Transition to Trajectory Based Operations (TBO)

Components of the future ATM system in the Netherlands

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Management Summary

Trajectory Based Operations (TBO) have been proposed as an important enabler to achieve the performance goals set by the Single European Sky ATM Masterplan. The ICAO global TBO concept describes an ATM environment where the flown flight path is as close as possible to the user-preferred flight path by reducing potential conflicts and resolving demand/capacity imbalances earlier and more efficiently. In such an environment, a four-dimensional (4D) flight trajectory, collaboratively developed, managed and shared, would serve as a common reference for decision-making across all stakeholders.

TBO is recognised as one of the key enablers for more efficient and environmentally friendly operation in the future Dutch airspace redesign. For the Schiphol operation TBO will mainly focus on the departure and arrival phases of flight. This then is also where most benefits are to be expected.

This report builds on the AAA replacement business case, that LVNL provided to the Department of Infrastructure in 2015, in support of the decision to replace the AAA ATM system with the iCAS system (projected for 2023/2024). The investments needed to replace the AAA system are justified by the benefits which are enabled by the new system. These benefits can be found in two main areas:

1) The iCAS system provides a platform for common development with the iTEC consortium partners. System development on the basis of common requirements is an important cost saving strategy.
2) The iCAS system provides a platform to create interoperability between systems, and to develop new functions in support to the transition to TBO.

For departures, sharing flight performance information and trajectory information by the airline and by the aircraft itself allows conflict detection and resolution prior to departure. Downlinking the trajectory via ADS-C EPP also supports verification of selected runway and departure route. Finally, sharing this information with downstream ANSPs allows more accurate planning on their side.

For arrivals, improved performance data shared via SWIM allows more accurate trajectory prediction which in turn leads to more stable and accurate planning. SWIM also enables sharing arrival information with the flight crew well before the approach phase of flight in the Dutch airspace, allowing better planning and use of the FMS. Furthermore, the same channel allows sharing desired trajectory modifications to meet arrival times with upstream ANSPs, even beyond the immediate adjacent centres. In the longer term, up-to-date trajectories shared through iCAS-enabled eIOP ensure a consistent view on the trajectories between ANSPs.

The use of trajectory-based conflict management enables integral trajectory management. This allows traffic in and out of other airports to be planned in and trough the traffic in and out of Schiphol.

The transition to TBO requires the deployment and utilisation of new technology, such as iCAS interoperability and air-ground datalink, but also requires conceptual changes, i.e., changes in the way controllers handle traffic, and changes in which controllers are trained. This does not mean, however, that the transition to TBO is something to be expected in the distant future. Some of the conceptual changes can be supported (in part) by conventional solutions and existing technology. Therefore, the transition to TBO does not start at a moment in the future, or after the replacement of AAA: the transition to TBO starts in the present, or as explained in this report: the transition has already started!

This report explains the scope and content of the Transition to TBO and underpins recommendations for a successful transition. The main recommendation in this report is to develop a roadmap based on the following principles:

1) Build from current platforms
2) Prioritize development of arrival- and departure management functions
3) Start using SWIM-enabled applications to gain early benefits
4) Implement trajectory sharing enablers bilateral and in parallel
5) Develop applications by implementing small steps into operation
6) Involve all stakeholders in the transition to TBO

This report provides a high-level conceptual roadmap, but also details concrete actions for the transition to TBO.

Contents

List of abbreviations

(e)IOP	Essential Ground-Ground Interoperability
4D	Four dimensional
A-FUA	Advanced Flexible Use of Airspace
ABI	Advanced Boundary Information
ACARS	Aircraft Communications, Addressing and Reporting System
ACC	Area Control
ACS	ADS-C Common Server
ADS-C	Automatic Dependent Surveillance – Contract
AF	ATM Functionality
AFP	ATC Flight Plan Proposal Message
AMAN	Arrival Manager
ANSP	Air Navigation Service Provider
AO	Aircraft Operator
AOC	Aeronautical Operational Control
ASAP	Advanced Schiphol Arrival Planner
ASM	Air Space Management
ATC	Air Traffic Control
ATD	Actual Time of Departure
ATFCM	Air Traffic Flow Capacity Management
ATOT	Actual Time of Take-off
ATS	Air Traffic Services
ATSU	Air Traffic Service Unit
CDM	Collaborative Decision Making
CNS	Communication Navigation and Surveillance
CP1	Common Project 1 (new European regulation ensuring the continuation of sustainable ATM modernisation and digitalization through SESAR deployment)
CPDLC	Controller Pilot Data Link Communications
CPR	Correlation Position Report
CTOT	Calculated Take Off Time
CWP	Controller Working Position
DARP	Dutch Airspace Redesign Program
DCB	Demand Capacity Balancing
DCT	Direct
DFS	Deutsche Flügsicherung
DMAN	Departure Manager
EAT	Expected Arrival Time
ECAC	European Civil Aviation Conference
EHAM	Amsterdam
EPP	Extended Projected Profile
ETD	Estimated Time of Departure
FDIM	Flight Deck Interval Management
FDP	Flight Data Processing
FABEC	Functional Airspace Block Europe Central
FDPS	Flight Data Processing System
FF-ICE	Flight & Flow Information for a Collaborative (A concept to support future ATM Operations Environment)
FIR	Flight Information Region
FMS	Flight Management System
FO	Flight Object
FPL	Flight Plan
GANP	ICAO Global Air Navigation Plan
HMI	Human Machine Interface
ICAO	International Civil Aviation Organization
IOP	Ground-to-Ground Interoperability

IPI	Intermediate Projected Intent
iTEC	Interoperability Through European Collaboration (Next-generation air traffic management system developed by Indra in collaboration with ANSPs)
LVNL	Luchtverkeersleiding Nederland
MTCD	Medium Term Conflict Detection
MUAC	Maastricht Upper Area Control
NATS	National Air Traffic Services
NM	Network Manager
OLDI	Online Data Interchange
OSM	Operational Strategic Management
PCP	Pilot Common Project
RECAT-PWS	Reduced wake vortex separation minima – Pair-Wise Separation
R/T	Radio Telephony
RTCA	Radio Technical Commission for Aeronautics
SAM	Slot Allocation Message
SDM	SESAR Deployment Manager
SESAR	Single European Sky ATM Research
SID	Standard Instrument Departure
SMAN	Surface Manager
SWIM	System Wide Information Management
TBO	Trajectory Based Operations
TBS	Time Based Separation
TOBT	Target off-block time
TOD	Top of Descent
TP	Trajectory Predictor
TSAT	Target Start-Up Approval Time
TTA	Target Time of Arrival
TTOT	Target Take-Off Time
UDPP	User Driven Prioritisation Process
XMAN	Extended Arrival Management

1 Introduction

This chapter describes the background, objective, and scope of this study on transition of Trajectory Based Operations (TBO) in the Netherlands. The chapter also addresses the project approach, assumptions, and target audience.

1.1 Background

Air Traffic Management (ATM) is informed about the intentions of airspace users via the ICAO flight plan format. These flight plans contain basic information about the intended flight such as call sign, type of aircraft, flight rules, departure airport and time, destination, route, cruising altitude and speed. Once filed, the flight plan is used for Air Traffic Flow and Capacity Management (ATFCM) purposes and distributed to the Air Traffic Service (ATS) units involved in handling of the flight. Individual ATS units add information such as departure runway, SID, STAR, landing runway and attempt to accurately predict what the trajectory is going to be for planning purposes, while making various assumptions on aircraft performance, weather, speed schedules, etc. Moreover, the flight plan is subject to changes prior to, and during, flight execution. Add to this the lack of system integration between airspace users, airports and air traffic service providers, and it's not hard to understand why today's fragmented ATM system has inefficiencies, is not as predictable as desired and is unable to respond to airspace user's business interest.

Trajectory Based Operations (TBO) have been proposed as an important enabler to achieve the performance goals set by the Single European Sky ATM Masterplan. Many reports have already been written about the subject. At the same time, there is no single definition of TBO or the full operational concept. The current documentation provides a collection of (possibly competing) concepts and technologies for different phases of the flight and different airspaces. Due to this lack of definition, there also is no clear plan of steps to take toward implementation.

The Dutch Airspace Redesign Program (DARP) foresees TBO as the key enabler to achieve accurate arrival management. This in turn should enable fixed arrival routes and Flight Deck Interval Management. The latter two should improve capacity while reducing impact of aviation on the surrounding communities.

For the Schiphol operation, the transition to TBO is a very important development. For arriving aircraft, which are well in their descent before they enter the Dutch airspace, it is important to influence their trajectory prior to leaving the cruise altitude. Currently LVNL lacks the ability to synchronise arriving traffic prior to airspace entry, and thus must manage traffic bunches within the small airspace that surrounds Schiphol, one of the busiest and most complex airports in Europe. TBO provides the tools to start traffic synchronisation prior to descent, which in turn enables descent profile optimisation, and generates related efficiency benefits.

This report builds on the AAA replacement business case, that LVNL provided to the Department of Infrastructure in 2015, in support of the decision to replace the AAA ATM system with the iCAS system (projected for 2023/2024). The investments needed to replace the AAA system are justified by the benefits which are enabled by the new system. These benefits can be found in two main areas:

1. The iCAS system provides a platform for common development with the iTEC consortium partners. The development based on common requirements is an important cost saving strategy.
2. The iCAS system provides a platform to create interoperability between systems, and to develop new functions supporting the transition to TBO.

The transition to TBO requires the deployment and utilization of new technology, such as iCAS, and air-ground datalink, but also requires conceptual changes, i.e., changes in the way controllers handle traffic, and changes in which controllers are trained. This does not mean however, that the transition to TBO is something to be expected in the distant future. Some of the conceptual changes can be supported (wholly or in part) by conventional solutions and existing technology. Therefore, the transition to TBO does not start at a moment in the future, or after the replacement of AAA: the transition to TBO starts in the present, or as explained in this report: the transition has already started!

1.2 Objective

This report will explain how the transition to a TBO environment can be shaped in the Netherlands. The report aims to outline the TBO operational concept as applicable to the Netherlands and identifies the required enablers, potential TBO applications and implementation considerations.

By doing so, the report will serve the following purposes:

- Outline the TBO operational concept, enablers and applications as applicable to the Netherlands.
- Provide implementation considerations to support project portfolios at LVNL, Schiphol, and the airspace users.
- Support LVNL’s input in the development strategy for iTEC.

1.3 Scope

The generic TBO concept is applicable from gate to gate and applies to a flight from initial route development, through flight planning, through execution up to arrival at the destination gate. For this study the focus is on the tactical part of the operation that is relevant to the Dutch FIR and its area of influence. The scope of this report therefore encompasses:

- The area of influence for ATM by LVNL (and CLSK): This is the lower part of the Dutch FIR and the area in adjacent airspaces needed to enable trajectory management in a manner consistent with the principles of TBO.
- The management of arrivals and departures, since overflights consist of a small set of operations in the Dutch controlled airspace. The focus is on the operation in and out of Schiphol. However, once established, the knowledge and technology gained, supports a multi-airport operational concept.
- Regarding the timeline, the scope focusses on enabling the operational concept for the Dutch Airspace Redesign Programme. The strategy therefore focusses on the development of the current operation up to the year 2035.

1.4 Project approach

Given the complexity of the subject matter, the approach taken to this study is one of broad involvement of experts active in the field of systems- and operations development. As for the KDC foundation: all KDC partners have been invited to contribute to the project, in order to involve a broad knowledge base. This approach was not only taken with the aim to engage the national knowledge base, it was also taken to disseminate the information coming out of the study, in order to create a level playing field for any subsequent study to follow.

As a first step the group of experts performed desk research and interviewed international parties with expertise in the field of TBO, as well as organisations in similar positions to LVNL (e.g., neighbouring ANSPs).

The findings from this research are used to define TBO enablers and applications for the Netherlands and describe considerations on the implementation of such elements during the transition towards full TBO employment.

1.5 Assumptions

This report builds on the foundation laid in the AAA replacement business case (2015). Its findings are adopted as assumptions in this report, in as much that no proof has been provided otherwise.

It is assumed that, although some development towards TBO could be facilitated on the basis of the AAA system, LVNL cannot comply with European regulations without replacing AAA.
It is assumed that LVNL will replace AAA at the earliest possible date, and will upgrade AAA at the earliest possible dates, to achieve the benefits of TBO, as presented in the replacement business case.

It is assumed that LVNL will seek commonality within the iTEC framework for the transition towards TBO (where LVNL has sought commonality with DFS, in iCAS, in the replacement of AAA).

1.6 Target Audience and Reading guide

The document is structured in a way to provide information to the reader step by step, increasing the level of detail of what TBO means for LVNL. Chapter 2 provides an overview of the findings and proposed recommendations of the project. Chapter 3 provides a description of the general concept of TBO, the scope of TBO in the Dutch airspace and area of influence and the potential benefits. Chapter 4 provides an overview of enablers for TBO that are or will become available in the future to share data to support TBO operations. In chapter 5 potential applications of TBO in the Netherlands are explored. Chapter 6 presents implementation considerations for the transition to TBO in the Netherlands.

2 Conclusions and recommendations

2.1 Conclusions

Air Traffic Management systems nowadays are fixed to boundaries with limited information sharing and collaboration. However, air transport operations cross these boundaries. Flight trajectories span multiple ATM regions, in which services can differ significantly.

TBO for the Netherlands focusses on the initial and terminal phases of flight. En-route control over the Netherlands is largely managed by EUROCONTROL MUAC. The mechanisms and benefits of TBO are realised in departure management and arrival management for Schiphol and the integration of traffic in and out of the other Dutch airports within the flows to and from Schiphol.

This report identifies several applications for the operation in the Netherlands which will be enabled by sharing of trajectories and trajectory information. It should be noted that the transition to the end stage of Trajectory Besed Operations, in which trajectories a fully managed, will require a considerable period of time. Nevertheless, sufficient benefits will be generated by early stages of TBO to support investment business cases.

2.1.1 Departures

- More accurate trajectories through detailed performance information from FF-ICE allows conflict detection and resolution as part of departure management.
- Upstream ANSPs can perform better planning by sharing the up-to-date departure trajectory including route changes during departure.
- ADS-C EPP allows checking the selected departure runway, SID and vertical profile against the clearance and conflict detection prior to departure

2.1.2 Arrivals

- FF-ICE and ADS-C EPP provide more accurate performance information for predicting the arrival trajectory resulting in a more accurate and more stable arrival management at a longer horizon.
- ADS-C EPP adds up-to-date information on vertical constraints as the aircraft approach allowing more accurate prediction of the arrival trajectory.
- 3rd party trajectory information supports predictions outside LVNLs surveillance range which supports arrival management at a longer horizon.
- eIOP provides the up-to-date agreed trajectory from upstream ATS units once implemented on iCAS.
- Using ED-254, crew can receive timely information on runway and transition. Subsequent downlink of the FMS's trajectory then provides even more accurate trajectory information for use in arrival management.
- ED-254 supports AMAN requests to upstream ATS units, even beyond the directly adjacent centres.
- CPDLC Baseline 2 ultimately allows uplinking complex arrival clearances supporting advanced arrival management.
- Downlinking trajectories via ADS-C allows continuous verification of the aircraft's intent against the planned trajectory.

2.1.3 Integral Trajectory Management

- The above concepts are highly focussed on the operation in and out of Schiphol. However, once established, the knowledge and technology gained, supports a multi-airport operational concept.
- Sharing of trajectories via FF-ICE and ADS-C EPP allows synchronisation of traffic to and from the other airports in the Netherlands.

- Especially here, highly accurate trajectories allow conflict management tools to resolve conflicts between the different traffic streams while reducing the impact on the original plan.

2.2 Recommendations

This study recommends to develop a roadmap based on the following principles:

1. **Build from current platforms**

   iCAS and the later versions of iTEC will be the core ATM system on which LVNL will implement TBO. However, these changes to operation depend on the timeline of iCAS and the timeline of the further common iTEC development within the consortium.

   Independent systems at LVNL provide early opportunities for the development and implementation of TBO applications. The arrival manager ASAP in particular is a likely avenue to benefit from near term data sharing via FF-ICE and ADS-C EPP via SWIM.

2. **Prioritize development of arrival- and departure management functionality**

   Given the fact that almost all air traffic in the Dutch airspace is either approaching/descending to Schiphol airport or departing/climbing out of Schiphol airport, most benefits of TBO for the Dutch operation are expected through improved arrival management and departure management and development on these operations are less dependent on the iCAS/iTEC deployment timeline.

   The experience and applications developed for Schiphol arrival and departure management can subsequently form the basis for systems and tools for multi-airport integration.

3. **Start using SWIM-enabled applications to gain early benefits**

   SWIM is a technical infrastructure with set of data, services and protocol definitions that allow sharing of data between stakeholders in ATM. The so-called SWIM Yellow profile provides a flexible and secure way of unlocking data and LVNL is already connected.

   A key component of many SWIM services is that the receiving party can decide to use the information as and when their operation and technology can use it. This enables benefits without requiring all stakeholders to change their systems and operations at the same time.

   Connecting to services does not require waiting until a TBO application is operational: Connecting early to available services allows evaluation of the quality of the data and development of applications that create stakeholder value.

4. **Implement trajectory sharing enablers bi-lateral and in parallel**

   The deployment of TBO is Europe is a multi-faceted development. Some TBO applications require a broad installed base to generate benefits, other applications can generate benefits even when only two parties use them. Furthermore some TBO applications provide similar functionalities as existing ones, but can provide added value still. Sharing services such as FF-ICE and ADS-C provide similar or even identical parameters. However, by parallel implementation of the resulting application can be made less dependent on the sharing parties' equipage and the best available data can be used.

   Therefore the transition to TBO will require an open mind to multiple deployment paths, both bi-lateral and in parallel.

5. **Develop applications by implementing small steps into operation**

Traditionally, ATM system changes implemented in a linear fashion from concept definition to implementation. The transition to TBO cannot take place in this fashion as
1) the end-stage of TBO is not defined,
2) there are many potential transition paths,
3) none of the intermediate steps are validated

The nature of the transition to TBO in the Netherlands therefore needs to be shaped as a pathfinding development: defining, evaluating and implementing multiple small steps. By developing applications in small steps and implementing these in (initially limited) operation, the details of the applications can be developed and tailored to the Dutch operation and early benefits may be gained as and when stakeholders become technically and operationally equipped.

6. **Involve all stakeholders in the transition to TBO**

Collaboration with different stakeholders is key for implementation of TBO. The entire concept is based on increased sharing of data and information. This requires alignment of standards but also of equipage / implementation of enablers.

Several international collaborations are defining standards for data sharing, operations and applications within TBO. Based on who is involved, these standards may not support all needs for the specific operation in the Netherlands.

Active collaboration supports ensuring that standards are in line with the needs for the Dutch operation and that applications are developed when stakeholders are equipped to use and benefit from them.

As a basis for a future roadmap, we recommend the following high-level roadmap. A more detailed proposal with concrete actions is provided in Section 6.6.

1. Now / short term
   - Start development of concepts for the use of ADS-C EPP and FF-ICE data.
   - Implement data channels for the same via SWIM.
   - Actively participate in the development of the iTEC V3 requirements.
2. When data sharing connections have been established
   - Start collecting data for development purposes.
   - Start developing prototypes for applications on the non-core ATM systems such as ASAP.
   - Start trialling those prototypes into limited operation and expand from there.
3. When iCAS is operational
   - Start implementation of TBO applications on the core ATM systems.

3 Introduction to Trajectory Based Operations

This chapter describes the operational concept of Trajectory Based Operations (TBO), its functions and why this is relevant for the aviation stakeholders in the Netherlands including expected benefits.

3.1 Operational concept

Air Traffic Management (ATM) is defined by ICAO (Doc 4444) as the dynamic, integrated management of air traffic and airspace including air traffic services, airspace management and air traffic flow management — safely, economically, and efficiently — through the provision of facilities and seamless services in collaboration with all parties and involving airborne and ground-based functions.

In the current situation throughout the world, ATM service provision is hampered by limited or sometimes even lack of information sharing between stakeholders, inconsistent and inaccurate trajectory predictions, and lack of or limited management of trajectories beyond sector and/or FIR boundary. This leads to locally optimised traffic flows, limiting the overall performance of the global ATM system in terms of efficiency, predictability, capacity, flexibility and global interoperability.

The aim of the ICAO global TBO concept (ICAO, 2021) was developed to overcome these shortcomings. The concept describes an ATM environment where the flown flight path is as close as possible to the user-preferred flight path by reducing potential conflicts and resolving demand/capacity imbalances earlier and more efficiently. In such an environment, a four-dimensional (4D) flight trajectory, collaboratively developed, managed and shared, would serve as a common reference for decision-making across all stakeholders.

Different implementations of the TBO concept are under development in different parts of the world. In Europe TBO is adopted as the main component of the ATM operational concept as described in the SESAR concept of operations (SESAR JU, 2019).

Each region has its own local specifics and focus, but they are all performance based. This means that function and performance are specified rather than a technology. When it comes to technology the central requirement is that it must be interoperable, i.e. enabling distributed ATM service provision as if it were through a single system.

The major changes involved to develop towards TBO are represented by three key words in the ICAO definition:

- Trajectory information as a common plan for the flight,
- Sharing of trajectory information, and
- Management of the trajectory.

3.1.1 Trajectory Information

In its basic form, trajectory information represents a reference of the aircraft's location in four dimensions, i.e., latitude, longitude, altitude, and time (See Figure 1).

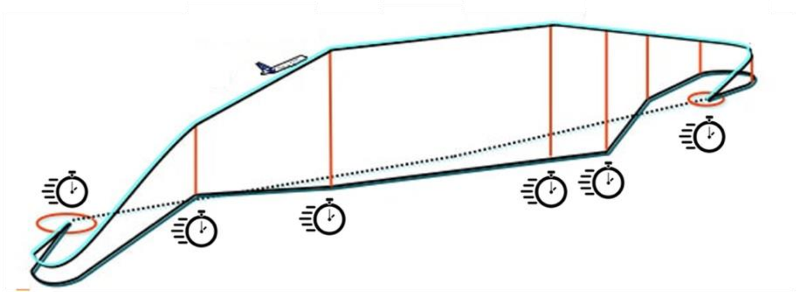

Figure 1: 4D trajectory

The 4D-trajectory is initially constructed by the airspace user during the flight planning processes. During the lifecycle of the trajectory, other stakeholders such as the network manager, airports and ATS units, update and enrich the trajectory with control elements prior to and during the flight in response to emerging conditions and stakeholder inputs:

- Up to the time of departure the trajectory is updated in response to restrictions from flow and capacity management processes as well as the departure airport,
- Distributed parts of the trajectory are used by ATC to plan and manage the traffic and provide clearances,
- In response to changing conditions amended clearances (direction, altitude and/or speed) may be required during the flight (weather avoidance, avoiding action, diversions, non-normal situations, etc).

At a high level of abstraction this is no different from the current operation, but in trajectory-based operations, the 4D trajectory has a greater level of detail and is enriched by a broad range of information relevant for management of the trajectory. The information is continuously updated, available to and can be used by all stakeholders, where each stakeholder has particular requirements for use of the data. This means that trajectory information is not only a string of 4D positions for a particular flight, but rather a collection of control elements used to control and manage the trajectory while allowing for optimisation.

3.1.2 Trajectory Information Sharing

In the current operation trajectory information is shared between the airspace user and the ATM system via the ICAO flight plan format. This 50-year-old ICAO format contains only basic flight information such as departure and destination aerodrome, planned off-blocks time, flight time, cruising altitude and speed, route, etc. The information provided to the flight crew to execute the flight is much more detailed and extensive. After the flight plan has been filed the trajectory information starts to lead a separate life.

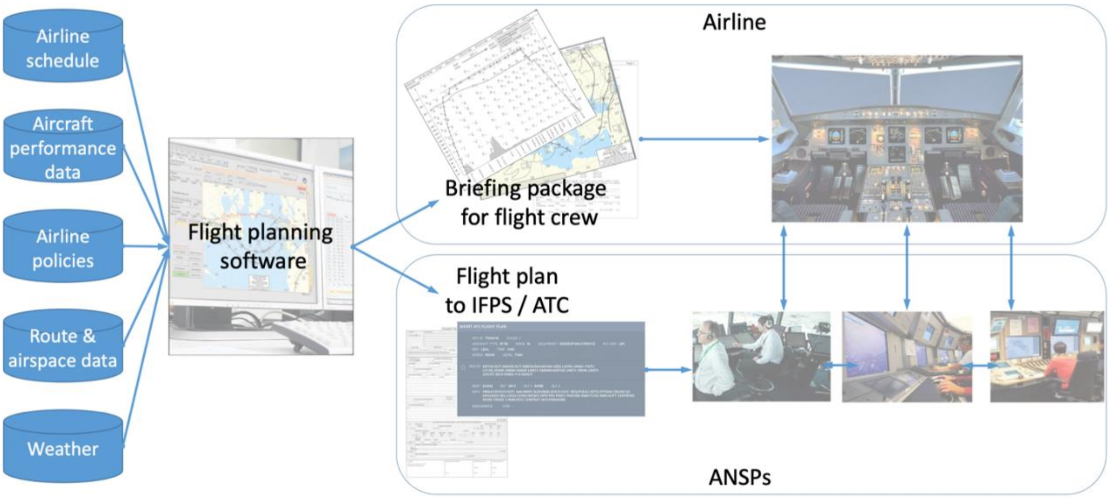

Figure 2: Current flow of (non 4D) trajectory information

ANSPs amend flight plan information with other information sources for trajectory prediction within their own area of responsibility for planning and handling of the traffic with limited awareness of amendments made by upstream ATS units, airline operational preferences and crew intentions that may occur during the flight. Flight crews have limited awareness of operational conditions in airspace and at airports. Consequently, all stakeholders have only a limited set of information relevant to them, and no one has all the information pertinent to their task.

In the TBO concept trajectory information is shared amongst stakeholders. This includes information sharing between ATS units, between ground and airborne actors and systems, airports, operators, meteorological service providers, etc.

Trajectory information sharing allows ground and airborne actors and systems to have access to consistent and up to date four-dimensional flight information, meteorological information, airspace information and aerodrome information, to provide a consistent view of the factors that affect each flight's trajectory.
Not all information is always relevant for all stakeholders. Information sharing is based on operational needs to the extent needed for TBO.

With effective trajectory information sharing, all stakeholders are provided with a clear view of the trajectory the aircraft is expected to fly with the lateral, vertical or time trajectory and/or generic constraints that define it, as well as of the operational factors that may affect it. This continuous sharing and updating is enabled through technological developments in information management, air-ground datalink and automation.

3.1.3 Trajectory Management

Management of trajectories involves the use, modification, and coordination of trajectories by (a group of) ANSPs. The main functions that can be distinguished in Trajectory Management include:

- Trajectory generation & prediction,
- Planning and
- Execution.

In its most basic form this is not different from the current operation. The difference in a TBO environment is that more extensive and predictable trajectory information is available that can be used to optimise the handling of traffic.

Prior to departure the airspace user's initially planned trajectory is generated and used as a starting point for planning purposes at the network level. Airspace configurations are planned based on the operational conditions such as weather, CNS/ATM system availability and expected volume of traffic. Capacity bottlenecks may constrain (parts of) the initially planned trajectory and trigger a coordination process that leads to modification of the plan. Once an agreement is reached the user's initially planned trajectory has developed into an agreed trajectory[1].

The agreed trajectory may be subject to change to accommodate requirements from an airport departure management process. Within certain tolerances a delayed departure time can be accepted without affecting the network planning by the Network Manager including the arrival demand at the destination airport. When the consequences have been considered and found to be acceptable, the flight's trajectory is modified and used as the new agreed trajectory. At some time prior to departure, the local ATS unit provides a pre-departure clearance based on the latest version of the agreed trajectory.

During flight, clearances will continue to provide the authorisation for an aircraft to proceed under conditions specified by an ATS unit. The main difference in a TBO environment is that the clearance is based on the agreed trajectory. When executed in accordance with the clearances, the trajectory flown is the agreed trajectory within the execution precision of the flight.

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[1] In SESAR the four-dimensional (4D) trajectory is called *business trajectory*, and once agreed it becomes the *reference business trajectory*. However, these are conceptually identical to the *agreed trajectory* as defined by ICAO.

TBO and new technology for air-ground integration will provide controllers with additional opportunities to monitor adherence to the agreed trajectory, e.g., to monitor if the correct procedure has been loaded in the aircraft's Flight Management System (FMS). Should any anomaly be observed, then the controller could intervene earlier to ensure that the correct procedure is loaded before it is flown, or the agreed trajectory is updated.

In a TBO environment conflict management will continue to be provided in three layers:
1. Strategic conflict management, i.e., reducing the likelihood of conflicts through proper airspace organisation, traffic demand management and synchronisation of traffic flows.
2. Separation assurance, i.e., separation of a flight's trajectory from hazards during flight execution for a limited look-ahead time (conflict horizon), and
3. Collision avoidance, i.e., an independent safety net to deal with situations where separation provision has been compromised.

An important difference with the current operation is that the improved content and quality of the trajectory information in a TBO environment facilitates detection and resolution of potential conflicts beyond the conflict horizon for separation assurance. Trajectory coordination between multiple ATS units may be required before an agreed trajectory can be modified.

If any of the stakeholders involved in execution of the flight (ATC, flight crew, operator, etc) has a need to modify the agreed trajectory during the flight (e.g., for separation assurance, weather deviation, step climbs), a replanning, coordination and modification process is executed that results in an updated agreed trajectory.

3.2 Scope of TBO in the future ATM-system in the Netherlands

In the TBO operational concept aircraft trajectories are managed from gate-to-gate and affect all phases of flight. Flights operating across multiple ANSPs encounter some additional considerations in the planning and execution of trajectories. This applies to the situation in the Netherlands, considering the relatively small dimensions of Dutch controlled airspace (Amsterdam FIR). Figure 3 shows the FIRs surrounding Amsterdam FIR, which affect TBO in the Netherlands.

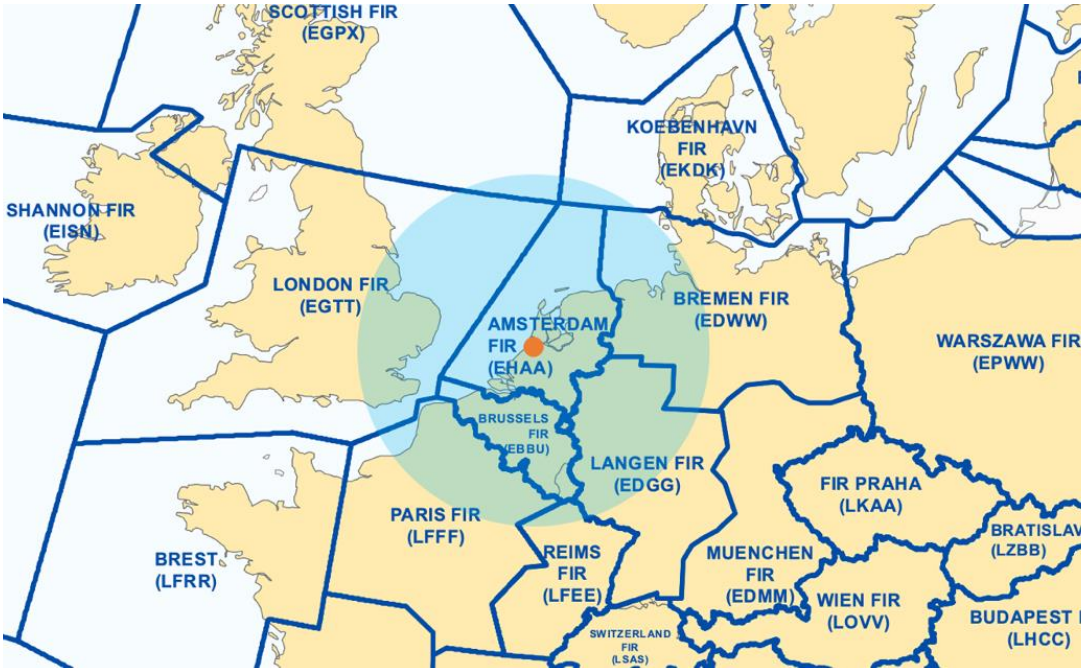

Figure 3: Amsterdam FIR including surrounding FIRs in the Lower Airspace

This paragraph aims to scope the aspects of TBO that are considered relevant for this study.

3.2.1 Trajectory generation and ATFCM planning

Trajectory generation by the airspace user and subsequent planning as part of the air traffic flow and capacity management (ATFCM) process is considered outside the scope of this study. Interfaces with these processes shall be addressed to ensure that trajectory information can be shared unambiguously and effectively.

3.2.2 Departure planning and execution

The stakeholders at Dutch airports (airspace users, airport operator, handling agents, local ATS unit) collaboratively develop departure plans based on the agreed trajectory from the ATFCM process. This is similar to the current airport-CDM activities, but with greater predictability.

The improved predictability is reflected in stable target off-blocks time (TOBT) prediction by the ground handler and airspace user, stable target startup approval time (TSAT) planning by the local ATS unit, stable target take-off time (TTOT) planning by the local ATS unit considering runway usage, taxi route, operational conditions, etc.

Execution of the agreed trajectories, i.e., provision of start-up, pushback, and taxi-clearances, should be done in accordance with the agreed plan and result in accurate actual times of take-off from the runway (ATOT) as compared to the planned (and/or updated) TTOT. Events subject to uncertainty, such as pushback, are managed by continuous monitoring and updates of the agreed plan.

When the flight has taken off, estimated times along the aircraft's trajectory are more accurate as the departure time uncertainty no longer applies. This greater predictability of outbound traffic is beneficial for the greater network outside Dutch airspace.

In addition to time, downlink of aircraft derived data allows ground systems to use trajectory information such as planned speed and altitudes to ensure consistency with the agreed trajectory and update it as necessary. It also facilitates conformance monitoring during the flight execution, such as incorrect selection of a SID in the FMS that could be identified before it causes a separation conflict.

During flight the aircraft will not fly exactly where predicted due to wind and performance uncertainty. The prediction may be adjusted to account for this uncertainty using information sources such as surveillance data and aircraft-derived trajectory information (if available). When the prediction shows that established tolerances are exceeded, the agreed trajectory is updated and shared with all relevant stakeholders.

Improved predictability not only increases the efficiency at a single airport. TBO also provides opportunities to incorporate trajectories from other nearby airports in a single operating plan and improve the efficiency of multi-airport operations at Schiphol and other (Dutch) airports.

3.2.3 Climb and enroute planning and execution

After departure from an airport a flight proceeds in climb and/or enroute flight. During these flight phases ATC provides clearances in accordance with the agreed trajectory. The clearance is generally limited to the borders of the ATS unit's area of responsibility unless coordination with the adjacent centre has taken place. For air transport category aircraft flying in the lower Dutch airspace this transfer generally occurs before passing FL245 or the FIR boundary. Considering that the cruising altitude of these aircraft is generally well above FL300, enroute planning and execution is seldom applicable within the scope of this project.

Enroute planning and execution may be applicable if the flight involved is a domestic flight. For domestic flights the cruising level is generally not above FL100. For these flights planned step climbs are not very likely to occur.

Trajectory revision requests in the lateral plane can be expected (e.g., request for weather deviation or a request direct to a waypoint) for both climbing and enroute traffic. The flight is provided a clearance to deviate some number of nautical miles laterally from the route. When deviating for convective weather, the agreed trajectory is maintained with knowledge of higher uncertainty after the expected end of the manoeuvre. Once the flight has passed the weather, the agreed trajectory may be revised and updated as necessary to account for the outcome.

Trajectory prediction in ATM ground systems is used for conflict detection and resolution. In a TBO environment conflicts are detected and solved strategically and tactically by controllers when required. Separation provision by controllers should preferably be resolved while meeting downstream constraints. When this is not feasible the agreed trajectory needs to be updated.

In a TBO environment, the agreed trajectory is continually updated and shared across ANSPs.

Downstream ATS units no longer rely on a periodic update of data from the Flight Plan (FPL) to the Current Plan (CPL) or Advanced Boundary Information (ABI) ATS messages. Instead, downstream ANSPs are constantly informed as the flight is being planned and executed via sharing of the agreed trajectory. Revisions to the agreed trajectory allow the downstream ASP to be informed of anticipated boundary conditions as they are planned and not necessarily via fixed waypoints on the airspace boundary.

3.2.4 Descend, arrival and approach planning and execution

When air transport category aircraft approach the arrival airport in the Netherlands, the distance to fly is generally more than 120 NM away from the destination airport when the descent is initiated. The aircraft is under control by a foreign (i.e., non-Dutch) ATS unit.
In a TBO environment detailed and predictable trajectory information about arrivals is available at an early stage. This provides the opportunity to influence traffic at greater distances from the destination airport, i.e. outside Dutch airspace, cross-border. This includes timely informing flight crew of the expected runway and transition which allows planning an optimal arrival in the FMS.

When demand and capacity are closely matched, an arrival management function may need to provide a more constrained time of arrival to synchronise arrivals. This process can result in a trajectory revision to meet the arrival time at which the aircraft can be accommodated. The agreed trajectory is revised to account for any new constraints. Upstream centres can provide clearances (e.g., routeing, altitude or speed instructions) to the flight in accordance with the agreed trajectory.

For fully capable aircraft and ATS units, the flight has received a clearance including the speed profiles and speed/altitude constraints along the descent profile. Properly equipped aircraft may also provide the aircraft-derived trajectory information (e.g., the location of the Top of Descent, TOD) to the ground systems to reduce trajectory prediction errors and update the agreed trajectory as the flight executes.

3.3 Expected benefits

The ICAO global TBO concept (ICAO, 2021) describes expected benefits of TBO across multiple Key Performance Areas (KPA), such as efficiency and predictability, capacity, flexibility participation by the ATM community and global Interoperability.

In the SESAR operational concept (SESAR JU, 2019) benefits of TBO are expected in the field of enhanced safety, enhanced security, enhanced predictability and reduced fuel consumption and emissions.

Benefits of TBO in the Netherlands are a combination of the performance areas mentioned in both concepts. The key benefit is that TBO improves the predictability of trajectories. Planning during different stages of the trajectory lifecycle (i.e. layered planning) enables conflict detection and resolutions at greater time horizons. When planning and execution in accordance with the agreed trajectory is carefully monitored and safety nets are in place, separation assurance and tactical intervention by controllers is required less frequently and workload is potentially reduced. This is expected to have benefits in terms of safety and capacity. Provided that more optimum trajectories (fixed terminal routes and free routes in higher airspace combined with continuous climb and continuous descent operations) become feasible, reduced fuel consumption and emissions can also be expected as a benefit.

4 Enablers for Trajectory Based Operations

Trajectory Based Operations essentially consist of the sharing of trajectory information and controlling the trajectory by exchanging control information. Enablers for TBO are the different technologies and methods used and under development for the sharing of trajectory information between parties.
This chapter describes enablers for TBO in The Netherlands. The descriptions aim to explain the ability that an enabler adds to the operation. At the end of each section a short description of the operational readiness and relevant mandates is provided. These enablers are further detailed in Appendix 7.1.

Enablers are categorized in one of the following groups:

- Platform: enablers that can host (parts of) the enablers in the other groups
- Medium: enabler that facilitates the exchange of trajectory (control) information
- Information sharing: enablers that represent the interaction between different stakeholders in the TBO process.

4.1 Platform enablers

The platform enablers are the ATM support systems that can host the different TBO applications/enablers. The platform enablers are divided in core ATM and purpose specific ATM support systems, which are described in this section.

4.1.1 Core ATM support systems

The core ATM support systems (AAA and iCAS/iTEC) provide the platform for:

a) Integral Trajectory Management Support,
b) The HMI for Trajectory Management applications. In some cases, elements of the controller HMI form components of the TBO application.

AAA is the current main ATM System supporting APP and ACC. Since this system is going to be replaced by iCAS, changes to the AAA system can no longer be accommodated due to a functionality freeze. Any changes that would be needed to this system have either to be postponed till after the commissioning of iCAS, or temporarily hosted on an auxiliar system if possible and desired.

An essential element in the transition to TBO is the development of the iCAS system, in essence the development of flight data processing- (FDP) and controller working positions (CWP) technology. The iCAS system enables the controller to manage aircraft trajectories in real-time and provides data exchange capabilities with adjacent centres (through IOP and SWIM), the Network Manager (through SWIM) and the aircraft (Though SWIM and Air-Ground Datalink)

The development of iCAS is performed within the framework of the iTEC system consortium in which ANSPs have agreed to align their system development on the basis of common requirements. Within the iTEC framework iCAS is a common development between DFS and LVNL, which has been labelled as iTEC V2 (version 2). For LVNL the iTEC V2 implementation is a one-to-one system replacement of the AAA system.

The first significant system upgrade for LVNL will be iTEC V3, which will comprise a step towards system commonality and a step towards TBO. As a matter of principle it can be stated that new TBO functionality, will by definition be a step towards commonality, as there is no reason why LVNL would want to implement any Schiphol specific functionality in support of TBO.

As part of the iTEC V3 Definition Phase (2020 – 2022) an iTEC V3 CONOPS is drafted, which contains several TBO related building blocks. Parallel to the CONOPS development, the V3 Definition Phase focusses on the standardisation of IOP, the FDP interoperability standard. In short the iTEC V3 development can be summarised in two main focus areas:

1) Trajectory management related solutions (FDP and CWP)
2) Data exchange solutions (IOP, SWIM, Air-Ground Datalink)

Most partners in the iTEC consortium currently focus on the application of TBO concepts in the en-route phase of flight. The deployment of iTEC V3 in an airspace that is mainly characterised by departures and arrivals introduces different needs on TBO functionalities. This requires active involvement in the requirement specification phase.

Finally, the V3 definition and deployment may lack functions that are needed for Schiphol specifically, but not for other airports. If Schiphol specific functions are needed, which will not be adopted in the common definition, then there will be no cost sharing possibility for these functions. These functions may still be implemented or upgraded, provided they have a business case (despite the lack of cost sharing), but they will have to come in Schiphol specific releases. The key to enable this non-common part of the TBO development is a timely development of requirements, as implementation is dependent on an iTEC wide change release planning.

4.1.2 Purpose specific ATM support systems

Apart from the core ATM support system, in modern ATM System architectures, separate applications, designed for a specific purpose have been introduced. Currently these entail:

- **AMAN**: The Arrival Management capability is hosted by the ASAP system. It provides functionalities for prediction, planning and execution of the arrival planning. It has been developed as a platform independent from the core ATM System. The ASAP platform and its functionalities, therefore, can be developed independently from AAA or iCAS if no controller HMI in support of these developments are needed. In some cases, for the purpose of decoupling AMAN developments from the iCAS development planning, as well as to facilitate AMAN innovative activities, a temporary auxiliary HMI could be used.

- **DMAN**: The Departure Management capability is hosted by the TWR systems environment. Currently the functionality is limited to managing the departure flow towards the departure runway and does not include management functions of departures trajectories.

- **Integral Trajectory Manager:** this is a future system that is intended to host capabilities that integrate all trajectories being managed by LVNL. These capabilities comprise multi-airport traffic synchronisation support and advanced trajectory conflict management functions. The latter functions are expected to be employed in support of the 3D fixed TMA-route system.

4.2 Enablers for the communication medium

This section describes the enablers for TBO that offer a communication channel between stakeholders to perform information exchange for trajectory management.

4.2.1 SWIM (Yellow profile)

The SWIM yellow profile protocol defined by SESAR provides a convenient channel for information exchange. Since the protocol is based on ‘light-coupling’ between sender and receiver, the implementation complexity is limited yet fully secure.

It is important to note that these information exchange services have been chosen as the medium of choice for three essential information sharing enablers (described in paragraph 4.3):

- FF-ICE
- ADS-C Common Server (ACS)
- ED-254 for communicating Extended Arrival Management information

State of the art
The physical network connection for SWIM is already in place at LVNL. The status at other Dutch stakeholders is unclear. The FF-ICE and ED-254 services are operational in limited trial settings.

4.2.2 (e)IOP

The (e)IOP enabler provides the connection as well as the process for Ground-to-ground interoperability (IOP). It supports the sharing of an up-to-date Flight Object (FO) between systems of all relevant ANSPs. The FO contains the agreed trajectory. The FO also contains all constraints to which the trajectory must comply and the intent on which it is based.

In IOP, the agreed trajectory is generated and maintained by a central flight data management service. The latter is expected to be the ANSP that is currently in contact with the flight. A drawback of this approach is that the responsible ANSP must be completely aware of all constraints in all downstream airspaces.

Essential IOP (eIOP) is a variant of IOP with the same objectives and functionalities. The key difference is that the central flight management service can, but does not need to, predict the full 4D trajectory. If unable to predict a section of a trajectory in some airspace, the flight management service can delegate predicting that section to the local ATSU. Subsequently the central flight management service will validate and integrate that in the complete FO and distribute the latter to all relevant ATS Units.

State of the art
An initial standard for IOP has been developed. As time progressed however, this standard proved too complex to implement. According to several of the interviewed experts, the original IOP standard is unlikely to be realised. As a solution, the eIOP standard is being developed by the system integrators and ANSPs. The eIOP concept is already partially specified in the iTEC V3 requirements definition but likely to change as the standard develops.

4.2.3 Dedicated connections

Existing ground-ground communication connections remain in place. These typically concern the OLDI based connections between ATC centres.

4.3 Information sharing enablers

Trajectory Based Operations essentially consists of the sharing of trajectory information and controlling the trajectory by exchanging control information. In this section, the enablers that facilitate the sharing of trajectory information are described.

There are different stakeholders involved in the sharing of trajectory related information:

- ANSP
- Aircraft
- Aeronautical Operational Control (AOC)/Airline
- MET providers
- 3rd party trajectory providers

Different technologies and methods are used and under development for the sharing of trajectory information between these parties:

- Aircraft-ANSP: Exchanging information between the aircraft and ANSPs serves two purposes:
  - the aircraft can inform the ANSP of its current trajectory and intentions. This allows ANSPs to verify clearances and create the most accurate trajectory management solutions.
  - ANSPs can deliver clearances to the aircraft in a digital way. This allows not only for workload reduction, but also the use of more advanced clearances, typically used for ground management purposes in a TBO environment.
- ANSP-ANSP: The very nature of TBO is to control the trajectory in meaningful segments. This inevitably, for The Netherlands, implies tight collaboration on the management of trajectories for a TBO environment. To this end, information needs to be exchanged on flight progress and control actions between ATS units.
- Airline-ANSP: The purpose of TBO is to facilitate as much as possible that the airspace user can fly according to its preferences in the most efficient and effective manner. Often, information expressing such preferences, referred to as intent, is available to the airline's Airline Operations Centre (AOC). Establishing a tighter coupling between ATS and the AOC's can foster this objective by communicating intent and possibilities between parties.
- 3rd Party Trajectory providers: Traffic and trajectory related information is no longer a field exclusively managed by the ANSPs and airlines. New, third-party sources have become available that may provide information on aircraft position, as well as trajectory prediction information. This information can supplement, as appropriate, existing information sources.
- Meteo: weather information plays an important role in deriving accurate trajectories for both planning as well as execution. It concerns upper winds and temperatures. For the ground systems it is important to establish accurate and feasible trajectory plans. Furthermore, during execution, for monitoring the progress of the execution of the plan as well as separation assurance, the quality of this information is important to establish the most effective control actions. For the aircraft, accurate information yields a more flight efficient plan with less deviations caused by unexpected wind situations. This in turn will result in less controller interventions needed to keep the planning intact.

Enablers for these different types of information sharing will now be described in more detail.

4.3.1 Air-ground integration

In the current operation the assumed trajectory of a flight often differs between the FMS and the ground systems. At the same time, neither will have the most accurate trajectory: The airborne system is best aware of the aircraft’s actual performance and intent. The systems at ANSPs often have more information about the constraints to the remaining trajectory (such as the exit level of a sector).

Ensuring that both have, and use, the same agreed trajectory requires the means to share the trajectory, and the underlying constraints from aircraft to ground and vice-versa. Furthermore, current airborne systems often use limited and/or outdated weather information. This section describes three enablers that would support aligning the trajectory on the ground and in the air.

4.3.1.1 CPDLC baseline 2

Controller Pilot Datalink Communication (CPDLC) Baseline 2 allows ATC to share a complex 4D clearance with the aircraft so that they can be loaded and executed safely and predictably by the aircraft FMS.

A 4D clearance (2D positions, altitude and speed constraints) can be too complex to be communicated by voice and entered in the FMS by the crew. By digitally uploading the clearance and automatically loading it into the FMS, the loop in trajectory management (clearance uplink, execution, downlink of trajectory and confirmation) can be closed. ATC, the crew and FMS have an unambiguous definition of the agreed trajectory through this technique.

State of the art
At least 100 aircraft are equipped but there is no operational use of the concept. There is no mandate for this capability.

4.3.1.2 ADS-C EPP

Automatic Dependent Surveillance-Contract Extended Projected Profile (ADS-C EPP) allows downlinking the flight's trajectory as predicted by the FMS to ATC. This provides the ability to both understand the flight's expected performance as well as a verification of the trajectory as understood by the airspace user.

This trajectory is described in up to 128 four-dimensional points (waypoint, altitude and time). However, it also contains information on lateral, vertical and speed intent data (its planned speeds), the range of speeds that the aircraft can fly and its mass. With this information a ground TP can construct its own trajectories for Trajectory Management purposes.

ADS-C requires an ANSP to establish a contract with an aircraft to share data. Since multiple ANSPs may be interested in the information a project to share this data has been started. The ADS-C Common Service foresees a central connection to the aircraft and sharing of the data via SWIM Yellow Profile.

State of the art
At least 100 Airbus aircraft have been equipped and the technique is used operationally by MUAC for these aircraft. All new aircraft that are to fly in upper airspace have to be equipped from 1 January 2028.

The ADS-C Common Service project is in progress but it's timeline could not be determined.

4.3.1.3 Meteo uplink

Digital uplink of weather information such as wind and temperatures to aircraft could improve the trajectory prediction of the onboard flight management computer when compared to the use of (relatively old) weather data collected during the flight planning process. The improved trajectories could be used for improved fuel predictions and/or ATM planning purposes. Uplink to the aircraft is done via ACARS AOC datalink, a dedicated connection between the airline's operations centre and the aircraft.

The uplink will also aid in a more accurate execution by the FMS of any (ATC instructed) speed schedule for planned, FMS managed descents. Such descents are desirable in a TBO context as they minimize the number of interventions required by ATC and therefore enhance predictability and above all capacity.

State of the art
Several versions of the concept are operational with different airlines.

4.3.2 Ground-Ground/AOC trajectory information sharing

The future form of trajectory information sharing between ANSPs is ground-to-ground interoperability (IOP). This approach shares the trajectory and all relevant parameters to generate a trajectory (combined as the Flight Object, FO). However, many other forms of sharing (parts of) the FO provide alternative routes or early enablers until the concept is operational.

Information with which a trajectory can be calculated (such as speed, mass, intent) enables local generation of trajectories. These may be necessary to generate trajectories in a form that fits local needs but, more importantly, allows exploration of alternative trajectories. These 'what-if' trajectories allow downstream ANSPs to develop a solution to a separation or spacing conflict and determine the optimal trajectory modification to resolve the conflict.

4.3.2.1 (e)IOP

Ground-to-ground interoperability (IOP) is the information sharing of an up-to-date Flight Object (FO) between systems of all relevant ANSPs. The FO contains the agreed trajectory. The FO also contains all constraints to which the trajectory must comply and the intent on which it is based.

In IOP, the agreed trajectory is generated and maintained by a central flight data management service. The latter is expected to be the ANSP that is currently in contact with the flight. A drawback of this approach is that the responsible ANSP has to be completely aware of all constraints in all downstream airspaces.

Essential IOP (eIOP) is a variant of IOP with the same objectives and functionalities. The key difference is that the central flight management service can, but does not need to, predict the full 4D trajectory. If unable to predict a section of a trajectory in some airspace, the flight management service can delegate predicting that section to the local ATSU. Subsequently the central flight management service will validate and integrate that in the complete FO and distribute the latter to all relevant ATS Units.

State of the art
An initial standard for IOP has been developed. As time progressed however, this standard proved too complex to implement. According to several of the interviewed experts, the original IOP standard is unlikely to be realised. As a solution, the eIOP standard is being developed by the system integrators and ANSPs. The eIOP concept is already partially specified in the iTEC V3 requirements definition but likely to change as the standard develops.

4.3.2.2 AFP to NM

By sharing changes to the route of a flight with NM, ANSPs can enable NM to generate more accurate estimates. This enables a more accurate traffic picture within the ECAC area and supports more accurate information on the flight with downstream ANSPs.

Currently, NM receives messages from ANSPs in the ECAC area to inform NM about the progress of the flight. These messages primarily concern the actual position of each flight in the ECAC area by means of a so called Correlated Position Report (CPR) message. All ANSPs in the ECAC area provide this message to NM, based on their own surveillance sources.

There are also other OLDI message types defined to inform NM about changes to flightplan information (AFP). One of the most relevant messages in this group concern updates with respect to flight routing, in particular direct routing issued by ATC to the flight.

Ensuring that NM has the most up-to-date information with respect to actual position and planned trajectory, enables three benefits:

- NM can be more effective when regulating traffic
- NM can provide more accurate estimates to downstream ANSPs
- NM can provide connected ANSPs with more accurate routing information. This enables ANSPs to perform more accurate Trajectory Management themselves.

State of the art
The message protocol exists. However, only a limited number of ANSPs in the ECAC area provide these messages to NM.

4.3.2.3 ED-254 Arrival Sequence Performance Standard

EuroCAE ED-254 Arrival Sequence Performance Standard allows one-way communication of extended AMAN related information from an AMAN centre to upstream centres. This standard enables transmission of speed modification and route variations for delay absorption to upstream centres beyond the immediate upstream centre. Furthermore, it enables sharing arrival information with the flight crew through the upstream centre.

The current OLDI AMAN capability allows two-way communication of AMAN trajectory modifications but only with the immediate upstream centre that the flight passes through. Using ED-254, all relevant upstream centres can be informed of AMAN requests and the current responsible ANSP can execute the request.

Note that it is one-way communication only: The upstream centre cannot give confirmation of execution. ADS-C could provide a confirmation back to the AMAN sequence manager that modifications have been effected.

The standard also enables sharing of other arrival details to the upstream centre such as the expected arrival runway and routing in the TMA. Any subsequent trajectory downlinks from the aircraft will deliver more added value as the profile will match the eventual profile required by ATC to a greater extent.

The upstream centre, when in contact with the flight, can communicate the arrival information to the flight via either voice or CPDLC.

State of the art
The standard is defined, but no operational implementations are known.

4.3.2.4 FF-ICE

Flight and Flow – Information for a Collaborative Environment (FF-ICE) is a data and information exchange process between all stakeholders (ANSPs and airlines) in a specific format for planning, coordination and notification of flights. Most notably, this process will lead to the replacement of the standard ICAO 2012 flight plan format.

In its full form, FF-ICE is intended to facilitate sharing information throughout the life cycle of the flight (i.e. from flight intention months before departure until arrival at the destination gate). The first release (FF-ICE Release 1) consists of everything related to the planning until departure.

Within the scope of TBO for The Netherlands, the most important change is the ability to share much more information on the intent of the airspace user that can be shared in the ICAO 2012 flight plan format. This would allow airspace users to provide information on preferred speeds for example. Such information could then be used by local systems to generate trajectories that are more accurate and most likely closer to the preference of the airspace user.

State of the art
FF-ICE Release 1 is fully specified and sharing using this format via SWIM (Yellow Profile) is mandated per 2025. However, the information contained in the format does not need to be more than the information contained in the ICAO 2012 flight plan. Enabling further benefits through FF-ICE requires airspace users to provide additional information such as speeds during climb and descent. The implementation of FF-ICE capable planning systems foreseen at major carriers at Amsterdam and initial sharing of FF-ICE data between an airline and the Network Manager is being trialled.

FF-ICE Release 2 aims to support sharing information and negotiating changes to a trajectory during the flight. Definition of this release is still highly conceptual, and more details are not expected before 2025.

4.3.2.5 3RD Party Surveillance

Trajectory prediction for inbound aircraft starts from the current (estimated) location of the aircraft. Currently, an accurate initial position is only available when the aircraft is within LVNL's own radar coverage.

The full TBO concept foresees sharing of the up-to-date trajectory between all actors. However, this requires upstream ANSPs and all aircraft to be fully TBO enabled as well. In the intermediate period, trajectory predictions will be made at LVNL for those flights for which no trajectory information is available.

By using surveillance information from other sources than local radar, it is possible to generate local trajectories while aircraft are further from the Dutch FIR. These surveillance sources can be radars of neighbouring ANSPs but also information from non-ANSP providers.

Beyond extending the surveillance coverage using nearby radars, satellite-based ADS-B provides coverage that is independent of location. This would allow an arbitrary surveillance horizon and the ability to generate trajectories and use from that horizon during the transition to full TBO.

State of the art
Sharing of surveillance data between ANSPs already happens. A number of providers also provide satellite-based ADS-B data. These capabilities are already used operationally by a number of ANSPs.

5 TBO applications

In this chapter the potential applications of TBO for the Dutch ATM system are described, based on the operational concept discussed in chapter 3 and the enablers in chapter 4.

The key element of TBO in the Dutch ATM system is that sharing of trajectory information facilitates trajectory management of departing and arriving Schiphol traffic and integration of traffic to and from other Dutch airports.

Trajectory management in these three application areas all involves prediction, planning and execution of trajectories. This is expected to significantly reduce the need for tactical intervention and result in greater predictability, increased safety, improved efficiency, and environmental benefits.

5.1 Trajectory management of Schiphol departures

Departure management plays an important role in making optimum use of the available departure capacity at a busy airport like Schiphol. The various processes involved are not different than in the current operation, but with Trajectory Based Operations the departure planning can benefit from the trajectory information that is shared and maintained among all stakeholders.

With agreed trajectories coming out of the ATFCM process the local ATS unit has a clear understanding of the future traffic demand and is able to better predict the departure trajectories due to the information provided by FF-ICE. Together with weather forecasts, runway use preferences and operational constraints, this information is used to plan the runway combinations that are used at the airport.

An improved Departure Manager (DMAN) could benefit from the greater level of detail of the departure trajectories to optimise departure flows. It calculates the departure sequence per runway by considering the target off-blocks time (TOBT), taxi time, assigned SID, wake turbulence category and any ATFCM constraints. Knowing the route, vertical profile and preferred speeds, the planning process could use conflict detection and resolution functions to identify potential conflicts between subsequent departures and assign a different speed or route if needed.

When integrated with the Arrival Manager (AMAN) and Surface Manager (SMAN) if available, any constrains on departures, resulting from arrival and taxi-operations at the airport, could be incorporated. The resulting target take-off times (TTOT) and target start-up approval times (TSAT) are used to update the agreed trajectory and shared among the various stakeholders at the airport (airline, ground handling, airport, and ATC) via suitable communication channels (e.g., SWIM or other enablers).

Airport Collaborative Decision Making (A-CDM) processes are improved through the availability of more predictable and reliable trajectory information but remain vulnerable to disturbances during the turnaround process of an aircraft. Timely update of target of blocks time (TOBT) by airline and ground handling remains an important condition for predictability.

When a stable departure planning is achieved, the flight crew is provided with a clearance that defines the agreed trajectory. In addition, the trajectory information including departure time and accurate information about the route and flight profile of the flight can be shared with upstream ATS units via eIOP.

Departure planning information reduces the uncertainty and improves predictability for adjacent and upstream centres and may contribute to a reduction of ATFCM regulations. Information sharing of departure information is improved compared to the current operation by addition of complementary information channels via the Network Manager (NM) and via ADS-C EPP.

Trajectory execution in a TBO-environment is primarily based on provision of clearances in accordance with the agreed trajectory and monitoring of conformance with the agreed trajectory. Conflict detection and resolution in the planning phases may have already prevented that many potential conflicts occur and allow a flight to operate against its plan with minimal intervention by ATC.

With clearances becoming increasingly more complex, checking of the flight's progress compared to the intended agreed trajectory is also becoming more complex. Trajectory information is therefore foreseen to be used to monitor conformance of the FMS-loaded plan (aircraft intent) with ATC's plan or instructions (ground intent). Air-ground datalink capabilities such as ADS-C EPP, provide the capability to check if the correct departure procedure and subsequent routing have been loaded in the FMS. Using ADS-C EPP data the conformance monitoring function provides a continuous, pro-active, check of an aircraft's intended trajectory versus the ATC-held trajectory data. It enables discrepancies to be identified and resolved before the aircraft deviates from ATC's expected trajectory and complements existing surveillance-based, reactive, flight path monitoring.

Prior to departure, conformance monitoring functions using ADS-C EPP could identify if the correct runway and SID have been loaded in the aircraft's FMS and consider if any deviations from the cleared trajectory are to be expected that could negatively affect safety, e.g. in case of parallel departures at Schiphol. Conformance monitoring could also identify at an early stage if altitude constraints on the route can be met in the Schiphol TMA with a 3D route structure. Non-conformance due to weight is then signalled early to ATC, allowing for measures to be taken. This will contribute to a more robust 3D TMA-route operation. In addition, the speeds that are planned to be used are known and deviations from assigned or expected speeds could be identified by conformance monitoring.

TBO conformance monitoring increases predictability. Tactical conformance monitoring by the controller remains applicable for situations that require tactical intervention. Clearances that result in an update of the agreed trajectory between the runway and transfer to the adjacent centre (e.g. due to weather) are shared automatically via eIOP and the NM is informed via AFP to NM.

5.2 Trajectory management of Schiphol arrivals

The main advantage of TBO for Schiphol is the management of arrival trajectories in both the prediction, planning and execution phases.

The prediction of arrival trajectories is significantly improved with new enablers such as:

- FF-ICE/ADS-C EPP data from the airline and aircraft to provide better information on expected speeds to be flown during descent,
- ADS-C EPP data from the aircraft to provide better trajectory information such as altitude at specific waypoints,
- eIOP to provide up-to-date trajectory information from upstream ATS units, and
- 3rd-party trajectory information to provide initial trajectory information beyond current horizon.

The improved trajectory information allows the ground system to use the best available source of information and plan arrivals beyond the current planning horizon.

Arrival management (AMAN) involves a continual process of calculating arrival times for traffic arriving at an airport by considering the assigned runway, landing interval, sequencing, weather information, expected trajectory, etc.

With accurate trajectory information available in a TBO environment the time horizon for arrival planning can be extended to a point in time where the aircraft is still in the cruise phase (e.g. 45

minutes prior to landing). By influencing arrivals at greater distances from Schiphol, upstream centres can assist in meeting merging and metering requirements through speed and/or routing instructions to reduce traffic bunches occurring in Dutch airspace, enable optimisation of the descent profile and generate efficiency benefits.

Extension of the planning horizon is possible when there is a good balance between accuracy and stability of the planning. The main issue is how to minimise the uncertainty of predicted arrival time in relation to a stable planning. In general, the uncertainty increases in proportion to flight distance from the destination airport, but also flights with a flying time less than the planning horizon (so called pop-up flights) introduce uncertainty surrounding its departure time into the arrival management process. Accurate and reliable trajectory information could contribute in reducing the uncertainty.

Initial arrival planning information can be shared with upstream ATS units via the ED-254 Arrival Sequence Performance Standard. When in contact with the flight an upstream centre could inform the flight crew via (CPDLC baseline 2) datalink about the routing that can be expected to the landing runway. This is only advisory information (not a clearance) to ensure that the correct route is available in the aircraft's FMS. With advanced meteorological data in the FMS subsequent downlink of the aircraft trajectory via ADS-C EPP by suitably equipped aircraft can provide the TP with flight-specific performance data, instead of generic BADA values to improve the performance of ground-based trajectory predictions. This provides more accurate predictions of the aircraft's trajectory to the landing runway. For non-equipped aircraft the trajectory predictor (TP) in the ground system will remain to estimate the trajectory based on generic route and aircraft type specific performance data. The performance data can still be improved by taking data from the FF-ICE flight plan when such data is available.

An important quality of the arrival plan is that it must be robust. This implies that disturbances due to trajectory uncertainty (e.g. due to delay, route assignment such as a SID change in Madrid or action for separation provision or weather deviations) do not result in frequent updates of the arrival plan. The other way around, changes in the Schiphol arrival plan should not propagate throughout the entire network. This could be avoided by ensuring that departure, enroute, and arrival plans are loosely coupled.

The agreed trajectory information resulting from the arrival planning process is shared with upstream ATS units via ED-254. This facilitates that upstream ATS units can provide clearances in accordance with the arrival plan and the traffic situation in the sector the flight is flying at that time.

When entering the Amsterdam FIR, the flight is generally already descending. Conflict detection and resolution in the planning phases may have already prevented that many potential conflicts occur and allow a flight to operate against its plan with minimal intervention by ATC. Clearances are provided to the flight crew in accordance with the agreed trajectory. Complex instructions could be provided via CPDLC baseline 2 and loaded in the FMS.

TBO conformance monitoring allows checking of the flight's progress compared to the (complex) cleared trajectory loaded in the aircraft's FMS using air-ground datalink capabilities such as ADS-C EPP. This enables discrepancies to be identified and resolved before the aircraft deviates from ATC's expected trajectory and complements existing surveillance-based, reactive, flight path monitoring.

TBO conformance monitoring for arrivals incorporates a check on lateral and vertical clearances. The path for arriving flights may be modified for the purpose of delay absorption. A check on the lateral routing and vertical constraints provides for a more robust and safer operation. Conformance monitoring can also be used to detect deviations from the system track and to update the trajectory prediction with those changes.

In addition to meeting altitude constraints and monitoring of descent speeds, conformance monitoring could include a check if the correct landing runway and approach procedure has been loaded. This could increase the safety of parallel approach operations.

To assist air traffic controllers in handling traffic in a TBO environment the controller working position (CWP) is assumed to accommodate visualisation of relevant information about the agreed trajectory and facilitate inputs to make changes to the trajectory when required. Specific tools could be developed to support controllers by visualising separation between trajectories at specific points or areas, monitor conformance to the agreed trajectory and or show potential conflicts. For arrivals this would include a merge support tool at points where arrival flows are merged.

The DARP foresees Flight Deck Interval Management (FDIM) as a means to maintain capacity on fixed arrival routes. Through AMAN supported by TBO, the required delivery accuracy at the Initial Approach Fix may be achieved. Once under FDIM, the aircraft will follow the lateral and vertical trajectory but may adjust its speed to meet the relative spacing objective with its leader. ADS-C EPP allows sharing the adjusted profile to support monitoring of the operation by ATC.

Tactical conformance monitoring by the controller remains applicable for situations that require tactical intervention.

5.3 Integrated trajectory management of multi-airport traffic

Both the departure and arrival trajectory management processes discussed in the previous paragraphs, result in improved predictability of Schiphol traffic. In a TBO-environment, this management of Schiphol traffic can be extended to allow synchronisation of traffic to and from multiple regional airports in the Netherlands and support a multi-airport operational concept.

Data from FF-ICE, eIOP and ADS-C EPP allows better trajectory prediction that can be used for planning and execution of the multi-airport trajectories. It is expected that traffic synchronisation is initially applied between Schiphol traffic and regional airport departures. The assumption is based on the notion that the timing of such departures can be more easily adapted than the timing of Schiphol traffic flows. The trajectory accuracy provided by TBO is expected to facilitate the application of narrower vertical windows needed for Schiphol arrivals and departures. This will create more room to plan conflict free trajectories for other multi-airport flows.

Further investigation is needed on how the synchronisation operational concept and application can be developed, but accurate trajectory information and conflict detection and resolution functions in the planning phase will be essential building blocks.

Conflict management (CM) tools in the executive domain could help controllers to assess conflicts in a multi-airport environment between departures, arrivals and crossing traffic. Conflicts that could not be resolved in the planning phase or arise because of disturbances need to be addressed by controllers at a tactical level, but still in an early stage, hence mitigating significant deviations from or updates to the original plan. Trajectory information produced by the planning phase and updated during the execution phase will provide the input for this capability.

Currently, trajectory information lacks the accuracy to enable a Medium-Term Conflict Detection (MTCD) function in support of arrivals or departures. With TBO, the trajectory information should gain sufficient accuracy to allow the use of this type of conflict detection (CD) tool without generating too many false alerts. Moreover, having more trajectory accuracy and detail will allow for the creation of more advanced CD algorithms and visualisation techniques, aiding the controller while interpreting CM information. This should contribute to more controller acceptance and subsequently application of this support with an aim to reduce the impact on the original plan.

For the execution phase CPDLC baseline 2 is used to communicate complex trajectory clearances and load directly into the aircraft FMS. Conformance monitoring is facilitated when ADS-C EPP data is available to monitor the routing, vertical profile and performance data loaded in the FMS versus the ATC plan or instructions.

Tactical conformance monitoring by the controller remains applicable for situations that require tactical intervention.

6 Implementation strategy

To move from the current operation to the operation foreseen in Chapter 3, the enablers and applications need to be further developed and implemented. This chapter provides a first roadmap towards implementing TBO in the Netherlands and relevant considerations for such a strategy.

The recommended approach is based on the following considerations. These considerations are further described in the next sections:

- Build from current platforms: TBO will be implemented on existing systems and systems already in development. This allows starting the transition process now.
- Implement information sharing mediums early: By connecting to the channels envisioned for TBO, development on applications can start using early shared data.
- Implement different sharing enablers in parallel: Parallel implementation provides the best data available while reducing the need for all stakeholders to have transitioned as well.
- Develop and implement TBO in small steps: By implementing in small steps and designing trials with the intention to keep the development in operation, the concept can be refined while already exploiting early benefits.
- Start further development with all stakeholders: TBO requires stakeholders to share information and operations. This will require developing standards and operations together.

Based on these considerations, a first roadmap is defined in Section 6.6. A summary of this roadmap can be defined in three timeframes:

- Now / short term
    - Start development of concepts for the use of ADS-C EPP and FF-ICE data.
    - Implement data channels for the same via SWIM.
    - Actively participate in the development of the iTEC V3 requirements.
- When data sharing connections have been established
    - Start collecting data for development purposes.
    - Start developing prototypes for applications on the non-core ATM systems such as ASAP.
    - Start trialling those prototypes into limited operation and expand from there.
- When iCAS is operational
    - Start implementation of TBO applications on the core ATM systems.

6.1 Build from current platforms

Chapter 4 recognised that many of the enablers will be built on the core ATM system. Therefore, fully fledged use of those enablers will happen after replacement of AAA by iCAS. However, other support systems are relatively independent from the core system while providing avenues for TBO concepts.

The iCAS and iTEC concepts are the target system for many TBO related functionalities. Development of the specifications of these systems will involve defining the needs for TBO in the Netherlands. Work should start now on ensuring that these specifications match the local needs. This requires active involvement in the iTEC consortium’s effort to specify the future versions of iTEC.

However, the iCAS/iTEC timeline does not fully govern the timeline for implementation of TBO. Especially the AMAN system (ASAP) provides a route to start implementing early concepts as arrival management is a key operation through which TBO provides benefits. The independence of the core ATM system and the ability to develop and specify new algorithms provides an early route to implementing several of the enablers, such as ADS-C EPP, FF-ICE and ED-254. This would support early implementation of more accurate predictions as part of arrival management.

6.2 Early use of new information sharing mediums

To enable TBO, the current data-sharing connections within ATM are to be expanded by SWIM and (e)IOP. To start development of local TBO implementations, early connection to those mediums is essential.

SWIM (Yellow profile) is recognised as low-complexity yet fully secure way of sharing information between all stakeholders. The enablers FF-ICE, ADS-C EPP and the ED-254 XMAN standard will be applied over this system. The physical connection for this system already exists at LVNL.

The first next step would be to start collecting shared information to allow research and development. This supports prototyping and development of early enablers such as the use of performance data in the AMAN trajectory predictor using actual data.

(e)IOP is a dedicated way of sharing data between ANSPs. Future versions of iTEC plan to implement (e)IOP. However, this requires the standard to be finalised between iTEC and non-iTEC ANSPs.

6.3 Parallel implementation of trajectory sharing enablers

Several technologies for trajectory sharing can, and should be, implemented in parallel, even if they appear to be competing in function. This unlocks the maximum benefit without requiring all stakeholders to be equipped or enabled to share data.

Chapter 5 describes how several enablers (e.g., ADS-C and FF-ICE) provide identical data items. These data items can often be used interchangeably. However, they need not be available at the same time. The availability of the data items depends on both on the equipage level of the sharing party and the phase of the flight; Sharing data requires the other party to have technology, and the data needs to be available (for example: ADS-C EPP is only available once the trajectory is loaded in the FMS).

By implementing these enablers in parallel, the applications can use the best information available for that flight and for that moment. For example: the descent speed of a flight in a TP can come from static adaptation data, the speed given in an FF-ICE flight plan, or the speed provided through ADS-C. The most accurate data depends on whether the airline shares the speed in the flight plan, whether the aircraft is equipped with ADS-C and whether the ADS-C connection has been established.

Through this technique, early adopters of a technology will be rewarded with more accurate planning. The benefit increases as more stakeholders adopt the technology.

6.4 Stepwise development into operation

In the process of assessing the state of implementation of TBO in Europe, and the plans for further deployment, several remarks were made by ANSPs about the development and implementation processes applied. It appeared that different approaches were taken from what was called *the traditional way of doing things.*

The traditional way of developing and implementing system changes in ATM can best be described as a “funnel” where a broad range of solutions are evaluated based on operational feasibility, after which benefit assessments are made as part of building a business case for implementation. The implementation process itself consist of specifying, building, testing, training and commissioning. All together it’s an almost linear process from initial concept definition to implementation.

In the world of system development, trends have emerged to break-away from the linear approach to methods in which short development cycles, and prototype testing (as part of the specification process) play an important role.

When it comes to the transition to the TBO concept, or in essence the development of TBO applications, a similar non-linear approach has been taken by ANSPs like EUROCONTROL Maastricht UAC (MUAC). MUAC relies heavily on prototype testing, and evolutionary deployment. There are a several arguments to take on such an incremental approach in the development of TBO:

1) TBO consists of a very large conceptual change to the ATM system, a change that will take several decades to be fully completed by all stakeholders.
2) The definition of TBO is not specific. There are many interpretations about what TBO exactly is, and in what timeframe the changes will come about.
3) The most promising path towards TBO is yet to be defined. Paths may be defined based on different KPIs. E.g., feasibility, costs, benefits, implementation time and effort. Also, the availability of deployment partners plays a role in the definition of the path. Afterall, TBO only becomes powerful when it’s deployed over a larger region with multiple stakeholders.
4) The deployment of TBO largely consists of making available decision support information, more accurately, or timelier, to planning and executive processes. The effectiveness of decision support information requires evaluation in a real-life environment. Simulations in this context have limited use.
5) There are competing or sometimes complementing technological solutions available, with new solutions coming on the stage over time (and others gradually leaving the stage). Technological solutions tested and deployed elsewhere, require operational evaluation for each environment for which they are proposed.

To this end, MUAC has adopted a development and implementation strategy which is characterised by many (very) small implementation steps. Each step may appear to be insignificant, but over time, the strategy is effective to create progress in the challenging realm that ATM innovation poses. The strategy also allows for a certain level of pathfinding in the development, which means that the strategy can be progressed based on successful implementations, rather than putting effort in the definition of the final result.

The most important changes that MUAC has made to its way of working are:

a) Definitions of small promising increments based on lab testing
b) Deployment into the operational environment, with limited use (making the change available to a selective group of controllers for evaluation purposes)
c) Gradual deployment with limited training effort per change

Based on the approach at MUAC the following approach is recommended:

1. Identify the concepts that have potential in the Dutch context. This study forms a basis for this identification.
2. Develop the technical capability required for operational implementation. An example:
    - Connect to the data streams. This validates the technological requirements of the concept for data sharing.
    - Study the available data and its application to the concept. Once data becomes available, off-line research into suitability of the data for different concepts and development of new algorithms is possible.
    - Develop the operational concept using the knowledge of the data.
    - Connect in non-operational system / mock-up and start pre-operational evaluation. At this point operational experts can evaluate the concepts without yet influencing the operation.

3. Start trials in which these concepts are progressively introduced into operation. Note that trials are designed such that the concept/system can remain active when suitable.
    - Deploy in operational setup but with limited scope. To finetune the concept further before full operational implementation, the concept could be deployed with limits. This could involve traffic situations (e.g., night operational only) or, as MUAC does, only used by a subset of controllers. In this process, the operational experience can help in further detailing the concept and technology.
    - Based on the experience, the scope of implementation is finally broadened until fully implemented.

6.5 Collaboration and partnerships

Collaboration with different stakeholders is key for implementation of TBO. The entire concept is based on increased sharing of data and information. There are several stakeholders with whom it is important to collaborate and form/continue and develop new/existing partnerships towards implementation of TBO:

- Nearby ANSPs: TBO is per definition working together with the other ANSPs. As data sharing and data exchange is a crucial part of TBO, active participation and collaboration with the ANSPs to develop toward using compatible standards and procedures is essential. The responsible ANSPs of the adjacent FIRs of the Netherlands (except for NATS and CLSK) are grouped within the FABEC consortium, therefore FABEC is one likely route of searching for collaboration.
- iTEC consortium: TBO will be performed using a further development of iCAS based on iTEC. The consortium of different European ANSPs will often have aligned needs for the system. However, each local airspace may have specific needs from the system. Furthermore, connections to neighbouring non-iTEC ANSPs may define particular needs on standard for interoperability with other systems such as CoFlight and SAS. Active collaboration ensures that the future system matches the needs for TBO in The Netherlands.
- Airlines: Particular attention should be given to (home-based) operators and airlines at Schiphol and the wider industry bodies such as IATA and A4E. Enablers such as FF-ICE and ADS-C are based on equipage and more sharing of information on the (preferred) trajectory. To unlock the benefits through these enablers, airspace users need to embrace the benefits and the required changes that airspace users will have to deal with.
- ADS-C Common Service development: This project enables sharing ADS-C EPP data for all relevant flights while data is also shared with other ANSPs. The key players in the current project are en-route ANSPs. Collaboration should be primarily aimed at ensuring that the concept extends to the terminal and even ground phases of the flight. NATS is one of the key players in this development, and having terminal operations, NATS intends to make use of ADS-C data right down to the ground.
- SESAR: The European entity responsible for coordination of research and development activities in the domain of ATM. The R&D activities within SESAR should be enablers of the Single European Sky initiative. SESAR is an excellent platform to initiate and develop concepts and technologies that are not yet in an operational maturity, also those that are crucial for TBO. SESAR offers funding possibilities to support organisations with the research, development and implementation of new concepts, technologies, and applications.

6.6 Initial roadmap

The following table provides a starting point for a roadmap toward implementing TBO according to the considerations in the previous sections. The years in this table are a recommendation for activities to start. In a number of cases the recommendation is to start this year, 2022. The reason for this is that in many cases the actual development and implementation will be done within the iTEC framework, in which commonality with iTEC partners is sought. This systems development approach requires for LVNL to engage herself in time, in order to contribute to the common specification process.

Domain	Topic	Involved parties	~ Start year	End year	Required item	iCAS needed	iCAS impact	Comment
Arrivals								
A-1	ED-254 XMAN sharing							
A-1a	Procure ED-254 gateway	S&I	2022	2023		No	No	
A-1b	Transmit AMA equivalent via ED-254 to MUAC in parallel with AMA	S&I/MUAC	2022	2023	A-1a	No	No	Validate equivalency of ED-254
A-1c	Replace AMA to MUAC by ED-254	S&I/OPS/ MUAC	2023	2024	A-1a	No	Yes	OLDI Gateway change
A-1d	Transition with MUAC to uplink RWY/Transition, starting night-time	KDC/OPS/ MUAC	2023	2024	A-1a, DST	No	No	
A-1e	Develop ASAP XMAN integration	KDC/S&I	2022	2024	A-1a	No	Yes	
A-1f	XMAN with progressively more ANSPs	KDC/OPS/ PRO/S&I MUAC/NA TS/skeyes /DFS/DSN A	2023	2025	A-1e	No	Yes	SESAR funding?
A-1g	Integrate XMAN into iCAS	S&I	2026	2030	A-1f	Yes	-	
A-1h	Continued development of XMAN (horizon/deconfliction)	KDC/S&I	2026	2035	A1-g	Yes	-	
A-2	ADS-C EPP							
A-2a	Get involved with ACS prototype activity		2022	2023		No	No	
A-2b	Connect to prototype		2023		A-2a	No	No	
A-2c	Develop ASAP algorithms using ADS-C EPP data	KDC/S&I	2023	2025	A-2b	No	No	Off-line develop-ment of TP algorithm
A-2d	Develop ASAP for ADS-C EPP	S&I	2023	2028	A-2c	No	No	ASAP system specification
A-2e	Use ADS-C APP to verify selected approach on auxiliary systems	KDC/S&I	2024	2030	A-2b	No	Yes	
A-2f	Integrate ADS-C in iCAS	S&I	2028	2030	A-2	Yes	-	
A-2g	Integrate approach verification in iCAS	S&I	2030	2035	A-2f	Yes	-	
A-3	CPDLC B2							
A-3a	Uplink non-published constraints, validate via ADS-C. First in night	KDC/MUA C	2022	2024	A-2b	No	No	
A-3b	Use ADS-C for improved vertical profile in ASAP	KDC/S&I	2022	2024	A-3a, A-2c	No	No	

Domain	Topic	Involved parties	~ Start year	End year	Required item	iCAS needed	iCAS impact	Comment
A-3c	Uplink ACC route for AMAN	KDC/S&I/ OPS	2025	2030	A-1d, A-3a	Yes	-	
A-4	FF-ICE							
A-4a	Connect to SWIM FF-ICE service		2022	2023		No	Yes	
A-4b	Engage with airlines to provide additional information	KDC/Airlines	2022	2023		No	No	Demonstrate value of information
A-4c	Develop ASAP algorithms using FF-ICE data	KDC/S&I	2023	2025	A-4a, A-4b	No	No	Off-line develop-ment of TP algorithm
A-4d	Develop ASAP for FF-ICE	S&I	2023	2028	A-4a, A-4c	No	No	ASAP system specification
A-4e	Display of aircraft intent	S&I	2023	2028	A2-b, A-4a	No	Yes	
Departures								
D-1a	Analyse ADS-C data for SID warning	KDC/S&I	2022	2028	A-2b	No	No	
D-1b	Analyse ADS-C /FF-ICE speed information	KDC/S&I	2024	2028	A-4a	No	No	
D-2	Build prototype for display data on aux screen at TWR/APP (SID & speed data)	KDC/OPS	2023	2025	D-1a, D-1b	No	No	
D-4	Incorporate ADS-C/FF-ICE data into iCAS/TWR	S&I	2030	2035	A-4a, A-2f	Yes	-	
Integrated TBO								
I-1	develop multi airport / 3D operation application	KDC/S&I	2023	2028		No	Yes	
I-2	Incorporate ADS-C/FF-ICE data into multi-airport TP	KDC/S&I	2023	2025	A-2b, A-4a	No	No	
I-3	integrate multi airport support in iCAS	S&I	2028	2035	I-2	Yes	-	
I-4	Modify TP default performance data update process	KDC/S&I	2028	2035	A-2c	No	No	

7 Appendices

7.1 Description of enablers and applications

In this appendix further details about the enablers and applications for TBO are provided. After a general description, the state of law shows relevant mandates, the state of technology gives insight in operational readiness and finally, details about which information is shared is provided (if applicable).

ADS-C	
Description	• ADS-C allows ANSPs to set up a contract to receive Trajectory information at regular intervals. The Trajectory information comprises lateral, vertical and speed intent data with which a ground TP can construct its own trajectories for Trajectory Management purposes. ADS-C also contains the output of the FMS TP itself. Most of this information is contained by the Extended Projected Profile. It contains a detailed description of the flight's remaining trajectory described in up to 128 detailed trajectory points and aircraft mass. However, it also contains information on the range of speeds the aircraft is capable of flying. This information is relevant input for deriving Trajectory Management solutions by the ground systems. Finally, it provides surveillance information comprising the actual 4D position and local wind and temperature. Since ADS-C information can be received via satellite connections, there is no technical limit on the range at which the information can be received. • A technical limit on ADS-C data is that it can only be sent to the ANSP the aircraft is currently logged on to. To remove this limitation, the SESAR PJ38 project is defining requirements for a common ADS-C Common Server (CS) to which all relevant ANSPs can subscribe to receive ADS-C data at any time and range.

State of law	Mandated
	• CP1 AF-6
	  ○ ATS and NM: Above FL285 by 31 December 2027
	  ○ Airspace User: All new aircraft after 31 December 2027
	  ○ Note: Airbus has recommended retrofit deadline by 2035 in their comments on CP1, but these were not implemented in the final version.

State of technology	Operational • Currently MUAC is receiving EPP from about 100 Airbus Narrowbodies and uses it for operational conformance monitoring • Airbus expects to equip all future medium-bodied aircraft delivered to European airlines.

Information shared	• Basic information: 4D aircraft position
	• Air and ground related speeds (IAS, TAS and groundspeed)
	• Meteo information (winds and temperature)
	• 4D Trajectory (as calculated by the FMS)
	  ○ Baseline trajectory
	  ○ Perform conformance monitoring
	• Lateral path (as calculated by the FMS)
	  ○ Perform conformance monitoring (ARR/DEP)
	• Altitudes (as predicted by the FMS)
	  ○ Cruise altitude / earlier information when already descended (e.g. The Reims-MUAC constraint)
	  ○ Top of Climb/Descent and other soft points
	• Speeds

ADS-C	
	○ Expected cruise/descent/climb speeds (note: benefit has been demonstrated in scientific studies) ○ Allowed speeds for speed control

Meteo uplink	
Description	• Digital uplink of weather information such as wind and temperatures to aircraft could improve the trajectory prediction of the onboard flight management computer when compared to the use of (relatively old) weather data collected during the flight planning process. The improved trajectories could be used for improved fuel predictions and/or ATM planning purposes. Uplink to the aircraft is done via ACARS AOC datalink. • The uplink will also aid in a more accurate execution by the FMS of any (ATC instructed) speed schedule for planned, FMS managed descents. Such descents are desirable in a TBO context as they minimize the number of interventions required by ATC and therefore enhance predictability and above all capacity.
State of law	Not mandated
State of technology	Operational • Weather uplink is used by specific aircraft operators when a positive business case has indicated that it is beneficial to do so.
Information shared	• Wind profile ○ Wind direction and speed at three to five different altitudes, preferable generated by an intelligent system that dynamically generates the best altitudes for optimum FMS performance. • Temperature (or deviation from ISA) at cruise level • Average temperature during descent

IOP	
Description	Ground-to-ground interoperability (IOP) is the sharing of an up-to-date Flight Object (FO) between all relevant ANSPs. The FO contains the Business Trajectory, which is the agreed 4D trajectory that AU is planning to fly and the ANSPs agree to facilitate. Furthermore, the FO also contains all constraints to which the trajectory has to comply. The Business Trajectory is generated and maintained by a central flight data management service, which may be the current responsible ATS Unit.
State of law	No applicable legislation
State of technology	Concept • A standard (ED-133) has been written but has yet to be agreed on by all parties. Obstacles to agreement are both technological (e.g. the way a trajectory is defined) and practical (e.g. all flight data management services need accurate and up to date information on all restrictions in all airspaces that a flight will cross).
Information shared	The full FO including the agreed 4D trajectory.

eIOP	
Description	Essential IOP is a variant of IOP with the same objectives and functionalities. The key difference is that the central flight management service can, <u>but does not need to</u>, predict the full 4D trajectory. If unable to predict a section of a trajectory in some airspace, the flight management service can delegate predicting that section to the local ATS Unit. Subsequently the central flight management service

eIOP	
	will validate and integrate that in the Flight Object and distribute the updated FO to all relevant ATS Units.
State of law	No applicable legislation
State of technology	Concept • Concept is under development with mainly the major ATM systems integrators in the lead.
Information shared	The full FO including the agreed 4D trajectory.

AFP to NM	
Description	Currently, NM receives messages from ANSPs in the ECAC area to inform NM about the progress of the flight. These messages primarily concern the actual position of each flight in the ECAC area by means of a so called Correlated Position Report (CPR) message. All ANSPs in the ECAC area provide this message to NM, based on their own surveillance sources. There are also other AFTN message types defined to inform NM about changed to flight plan information (AFP). One of the most relevant messages in this group concerns updates with respect to flight routing, in particular direct routing issued by ATC to the flight. Ensuring that NM has the most up-to-date information with respect to actual position and planned trajectory, enables two benefits: • NM can be more effective when regulating traffic • NM can in turn provide connected ANSPs (through NM-B2B) with more accurate routing information. This enables ANSPs to perform more accurate Trajectory Management. This benefit needs to be seen in conjunction with the ADS-C benefits. These information sources can be complementary and facilitate a transition path towards an end-state where all relevant information is shared through SWIM.
State of law	No applicable legislation • The transmission of AFP messages to NM is not mandatory.
State of technology	Operational • Some ANSPs in Europe transmit updates triggered by for example direct (DCT) instructions issued by ATC. The incentive for ANSPs to transmit these messages is that it allows NM in turn to provide better flight predictions through their B2B link. This improved predictability enables ANSPs to make better informed decisions with respect to regulations, but may also contribute to XMAN operations while no data is received from the aircraft (ADS-C Common Server). • For LVNL, AFP messages are sent in case of missing flight plan, when a flight diverts, or when its actual route changes (this does not include a DCT, since in AAA this is considered a status modification to an unchanged route). • ANSPs like NATS, DFS and DSNA do not currently send AFPs to NM. • It is planned that the new eFDP systems like iTEC and Coflight will send more AFP messages to NM using the OLDI protocol.
Information shared	Since the AFP contains Actual Flight Plan information, most changes to a flight plan can potentially be sent to NM using this message: • DEST, • Routing, • RFL, • Speed.

ED-254 Arrival Sequence Performance Standard	
Description	• The EuroCAE ED-254 Arrival Sequence Performance Standard is the first Eurocontrol SWIM standard based Information Service Design. The standard is intended to communicate extended AMAN related information from an AMAN centre to upstream centres. It is a one-way communication, i.e. no feedback is given to the AMAN centre. The specification allows for the sharing of Trajectory Management information with several clients simultaneously by means of a publish-subscribe service. This is contrary to OLDI that is peer-to-peer based. • The upstream (UAC) centre, when in contact with the flight, can communicate the details of the to-be-expected terminal routing, including the landing runway, to the flight crew. For this either voice or CPDLC FANS or ATN (Baseline 2) could be used. If the UAC centre at the same time ensures that all relevant constraints are made known to the cockpit, any subsequent trajectory downlinks from the aircraft will deliver more added value as the profile will match the eventual profile required by ATC to a greater extent. • The standard also allows for sharing of speed modification and route variations for delay absorption. Together with terminal routing instructions, this is an important enabler for Trajectory Management of arriving flights across multiple sectors and centres.
State of law	Mandated • This SWIM service must be deployed in support of Extended AMAN concept in 24 major European airports. The Implementation Regulation requires implementation of XMAN by 2028.
State of technology	Not operational • Currently, predecessors of the ED-254 standard are in use by NATS and DSNA to support XMAN operations at Heathrow. • NATS has indicated that any future implementation of XMAN, should involve the implementation and use of the ED-254 specification.
Information shared	Many different information items relevant to not only the arrival planning, but also other flight plan items can be shared via an ED-254 based service. This includes, but is not limited to: • Speed advisories, • Landing runway, • Transition, • CTA routing, • TTL/G, metering fix and required times.

FF-ICE	
Description	• Flight and flow – information for a collaborative environment is a process of exchanging data and information in a specific format that will be needed for planning, coordination, and notification of flights. The exchange of information is not limited and should be accessible to a variety of stakeholders in the ATM community. The exchange of flight/flow information will assist the construction of the best possible integrated picture of the past, present and future ATM situation. The information sharing starts with the early submission of the flight plan, and ends with archiving relevant information post flight. This exchange of information enables improved decision making by the ATM actors involved in the entire duration of a flight, i.e., gate-to-gate, thus facilitating 4- D trajectory operations. FF-ICE will use an increased amount of data rather than R/T. Once FF-ICE is created all interested and authorised parties will have access to all the information it contains. There will be an increased amount of data used and processed, implying changes for operators and services providers, for example for planning and processing systems and overall way of working (and thus training!).

FF-ICE	
	• Along with the FF-ICE concept, a set of FF-ICE services are defined, intended to facilitate the exchange of data. Six services are defined so far: Filing service, flight data request service, planning service, trial service, data publication service and notification service. • FF-ICE release 1 consists of everything related to the planning until departure. The period until when the airplane goes off-block, it allows dynamic exchange of information. The concept should be implemented via SWIM compatible solutions.
State of law	Mandated Included in the CP1 regulation • By 2025 NM must be able to provide FF-ICE release 1 filing service • By 2025 airspace users and ANSP systems must support the exchange of FF-ICE Release 1 filing services (once available) SWIM yellow profile must be used for FF-ICE R1 services
State of technology	Operational So far, from the ANSP's that were interviewed, only ECTL already uses FF-ICE services.

Information shared	• The FF-ICE Release 1 filing service consists of the evaluation of a filed flight plan (eFPL) for the provision of air traffic services and indication of flight plan acceptability. Within the FF-ICE Release 1 filing service (mandatory in EU) following information is shared.
	  o Preliminary flight plan:
	    ▪ Globally unique flight identifier (GUFI)
	    ▪ Aircraft identification
	    ▪ Departure aerodrome
	    ▪ Estimated off-block date and time
	    ▪ Destination aerodrome
	  o Filed flight plan
	    ▪ Aircraft identification
	    ▪ Flight rules and type of flight
	    ▪ Number and type of aircraft and wake turbulence category
	    ▪ Equipment
	    ▪ Departure aerodrome
	    ▪ Estimated off-block time
	    ▪ Cruising speed
	    ▪ Cruising level
	    ▪ Route to be followed
	    ▪ Destination aerodrome and total estimated elapsed time
	    ▪ Alternate aerodrome
	    ▪ Fuel endurance
	    ▪ Total number of persons on board
	    ▪ Emergency and survival equipment
	    ▪ Other information
	• The European mandate on FF-ICE does not specify which information is mandatory on top of the information that was already used and available in the FP2012. FF-ICE is however capable of sharing an increased amount of data implemented in UML and XML. The extra information is defined in unique identifiers, but it is up to the users to decide what information they will share.

3rd party surveillance	
Description	3rd party surveillance allows tracking and surveillance of aircraft for ANSPs and other stakeholders outside of conventional horizons. The foremost technology that can be seen as 3rd party surveillance is space-based ADS-B. Space based ADS-B is a tracking and surveillance system using satellite-based receivers (as

3rd party surveillance	
	additional payload in Iridium Next Satellites) to use and process ADS-B data emitted by aircraft on the 1090 MHz frequency (extended squitter) rather than the currently used ground-based ADS-B receivers. Received ADS-B message on the satellite receiver are further forwarded using the satellite network before eventually being downlinked to the payload operations centre. From there the data is processed and all messages forwarded to clients (usually ANSP's, but also airlines). The satellite-based receivers can be used all over the globe, particularly interesting in areas where ground receiver coverage (ADS-B and/or radar) is currently not possible (e.g. oceanic regions, polar regions,…). Furthermore, third parties can supply estimates of positions or trajectories that are enabled by for example ADS-B monitoring. Commercial parties have started working on these services and are expected to add value with data input for trajectory management.
State of law	not mandated
State of technology	Operational In use by several ANSP's around the world, in particular the ANSP's that are also shareholder in the hosting company. Users include: NAV CANADA, NATS, ENAV, IAA, Naviair, DC-ANSP, ATNS.

Information shared	Space based ADS-B shares identical information as would be received by ground-based ADS-B receivers:
	• Aircraft identification
	  o Identification or call sign
	  o Unique 24-bit aircraft address
	  o Aircraft type and wake vortex category
	• Airborne position
	  o With Baro altitude
	  o With GNSS height
	• Surface position (different update rate when moving or not moving)
	• Airborne velocity
	• Aircraft Operational status (e.g., NAC, SIL, NIC)
	• Aircraft status
	  o TCAS RA
	  o Emergency/priority
	• Target state and status information

iTEC TP enhancements	
Description	The TP of the iTEC system provides trajectory information to many capabilities in the iTEC system, like Conflict Detection and trajectory sharing with adjacent centres. The current TP as implemented in iTEC, calculates trajectories based on information received from external ground sources and controller input. Trajectory information received from the aircraft can be used to augment these calculations. Amongst them, but not limited to, are aircraft planned speeds and altitudes. It is expected that the integration of this information will improve the accuracy of the trajectory information available to the iTEC functions. The increased accuracy will facilitate the use of conflict management functions in LVNL airspace and contribute to more accurate trajectory information that can be shared with adjacent centres.
State of law	Not mandated The improvements of the iTEC TP using aircraft information is conceptual and need to be developed and validated in the current iTEC TP algorithms. They are contingent upon the ADS-C Server becoming available.
State of technology	n/a

iTEC TP enhancements	
Information shared	n/a

AMAN Planning Enhancements – Sharing Speed Envelopes	
Description	Knowledge on the acceptable speed envelope from shared data allows realistic options for AMAN speed control. The roadmap in LVNL's AMAN foresees *speed advisories* in which the AMAN provides a recommended speed for an inbound aircraft to meet the Expected Approach Time (EAT). Using shared information on the possible speed ranges for the flight (e.g. shared through ADS-C EPP) would provide realistic bounds for the speed advisories.
State of law	Not mandated The concept of speed advisories is developed and the implementation in the current AMAN is on the development roadmap
State of technology	n/a
Information shared	n/a

AMAN Trajectory Predictor Enhancements through Shared Data	
Description	• The Trajectory Predictor (TP) that is core to LVNL's current AMAN can, with limited modifications, use information on speed and altitude that is shared by the AU or upstream ANSPs. • The current TP uses empirical information based on historic behaviour to estimate the speeds of an aircraft as it approaches Amsterdam. Shared information on cruise and descent speeds can replace the current empirical information to generate a more accurate speed profile which will lead to more accurate estimate of arrival time. • Similarly, updated information on cruise altitude and Top of Descend (TOD) could help in making a more accurate vertical profile. This in turn will lead to a more accurate speed profile. • In the early stages, before incorporating this information in the AMAN system, benefits can be obtained by the airlines by showing this information to the ACC controller. The controller can then take this information into account while constructing the sequence. A flight with a higher speed profile (due to network considerations) could then be taken before a flight this flying slow when this flight is arriving early for instance.
State of law	Not mandated
State of technology	These changes are limited modifications to the algorithms and display of data and could provide early benefits of using shared data.
Information shared	n/a

Conformance Monitoring	
Description	• Plan conformance monitoring is enabled by ADS-C when the aircraft shares its intention with respect to the Trajectory. Plan conformance concerns functionalities that allow ATC to perform crucial checks on the intent of the aircrew as input by them in the FMC. Some examples of such functionalities are: o Pre-departure check of correct take-off runway and SID programming. This will alleviate the restrictions on parallel departures at Schiphol.

Conformance Monitoring	
	- Pre-departure check of achievable altitude in the Schiphol TMA where a 3D route structure is going to be used. Non-conformance due to weight is then signalled early to ATC, allowing for planned measures to be taken. This will contribute to a more robust 3D TMA-route operation. - Parallel arrivals check: Before entering the runway pattern, the APP controller can be warned if the flight has the incorrect landing runway loaded. This is especially useful when operating parallel landing runways. If these restrictions could be reduced or removed, significant noise and fuel benefit may be obtained. - Check on lateral and vertical clearances: in advanced Trajectory Management solutions, the path for arriving flights may be modified for the purpose of delay absorption. A check on the lateral routing and vertical constraints provides for a more robust and safer operation. • Tactical Conformance monitoring is a function of a Flight Data Processing System (FDPS) that compares the track the system expects (based on the plan and clearances provided) and the actual flight track to alert the controller of any deviation. Additionally, conformance monitoring can also be used to detect deviations from the system track and to update the trajectory prediction with those changes.
State of law	Not mandated
State of technology	Operational Several ANSPs use conformance monitoring tools in their FDPS. Applications however are limited to upper area control in the tactical domain.
Information shared	• Information shared is dependent on the context the conformance monitoring is implemented in. See descriptions on ADS-C EPP for example. • Conformance monitoring provides warnings to the controller when deviations are larger than the pre-defined thresholds.

Target Time of Arrival (TTA)	
Description	TTA is a progressively refined planning time for the arrival of a flight to a specified point in the airspace, which is used to coordinate the arrival and departure managements and to support Demand Capacity Balancing (DCB). It was defined as part of the Target Time Management solutions proposed by SESAR, and it aims at increasing the awareness of timing for controllers and pilots so that they meet the required targets. By increasing the target time adherence in hotspots, it is expected that those hotspots can be more easily managed and thus CTOT delays will be more effective at managing the hotspots. In an operational context, the NM calculates the required target time for a specific flight in a regulated area and based on that it computes the CTOT for all affected flights. Both the CTOT and TTA are communicated to the Aircraft Operator by means of standard Slot Allocation Messages, and the AO communicates the information to the relevant flight crew prior to take-off.
State of law	Removed from AF4 of CP1 due to lack of maturity, not mandated
State of technology	Available for industrialisation/not deployed • Large scale demonstrations have taken place between 2013 and 2018 (Zurich, Paris, London, Palma).
Information shared	• Slot Allocation Message (SAM), from NM to AO, with requested time. - CTOT - TTA/TTO • Concept has been combined with Slot Swapping in trials, could possibly be combined with UDPP. Sharing of plan priorities from AO to NM.

UDPP / Airline priorities	
Description	User Driven Prioritisation Process (UDPP) is a concept that aims to give the Airspace Users (AU) more flexibility with arranging their schedule, so that capacity constraints and delays can be absorbed in a more prioritized way and business is affected as least as possible. The current context allows AUs little opportunity to propose different solutions to what is proposed by the Network Manager (NM), but the UDPP will allow them to recommend a priority order to the NM so that the preference is considered when assigning delays and constraints to the flights. UDPP goes beyond previous concepts, such as slot-swapping or departure flexibility from SESAR 1, and allows a more custom and interconnected approach that is enabled by new technology such as SWIM.
State of law	Not mandated
State of technology	Available for industrialisation/not deployed • Concept was developed as part of SESAR PJ07 Wave 1. It is currently available for industrialisation. Nothing found on deployment of the concept.
Information shared	• Airspace User priorities • Slot distribution

Flight Deck Interval Management (FDIM)	
Description	FDIM uses ADS-B In capabilities to manage spacing between aircraft. FDIM provides the controller with the opportunity to authorize a flight crew to use the ADS-B In avionics, to precisely achieve and maintain an ATC-issued spacing interval (in time or distance) relative to a lead aircraft. FDIM is a relative position based ATM solution rather than a reference trajectory based ATM solution. However, FDIM is considered to be part of the TBO concept as a solution where precision levels are required that cannot be obtained through reference trajectory based solutions. A proposed area of application TMA operations, to increase capacity and runway throughput while keeping the arriving and departing traffic streams on the fixed routes. FDIM has been listed as a cockpit-based TMA solution in the National Airspace Re-Design Programme, together with ground based TMA solutions such as TBS (Time Based Separation on final approach) and RECAT-PWS (pair-wise separation).
State of law	Currently there is no applicable legislation
State of technology	Concept Minimum Operational Performance Standards for IM avionics have been developed jointly with the Radio Technical Commission for Aeronautics (RTCA) and EUROCAE and were finalized in 2020. The installed base of ADS-B In is expected to increase as a result of the decision of KLM to replace its 737 fleet with A320 NEO aircraft. The status of FDIM development in SESAR is that activities have been halted as part of the SESAR Master Plan. However, FDIM validation exercises were part of SESAR-1, are part of SESAR 2020 and will be proposed as part of SESAR-3. The FAA has included FDIM as a solution to achieve its NextGen goals, with American Airlines as an active proponent with its A321 fleet. The FAA foresees both en-route and TMA aaplications for FDIM. FDIM is not part of the iTEC V3 CONOPS. The concept of application of FDIM for the Schiphol TMA still needs to be developed, taking into account other candidate solutions for fixed arrival routes with high capacity. The development of the new TMA concept with high capacity fixed arrival routes is part of the National Airspace Re-Design Programme.
Information shared	Whether or not additional trajectory information will needed to be fed back to the FDP in case of FDIM operations needs to be investigated.

7.2 Key findings from interviews

This appendix presents the key findings of interviews with organisations involved in the development of TBO in Europe. The input was gathered to obtain insight in the views on TBO, the current status of TBO, and developments in the field of TBO.

Organisations interviewed were:

- AVINOR
- LVNL
- MUAC
- Ministry of Infrastructure and Water Management
- Boeing
- DFS
- Eurocontrol NM
- DSNA
- Skeyes
- SESAR JU
- KLM
- NATS
- KNMI
- RSG
- INDRA

AVINOR

- AVINOR has a strong focus on system commonality within iTEC. The philosophy is: “What works in complex environments (such as UK or Germany), will work for us.”
- TBO is highly dependent on sharing data/data management. The exploitation of TBO to the full requires introduction of specific ‘TBO' tooling: Better predictability in strategic phase and higher precision in capacity management. TBO requires a big change for controllers and training programmes.
- E-IOP will be a first technical enabler for TBO with a lower deployment risk. Each ANSP is responsible for managing the trajectory in its own area. With e-IOP synchronisation between Coflight and iTEC systems is simplified.
- Timeline for AVINOR: Replacement of existing FDPS in 2024, IOP deployment in 2026/2027, benefits in 2029+

LVNL

- iCAS at LVNL will be a one-to-one replacement of AAA. The system will be as similar as possible to de-risk the transition.
- iCAS after implementation: In the first year bugs will be fixed. In the second year other projects will be prioritised. From the 3rd year onwards, evaluation and system improvements will be started.
- A gradual transition towards TBO tooling is desired for ATCo’s to adapt to new working methods.
- NATS is leading the iTEC development and has most experience with large projects alike. It is suggested that LVNL should follow the example given by NATS with the development of iTEC. iTEC V3 will be a common specification for all iTEC partners. It is important that LVNL keeps involvement in the development of this platform.
- iTEC and Coflight consider trajectories in a fundamentally different way. This causes discrepancies which will make the implementation of IOP cumbersome. e-IOP can be a solution for trajectory calculations over sector boundaries.
- Early benefits of more accurate trajectory information: debunching of traffic, more accurate (RNP) routing, more advanced safety nets.

MUAC

- IOP flight object is listed high on the agenda within the iTEC consortium, but no break-throughs have been realised in this area up till now.
- Mandates on new technologies (e.g. integrated datalink, FF-ICE) often only apply to the airborne side. The ANSPs are not forced to exploit these technologies. This holds back a lot of the benefits.
- It is desirable to keep flow management and real time tactical ATC separated.
- The more information shared, the higher fidelity trajectories are obtained. However, 100% accurate trajectories will never be a reality. The system always needs to expect a certain level of uncertainty.
- Implementation of TBO enablers, tools, technology at MUAC are implemented on a step by step basis. This allows for evaluation and adaptation in the process.

Ministry of Infrastructure and Watermanagement

- The Dutch Airspace Redesign Programme (DARP) expects TBO to provide better planning and more accurate traffic delivery at Approach Fixes or Coordination Points. This is required to enable an airspace concept with fixed arrival routes.
- It is expected that TBO will enable vectoring for arrivals based on fixed patterns. Area Control will make their sequences by adding waypoints to the trajectories instead of giving radar vectors.
- For outbound traffic it is expected that traffic follows a SID and then direct routes where possible.

Boeing

- For TBO, the ADS-C Extended Predicted Profile is the most important development. It allows to downlink trajectories from the FMS for ATM reference purposes.
- As Boeing needs to invest in Baseline 2 EPP development, a positive business case is required to make the investment feasible. For future sales, this business case may be beneficial, but a retrofit is not deemed likely. It is therefore expected that the future fleet will make a slow transition with a long period of mixed equipage. EPP is currently not available in Boeing aircraft, but the less advanced Intermediate Projected Intent (IPI) is an alternative.
- Integrated datalink will according to Boeing also be an important building block towards TBO. With integrated datalink, clearances can be uploaded to aircraft and synced directly into the FMS. When the pilot acknowledges the clearance, the aircraft will directly load it and follow the clearance. Boeing is reserved about the technology as the airborne side is mandated to implement this, but ANSPs are not. This will obstruct the benefits.

DFS

- iCAS is already a trajectory-based system which can as a standalone system bring tools to manage trajectories within its own Area of Responsibility. With IOP, this trajectory management can be extended across boundaries.
- DFS already has iCas running for upper airspace. Even though the involvement of DFS into the realisation of IOP, this is not implemented between centres at DFS. OLDI is still the standard for cross centre coordination.
- For data sharing within TBO context, a standard has to be developed. This is a long process without a direct necessity. The development of IOP is largely dependent on this standard, but also hold back by costs and political processes.
- eIOP is a necessary change that will allow to start share trajectory data within a world where different common systems are present (Coflight/iTEC).

EUROCONTROL NM

- NM expects TBO to improve data-sharing services. However, scepticism about the transition to TBO is present. An example is the development of IOP over blue profile connections, where barely any progress is found over the last 15 years. Intermediate steps that are more (cost) efficient are required.

- OLDI can already provide a lot of data to improve trajectory management, but this is not yet used to the fullest degree. A large part of the uncertainty in the output data from the Network Manager comes from the low fidelity and limited data that NM receives. Many ANSPs don't provide data to NM.
- IOP is a very complex system that needs agreed standards and cooperation from many stakeholders. NM can be a central alternative in the European context, via already existing communication channels such as OLDI.

DSNA

- DSNA will implement a new FDPS new system, COFLIGHT, which is part of the new generation Thales ATM systems, called 4-FLIGHT. COFLIGHT will be commissioned starting early April 2022 in Reims UAC. (4FLIGHT). The new system will work without paper strips and thus constitutes a big change for the controllers. Data sharing in this new system will be OLDI based.
- In 4-flight the data exchange between ACC's in France will be considered the same as exchange between neighbouring country ACC's. This means that everything will run via OLDI standards.
- The Paris situation is different from other hubs as it must deal with a curfew in Orly. Therefore the flow management concept was worked out in in which the times on the ground are the leading target times, in stead of airborne target times.
- Coflight developments are still uncertain to some extent. For example, how requests from downstream centres (e.g. XMAN requests) can be handled. This could be achieved via existing OLDI channels, but there is no clear strategy yet.

Skeyes

- Skeyes has not committed to be involved in the Coflight or iTec developments but is currently running a system that is supported by Thales. A major update of this system is foreseen to be implemented in 2024. Three options for a future system are most likely: Consortium with COOPANS, collaboration with MUAC or customizing an off the shelf system.
- Priorities for skeyes lay with the update of the current system, finding a future ATM system, and realising remote towers. No efforts are currently planned for TBO elements such as extended arrival management or FF-ICE. Skeyes aims to stay compliant until the future ATM system is implemented which brings them back up to date with the leading European ANSPs.

SESAR JU

- TBO is a vision about trajectory management based on CDM between operational stakeholders both pre-departure and post-departure. TBO aims to keep the trajectory continually optimised to the AU objectives, even which environmental conditions of a flight, e.g. related to meteo or network constraints, may change during the conduct of the flight. The level of collaboration varies depending on time-criticality.
- TBO is built on a large set of operational and technological improvements, with a varying degree of maturity. Some are still under research, while others are ready for deployment and already mandated. The SESAR JU has provided an overview of all TBO elements, and their corresponding maturity levels.
- The long duration of the validation of the IOP Blue Profile standard has resulted in parallel development of some TBO-functionalities based on the SWIM TI Yellow Profile that were earlier needed for operational validation. Examples of this include the extended AMAN service, STAM measure coordination, and the ADS-C EPP common service. For these TBO functionalities, the Yellow Profile has proven to be a simple, agile and effective alternative.
- Technologies such as ADS-C EPP, integrated datalink or speech recognition have great potential benefits. However, latency for uplink and acknowledgment of clearances can take significantly long times to be of full utilisation in lower airspace. The introduction of the new

A/G datalink configuration (multilink based on LDACS and SATCOM) will significantly reduce latency and increase the datalink capacity to avoid such delays.

KLM

- KLM is developing its long-term agenda towards ATM related innovations and will be a smart follower. The airline wants to be at the front of innovation and contribute to the success. However, still careful trade-offs should be made to make the investment successful. Transavia has a more reluctant approach and intends to find clear benefits before investing in new technologies early.
- Mandates for airlines are clear and executed properly. However, ANSPs are often exempted from mandates and thus benefits are sometimes not obtained. This needs to change, especially in TBO which depends on the involvement of all stakeholders.
- For training of flight crew it is important that the transition will be gradual. Changes impact the way of working and can therefore have an impact on the network. In TBO context, the information flood will be triangular between aircraft-ATC-Airline Operation Centre. Especially the link between ATC and the airline operations centre needs investment.

NATS

- NATS is one of the three founding iTEC members and is putting considerable effort into the requirement definition. With iTEC V3 NATS will be enable all NATS led centres to work with the same Flight Data Processing system. NATS is leading the iTEC V3 ADS-C requirements definition work, along with a number of other functional areas.
- Independent from iTEC, NATS is developing a system much like 4me (DSNA), that allows SWIM communicated XMAN constraints to be displayed on a separate display for ATCo's. It is separate from the FDP and scheduled for 2023. In iTEC this can be integrated in the system with a feedback mechanism.
- Conformance monitoring of trajectories as obtained from ADS-C EPP for example can be a building block for TBO that can be implemented relatively soon. Especially in upper airspace.
- Future ATM operations are being described nowadays such that the systems can be designed to meet these requirements. However, it can be hard to specify a technical system in detail that will support the future concept. Simply because there is no experience with the concept yet. Incremental steps towards an operational concept such as TBO seems to be a more sensible path.
- For NATS the deployment of iTEC is a massive restructuring of all technical architecture. A very large engineering effort is made to work out iTEC and all the data sharing services such as SWIM compatibility. This is comparable to the situation in the Netherlands.

KNMI

- Global and local weather models differ and need individual case assessment for best fit to be used for (segments of) trajectories. When local models are used, this is also a partial political question. There is a trend where meteorological institutes work together on the development of weather models which can benefit the transition to TBO.
- It is important for ATM purposes to specify the requirements for commonality of meteorological information along the trajectory. This means that specifications need to be made on the grid, time resolution and the parameters that are needed. These parameters could for example be winds and temperature at altitudes, convective activity and transition level. After specifications it is possible to evaluate how all stakeholders can make use of the best suiting models without too many discrepancies.
- Some relevant meteo tools are not exploited to the fullest benefit because of the deadlock between ATC and airline. For example, the use of METS (programming up-to-date winds in the FMS). For the descend, this can be irrelevant for an airline to enter as they expect ATC to vector the aircraft at their discrete. However, in the TBO concept, ATC would largely benefit an updated FMS. This more accurate trajectory can be downlinked over ADS-C EPP and would give ATC a far better idea on the intent of the aircraft that should be realised.

- For TBO the primary requirements are the wind & temperature at altitudes, pressure (or Transition Level) and convective activity.

RSG

- The airport is the initial and final station of the trajectory. For airport operations, the airport processes are very much benefited by a high accuracy prediction of the arrival times. This can be evaluated with respect to the initial planning in A-CDM , AOP and NOP processes.
- The airport sees potential in rewarding strategies for aircraft that are more actively participating in trajectory sharing. When aircraft are sharing their trajectory, intent, or other information relevant for TBO, the airport can prioritise services for these better equipped airspace users. This falls under the "Best Planned – Best Served", or "Best Equiped Best Served" ideas. Examples of rewards could be to introduce dynamic pricing or to assign electric taxi operations (taxi bot) to the highest scoring flight.
- RSG experiences most benefits by flights that are executed exactly as planned, for both arrivals and departures. This can improve gate occupation. TBO can help better planning and execution and thereby reduce early arrivals, ATFM delay, bunching and efficient use of ground infrastructure.
- TBO can be an enabler for 3D separated routes in the TMA, whilst maintaining capacity in the peaks.
- TBO can reduce nuisance to surrounding communities. When traffic is planned with higher accuracy, and the planning is executed with higher stability, secondary runway use can be avoided more often. Furthermore, the expectations of nuisance can become more reliable. These improvements that TBO will bring are included in the minderhinderschiphol.nl program.

INDRA

- Support for e-IOP will be delivered with iTEC V3. IOP might be supported, but the lack of progress with its definition and standardization makes it difficult to continue designing the system for IOP. Too much data needs to be shared. Essential IOP seems the only way forward to manage all information. It also solves the problems that NM has with the lack of information from ANSPs.
- The goal of Trajectory Based Operations is not the trajectory itself, but the relevant information that can be derived from the trajectory.
- The update releases of iTEC will be large and significant updates with many functionalities added. LVNL and Munich will be the first to implement the iTEC system in lower airspace.
- The ADS-C common server is still in conceptual development.
- Developing of functionalities run via the Operational Strategic Management (OSM) group where all partners in the iTEC collaboration are involved. The OSM will define the development path of the particular subject. This means that future system developments will be in collaboration with all iTEC partners.

7.3 Relevant mandate: Common Project 1 (CP1) – EC IR 2021/116

The CP1 regulation is an evolution of the previous Pilot Common Project (PCP), which was a first exercise for developing a common project regulation leading to the deployment of the Single European Sky. The CP1 now takes the existing ATM regulatory framework and extends it further in order to accelerate the digitalization and transition towards a greener European Air Traffic Management. This is based on consultation with operational and regulatory stakeholders, and by implementing the lessons learned from the PCP phase.

The CP1 contains the different ATM Functionalities (AF) and sub-functionalities compliant with the regulation and divides them onto 2 different categories: the AF that have reached enough maturity for implementation by December 31st, 2027, and those AF which are not mature enough but still deemed essential to the success of the project and which have targets for industrialization instead of implementation.

As with its predecessor, the SESAR Deployment Manager (SDM) plays a central role in managing and coordinating the modernization of European ATM by ensuring that the CP1 is implemented in a timely manner.

Six different ATM functionalities (AF) are identified in the regulation:

- **AF1.** Extended Arrival Management and integrated AMAN/DMAN in high density TMAs
- AF2. Airport Integration and Throughput
- **AF3.** Flexible Airspace Management and Free Route Airspace
- **AF4.** Network Collaborative Management
- **AF5.** System Wide Information Management
- **AF6.** Initial Trajectory Information Sharing

Out of these six functionalities mandated by the CP1, five of them are directly linked and relevant to Trajectory Based Operations and the applications and technologies that enable it: **AF1, AF3, AF4, AF5** and **AF6**. Enablers for TBO can be found in chapter 4, where each of them is linked to the regulation that mandates it, if there is any.

AF1: Extended Arrival Management and integrated AMAN/DMAN in high density TMAs
AF1 mandates the introduction of Extended Arrival Management (XMAN) and integrated AMAN and DMAN systems for airports located within high-density TMAs, which includes Amsterdam Schiphol airport within its scope. This functionality is strongly dependent on information exchange, and as such mandates that the information exchange must happen over System Wide Information Management (SWIM) once the AF5 is implemented.

AF3: Flexible Airspace Management and Free Route Airspace
AF3 mandates airspace management related aspects, such as the next system developments for an ASM process and the introduction of Advanced Flexible Use of Airspace (A-FUA). Additionally, it establishes requirements for data exchange, both airspace and flight related. In this regard, the functionality requires that ATC systems be able to receive and process aircraft's Extended Projected Profile (ADS-C EPP) by data link functionalities, as set out in AF6.

AF4: Network Collaborative Management
AF4 requires the Network Manager systems to implement short-term ATFCM measures. ANSPs and airspace users must use this functionality via SWIM once implemented.
FF-ICE R1 flight plan data must be used to enhance the quality of the planned trajectory information. The Network Manager must be able to support FF-ICE R1 filing services and the airspace users and ANSPS are required to support the exchange of these services, once available as set out in AF5.

AF5: System Wide Information Management
AF5 requires the implementation of the System Wide Information Management (SWIM) for the interconnection of European ATM information exchange services. According to this functionality, the whole European ATM Network must deploy SWIM Yellow Profile to enable flight information, network and meteorological information and aeronautical information to be shared in a standard way. SWIM is seen as an enabler for other applications mandated by the other functionalities and is thus paramount for the success of CP1.

AF6: Initial Trajectory Information Sharing
AF6 requires that trajectory information be shared between the air and ground using the EPP, as introduced in AF3, over the new datalink services ATS B2. This shared information must then be processed by the ATC system and used for planning aircraft trajectories. The information on aircraft trajectories must also be shared with other stakeholders, such as relevant ATS units, involved in handling the flight, which will be enabled by SWIM. AF6 is the functionality that requires TBO to be implemented, while the previous functionalities can be seen as enablers for it.

References

ICAO Doc 4444, 2016, Procedures for Air Navigation Services, Air Traffic Management, Sixteenth Edition.

ICAO, 2021, Global TBO concept.