

# RESULT FROM EVALUATION OF 4D TRAJECTORY MANAGEMENT WITH *CONTRACT-OF-OBJECTIVES*

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## **Abstract**

*Contract-of-Objectives* (CoO) is designed in the context of trajectory-based Air Traffic Management (ATM), using mutually agreed objectives between Air Traffic Control (ATC), airlines and airports. This paper provides an overview of the foreseen validation of CoO and discusses the results of the first Human-in-the-Loop (HIL) evaluation of the concept of operations using CoO between Air Traffic Controllers (ATCOs). This HIL real time evaluation is carried out in October 2008 in SkyGuide premises in Geneva, Switzerland. Measurements on system performance (i.e., Safety, Efficiency, and Capacity) as well as Human performances (i.e., workload, Situation Awareness, and acceptability) were collected and analyzed. Results show that ATCOs are positive with the concept of operations, and they do agree on the principle of flying what were “planned, agreed and negotiated” on the planning phase as opposed to “first come, first served”. Results of the evaluations also show that CoO can be applied to 2008 and 2020 traffic level in Europe without any impact on System Safety.

## **Introduction**

Since years, the Air Traffic Management (ATM) situation has changed, and, while safety and capacity are still major issues, the picture has become more varied with a greater emphasis on performance and cost efficiency. There is a constant: overall Air Transport will continue to grow while facing demanding challenges. Considering the current ATM system, there is a clear need for more capacity, more efficiency and more safety. There is a clear need to introduce measures to meet these important objectives.

Air transport business stimulates national economies, global trade and tourism [1]. Business imperatives will always push for cutting costs, and

stronger competition and liberalization will continue to present a challenge for businesses, with an opportunity for new cost-models (e.g., low-cost airlines). The air transport supply-chain as a whole, therefore, needs to become more cost-efficient. Since the ATS supply-chain is a complex one involving many partners (such as airports, airlines and Air Navigation Service Providers (ANSPs)), these business imperatives will have to be supported and shared by everyone, even if their interests or cost-models are different. Even ANSPs will not be able to avoid these radical changes, but the need to retain safety as the prime objective will remain. “Business as usual” is not retained as an option by SESAR [2].

In Single European Sky ATM Research project (SESAR), the future system should be performance-based [3]. The future ATM system should integrate ground and airborne segments more closely, respect schedule integrity, and enhance interoperability. Initiatives with similar objectives to SESAR are currently in the US [4] and Australia [5]. Both initiatives share with SESAR the advocacy of a paradigm shift towards trajectory-based operations. As mentioned above, the air transport supply-chain involves many different service providers, which very often are not aware of the overall target, sometimes disagree with, and do not share, the same objectives. There are, however, a number of initiatives for developing collaborative decision-making systems at airport level. At present, the main actors mostly optimize their own processes locally in accordance with their own constraints and business objectives, sometimes without considering the impact on global system optimization. The promotion of highly collaborative and system-wide approaches seems to offer a promising strategy to achieve overall system optimization, with opportunities for variables and constraints distributed across the system [6] [7]. However, further R&D work is required to go from a high-level concept to operations, and also to evaluate

impacts and prove the potential for real delivered benefits.

In tandem with this challenge, the management of uncertainty and the 4D trajectories is essential. An abundance of articles dealing with these topics have been edited and studied in the State of the Art of the Contract-based Air Transportation System Project (CATS) [8]. An ATM system based on 4D trajectory management will hopefully benefit from prediction analysis [9] [10] and Flight Management System (FMS) accuracy [11] [12] [13] [14], allowing for a reduction of trajectories' uncertainty [13]. Focusing not only on the execution phase as [15] [16] [17] [18], but on all phases of the ATM system, 4D trajectory management should bring essential benefits when obtaining a future efficient and cost-effective ATM system, as shown by SESAR D2 [3]. The link between planning and execution phases seems also to be a big challenge for the future ATM system.

The CATS project was launched in November 2007 to assess a new ATM paradigm based on an innovative operational concept: the *Contract-of-Objectives* (CoO) [1]. This concept introduces a new way of managing ATM using mutually agreed objectives, leading to a market-driven air transportation system. The concept addresses the air transport supply-chain by reconciling operational links between air and ground services.

This enhanced air-ground link is expected to improve efficiency by increasing system predictability (allowing actors to organize themselves to be more cost efficient) and punctuality (arriving on time at the destination). This contract provides well-defined objectives for each actor involved in a flight (air traffic controllers, aircrews, airports, airlines, air navigation service providers) and through the *Contract-of-Objectives*, a guarantee of results, such as respect of punctuality, is offered to the airspace users. Objectives are negotiated and assigned through collaborative decision-making processes, during planning phases. This concept proposes a transition from means-based management to performance-based management (through a contract-based system) and could provide one mechanism for achieving the SESAR business trajectory [19]. The CATS project could also contribute a significant understanding of the validation required for such complex concepts.

## Concept Overview

CATS is based on concepts initiated by EUROCONTROL Experimental Centre's Paradigm SHIFT Project [20], namely the *Contract-of-Objectives* (CoO) and associated *Target Windows* (TWs).

The purpose of the CoO is to create an operational link between all air navigation actors (airlines, airports and ANSPs). The CoO represents a formal, collaborative commitment between all the actors in the Air Transportation System (ATS). CoO establishes the role as well as the tasks and responsibilities of each actor based on well-defined, agreed and shared objectives. These objectives represent the commitment of each actor to deliver a particular aircraft inside temporal and spatial intervals; this is known as *Target Windows* (TWs). These commitments are agreed by all involved actors for specific transfer of responsibility areas (e.g. between two Air Control Centers (ACCs)). As a consequence, each actor will be fully accountable for its own achievements. The ultimate objective of the CoO is punctuality at the destination, while improving the system efficiency and predictability by means of enhanced collaboration between air transport actors.

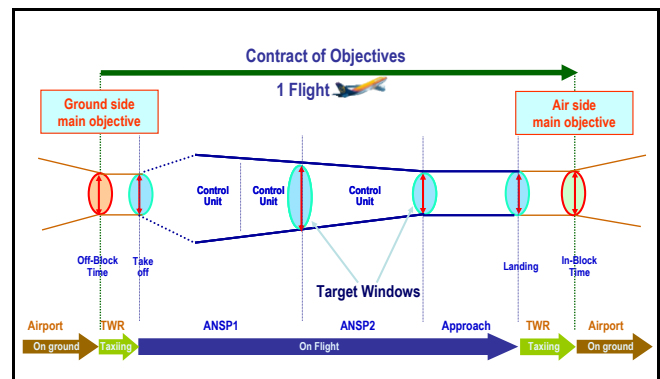


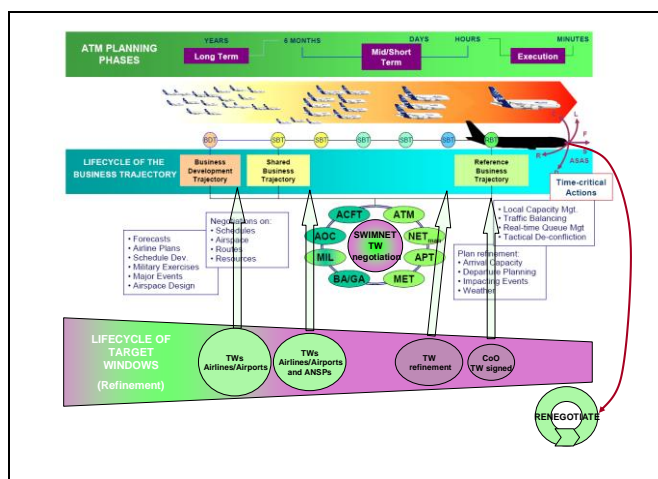
Figure 1. Contract-of-Objectives

For a formalization of the *Contract-of-Objectives* and its refinement for each local actor, a concrete manifestation of the CoO is proposed through the *Target Window*. TWs create a common language between all the involved operators, and also between the planning and operational phases. Instead of precise 4D points, the TW is expressed in terms of temporal and spatial intervals. They are defined on

the basis of transfer of responsibility areas (Figure 1). Their sizes and locations reflect negotiated objectives resulting from downstream constraints, such as punctuality at the destination, runway capacity, congested en-route areas or aircraft performance. TWs provide room for manoeuvre to ensure resilience in case of disruption and conflict management; and, lastly, impose constraints only if necessary. Uncertainty will always be a component of the system and can never be entirely erased. The CATS concept proposes, instead of removing this uncertainty, to keep it under control by managing disruption via the size of the TWs and to limit the side effects of any disruption. Divergence from this planning (either through operational issues or owing to uncertainty) still remains possible; but, if so, this triggers a specific decision-making process - called renegotiation - at a system-wide level.

These TWs are negotiated by utilizing a Collaborative Decision-Making (CDM) process, supported by System-Wide Information Management (SWIM), in terms of punctuality at the destination, while taking into account all actors' constraints. This negotiation process (Figure 2) can be described as follows:

- Long-term planning phase (from years to months): development of an initial schedule, not overly detailed, constituted by TWs at departure and arrival airports, taking into account infrastructural and environmental constraints;
- Medium-term planning phase (from months to days): development of business trajectories and negotiation of TWs through an iterative process; integration of weather predictions;
- Short-term planning phase (from days to minutes before the execution phase): continuous refinement of the TWs up to CoO signature.



**Figure 2. TW Lifecycle**

Then, the execution phase of the flight can start. The CoO provides the controller and aircrew with a means of managing the imprecision inherent in air traffic in accordance with their own objectives. The crews' objectives, therefore, are to adhere to an arrival schedule defined through TWs. Controllers, on the other hand, must ensure aircraft safety while keeping aircraft within the envelope defined in the contract, which guarantees that the contract will be observed.

If, for any reason (weather ...), one of the TWs cannot be fulfilled, a renegotiation process will commence between the impacted actors, resulting in a new CoO. The renegotiation process is performed using SWIM network facilities.

The SESAR Concept of Operations (CONOPS) [19] changes the approach of ATM to a performance-based approach. Trajectory-based operations ensure that the actual trajectory flown by the airspace user is close to its intended one, integrating ATM and airport constraints. The proposed Business Trajectory should then go through these different TWs to ensure the system's predictability (compliance between what is planned and what is flown) and overall efficiency. It should be here noted that the current generation of FMS offer very precise 4D trajectory predictions, nevertheless as uncertainty is inherent in ATM, the link between what have been planned and what will be flown remains doubtful. The airspace users, owner of the BT, may define precisely an optimum flight, based on weighting factors, unfortunately they cannot

operate in isolation, traffic density over Europe exceeds sometimes capacity. Then the overall ATM system has to be optimized to handle future traffic, and this is what the CoO and associated TWs will offer.

## Validation Overview

The main aim of the CATS Project is to assess the CoO and associated TWs by involving the major actors in the supply-chain (i.e., airlines, airports, and ANSPs). The CATS consortium has been built to involve representatives of the main stakeholders of the Air Transportation System. The consortium includes:

- Frequentis
- EUROCONTROL Experimental Centre
- Air France Consulting.
- L'Ente Nazionale Assistenza al Volo (ENAV SpA)
- Unique
- University of Leiden
- Swiss Federal Institute of Technology
- Laboratorio di Ricerca Operativa Trieste University
- SkySoft ATM.

The CATS Consortium contains major key areas of expertise to ensure the success of the project, such as ATM and pilot operational expertise, Airline and Airport Operational expertise, Decision-making technologies and Simulator design skills, Experimental design and Human factor skills, International aviation law and Economic skills.

The assessment of the concept, following European Operational Concept Validation Methodology (E-OCVM) [21], is conducted by two main means: an operational validation, led by three HILs experiments; and a systemic validation, with a more global approach. This paper will present the results of the first operational assessment.

The systemic assessment highlights the benefits for the overall air transport system, and concentrates on three core aspects:

- Safety and risk assessment
- Benefit assessment

- Legal assessment.

The operational approach will analyze how the proposed CoO and the associated TWs will impact the system performance regarding selected Key Performance Areas (KPAs) defined by SESAR D2 [3]. The proposed operational assessments will focus on three main validation objectives:

- Evaluation of the impact of the CoO between ATCOs: the acceptability and impact of the CoO, mainly by means of the TW, are evaluated in the context of the transfer of responsibility area between two ANSPs. The evaluation environment is restricted to two en-route Controller Working Positions (CWPs) managing the traffic and coordinating the aircraft (i.e., the transfer mechanism).
- Evaluation of the impact of the CoO between ATCOs and aircrew: the acceptability and impact of the CoO, as expressed mainly by means of the TW, are evaluated in the context of the interaction between an ATCO and the aircrew in a given sector.
- Evaluation of the renegotiation process involving ATM actors (airlines, airports and ANSPs): this is the evaluation of the renegotiation mechanism involving all ATM actors if a CoO is not fulfilled. The evaluation environment is based on the previous environments deployed (i.e., ATCOs and pseudo-pilot positions) and gaming exercises through mock-ups of an airline operational centre, airport command centre, and ANSP command centre.

The Performance Framework, proposed by the Episode 3 Project [22], is the basis for all validation activities performed within CATS, which allows for a comparison between the various research projects.

## The First Experiment

The first operational assessment was carried out from 20-to 31 October 2008 in Geneva. The main aim was to evaluate the impact of the *Contract-of-Objectives* and associated TWs between ATCOs through a Human-in-the-Loop (HIL) simulation. The hypotheses to validate through this assessment were:

- CoO implementation allows safe operations
- CoO is still manageable even with increase of traffic as foreseen in 2020 (same route structure)
- CoO implementation affects positively the aircraft outputs in the sector (flight duration ...)
- Implementation of TWs ensures the respect of schedule
- TWs integrate flexibility to cope with uncertainty
- The working methods offered to ATCOs, as a result of the CoO implementation, are feasible and acceptable (task sharing, role and responsibility, as well as the offered support tools)
- Implementation of CoO results in acceptable workload for ATCOs.

## Experiment Variables

Two independent variables have been manipulated during the experiment: 1) traffic loads; and 2) the *Target Windows* (present vs. absent).

Two traffic loads have been used during the experiment: current 2008 traffic level in the simulated area; and a 2020 foreseen traffic. The expected level of traffic in 2020 was determined by the EUROCONTROL STATFOR services.

The objectives represented by the CoO are the TWs, 4D intervals located at the border area between two ACCs. During the experiment, two conditions, with and without TWs, have been measured.

Given the above variables, the CATS experiment followed a 2 (traffic loads) x 2 (TWs conditions) repeated measurements design, resulting in 4 experimental conditions with eight repeated measurements for each condition.

## Measurements

Two kinds of measurements were collected during this experiment: (1) system performances, through KPAs; and (2) human performances.

From the stakeholders' concerns and performance framework [22], 3 of the SESAR KPAs

have been identified as potentially improved by CoO and associated TWs introduction, mainly capacity, safety and efficiency. This first objective (system performances) is a key aspect of the validation. The aim is to assess if the benefits are delivered as proposed.

The aim of the second objective (human performances) is to see if the contribution of the human-to-overall system performance is within expected capabilities (workload, situation awareness, working methods, acceptability ...) and not reaching the human limits. The human performance could be seen as an enabler to reach the system performance.

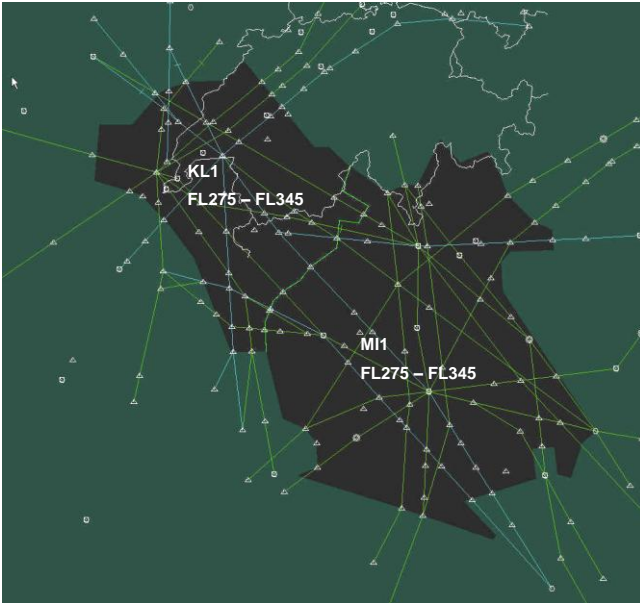
Various techniques were used, such as observations, recorded data, questionnaires and self-assessments, as presented Figure 3.

Objectives relating to system performance	Objectives relating to human performance
SAFETY	<ul style="list-style-type: none"> <li>■ Feasibility and acceptability of the ATCOs' working methods due to the CoO execution</li> <li>■ Impact of CoO execution on ATCOs' performance</li> <li>■ Impact of CoO on ATCOs' activity</li> </ul>
CAPACITY	
EFFICIENCY	
Indicators	Indicators
SAF.LOCAL.ER. PI (1, 2, 3, 5, 6 & 8)	<ul style="list-style-type: none"> <li>■ Workload: ISA, NASA-TLX, Interviews, Observations, Performance outcomes, Questionnaire</li> <li>■ Situation Awareness: SASHA_Q, Interviews, Observations, Performance outcomes, questionnaire</li> <li>■ Error production and management: Observations, Questionnaire, Interviews, Performance outcomes</li> <li>■ Operator's activity: Cognitive processes, Decision making, Risk management, etc.</li> <li>■ Collaborative activity: Communications (number, time, content, speaker and receiver, etc.)</li> </ul>
CAP.LOCAL.ER. PI (2, 8, 10, 11, 12 & 13)	
EFF.LOCAL.ER. PI (1, 7, 8, 9, 10, 11)	
Number of TWs fulfilled	

**Figure 3. Performance Assessment Techniques**

## Experimental Environment

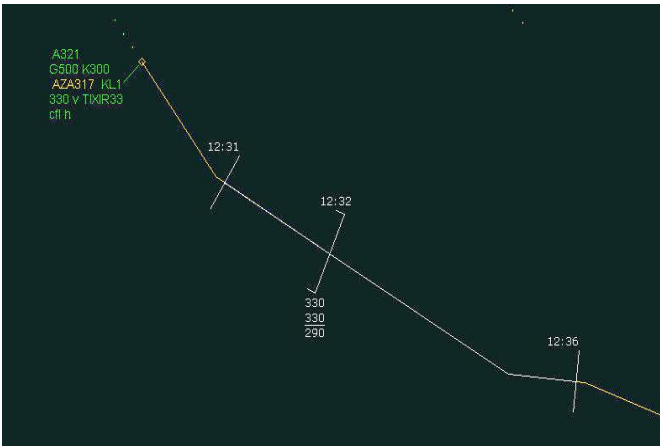
The airspace chosen for this experiment was two en-route sectors (Milan MI1 and Geneva KL1) at the border of two ACCs (Figure 4).



**Figure 4. Measured Sectors**

A total of 4 controllers participated in the CATS first HIL. They were from Roma ACC and Brindisi ACC (ENAV); all had over 10 years of qualified experience, and all work currently as controllers in en-route sectors.

The platform used for this experiment was the SkyGuide simulator, with the standard Geneva services and tools. Specific Human Machine Interface (HMI) for TWs display (Figure 5) and associated tools have been developed by SkySoft ATM.



**Figure 5. HMI Display**

The experiment period timetable encompassed:

- Half-a-day for simulation devices presentation: functions and limits
- One day for familiarization with the simulation devices, HMI, airspace, and CoO, followed by one-day-and-a-half for training purposes, on operational scenarios and experimental environment
- Six days for performing the experimental runs
- Final debriefing with all attendees closed the HIL1 experiment period

Simulation exercises have been conducted based on three exercises per day. Each exercise ran for about 1h with 30 minutes added for completing questionnaires.

Each run encompassed:

- Short run presentation and briefing.
- Run performing (one hour).
- Break
- Questionnaires and self-evaluation scales performing (15 minutes)
- Debriefing (30 minutes)

## Results And Discussion

Results of this HIL will be reported firstly regarding the human performances (*i.e.*, workload, situation awareness and acceptability) and secondly regarding the 3 KPAs data.

### Workload

Workload was measured through two subjective methods: Instantaneous Self-Assessment of Workload (ISA); and NASA-Task Load index (NASA-TLX) [23]. The workload assessment purpose was to measure the impact of *Target Windows* (TWs) management on the controllers' workload. The way to assess this assumption was to compare two similar traffic management situations: one without TWs; and one with TWs. At the end of each run, a post-run questionnaire also tackled this issue. The results were subjected to a Wilcoxon test to measure if it was significant or not.

Error! Objects cannot be created from editing field codes.

TW: p>0.123486

## Figure 6. ISA Sector MI1 Executive

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TW:  $p > 0.674424$

## Figure 7. NASA TLX Sector MI1 Executive

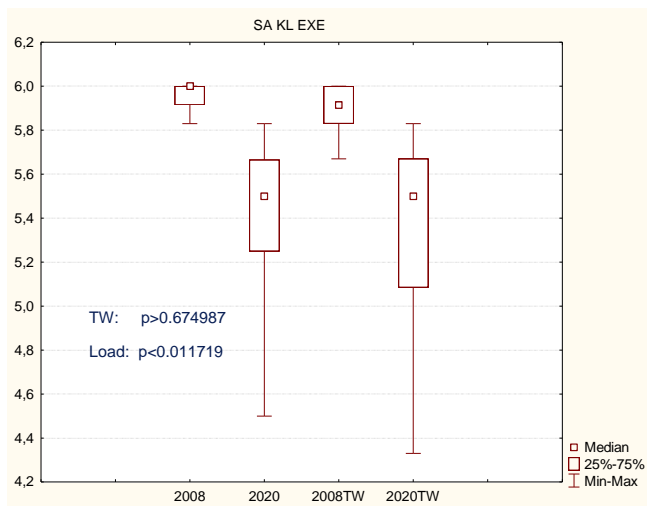
Load:  $p < 0.011719$

The workload assessment showed (Figure 6) (Figure 7) that the workload was not statistically impacted by the TWs management, whatever the traffic load, even if the controllers perceived (from the debriefings and questionnaires) the TWs as an additional task, slightly impacting the traffic management.

### Situation Awareness

Situation awareness is the way in which the controllers understand the traffic dynamics, and are able to properly manage the aircraft to ensure safety and efficiency.

The situation awareness was evaluated through SASHA questionnaires [24] and also tackled during post-run questionnaires.



## Figure 8. SASHA Sector KL1 Executive

As for the workload data, the results (Figure 8) were subjected to a Wilcoxon test to measure a significant value.

There is no significant difference ( $p > 0,05$ ) between the "without TW" and "with TW" conditions, whatever the traffic loads ( $p$  values range

from 0,35 to 0,67). This result was observed whatever the control position (executive or planer) and whatever the controlled sector (KL or MI).

Significant difference ( $p < 0,05$ ) was found between the two traffic load conditions, whatever the control position and the controlled sector. The  $p$  values range from 0,011 to 0,046.

In addition, the analysis of median values shows the level of situation awareness of 2008 traffic load conditions was always higher than for the 2020 traffic load conditions.

These results show heavy traffic load (2020 forecast) impacted more on the level of situation awareness than the TWs management, even if the TWs management shows a non-significant tendency to decrease slightly the situation awareness.

The controllers' feeling (expressed in post-experiment questionnaires and during debriefings) about the impact of TWs management on the situation awareness was unanimous: the TW use increased traffic situation awareness. For the four controllers rated on the post-run questionnaires, they all agreed (level 4 on the five-level scale) the situation awareness was increased with TWs. This feeling was a slightly more important for the executive controller than the planner controller.

The explanation given by the controllers during debriefings was that the TWs information displayed were very useful for aircraft management.

### Usability and Acceptability

Unanimously, controllers strongly agreed TWs were easy to use whatever the control position (executive or controller). This feeling was largely developed during the post-run debriefings. Controllers quickly became familiarized with the concept, and were autonomous on their control working positions.

This feeling was reinforced by the fact the controllers found the TWs management easy to learn. They were satisfied with the training and familiarization programme. The training was evaluated as satisfactory in imparting a good understanding of the concept and its use.

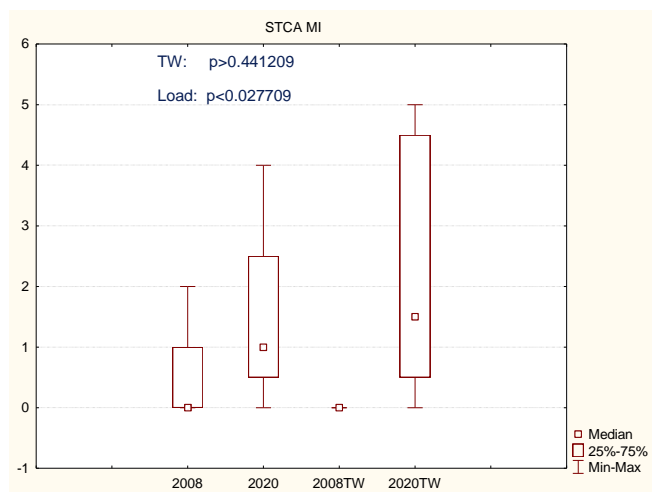
The high level of usability assessed during the simulation is a strong point of the concept for its

future development. This means the learning process is not a barrier for the next CATS HIL experiments, and for the TWs potential implementation in the real operational rooms. Of course, this should to be confirmed through the next experiments.

### Safety

Safety is the major concern of Air Traffic Control. The challenge for the future is to increase the level of capacity with, at the least, the same level of safety as today.

For this experiment, safety was evaluated through dedicated questions in post-run questionnaires, and also through the number of Short Term Conflict Alarms (STCA).



**Figure 9. STCA Sector MI1**

The number of STCAs occurring in each exercise (Figure 9) may seem high. In fact, these values need to be weighted by the STCA features. The observations and controllers' comments during the post-run debriefings showed that most of the STCAs were under control or were as a result of the STCA algorithm, and were not valid. In accordance with the controllers' responses and the observations, only one loss of separation occurred along the 16 simulation exercises. This STCA occurred during a "2020 TW" condition. This occurrence cannot have any statistical meaning, which implies that there is no significant difference between the "without TW" and "with TW" conditions for the STCA occurrences. However, STCAs may be used for indicating a

degree of minimal distance between aircraft occurring during the exercises. In this way, the tables above show that there is no significant differences between the "without TW" and "with TW" conditions, whatever the level of traffic load and the measured sector ( $p > 0.441$ ). However, there is a significant difference between the levels of traffic load ( $p < 0.046$ ). The traffic load level impacted the minimum distance between aircraft, whereas the TW use did not.

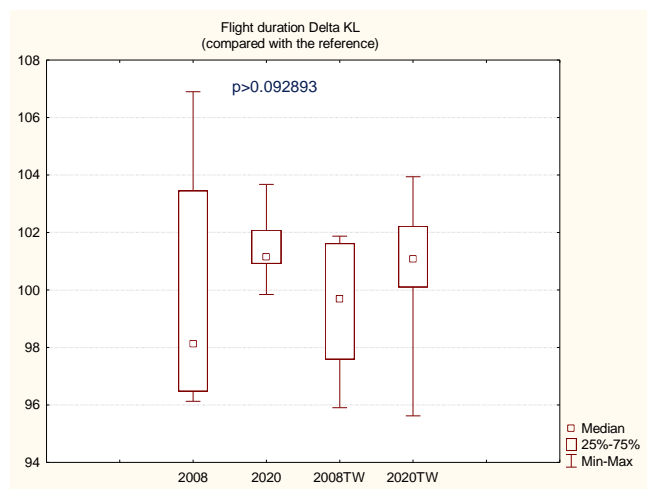
Post-run questionnaires and debriefings data were also consistent with quantitative data to establish that safety was not impacted by the TWs use, even when the capacity matched the 2020 expected traffic load.

### Efficiency

The traffic efficiency was then assessed through two indicators: the "flight duration" and the "number of fulfilled TWs" to see if the TWs implementation affected positively the aircraft outputs.

#### Flight Duration

There is no significant difference ( $p > 0,05$ ) in the KL (Geneva) sector between "without TW" and "with TW" conditions (Figure 10).



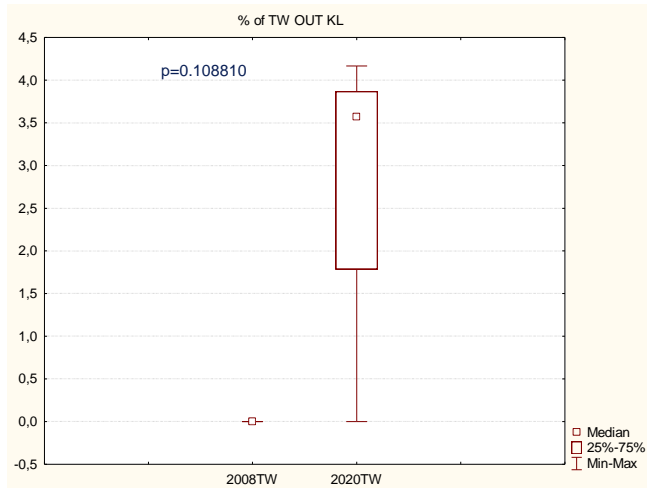
**Figure 10. Ratio Of Flight Duration Sector KL1**

The TWs use did not impact the aircraft flight duration in the sector; so, in this sector, the efficiency was not impaired by the TWs use. But, even if it is

insignificant, with the TWs, the median is close to the 100 value (representing the ratio between the duration of the flown trajectory and the duration of the planned trajectory), indicating that with the TWs, the aircraft flew close to the flight plan. These results mean the TWs use increased the traffic efficiency.

### Amount Of TWs Non Fulfilled

The percentage of "out TW" was relatively low (Figure 11) and appears to be acceptable by the controllers, as expressed during the debriefings.



**Figure 11. Percentage Of TWs Not Fulfilled Sector KL1**

The TWs fulfilment was not statistically impacted by the TWs use or the traffic loads. However, the TWs fulfilment seems to be sensitive to the sector shape, airspace structure, and traffic conditions. These results should be further studied in the next experiments.

### Capacity

The results obtained during the experiment, mainly regarding the System Performances, indicated that the 2020 expected capacity was properly and safely managed.

### Conclusion

The main aim of this simulation was to present the CoO concept and associated TWs to controllers, to investigate the impact of this concept on the

current ATC activity, and evaluate the operational acceptability from a controller point of view.

To summarize, ATCOs were very positive about the concept, even if they thought potential benefits were of more concern for airlines. They agreed on the principle around CATS proposal, where the idea is to fly what was planned, agreed and negotiated, as opposed to current "first come-first served" approach, or full 4D implementation, based on 4D capable avionics and data-link, proposed for the future. Allocation of resources could then be coordinated in the right way during the planning phase.

Results of this experiment [25] demonstrate that the *Contract-of-Objectives* concept was manageable with the 2008 current and 2020 expected traffic loads in the two measured sectors, without any impact on the traffic safety. Controllers judged the TWs management as feasible and acceptable, even if the TWs added some constraints when considering conflict resolution. Controllers were more constrained by the heavy traffic load than by the TWs use. However, the TWs management involves more information, which increases the perception of workload. But this increase in information was also considered as a positive aspect for improving the situation awareness. Objectively, quantitative data revealed that the TWs use had no impact on the workload and situation awareness. This outcome is a strong indicator for future development and concept acceptability. The results obtained in terms of System Performance indicated the capacity, expected in 2020, was properly and safely managed, even if next HIL experiment will have to further strengthen this outcome by reducing the platform limitation.

This experiment was the first step of the operational assessment foreseen to validate the CoO concept. This will be followed by a second step, in October 2009, dealing with the impact of the CoO and associated TWs between aircrews and controllers. This study will be very important in the evaluation of the acceptability of the concept from a crew point of view, and particularly the impact of TWs introduction on task sharing between ATCOs and crews.

The CATS concept could be seen as a possible driver to implement the SESAR Business Trajectory, and its assessment could also contribute a significant understanding of the validation required for such complex concepts.

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