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AIR TRAFFIC MANAGEMENT REQUIREMENTS AND PERFORMANCE PANEL (ATMRPP)

25th WORKING GROUP MEETING

Toulouse, France, 10 to 14 March 2014

Agenda Item 1.3: Proposal for the development of TBO concept

Managing unpredictable evolution in trajectory based operations

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SUMMARY

Since flights are operated in a non-deterministic dynamically changing environment, unpredictability is an intrinsic element of aircraft operations. This paper begins by identifying elements of uncertainty of aircraft behaviour, their impact on ATM functions, their cause and potential solutions that reduce uncertainty to unpredictability only, taking out all elements that are caused by insufficient information exchange. Trajectory based operations need to be able to deal with the remaining unpredictability. Within the conflict horizon, ATC constraints can be applied to compensate for the unpredictability when required. Outside the conflict horizon, a multi-actor framework is established to coordinate and agree trajectory changes required as a consequence of an evolving environment. Closed loop versus open loop, the concept and role of the downlinked trajectory intent (EPP) and the transition from flight intent to commitment are explained. Implications for the set-up of a multi stakeholder coordination framework and its supporting systems architecture are described.

The meeting is invited to agree the following actions.

i. *Address in the TBO concept the required multi-actor framework, in support of a stable, consistent and converging interaction of all ATM functions that act on the flight trajectory.*

ii. *Address in the TBO concept the role of uncertainty, unpredictability and inter-regional coordination of what-if scenarios and implemention of the agreed scnenarios.*

iii. *Identify in the TBO concept the required inter-regional information exchanges in support of i) and ii) including an assessment of the need for global standardization.*

iv. *Through the FIXM CCB, support the SESAR request to modify the FIXM schedule to address the topics of uncertainty, unpredictability and what-if scenarios in a new “4DT 3rd package” in FIXM 5.0*

1. INTRODUCTION

1.1 The Business Trajectory represents the preferred (optimal) profile for a flight from departure to destination as determined by the aircraft operator. It will be defined in 4 dimensions – a three dimensional flight profile with planned times associated at key points. Where necessary for ATM reasons the business trajectory will be amended to reflect ATM constraints, determined so as to meet the needs of the individual flight while considering overall network performance. The Shared Business Trajectory (SBT) is defined and submitted prior to departure, and once agreed by ATM, becomes the Reference Business Trajectory, RBT. Information on future Business Trajectories is neccesary for ATM and airport resource planning.

1.2 The RBT will be maintained and updated throughout the flight as required. The goal is that the RBT will at all times represent the agreed path of the aircraft. The RBT will provide a common view of the remainder of the trajectory for a flight and has to be shared between all ATM stakeholders.

1.3 Trajectory based operations will consist of a range of ATM functions which operate across the whole ATM system, from demand and capacity balancing (DCB), advanced flexible use of airspace (AFUA), limiting complexity usually by de-confliction of traffic flows, all the way to tactical separation provision and safety nets acting on invidual trajectories.

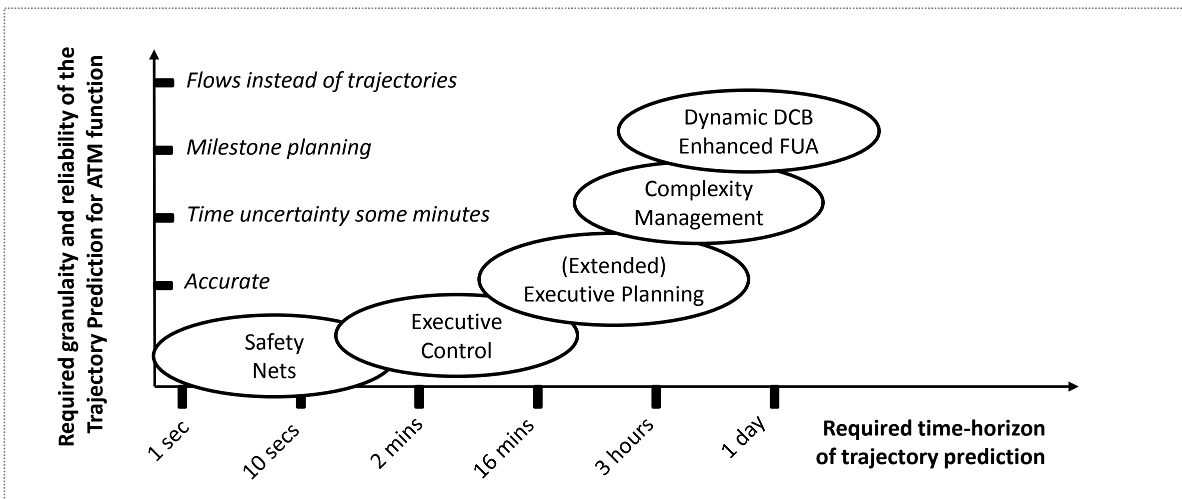

Figure 1 – ATM functions and required trajectory prediction

1.4 All these ATM functions require information about the planned trajectory of each flight. By having a consistent and up-to-date view of each flight's trajectory it will be possible for ATM functions to work in a coordinated fashion, both to meet individual airspace user needs as expressed through the business trajectory, and to maximise the overall efficiency of the ATM network.

1.5 The ATM functions differ significantly in the nature of the trajectory information they need, in particular their time horizon. Network Management functions typically need the flight profile for the whole flight. In current operations, tactical functions need the trajectory prediction only with regard to the current sector, looking ahead less than 20 minutes. There is a corresponding trade-off in the time-horizon and the granularity and reliability of the prediction of the trajectories. Lower granularity and reliability for long look-ahead tools and vice versa.

1.6 From a network perspective, rather than a single aircraft view, at any one instant during the course of the flight, there may be a number of separate ANSPs processing the flight, working at different look-ahead times.

For example an inbound aircraft which is at cruising level will be managed tactically in its current airspace for separation provision while simultaneously being considered by arrival management (AMAN) for the destination (extended) TMA.

1.7 Where multiple ATM functions act on the same time-horizon of a trajectory, either unambiguous criteria or a coordination process needs to be put in place to ensure a stable, consistent and converging trajectory management system. The question is how to take constraints from the various processes into account in modifying the RBT, especially if the constraints are conflicting. The principle of trajectory management is to adhere to a plan that has been defined in the longer time horizon and is refined during flight execution, all the way to the shorter time horizon (figure 1, right to left). However, in reality priority works the other way around and short term measures may undermine a longer term plan (figure 1, left to right).

2. REDUCE UNCERTAINTY TO UNPREDICTABILITY ONLY

2.1 Since flights are operated in a non-deterministic dynamically changing environment, unforseeable evolution of the environment, requiring re-baselining of the planning, is an intrinsic element of aircraft operations. Significant effort is spent in SESAR on reducing uncertainty[1], taking out all elements caused by insufficient information exchange. However, some level of inherent unpredictability[2] will always remain. Any trajectory management framework needs to provide the means to deal with this residual unpredictability. The following sections clarify these causes of unpredictability in more detail.

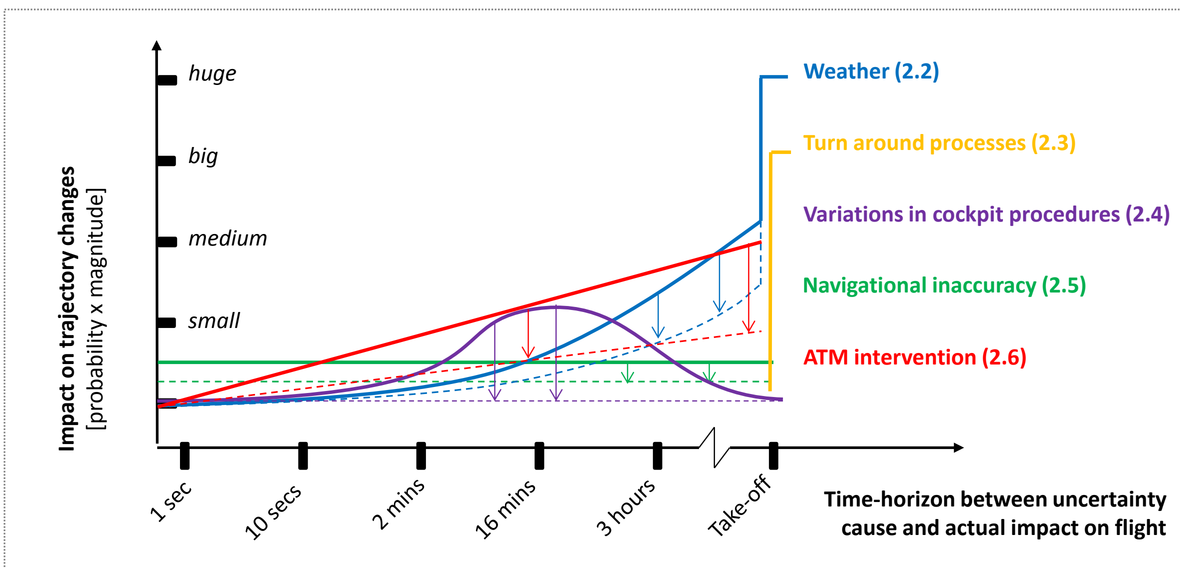

Figure 2 – Impact of uncertainty

[1] The estimated amount or percentage by which an observed or calculated value may differ from the true value.
[2] A consistent repetition of a state, course of action, behavior, or the like, making it possible to know in advance what to expect.

2.2 Weather is an prominent factor of uncertainty in aviation. Dependent of how sensitive the RBT is for weather, improvements, changes and refinements in weather forecast may impact the RBT. If changes are within the ‘sensitivity threshold’ there is no need to update the RBT. Research is ongoing within SESAR to deepen the understanding on the relation between the required accuracy of the meteorological data and the sensitivity of the RBT. This flipping point drives the need for the provision of weather updates. Particularly for medium and long haul flights the longer time-horizon requires updates of meteorological informaton during flight execution to reduce the difference between weather forecast and reality.

i) An unpredicted wind direction or the unpredicted existence of strong gusts may change the earlier predicted runway combinations and therefore may impact an airport’s landing and departure capacity. Such a change impacts individual trajectories both by adding or changing time-constraints (landing slot) and changing their 2D projection, as the aircraft needs to land on a runway, different from the one that was originally planned.

ii) Geospatial and temporal details of thunderstorms and Cbs can be predicted with sufficient accuracy for the planning of a flight. However, specifically for medium and long haul flights refinement of geospatial and temporal details usually occur during flight execution. Current operations are not used to work with level of uncertainty in meteorological predictions.

iii) Varying winds can also lead to non-adherence to an intended trajectory. For example, an unpredicted 10 KT headwind would slow an aircraft down at a rate of 1 NM every 6 minutes. Therefore, such a wind, if not known to the trajectory predictor (TP) and/or FMS, would cause a TP inaccuracy of 3NM 18 minutes in advance. This deviation is significant, if we take into account a separation minimum of 3 or 5 NM. See also section 2.4 iii.

iv) Insufficient granularity on the variance of high-winds with altitude, leads to inaccuracy in the trajectory predictions for climbing and descending aircraft. This aspect is not considered intrinsic un-predicatibility but rather uncertainty that can be reduced by improving the distribution of wind predictions.

v) Pilot reported severe turbulence leads to an increased vertical separation requirement reducing airspace capacity.

2.3 The turn-around process involves many actors, systems and planning functions which work towards a shared common departure time. Elements of disturbance impacting the flight till take-off stem from irregularities with security, passengers, fueling, aircraft technical maintainance, baggage handling, etc.

2.4 Different airspace users may apply different operational procedures. When sharing the applicable operational procedures with the ground, by downlinking the trajectory through the EPP (see section 3.3), this ground perceived uncertainty may be reduced. Actions not managed by the FMS in managed mode, will continue to contribute to uncertainty for ground-based operational actors.

i) During approach and final, flap settings, time for gear down and speed reduction schedule differ between AC type, crew and other factors like for example AC weight.

ii) Cruise, climb and descend profiles may differ, depending on airspace user policy and cost-index settings. This includes procedures for noise abatement.

iii) The FMS may change thrust settings to compensate for example for unexpected winds. The way this is done depends on the cost-index, which sets how important a delay due to a headwind is and whether it is worth burning more fuel to compensate or not.

2.5 Navigational capabilities address the accuracy concerning adherence to lateral, altitude or time constraints.

i) Regarding the lateral dimension, RNP provides accuracy, integrity and continuity in lateral navigation with high level of reliability and very few risks it will not be achievable by avionics, including on-board performance monitoring and alerting regarding RNP specified limits. Work is ongoing to improve RNP to support more deterministic Fixed Radius Transition (FRT) and scalable fixed RNP values defined per segment leg; both in en-route (e.g. A-RNP 1), and in TMA through a deterministic Radius-to-Fix turn (RF) (e.g. RNP0.3).

ii) Regarding the vertical dimension only indication of accuracy along the vertical profile and at altitude constraint can be provided. According to AC-20-138, consensus estimates based upon experience and some limited testing indicate that flight technical errors along a specified 3D profile can be expected to be less than 200ft below 5000ft and 300ft above 5000ft on a three sigma basis. Inaccuracy of interception to a specified altitude is less than 150ft below 5000ft and 240ft above 5000ft on a three sigma basis.

iii) Regarding the time dimension, flights usually are permitted to fly at planned speed ± 5% to meet their company objectives, reflected for example in the cost-index. Navigational capabilities have been validated to be able to adhere to a time constraint set on a fix to a certain degree of accuracy, for example ± 30 seconds or ± 10 seconds 95% of the time. However, from an airline perspective such time constraints may be conflicting with company objectives. For example, the effort to compensate for unexpected winds may lead to non-optimal flight performance.

2.6 Air traffic behaves as a complex system, not just as a consequence of non-deterministic external factors influencing execution (e.g. weather or passengers) as previously explained, but also because of the high degree of interaction between many parallel operations: Individual flights interact with each other as they share the same resources like airspace and runways (separation shall be assured) and air traffic control (overload of sectors shall be avoided, complexity shall not exceed certain levels). A change in one flight may affect many others. See also section 1.7 on the interaction of ATM processes.

i) The initial vision of trajectory based operations has been to predict in what way a flight is best optimized within all environmental constraints, and then to stick to this plan. Only when environmental changes exceed beyond a level to which the plan can be adhered to, the plan needs to be re-baselined, after which a flight will stick to the plan again.

ii) The challenge in refining this initial vision is to find the balance between the inflexible constraint of sticking to the plan to stabilise the complex system, versus flexibility required for in-flight optimisation driven by the airspace user's objectives like the cost-index.

iii) The transition from current vector based operations to trajectory based operations needs to be defined.

3. THE TRANSITION FROM INTENT TO COMMITMENT

3.1 According to ICAO PANS-ATM, an air traffic control clearance is defined as an authorization of an aircraft to proceed under conditions specified by an air traffic control unit.

i) Before departure, IFR flights receive a clearance from the clearance delivery position at the departure airport. This clearance contains the flight identification and assigned SSR code, a clearance limit, which is normally the destination aerodrome, the assigned SID if applicable and the initial FL, if not already contained in the SID. This departure clearance is to be considered an acknowledgement from the ATM system that the flight plan has correctly been entered into the system, but does not constitute a clearance to proceed.

ii) Flight crews having received a departure clearance need subsequent clearances from the departure aerodrome tower for start-up, taxi, line-up and take-off. After take-off, the aircraft can proceed on its assigned SID and climb to the initial FL contained either in the SID or the departure clearance, unless otherwise instructed. Once that initial FL is reached, the aircraft can’t climb further unless they receive an ATC clearance to climb. The 2D route can be followed by default after the last point in the SID (i.e. no clearance to proceed is necessary) all the way until the clearance limit at the destination aerodrome. This clearance limit is usually the IAF, or the clearance limit specified at the STAR if the aircraft has been assigned a STAR by ATC. Before the clearance limit, aircraft are expected to receive an explicit clearance for approach from ATC, followed by a clearance to land from the tower at the destination airport.

3.2 Due to the residual unpredictability of aircraft operations (section 2), it cannot be assured that the intended flight path (trajectory) will remain free of conflicts, even if it would have been completely de-conflicted from all other trajectories during the initial setup of the RBT. When unpredictability grows to the order of magnitude of the applicable separation criteria there is no point in further de-conflicting individual trajectories. The conflict horizon is the extent to which hazards along the future trajectory of an aircraft are considered for separation provision (ICAO doc 9854).

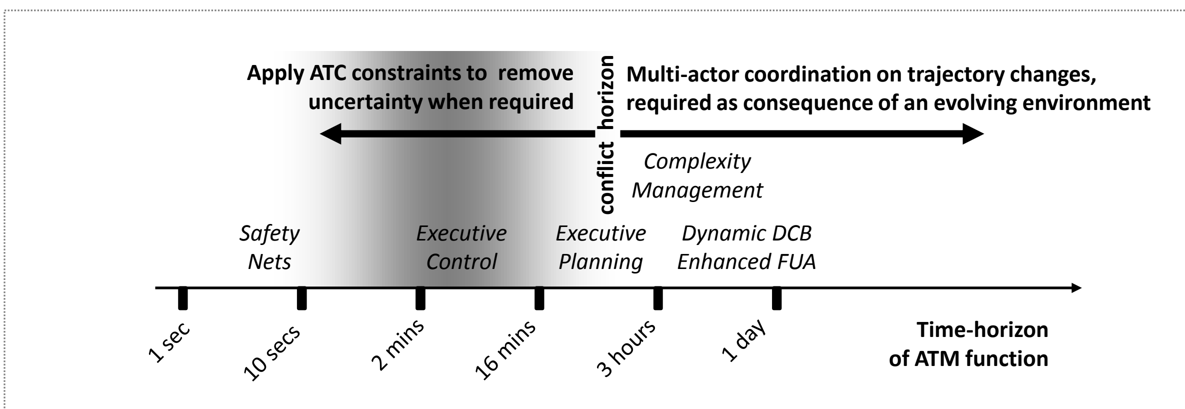

Figure 3 – The conflict horizon

The conflict horizon starts at the beginning of the RBT and keeps moving along as a sliding horizon as the flight advances. The horizon is variable depending on the phase of flight, ground tools, procedures, actors and navigation specifications.

i) Both unpredictability and inaccuracy play an essential role in separation assurance. Trajectory predictions that may appear de-conflicted, may still lead to a separation loss due to their associated unpredictability and/or inaccuracy. In such cases, and within the conflict-horizon, one or multiple additional ATC constraint(s) may need to be applied. See section 3.4.

ii) Outside the conflict horizon, traffic is more coarsely de-conflicted, i.e. not based on separation minima, but rather on complexity and capacity criteria. Measures generally impact multiple trajectories. Changes may require multi-actor coordination in a collaborative decision making process. See section 4.2.

3.3 To share flight intent between air and ground, the concept of the Extended Projected Profile (EPP), generated by the FMS and downlinked through ADS-C, is under development. The EPP is a report containing amongst other flight parameters, a maximum of 128 (pseudo) waypoints with associated estimates on vertical and horizontal position, time over, vertical and horizontal (ground/air) speed.

The drive for developing the EPP was that ground systems would know the intended trajectory from the flight-deck, reducing uncertainty perceived by ground-based ATC systems. For this purpose the EPP has been designed to be consistent with ATC clearances, so long as the flight crew has loaded and activated these clearances in the FMS.

In its current definition, adherence to the EPP is not guaranteed[3]. It is not a contract nor a closed loop 4D trajectory, it merely describes the intended flight trajectory. The actual trajectory may differ from the intended flight trajectory, due to the intrinsic flight operations uncertainties (section 2).

i) In the lateral (2D) dimension, adherence is bound by the RNP specification the aircraft flies to.

ii) Adherence in the time dimension is not guaranteed to any specific accuracy unless the aircraft is flying to a time constraint.

iii) Adherence to the vertical dimension of the EPP is a more complex subject. In a level segment of the EPP, the standard vertical adherence values (section 2.4) apply. For an EPP segment where an aircraft is either climbing or descending, potential deviations from the vertical profile are not bound by any specific value.

Worst-case estimates can be assumed by ground systems for the time and vertical uncertainties, but such bounding by worst-case values is expected to be insufficient to support high density traffic in the SESAR environment.

3.4 Two trajectories - flight intent downlinked through EPPs - that appear de-conflicted if ignoring their associated unpredictability, may still lead to a separation loss due to their associated unpredictability.

i) In such cases, an additional ATC constraint needs to be applied, e.g. to cross a waypoint at a certain level or to comply with a certain time-constraint.

[3] What is inserted into the FMS, is supposed to be flown. Normally the whole flight has been cleared from the departure clearance and each amendement of it is a “clearance”. Currently only the STARs may be put as“best guess” in order to close the loop of the FMS trajectory. The time element of the trajectory however is not part of the elements that need to adhered by the flight. In summary the 2D of the EPP are a contract but not the time element. Without a clearance due to loss of communications, the flight can proceed to destination .

ii) Alternatively, the intended flight trajectory limited to the conflict horizon needs to be transformed to a contract, minimizing uncertainty. The prediction then becomes the plan for execution. This alternative may seem similar to the first option of ATC constraints, but adds more constraints than strictly required for separation purposes.

iii) A balance between rigidity and flexiblity is aimed for. The guiding principle is to avoid unneccesary constraints by deciding earlier than required to act on a flight to provide separation. The time for decision is dependent on the unpredictability.

3.5 A closed-loop clearance is an ATC clearance resulting in the revision of one portion of the RBT, for example a direct route from a point of the original RBT to another point of the original RBT. Open-loop clearances are heading or altitude related instructions (called vectoring in the ATC jargon) that need to be closed by a subsequent ATC instruction. The air traffic controller who has issued a heading clearance will usually have a reasonably accurate plan in mind as to how he will clear the flight to resume own navigation, i.e. rejoin the RBT.

i) This plan may involve certain pre-requisites (e.g. another aircraft to vacate a certain flight level or finish a turn) which are not easy to register in a system. Even when the resume point is clear for the controller from the start, like is often the case when vectoring is used for en-route traffic separation provision, registration in the system is not done. Consequently, both airborne (Flight Management System, FMS) and ground trajectory prediction for a flight following an open-loop clearance need to be based on assumptions on when the loop will be closed. Furthermore, once the loop has been closed by the controller by issuance of a clearance for the aircraft to resume own navigation and fly to a certain waypoint, the ground systems will not know about it unless the controller inputs the direct-to-waypoint clearance in the system. Most ground systems will allow this type of entry, but controllers do not always have the time to perform this function.

ii) In current operations, separation provision makes extensive use of vectoring. As discussed, such operations make trajectory prediction hard until aircraft are cleared to resume own navigation. An additional drawback of these procedures is that when traffic density is high, controllers often provide the resume instruction later than desirable, which results in aircraft flying extra miles.

3.6 SESAR is considering the development of support systems that allow controllers to uplink a vector style separation instruction and the instruction to resume own navigation with a single data link command. As a result, “closed loop” trajectory prediction will be assured by removing ambiguity regarding resumption to own navigation.

i) Such improvement is not envisioned in the case of vectoring, point merge or tromboning for the purpose of sequencing aircraft for landing. Epecially during inbound traffic peaks there is a need to keep a high “pressure” on the runway in order to ensure a maximised runway throughput. Note, however, that accurate trajectory prediction in the last few miles before landing is not as relevant as in other phases of flight due to the fact that accuracy requirements on trajectory prediction after landing are less stringent compared to in-flight needs

4. AGREEING CHANGES TO THE INTENDED TRAJECTORY

4.1 The 'actual trajectory' of a flight will only represent the path that has been flown up to the current position. A 'predicted trajectory' represents the path that an aircraft is expected to follow from its current position onwards as derived from a set of input data and assumptions.

i) A great variety of input parameters need to be taken into account when defining, changing or predicting a trajectory. These parameters are inherent to the way the ATM process is organised and stem from the domains of airspace user objectives, aircraft performance characteristics, separation constraints, ATC network capacity, aeronautical structures and meteorological forecasts and actuals.

ii) The elements from the network, aeronautical and meteorological domains, are characterised by geospatial and temporal aspects. These aspects can change over time, and therefore an event driven update mechanism is required to trigger actors and systems of updates when surpassing a predefined threshold level, based on accuracy requirements for a specific ATM function.

iii) Though all objectives on safety and efficiency relate to the actual trajectory, the only way to achieve such objectives is by managing the predicted trajectory through the various ATM functions (figure 1).

4.2 Managing trajectories in a changing ATM environment requires a control loop consisting of operations monitoring, detecting a change or event, decide whether action is required, generate solutions, evaluate solutions, choose solution and apply the solution.

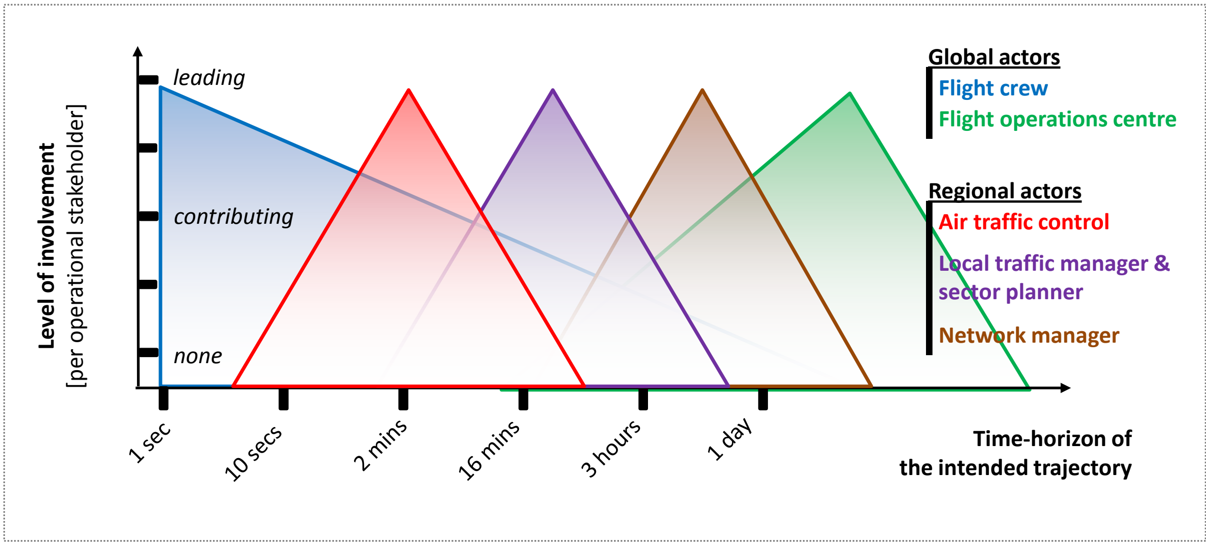

Figure 4 – Operational stakeholder involvement

The different ATM functions allow for involvement of different operational actors, with a combination of actors that vary with the time horizon. Operational actors include flight crew, air traffic control, local traffic manager and sector planner, network manager and flight operations centre, and their involvement is coarsely indicated in figure 4.

i) Within the conflict horizon, time for coordination amongst different stakeholders is limited. Only flight-crews and air traffic control are involved. Outside the conflict horizon, there is more time for assessing what-if scenario's involving multiple actors.

ii) Unambiguous criteria and a collaborative decision making process are required to orchestrate the interaction all stakeholders that aim to change input parameters (objectives or constraints) on a trajectory to ensure stability and convergence of the complex system of ATM.

4.3 A first pre-requisite to multi-stakeholder trajectory management is that all actors involved in managing the trajectory need to have a synchronized and consistent understanding of all the relevant input parameters and their proposed changes.

A second pre-requisite to multi-stakeholder trajectory management is that all actors need to be able to assess consequences of proposed changes. Proposed changes will be exchanged through "what-if" scenarios describing the proposed changes in input parameters.

System Wide Information Management (SWIM) is the key-enabler for both pre-requisites.

4.4 Managing trajectories through the different ATM functions is conducted by coordinating and agreeing on input parameters associated to that trajectory, resulting in a change of the intended trajectory, and – once agreed - eventually a change of the actual trajectory. All ATM functions require a trajectory predictor to assess the impact of changing input parameters – the "what-if" scenario - but their requirements on accuracy vary.

i) The need for accurate and up-to-date input parameters depends on the accuracy requirements of an ATM function. ATM functions requiring high accuracy, e.g. separation assurance, will need all input parameters and a low threshold level for updates, whereas other ATM functions, e.g. complexity management, have less stringent accuracy requirements and therefore a less stringent threshold level for updates on trajectory prediction input parameters.

ii) Understanding the accuracy of a trajectory prediction is particularly essential when assessing the need to apply additional ATC constraints for separation purposes.

5. ACTIONS BY THE MEETING

5.1 The meeting is invited to note and comment on the contents of this working paper

5.2 The meeting is invited to note and comment the following conclusions:

i) Different ATM functions relate to different time-horizons of the trajectory (see figure 1). These functions all act on different parts of the same trajectory. The trajectory is the common denominator for these ATM functions.

ii) Further refinement on rules of interaction of these ATM functions is required. A multi-actor coordination framework needs to be established, supported by clear decision criteria and automation.

iii) Stability, consistency and convergence of the combination of ATM functions is a pre-requiste for a safe and efficient ATM system of systems. Further investigation is required and ongoing to asses to what extent this pre-requisite is met.

iv) Attributes on the trajectory's uncertainty and trajectory related "what-if" scenarios need to be further defned and are candidates for global harmonization.

v) The provision of ATC clearances in trajectory based operations, and in particular their relation to the EPP, need to be further clarified.

vi) Though ATM functions may vary from ICAO region to ICAO region, some **inter**-regional information exchanges are a pre-requisite for proper functioning of these **intra**-regional implementations. The need for information exchange is likely to extend beyond the exchange of the trajectory prediction or related trajectory predition input parameters.

vii) Within an inter-regional environment, coordination of what-if scenarios and the way to implement the agreed ones, has not yet been defined. Operational scenarios and use-cases describing the way trajectories of medium and long haul flights crossing regional boundaries are managed, need to be developed in order to better understand the need for cross-regional information exchange. Such information exchanges are candidates for global standardization.

5.3 The meeting is invited to agree the following actions:

viii) Address in the TBO concept the required multi-actor framework, in support of a stable, consistent and converging interaction of all ATM functions that act on the flight trajectory.

ix) Address in the TBO concept the role of uncertainty, unpredictability and inter-regional coordination of what-if scenarios and implemention of the agreed scnenarios.

x) Identify in the TBO concept the required inter-regional information exchanges in support of i) and ii) including an assessment of the need for global standardization.

xi) Through the FIXM CCB, support the SESAR request to modify the FIXM schedule to address the topics of uncertainty, unpredictability and what-if scenarios in a new "4DT 3rd package" in FIXM 5.0

— END —