of information available and the capabilities of the models developed. Therefore, it is crucial to understand the following section as a comprehensive, but not necessarily exhaustive, definition of applicable measures of performance. As such, it defines a structure to be adapted following a process of consultation and validation with the relevant stakeholders. Naturally, this process should consider the degree of comparability with other instantiations of the CONOPS, thus the expected objectives of measuring performance through the KPIs is as important as the specific KPIs.

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5.2 Objectives & KPIs

5.2.1 Measuring Performance

Whilst most stakeholders have some method of performance assessment in place, the performance indicators and measurement methodology may vary significantly across partners. The results, therefore, may not be comparable locally or on a regional basis. For this reason, it is important to agree on common KPIs, so that the achieved improvements can be measured by comparing the status of the agreed performance indicators in the “before” and “after” situations.

Measurement of success is an iterative process that should be supported by feedback from each stakeholder. Performance assessment should be periodically reviewed to identify further system improvements.

5.2.2 Main objectives

Correct measurement of success is only possible if it is based on the right measuring process. In order to evaluate the effects of the MCDM implementation, post implementation performance needs to be compared against the same performance indicators that were used before implementation.

The success of the MCDM system will be measured not only against its own previous performance, but also in terms of the performance of the entire network. It is therefore important that the performance indicators, and the methods for measuring them, are consistent at European level.

The objectives and related performance indicators have been divided into two categories, in order to be aligned with the already existing ones:

- Generic objectives and performance indicators, applicable to all airport stakeholders and corresponding to four main improvement areas: efficiency, environment, capacity and safety.
- Specific improvement objectives and performance indicators defined for each airport stakeholder. Each specific objective is linked to at least one generic objective.

The specific objectives for each involved stakeholder can be summarised as follows:

- The objective of **Airport Operators** is to maximise the throughput and efficiency whilst complying with their operational plan. The major impacts of delays on Airport Operators are mainly the loss of image or reputation and a non-efficient use of airport resources and infrastructure. Although the passenger is an essential part of the operation, nowadays most relevant systems and operational enhancements are focused on the airside processes and aircraft turnaround optimisation. IMHOTEP proposes to use available passenger information and include passenger processes as part of the system.
- The objective of **Ground Transport Operators** is to efficiently manage their available resources in order to adapt them to the real passenger demand at each particular moment while maintaining punctuality and an optimal occupancy rate of their vehicles.
- Considering **passengers** as an actor of the system, their objectives are mainly to reduce uncertainty regarding travel and airport stay times as well as having the best possible quality standard at a reasonable cost.

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- Although the rest of the airport stakeholders (Aircraft Operators, Ground handlers, Service Providers, ANSPs and Network Operations) are not directly involved in the new concept, its implementation can entail big benefits for them too. For example, **Aircraft Operators**' objective is to meet their planned schedule, as delays will result in additional costs such as extra fuel consumption, missed connections and subsequent knock-on effects, etc. A more predictable and seamless passenger journey may mitigate the likelihood of passengers arriving late to the gate, thus preventing possible delays. **Ground Handlers**' objectives are to optimise the use of their resources and maintain Service Level Agreements (including departure punctuality and turnaround times). The best use of available resources depends partly on the quality of aircraft arrival and aircraft departure estimates; hence, Ground Handlers may also benefit from the reduction of potential delays resulting from passengers arriving late to the gate.

For the moment, specific KPIs have only been developed for Airport Operators, Ground Transport Operators and passengers.

5.2.3 Generic objectives and KPIs

Each section will be structured in the following way:

1. **Objective:** what is expected to be achieved.
2. **Strategic Performance Driver:** the means for reaching the strategic objective.
3. **Performance Driver:** how to achieve the objective.
4. **KPI:** what we get from the measurement.
5. **Performance measurement:** The measuring method. How each indicator is measured

5.2.3.1 Efficiency

Objective: Increase Airport and Ground Transport System efficiency

Strategic Performance Driver: Improve punctuality and reduce delays

Performance Driver	KPI	Performance Measurement
Reduce passenger waiting times[2]	- Ratio between the sum of waiting times and the door-to-gate travel time for departing passengers	- Measure the ratio between the sum of waiting (e.g., queuing) times and the door-to-gate travel time.
	- Ratio between the sum of waiting times and the gate-to-door travel time for arriving passengers	- Measure the ratio between the sum of waiting times (e.g., queuing, waiting for luggage, etc.) and the gate-to-door travel time.
	- Ratio between the sum of waiting times and the gate-to-gate travel time for connecting passengers	- Measure the ratio between the sum of waiting times (e.g., queuing) and the gate-to-gate travel time.

[2] KPI extracted from SESAR ER4 TRANSIT project deliverable D3.1 Multimodal performance Framework

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Performance Driver	KPI	Performance Measurement
Optimise passenger travel time[2]	- Ratio between the best possible travel time and the average travel time for the door-to-gate journey for departing passengers	- Measure ratio between the best possible travel time and the average travel time by users for the door-to-gate journey
	- Ratio between the best possible travel time and the average travel time for the gate-to-door journey for arriving passengers	- Measure ratio between the best possible travel time and the average travel time by users for the gate-to-door journey
	- Ratio between the best possible travel time and the average travel time for the gate -to-gate journey for connecting passengers	- Measure ratio between the best possible travel time and the average travel time by users for the gate -to-gate journey

5.2.3.2 Predictability

Objective: Increase Airport and Ground Transport System efficiency

Strategic Performance Driver: Improve punctuality and reduce delays

Performance Driver	KPI	Performance Measurement
Improve door-to-gate predictability	- Predictability of the door-to-gate time for departing passengers	- Measure the average and standard deviation of the difference between the Actual door-to-gate time and the Estimated door-to-gate time
Improve gate-to-door predictability	- Predictability of the gate-to-door time for arriving passengers	- Measure the average and standard deviation of the difference between the Actual gate-to-door time and the Estimated gate-to-door time
Improve gate-to-gate predictability	- Predictability of the gate-to-gate time for connecting passengers	- Measure the average and standard deviation of the difference between the Actual gate-to-gate time and the Estimated gate-to-gate time

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5.2.3.3 Environment

Objective: Reduce Ground Transport System emissions and noise

Strategic Performance Driver:

- Improve public transport use
- Reduce Ground Transport System congestion

Performance Driver	KPI	Performance Measurement
Reduce private traffic on the airport access and egress	- Number of vehicles in the airport access and egress routes	- Measure number of private vehicles in airport access and egress legs
Increase the use of public transport	- Percentage of airport passengers arriving or leaving the airport by public transport	- Compare the number of passengers arriving on public transport vs the total number of passengers

5.2.3.4 Capacity

Objective: Optimise the use of available capacity

Strategic Performance Driver: Increase Ground Transport System and Airport efficiency

Performance Driver	KPI	Performance Measurement
Increase overall capacity[2]	- Overall OD capacity	- Maximum number of passengers for an OD considering all the alternatives

5.2.4 Specific objectives and KPIs

5.2.4.1 Airport Operators

Strategic Objective: Improve passenger processing times efficiency

Performance Driver	KPI	Performance Measurement
Improve airport processes predictability	- Predictability of passenger arrival time at airport terminal	Measure the average and standard deviation of the difference between Actual Arrival Time (AAT) and Estimated Arrival Times (EAT) at each of the airport milestones.
	- Predictability of passenger arrival time at check-in desks	
	- Predictability of passenger arrival time at security control	
	- Predictability of passenger arrival time at passport control	

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Performance Driver	KPI	Performance Measurement
	- Predictability of passenger arrival time at gate	
	- Predictability of passenger arrival time at baggage claim belts	
Reduce passenger waiting times and improve predictability	- Predictability of passenger waiting time at check-in desks	Measure the average and standard deviation of the difference between Actual Waiting Time (AWT) and Estimated Waiting Time (EWT) at each of the airport milestones.
	- Predictability of passenger waiting time at security control	
	- Predictability of passenger waiting time at passport control	
	- Predictability of passenger waiting time at gate	
	- Predictability of passenger waiting time at baggage claim belts	

5.2.4.2 Ground Transport Operators

Strategic Objective: Improve punctuality

Performance Driver	KPI	Performance Measurement
Improve passenger access and egress predictability	- Predictability of passenger arrival time at end of each access ground transport leg	- Measure the average and standard deviation of the difference between Actual Arrival Time (AAT) and Estimated Arrival Times (EAT) at each of the ground transport milestones.
	- Predictability of passenger arrival time at egress transport mode	
Reduce passenger waiting times and improve predictability	- Predictability of passenger waiting time between each access ground transport leg	- Measure the average and standard deviation of the difference between Actual Waiting Time (AWT) and Estimated Waiting Time (EWT) at each of the ground transport milestones.
	- Predictability of passenger waiting time at egress transport mode	

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Strategic Objective: Improve occupancy ratio

Performance Driver	KPI	Performance Measurement
Optimise average occupancy ratio per vehicle	- Occupancy ratio	- Compare vehicle occupancy vs declared capacity for each transport mode. Each ground transport operator will have to define a target value depending on their priorities (e.g., improve passenger experience, maximise profit, maintain safety distances, etc.)

Strategic Objective: Optimise ground transport system

Performance Driver	KPI	Performance Measurement
Optimise ground transport resources	- Passenger waiting times at each stop	- Measure the average and standard deviation of passengers waiting time at each stop
	- Ground Transport vehicle's stand-by time at airport terminal	- Measure the average and standard deviation of the stand-by time per ground transport vehicle (e.g., waiting time of taxis at airport terminal)
	- Average number of vehicles in use per total fleet	- Measure number of vehicles in use per total fleet for each transport mode available
	- Number of passengers unserved by a given ground transport vehicle	- Measure the average and standard deviation of the number of passengers unserved by a given ground transport vehicle

Strategic objective: Reduce number of incidents on the trips to and from the airport and in the airport **surroundings**

Performance Driver	KPI	Performance Measurement
Reduce incidents on the airport access and egress routes[2]	- Number of incidents	- Measure the number of incidents

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5.2.4.3 Passenger

Strategic Objective: Improve punctuality

Performance Driver	KPI	Performance Measurement
Reduce journey duration	- Duration of the complete door-to-gate/gate-to-door/gate-to-gate journey	Measure the duration of the passenger journey stages: - door-to-gate - gate-to-door - gate-to-gate

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6 Safety, Performance and Interoperability requirements (SPR-INTEROP)

The IMHOTEP project was mainly focused on the validation and demonstration of the benefits that the implementation of the concept could bring to the involved stakeholders as well as the demonstration of the usefulness of the tools proposed, rather than on the actual implementation of the proposed concept and system in a real airport. Therefore, at this early stage, it is notably challenging to be able to identify and describe the different system and operation requirements, such as Safety or Security Requirements, at a detailed level.

Despite these difficulties, an initial set of high-level requirements has been identified. However, the CONOPs does not preclude the need for a detailed specification for each of the described elements, which should be developed as part of the implementation project considering local specificities and/or prevailing circumstances that may justify a different approach to achieve the same result. Such considerations are also subject to local pragmatism and financial decisions.

6.1 Interoperability between the Multimodal Collaborative Decision Making Platform and the existing systems (INTEROP)

The solution shall allow interoperability with the rest of the existing airport systems. This integration with the systems already in place will depend on the degree of implementation of the proposed concept and the characteristics and the level of automation of the implementation airport. As discussed through this document, the definition of the concept has been envisioned to allow its implementation in both CDM and non-CDM airports with different levels of automation as well as airports with TAM implemented (concept currently under development). Therefore, when implementing the concept in a TAM implemented airport or an A-CDM airport, the solution shall allow the interoperability between the MCDM system and the APOC or the A-CDM Platform, respectively, as they act as information integrator and contain the most up-to-date information on the status of the airport and ATM related system.

When implementing the concept in a non-CDM airport, this kind of information integrator systems may not be in place, therefore the MCDM system shall ensure the interoperability with the existing systems at the airport of implementation. These systems will depend on the level of automation of the airport, as some of them may have particular systems that act as data integrators, while in others this information may not be compiled in one unique system or database, so the MCDM system shall also allow interoperability with the different stakeholders' systems (e.g., AUs, AO, GH, etc.).

Additionally, the information that may be captured or that is already being captured may depend on the airport characteristics, even between the same category. As for example, in regional airports with A-CDM implemented, the number of milestones captured is reduced when compared to the normal application of the solution; or in non-CDM airports the type of information that is being captured may differ between airports (e. g., LCY uses the Real-time Aircraft Turnaround Tool system to capture the performance of turnarounds), therefore, the interoperability requirements may also change between non-CDM airports and A-CDM airports itself.

As the project has so far focused on implementing a PoC aimed at assessing the potential benefits of the concept by simulating the real-time operation, the actual integration between the proposed

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platform and the actual airport systems is still out of the picture. The interoperability requirements between the proposed system and the existing systems at the different airport categories (TAM, A-CDM with different degrees of implementation of the solution such as regional airports and non-CDM airports with different levels of automation) should be studied in further stages of the development of the concept.

6.2 Multimodal Collaborative Decision Making Extended Data Inputs

The concept proposed in this document establishes a paradigm in which the passenger becomes the central element of the complete transport system which includes the door-to-gate and gate-to-door journeys. This new vision entails an important change in terms of information management.

The main sources of data are the stakeholders involved in the MCDM system. In case of CDM airports, the data inputs will be the same as in traditional A-CDM, in addition to the information related to ground transport operators. For non-CDM airports, the information inputs may vary depending on the degree of automation implemented at the airport. An exemplary list of types of data which can serve as inputs to the MCDM system can be found below, together with the main information that will be required by the system classified by stakeholder. Additional sources may be added during the deployment phase to address specific needs and characteristics of the airport and others may not be available depending on the implementation airport:

Table 5. Multimodal Collaborative Decision Making Information Inputs

Passenger access and egress
Location of home point
Departing time to airport
Means of ground transportation available for airport access leg
Means of ground transportation selected by passenger
Time of arrival at terminal building
Time of departing from airport to final destination
Means of ground transportation available for airport egress leg
Arriving time at destination
Location of destination point

Passenger terminal processes
Check-in time per counter
Designated counters per flight/s
Time through security check point
Time to pass through passport control
Time at boarding gate from security/passport control
Flight arrival time to the airport
Time through passport control for connecting passengers
Time at gate for connecting passengers
Time to baggage claim belts
Time to ground transport in airport facilities

Airport Operations
Aircraft movement data
Priority of flights
Changes in turn-round times
TOBT updates
Planning data
Information concerning de-icing
Flight plans
Aircraft registration
Aircraft type

Airport Operations
Estimated Runway Updated
Estimated Stand Updated
Estimated Taxi Out Time
Actual Taxi Out Time
Estimated Take-off Time
Airport slot data
ADES
SOBT
Stand and gate allocation

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Airport Operations
Flight type
Flight Created
Flight Suspended
Flight De-suspended
Target Start-up Approval Time Updated
Data from flight plans
Minimum Typical Turnaround Time

Airport Operations
Environmental information
Special events
Reduction in airport capacity
Estimated In-Blocks Time
Estimated Off-Blocks Time

Service Providers
De-icing Requested
Estimated De-icing Commencement Time
Actual De-icing Commencement Time
Estimated De-icing Time
Actual De-icing Time

Air Traffic Management
FUM (Flight Status / ELDT) including change (CHG) or cancellation (CNL) messages
A-SMGCS data/radar information
Runway and taxiway conditions
Taxi times and SID (Estimated Taxi-in Time and Actual Taxi-in Time)
Runway capacity (Arrival / Departure)
TTOT
TSAT
SAM
SRM
ALDT

There is no one size fits all solutions for the IMHOTEP concept, and each implementation must be based on careful engagement across all airport and ground transport stakeholders. Any implementation of IMHOTEP concept must be based on assessment of current operational constraints as well as the airport accessibility options. Once knowing the preferences and constraints for each airport, the IMHOTEP solution system could be adapted to their specific needs.

There exist different types of airports depending on their size and characteristics, and the main objectives for each of them may be significantly different. Therefore, a key aspect is to consider the operational needs and ground transport connections in order to accordingly adapt the solution to the implementation airport. For instance, a hub airport may be more interested in facilitating ground access to a wider selection of places to improve their catchment area, while a regional airport may be more interested in improving the passenger arrival predictability in order to avoid congestion issues or bottlenecks at the airport terminal.

Depending on these needs, the information exchange may differ: following the previous example, a hub airport, more interested on their catchment area, may require more data on passengers' origin and destination; while a regional airport may be more interested in real time data provided by ground transport stakeholders

6.3 High-Level Operational Requirements (HLOR)

The High-Level Operational requirements for the MCDM system end users are described in the following sub-sections, divided into general requirements and specific requirements for each of the stakeholders potentially involved in the concept.

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In further development stages of the concept, aimed at the implementation of the proposed system in an actual airport, this initial set of requirements identified in the subsequent sections will need an exhaustive revision and assessment with the objective of describing them in higher detail.

6.3.1 General High-Level Operational Requirements

The initial set of general High-Level operational requirements identified at this stage are:

- IMH-HLOR-001: The system shall allow the estimation of the passenger flows (baseline scenario) prior to the day of operations from a wide range of data sources in order to allow the stakeholders to plan their resources in advance.
- IMH-HLOR-002: The system shall allow the involved stakeholders to provide relevant information as well as real-time data on the actual status of their processes/services.
- IMH-HLOR-003: The system shall allow the involved stakeholders to share their data in a secure way fulfilling all the existing data privacy rules and regulations.
- IMH-HLOR-004: The system shall allow to update the estimation of the passenger flows during the day of operations as more updated information become available.
- IMH-HLOR-005: The system shall allow the integration and the exchange of information between the MCDM platform and the already existing systems on the airport of implementation, which may depend on the level of automation of the airport.
- IMH-HLOR-006: The system shall allow the integration and the exchange of information between the MCDM platform and A-CDM Information Sharing Platform.
- IMH-HLOR-007: The system shall allow the visualisation of a set of indicators aimed at assessing performance of the complete transport system (this set of indicators may differ depending on the airport of implementation based on the different airport characteristics, needs and objectives)
- IMH-HLOR-008: The system shall allow to simulate different ‘what-if’ scenarios aimed at assessing the operational impact of different flow management measures and choose the best course of action.
- IMH-HLOR-009: The system shall allow to notify the passengers relevant information about their trip and the status of the transport system.

6.3.2 Specific High-Level Operational Requirements

Depending on the degree of implementation of the proposed approach, not all the agents presented next may be involved in the concept. Furthermore, in case of implementation in an A-CDM airport, most of these requirements may be already be satisfied by the A-CDM Platform, and therefore the exchange of this information would be included under requirement IMH-HLOR-006.

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Table 6. Specific High-Level Operational requirements

End user	High Level Operational requirement[3]
Airport Operator	- IMH-HLOR-010: The system shall allow the Airport Operator to provide real time information on the status of the airport processes (airport terminal occupancy, security/passport control status, baggage processes status, etc.)
Airspace Users	- IMH-HLOR-011: The system shall allow the Airspace Users to provide real time information on the status of flights during the day of operations (expected times, passenger boarding and deboarding status, passenger check-in status, etc.)
Ground Handlers	- IMH-HLOR-012: The system shall allow the Ground Handlers to provide real time information on the status of the turnaround processes (TOBT, taxi times, etc.)
Air Navigation Service Provider (ANSP)	- IMH-HLOR-013: The system shall allow the ANSPs to provide real time information on the status of the airspace surrounding the airport, which extension will depend on the particular needs of the airport (real time flight schedules, current status of the runways, etc.)
Network Manager	- IMH-HLOR-014: The system shall allow the Network Manager to provide real time information on the status of the network.
Other service providers (de-icing, MET, etc.)	- IMH-HLOR-015: The system shall allow the service providers to provide real time information on the status of their services (for instance, expected times and current status of the de-icing process in case of de-icing companies; or weather status in case of MET)
Ground Transport Operators	- IMH-HLOR-016: The system shall allow the Ground Transport Operators to provide real time information on the status of the ground transport network during the day of operations (e.g., schedules, occupancy, real time position of the fleet, etc.)

6.4 User Access and Administration Requirements (UAAR)

This general user access and user administration requirements of the MCDM system are summarised below:

- IMHOTEP-UAR-001: The solution shall be hosted in the cloud and should be accessible from a wide range of devices, including desktop, tablet or mobile. Likewise, the solution should be accessible through the operating system that best suit the stakeholders' needs and requirements.

[3] The final set of involved stakeholders, the information exchanged and the time lapse between information updates will depend on the implementation airport and will be agreed between the involved stakeholders depending on the airport needs.

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- IMHOTEP-UAR-002: The solution shall be integrable into the existing management system of the implementation airport without the need to acquire any specific hardware or equipment.
- IMHOTEP-UAR-003: The solution shall have multiple user profiles which shall be configurable depending on the needs at the implementation airport.
- IMHOTEP-UAR-004: The solution shall allow the creation of groups of users, for example, based on the type of stakeholder. The functionalities and permissions of the groups shall also be configurable.
- IMHOTEP-UAR-005: The solution shall have the functionality to transmit messages and alerts to the relevant users when required.

6.5 Safety and Security Requirements (SSR)

The deployment of new IT systems in a real environment can lead to potential safety and security risks due to an inappropriate implementation of the system, human errors or cyber security vulnerabilities, among others. Airports are critical and complex systems that integrate a large amount of relevant data and information; therefore, a proper design of the system as well as a proper integration with the already existing airport infrastructure is key for avoiding potential safety and security risks. Two categories of safety and security risk have been identified at this stage:

- Incorrect performance of the system
- Potential cyber threats from both internal and external sources.

The application of the best software development and cyber security practices can reduce the likelihood of IT system errors and cyber security threats that could cause damage to people, structures and assets. The following set of high-level safety and security requirements related to the MCDM system have been identified at this stage:

- IMHOTEP-SSR-001: The solution shall have a documented technical design and operational procedures related to safety and security.
- IMHOTEP-SSR-002: The solution shall be supported by a risk analysis, including human factors, sufficient to demonstrate that the implementation of the system does not increase the risk of operation.
- IMHOTEP-SSR-003: The solution provider shall provide sufficient documentation and information to airport authorities to ensure compliance with national and EU regulations and standards.
- IMHOTEP-SSR-004: The solution shall be designed according to the highest standards in industry against cybersecurity.
- IMHOTEP-SSR-005: The solution shall prevent unauthorized access to the system.
- IMHOTEP-SSR-006: The solution shall have a documented cyber security penetration test performed by an appropriate organization (e.g., a CREST member or similar).
- IMHOTEP-SSR-007: All the system functionalities shall have been tested both prior and after the deployment in a real environment in order to assure a proper performance of the solution.

The fulfilment of these requirements will assure the mitigation of the safety and security risks.

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The application of the proposed system does not entail significant security benefits, but it may lead to potential safety benefits, especially on the access and egress legs, where the holistic view of the flows of passengers accessing and egressing the airport can allow the application of flow management measures aimed at reducing traffic congestion, which can be translated in less road incidents.

6.6 Human Performance Requirements (HPR)

The high-level training requirements related to the new MCDM system are the following:

- IMHOTEP-HPR-001: The solution provider shall provide the documentation required for the airport to successfully implement the solution. These can include a Design and Architecture Manual, a User Guide, an Operation and Maintenance Manual, a Security Manual, etc.
- IMHOTEP-HPR-002: The solution provider shall provide sufficient training to the system users to adequately perform the required tasks. The required training material must also be provided in order to support this training.
- IMHOTEP-HPR-003: The solution provider shall provide airports with a non-operational environment for training and familiarisation with the system.
- IMHOTEP-HPR-004: The solution provider shall support the airport to adapt the solution to the airport needs and implement the MCDM procedures regardless of whether the airport already has a CDM system in place.

6.7 System Capacity Requirements (SCR)

A preliminary definition of the capacity requirements for the proposed MCDM solution is provided below:

- IMHOTEP-SCR-001: The solution shall have enough capacity to support 24-hour continuous operation.
- IMHOTEP-SCR-002: The solution shall have enough capacity to support the access to the platform by all the system users at the same time. The number of users will depend on the implementation airport needs.
- IMHOTEP-SCR-003: The solution shall be able to efficiently handle a number of messages per minute equivalent to the maximum number of passengers on peak day at the airport. This number will have to be defined for each airport during the implementation phase of this solution.

IMHOTEP-SCR-004: The solution shall be able to store all system data during the lifetime of the system. The data may be stored in the same system, being the data retrievable through the system interface or on a separate secure database, under request to the support desk.

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7 Reference and applicable documents

7.1 Applicable documents

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Appendix A Cost-Benefit Analysis

A.1 Stakeholders' identification and expectations

Table 7 summarises the most relevant stakeholders in the initial development phase; however, other stakeholders will be also involved in the process (ANSPs, Ground Handlers, Network Manager, etc.) and their main expectations will need to be analysed in more detail in future stages of the development of the concept. Similarly, the expectations reflected in the table must be adapted depending on the characteristics, needs and ambitions of the stakeholders involved in specific airport environments.

Table 7: Stakeholders' identification and expectations.

Stakeholder	Involvement	Why IMHOTEP matters to stakeholders
Airport Operator	AOs will provide historical and real-time information on the status of the airport facilities	AOs expect to improve the predictability of the passenger flows and the situational awareness. This will allow the airport to take an active role in managing its resources accordingly (e.g., handling, security, human resources, etc.) by considering the incoming passenger volumes in the expected arrival times. Specific expectations may be different depending on the characteristics of the implementation airport (e.g., with or without A-CDM implemented, with different levels of automation, regional airports, big hubs, seasonal airports, city airports, etc.).
Ground transport Operator	Ground transport operators will provide historical and real-time information on the status of the transport network supply and demand	Ground transport operators expect to better match the public transport supply with the real demand, especially at the terminal arrivals, as well as to better understand the passengers' profile in order to fulfil their particular needs (different types of passengers may choose different transport choices or routes). Specific expectations may be different depending on the characteristics of the implementation airport and the modal choices available.

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Stakeholder	Involvement	Why IMHOTEP matters to stakeholders
Airspace Users[4] **(Airlines)**	AUs will provide historical and real-time information on the status of the check-in and boarding processes, among others. AUs will also be in charge to inform the passengers of possible events or disruptions.	AUs expect to improve the predictability of the passenger flows attending their flights, thus allowing to take an active role in the management of its resources (e.g., modification on the check-in desk opening/closing hours, management of delayed passengers, etc.). Specific expectations may be different depending on the characteristics of the airline (e.g., low-cost, full service or regional carrier, number of daily frequencies at the airport).

A.2 Benefit mechanisms

The evaluation of the case studies demonstrates that the proposed concept entails significant benefits for the transport network as a whole and for the passengers. These benefits include, for example, reduction of congestion in the airport access leading to a reduction in carbon emissions, as well as a marked reduction in passenger waiting times and travel times and, ultimately, a reduction on the number of passengers who lost their flight due to a disruption.

The implementation of the concept also has specific benefits for each of the stakeholders involved. However, these benefits may depend on the airport of implementation and on the specific objectives and expectations of the involved stakeholders. The main identified benefits that the proposed concept may bring to the most relevant stakeholders are summarised in Table 8:

Table 8: Stakeholders' benefits

Stakeholder	Benefits
Airport Operator	The improvement of predictability of the passenger flows allows the AO to take an active role in managing its resources accordingly. This may be translated in a potential reduction of the **Costs** and an increase of **the Operational Efficiency**, due to a more optimal allocation of resources (avoiding overallocation of resources). This also leads to an improvement of the **Capacity** in different airport areas, such as the security control, allowing the processing of higher volumes of passengers due to the proper allocation of human resources in the control.

[4] The expectations collected have been extracted from different meetings and workshops with the airport partners, ground transport operators and other involved stakeholders. However, it has to be remarked that there are no airlines as project partners, therefore the conclusions presented may not be definitive.

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Stakeholder	Benefits
Ground transport Operator	The improvement of predictability of the passenger flows may be translated into a better correlation between the public transport supply and the real demand which may lead to a potential reduction of the **Costs** and an increase of the **Operational Efficiency**, due to a more optimal allocation of resources (human resources and vehicles); also leads to an improvement of the **Capacity** of the surface transport network in certain periods, due to an increase of the supply in predicted peak periods, allowing to allocate higher number of passengers. The forecast of possible road disruptions or congestions may be mitigated by advising the passengers to arrive earlier to the terminal or choose alternative routes, which leads to a reduction in the congestion, notably affecting the **Safety**, but also reducing the CO_2 emissions, thus reducing the **Environmental** impact.
Airspace Users **(Airlines)**	The improvement of predictability of the passenger flows may be translated into a better allocation of the airline resources which may lead to a potential reduction of the **Costs** and an increase of the **Operational Efficiency**, due to a more optimal allocation of resources (human resources, check-in desk allocation and opening/closing times, etc.); also leads to an improvement of the **Capacity** at the check-in, allowing the processing of higher volumes of passengers due to the proper allocation of human resources in the desks. Finally, there is a potential impact (possibly marginal) on the **Environment** due to a reduction of departure delays, which will in turn reduce the need for the use of accelerated fuel burn for delay recovery.

A.3 Cost mechanisms

The cost of implementing the concept on an airport may significantly vary depending on the specific circumstances and the stakeholders actively involved. As described in Section 3.3, the way the concept has been defined allows to implement it in very different airports, from A-CDM airport to non-CDM airports with very different levels of automation. At this stage, the main costs identified for the proposed concept may can be summarised as follows:

- **Development and implementation of the Multimodal Collaborative Decision Making Platform**.
- **Adaptation to the collaborative processes** with the introduction of the MCDM system, which may include training, potential increase of the staff, etc.
- **Costs associated to the integration of the MCDM Platform** with the already existing systems.
- **The impact of the new collaborative process on stakeholders' operations**. The deployment of the MCDM Platform may require modifications of the different stakeholders' operation in order to adapt the transport system to provide the best possible travel experience to the passengers. This kind of operational modification may involve an associated cost, which will depend on the type of stakeholders. The main potential costs identified at this stage are presented below.

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Table 9: Stakeholder's operational costs

Stakeholder	Infrastructure	Personnel	Other
Airport Operator	Costs associated to the **airport infrastructure** such as **electricity** or **machinery** costs derived of management measures such as opening new security control lanes.	Costs associated to the increment of the **staff** at different airport points such as the security control, the terminal (e.g., in order to guide passengers)	-
Ground transport Operator	Costs associated to potential management measures such as: • increase of PT frequency • changes of assigned vehicles • Modification of PT routes This includes **fuel costs** and **vehicles maintenance**.	**Staff** cost associated to potential management measures such as: • increase of PT frequency • changes of assigned vehicles • Modification of PT routes	-
Airspace Users **(Airlines)**	Costs associated to different management measures such as **check-in desks associated costs** in case of opening new check-in desks or opening check-in desks earlier	**Staff** cost associated to potential management measures (e.g., in check-in desks or boarding)	Potential costs derived from **delaying flights** in case a big proportion of passengers is expected to miss the flight

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