4D Trajectory management through 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 assessment of CoO and discusses the results of the three Human-in-the-Loop (HIL) evaluations of the concept of operations. Measurements were collected and analyzed of system performance (i.e., safety, efficiency, and capacity) as well as human performance (i.e., workload, situation awareness, and acceptability) for the human actors involved. Findings indicate that controllers and pilots are positive about the concept of operations, and they do agree on the principle of flying what was "planned, agreed and negotiated" during the planning phase, as opposed to the current "first come, first served" approach. The renegotiation was assessed as manageable, even with the 2020 traffic load, without any impact on safety. They all recognize that implementation of CoO increases the collaboration between crew and ground, as they share not only the same data but also the same robust objective all along the flight, i.e. the objective determined at strategic level through a Collaborative Decision Making process (CDM). Some improvements are still needed regarding the HMI and the generation of Target Windows (TWs). The airport and airline operators, as well as the network manager considered renegotiation to be feasible and acceptable. They were interested in the CDM process proposed. They found the principle of sharing the operational data of other actors to be a great improvement in the way the choices are made and validated.**

Keywords: Punctuality, 4D trajectory management Contract of Objectives, ATM, Global efficiency, crew-ground collaboration.

I. INTRODUCTION

In recent 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.

As stated by SESAR [1], the future system should be performance-based. The future ATM system should integrate ground and airborne segments more closely, respect schedule integrity, and enhance interoperability. 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 [2]. 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. 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 4D trajectories are also essential elements. An abundance of articles dealing with these topics have been edited and studied in the CATS State of the Art [3]. An ATM system based on 4D trajectory management will hopefully benefit from prediction analysis [4][5] and FMS accuracy [6][7][8][9], allowing for a reduction of trajectory uncertainty [8]. Focusing not only on the execution phase, but on all phases of the ATM system, should bring essential benefits when obtaining a future efficient and cost-effective ATM system, as shown by SESAR D2 [1]. The link between planning and execution phases seems also to be a big challenge for the future ATM system.

The CATS 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 [10]. The CATS project could also contribute a significant understanding of the validation required for such complex concepts.

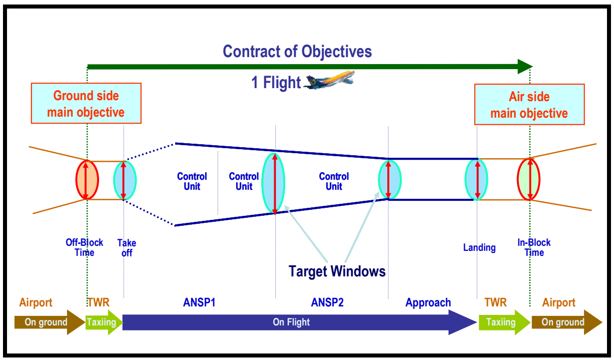

Figure 1. Contract of Objectives

II. CONCEPT OVERVIEW

CATS is based on concepts initiated during the EUROCONTROL Experimental Centre's Paradigm SHIFT Project [11], namely the Contract of Objectives (CoO) and associated Target Windows (TWs).

The CoO is an operational link between all air navigation actors (airlines, airports and ANSPs). The CoO represents a formal and collaborative commitment between all the actors by establishing the roles as well as the tasks and responsibilities of each actor, based on well-defined, agreed and shared objectives. These objectives are to deliver a particular aircraft within temporal and spatial intervals; this is known as Target Windows (TWs). These commitments are agreed by all actors involved in specific transfer of responsibility areas (e.g. between two 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 system efficiency and predictability by means of enhanced collaboration between ATS actors.

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 Windows. TWs create a common language between all the operators involved, and also between the planning and operational phases.

Instead of precise 4D points, the TW is expressed in terms of temporal and spatial intervals based on 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 [12][13] proposes, instead of removing this uncertainty, keeping 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.

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 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 hours before the execution phase): continuous refinement of the TWs up to CoO agreement.

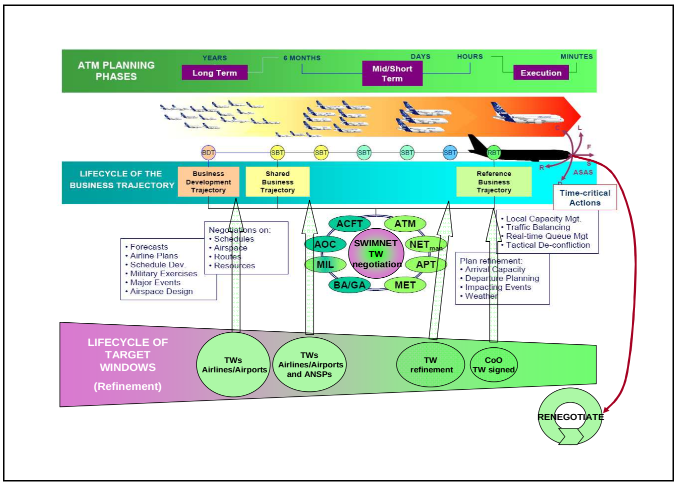

Figure 2. TW lifecycle

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, *etc*.), 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.

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.

III. Validation Overview

The aim of the CATS Project is to assess the CoO and associated TWs by involving the major actors in the supply chain. The CATS consortium has been built to involve representatives of the main stakeholders of the ATM.1.

The CATS concept assessment, following European Operational Concept Validation Methodology (E-OCVM) [14], is conducted by two main means:

- Operational validation which analyses how the proposed CoO and the associated TWs impact the operators' performance regarding selected Key Performance Areas (KPAs) defined by SESAR [1];
- Systemic validation, which highlights the impacts for the overall ATS on safety and risk management, cost benefits, and legal consequences. Specific results could be obtained in [16][17][18].

Operational validation is led by three successive Human-In-the-Loop (HIL) experiments which focus on different validation objectives:

- HIL-1. Evaluation of the impact of the CoO between Air Traffic Controllers (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.[19]
- HIL-2. 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.[20]
- HIL-3. 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, and gaming exercises through mock-ups of an airline operational centre, airport command centre, and ANSP command centre.[21]

This paper presents the results of the operational validation.

IV. Experiments

A. Objectives

The three experiments were carried out in Skyguide premises, Geneva, respectively in Oct2008, Oct2009 and Jun2010. The simulations devices encompassed coupled controllers working positions and cockpit simulators, as well as network manager, airport operation staff and airline operation staff positions.

The aim of these three HIL was to evaluate whether:

- CoO implementation allows safe operations;
- TWs integrate flexibility to cope with uncertainty;
- The ATCOs' and aircrews' working methods deriving from CoO execution and renegotiation are acceptable;
- CoO execution and renegotiation do not impact the ATCOs' and aircrews' performance;
- CoO execution and renegotiation do not impact the ATCOs' and aircrews' activity;
- Collaboration between ATCOs and aircrews is high;
- CoO is still manageable with growth of traffic as foreseen in the 2020.
- Renegotiation of TWs is manageable for airport, airline and network manager staff.

B. Variables

Two independent variables were manipulated during the experiment: Target Windows and traffic loads. Two conditions, with and without Target Windows, were measured. Two traffic loads were measured during the experiment: 2008 traffic level and 2020 forecast traffic.

The reason for the renegotiation may impact on the extent of the renegotiation and also how difficult it is. For that reason, five different triggers [22] were used during HIL3 to assessed the renegotiation process (i.e. airport closure, swap of slots, windshield crack…)

C. Measurements

Two kinds of measurements were collected during this experiment: system performance, and human performance.

The aim of the system performance evaluation was to assess whether the CATS benefits are delivered as proposed. From the stakeholders concerns and SESAR performance framework [15], four of the SESAR KPAs were identified as potentially improved by CoO and associated TW introduction: capacity, safety, efficiency, and predictability.

The human performance objective is to see whether the contribution of the human to overall system performance is within expected capabilities (workload, situation awareness, working methods, feasibility, acceptability, etc.) and does not reach human limits. Human performance could be seen as an enabler to reach system performance.

Different methods and techniques were used, such as observations, recorded data, questionnaires and self-assessments, as presented in the Table below.

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[1] The CATS consortium includes Frequentis, EUROCONTROL Experimental Centre, Air France Consulting, Ente Nazionale Assistenza al Volo (ENAV SpA), Zurich Airport, University of Leiden, Swiss Federal Institute of Technology, Laboratorio di Ricerca Operativa Trieste University, and SkySoft ATM. The project is co-funded by European Commission.

System performance	
Safety	- Potential losses of separation - Aircraft separations
Efficiency	- Number of fulfilled TWs - Number of renegotiated TWs - Planned flight time divided by flight time into the sector - Aircraft fuel consumption - Time needed to renegotiate TWs.
Capacity	- Number of aircraft crossing the sector each hour - Instantaneous number of aircraft - ATCO instruction number (speed, heading, flight level)
Predictability	- Planned flight time divided by flight time into the sector - Number of fulfilled TWs
Human performance	
Workload	- Instantaneous Self-assessment of Workload (ISA) – ATCO - NASA-TLX – ATCO & Pilot - Post-run debriefing – ATCO & Pilot/ Airline, Airport staff & Network manager - Post-experiment questionnaire – ATCO & Pilot/ Airline, Airport staff & Network manager
Situation awareness	- Situation Awareness for SHAPE Questionnaire (SASHA-Q) – ATCO & Pilot - Post-run debriefing – ATCO & Pilot - Post-experiment questionnaire – ATCO & Pilot
Activity	- Over-The-Shoulder (OTS) observation – ATCO/ Airline, Airport staff & Network manager - Post-run debriefing - ATCO & Pilot - Post-experiment questionnaire – ATCO & Pilot
Collaboration	- Communication duration and content – ATCO & Pilot/ Airline, Airport staff & Network manager - Decision-making process – Airline, Airport staff & Network manager - Post-run debriefing –all participants - Post-experiment questionnaire – all participants

Table 1: Validation Plan

D. *Environment*

The airspace chosen for this experiment was two en-route sectors (Milan MI1 and Geneva KL1) at the border of two ACCs (Figure 3). To sustain the renegotiation process five airports have been chosen, endorsed by the experts within the project. These airports are: LSGG, Geneva, LSZH, Zurich, LIML, Milano, LFML, Marseille and LFLL, Lyon.

A total of 4x3 controllers and 2x2 pilots participated in the experiments. The controllers were from Roma ACC and Brindisi ACC (ENAV) and all had over 10 years of qualified experience and were working as controllers in en-route sectors. The pilots had all retired in the last six months from operational service at Air France. Both were A320 captains with more than 8,000 flying hours on glass cockpit aircraft. During the last experiment one Network manager, one Airline Operational staff member and one airport operator staff member joined the experiment. The network manager was a FMP manager from Roma ACC, the airline operator had retired in the last three months from operational service at Air France, and the airport operator was from Zurich Airport, working in Airport Operation service as Duty Manager Airport Steering.

The simulation environment used was made up of two coupled simulators and a CDM platform:

- SkyGuide ATM simulator, with the standard Geneva services and tools. Specific HMI for TWs display and associated tools were developed by SkySoft ATM.
- Two A320 cockpit "flight simulator 2004". Specific HMI for TWs display were developed by SkySoft ATM on the Navigational Display.

In each run, 4 "flight simulator 2004" aircraft were piloted by the two pilots (2 aircraft by run, and for each pilot). The other aircraft were handled by automatic pseudo pilots that execute the controller instructions. In order to avoid decreasing the ATCOs' workload too much, a data link device was implemented at the ATCO working position, integrating latency delays between the instructions and their execution by aircraft.

- A CDM platform was designed by Frequentis for the renegotiation assessment. Dedicated mock-ups of an airline operational centre, airport command centre, and ANSP command centre were designed.

Figure 3. HMIs and simulation room display

V. RESULTS

The results of the experiments are reported firstly regarding the human performances, and secondly regarding the system performance.

A. *Workload*

The workload was measured through two subjective methods: Instantaneous Self Assessment of Workload (ISA) and NASA-Task Load Index (NASA-TLX)[23].The purpose was to measure the impact of TW management and renegotiation on controllers' and pilots' workload by comparing two similar traffic management situations: one without TWs and one with TWs, and one without renegotiation and one with renegotiation. The results were subjected to a Wilcoxon test. Debriefings were also a support for a deeper analysis of the operators perceptions.

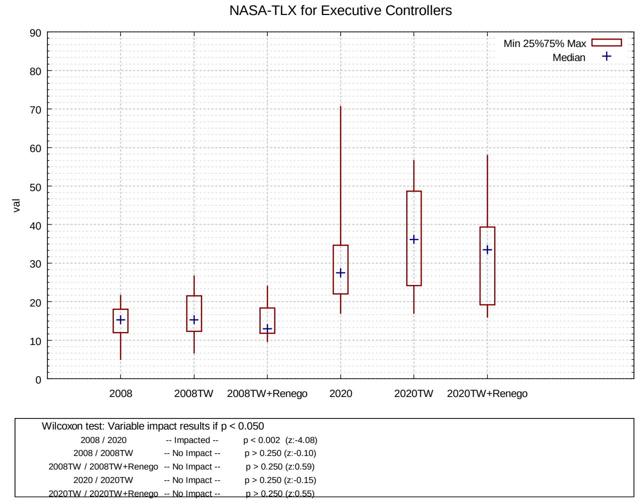

Figure 4. NASA-TLX for executive controllers

The ISA and NASA-TLX results are consistent: whatever the control position and the control sector, the ATCOs' workload was not impacted by TW management or renegotiation (p level>0.25). The workload was impacted by the traffic load (2008 vs 2020), although it remained manageable (level 3 of ISA). These results were confirmed by the debriefings. The ATCOs evaluated the renegotiation as quite easy. Only the duration of the renegotiation or a change in the FL renegotiated could impact their workload.

This perception was not equally shared by the pilots. Their workload was significantly ($p<0.05$) impacted by TW management and by the renegotiations. Debriefings showed that the workload, in the case of renegotiations, could vary from pilots' point of view and was related to the means of communication. The use of data-link with controllers and the airline is identified as essential in order to keep the workload at an acceptable level. The RT communications dramatically increase the workload. Pilots' workload is then impacted by TW management and renegotiation. This impact is fully acceptable, but should be further evaluated in cruise emergency situations or in other flight phases where the aircrew workload is high (e.g. descent or approach in complex environments).

The actors' workload was assessed through questionnaires and debriefings. All the results indicate that the workload was fair, although it increased when the number of renegotiations was high. The main impact on their workload was when their own margins decreased (e.g.: less capacity on airport or airspace, remaining fuel, etc).

B. Situation Awareness

The operators' situation awareness was evaluated through SASHA questionnaires [24] and also tackled during debriefings.

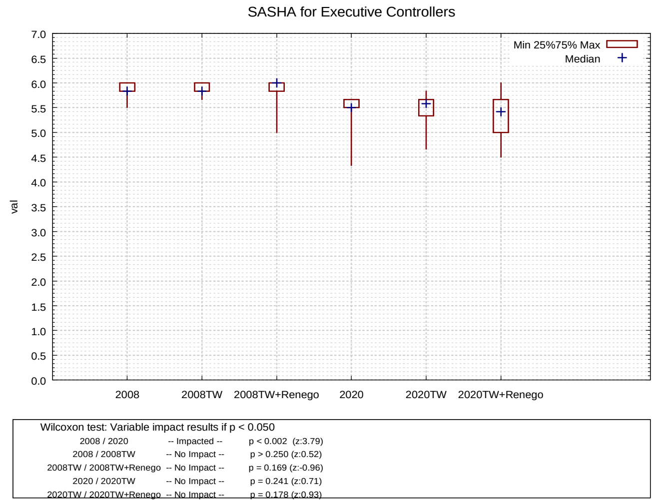

Figure 5. SASHA for executive controllers

Situation awareness was not significantly impaired by the implementation of TWs. However, the levels of situation awareness are always high whatever the experimental conditions. The controllers' perception of situation awareness is that TW information increases the traffic picture, although there was no statistically significant difference compared with the SASHA questionnaire results. Only the load of the traffic level impacts the SA.

Figure 5 shows that the controllers' situation awareness is not impacted by the renegotiation process whatever the controller position, the controlled sector, even with 2020 traffic conditions, and with a high number of renegotiations.

Figure 6 shows similar results for the pilots. Their SA was not impacted by the introduction of TWs.

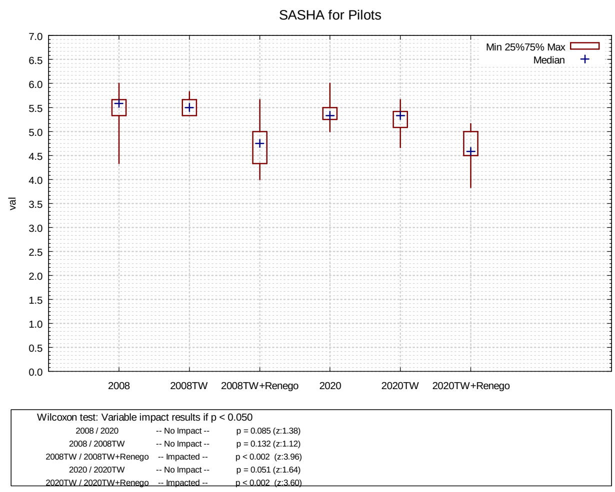

Figure 6. NASA-TLX for pilots

Nevertheless, the effect of the renegotiation is significant for pilots (p=0.002), although the average remains above the level 4.5, what is still acceptable. This was mainly due to the lack of speed data when pilots received the new set of TWs.

On the other hand, the three actors explained that the renegotiation process and the access to other information is an effective way of increasing the understanding of traffic.

C. Usability and acceptability

The number of control instructions given increased when traffic load increased, but independently of TW use. The way the executive controller solved conflicts is judged as slightly modified by TW implementation. Such a change is linked to the objective of fulfilling the exit TW, and then, to find the best solution to solve the conflict, respecting this constraint if possible.

Unanimously, controllers and pilots strongly agreed that TWs are easy to use whatever the control position (executive or planner controller). This feeling was widely expressed during the post-run debriefings. Controllers and pilots quickly became familiarized with the concept, and were autonomous at their control working positions. This feeling was reinforced by the fact that they found TW management easy to learn.

Controllers agree that the renegotiation process does not disturb the way the executive controller manages the traffic, detects and solves conflicts. They all affirmed the need to receive the new set of TWs by data link to avoid increasing RT with the crew.

Unfortunately, the HMI and tools proposed to the pilots were not judged adequate to support the renegotiation process. Improvements on CDU, speed management and the adding of electronic messages between pilots and AOC have been noted.

As the platform proposed to the actors (APOC, NM & AOC) was a mock-up of CDM interface and not a real operational platform (like for the controllers), the interface was judged slightly easy to use. They suggested adding tools/functions closer to the current operations (e.g. aircraft size for APOC, NOTAM or FL for NM). However, the three actors had no difficulty learning the functioning of their position and applying the principles of the renegotiation process. They were quickly familiar with the collaborative decision-making process.

D. Collaboration

On the basis of the debriefings and questionnaires, ATCOs and pilots feel that TW management does not require more communications between them. ATCOs and pilots felt that this feeling derives from the fact that the same TW data were shared by the cockpit and the control working position. Consequently, all requests or instructions are understood in the context of the TW data, without specifically stating them. When a request or instruction is not understood properly by the ATCO and/or the pilot, he clarifies the reference to the TWs.

ATCOs and pilots have no difficulty in finding vocabulary in order to communicate about TWs. Nevertheless, all expressed the need for a new specific phraseology. Use of the terms "due to Target Windows" seems accurate. By saying "due to Target Windows", the controller and the pilots immediately understand the context of a request or an instruction.

Regarding the renegotiation of TWs, there is no consensus between controllers. In fact, the need to communicate and collaborate more depends on the size and nature of changes in the new set of TWs regarding the old one. If the changes have major impacts on the way to manage the traffic (conflict solving), controllers increase their collaboration. Similarly, if the changes have major impacts on the next sectors, there is a need for greater collaboration with the adjacent sectors. Controllers agree that if the changes are small, the need for collaboration is very acceptable, and fully compatible with the traffic management load. When the number of renegotiations is high, and if these renegotiations make major changes to the new sets of TWs, the additional collaboration work may become appreciable.

The communication between AOC and crew increase slightly during the renegotiation process, mainly due to the lack of speed data in new sets of TWs. The results obtained through questionnaires and debriefings underline that the renegotiation process has no impact on the collaborative work between the pilots and AOC if some improvements, such as the use of electronic message could improve the situation.

E. Safety

Safety was assessed through the number of STCAs, post-run questionnaires, debriefings and analysis of aircraft separation performance through SPT tool [25]. Results from STCA and questionnaires show that the TW management and renegotiation do not impact safety, either positively or negatively, whatever the traffic load (2008/2020). Aircraft separation performance, as shown in Figure 7 confirms that a high level of safety is maintained even with the 2020 traffic load and TWs. The majority of the traffic is maintained at more that 10Nm and 1000ft, and most potential conflicts are avoided before the separation limits.

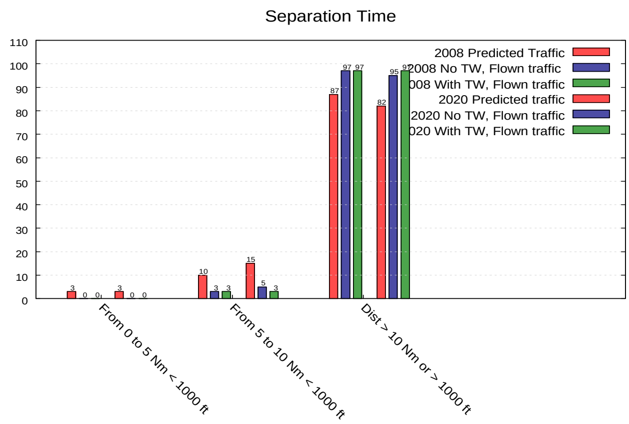

Figure 7. Aircraft separation

This feeling was also reported by the pilots: their safety impression was impaired neither by TW management, nor by TW renegotiation.

F. *Efficiency*

Traffic efficiency was assed through the flight duration, the number of TWs fulfilled and the duration of renegotiation. Flight duration is calculated by comparing the time flown by each aircraft in the sector during the experimental exercises, with a reference time which is the time to fly through the sector for the same aircraft without any ATC) actions (simulator flying the aircraft, following the flight plan).

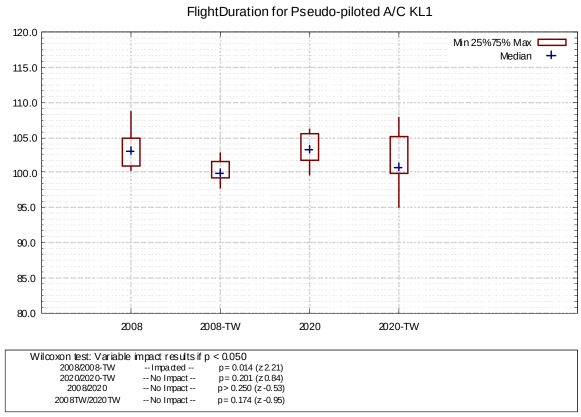

Figure 8. Fligh t duration

Results show that the traffic load condition has no impact on the duration of the flight. Whatever the measured sectors, the flight duration is shorter with TWs. The median values of flight duration with TW are closer to the 100 value than without TW, indicating that with the TWs, the aircraft flew closer to the flight plan.

The number of aircraft fulfilling their TWs is a strong indicator of the concept validity and traffic efficiency. The percentage of “out TW” is relatively low (median value at 0, max<10%), which appears to be acceptable. However, TW fulfillment seems to be sensitive to the sector shape, airspace structure, and traffic conditions.

The duration of the renegotiation is also a relevant indicator of the efficiency of the system. Figure 9 below shows that the average duration for all the renegotiation processes is 158 seconds (2 minutes and 3 seconds). This duration was assessed as fully acceptable by the actors and acceptable by the operators (pilots and controllers), although it was outlined that the shorter the renegotiation duration, the lower the impact on the pilots and controllers' activity.

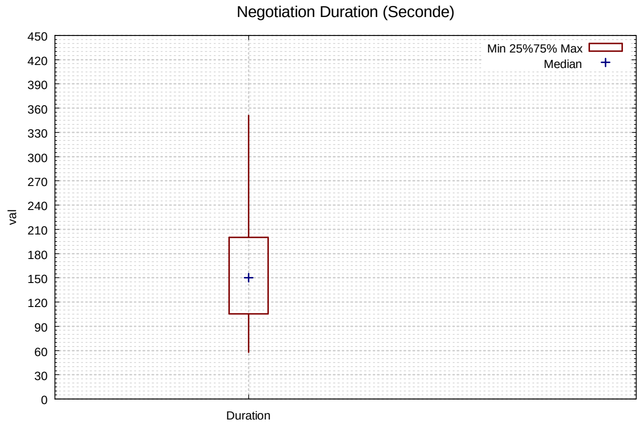

Figure 9. Renegotiation duration

The potential benefits of implementing such a concept are also underlined in [17], reflecting the net benefits for airlines and ANSPs .

G. *Capacity*

The choice made in the CATS assessment for evaluating the KPA capacity, was to assess two levels of capacity, and not to assess progressively a capacity growth and identify the breaking point. The two levels of capacity were 2008 capacity and 2020 forecast capacity. The results obtained during the three experiments, mainly regarding the system performance, indicated that the 2020 expected capacity was properly and safely managed.

VI. Conclusion

The three HIL experiments objectives were to assess the CoO concept and associated TWs, even if they cannot be fulfilled, to investigate the impact of this concept on controllers' and pilots’ activity and relationships, and to evaluate the operational acceptability from the point of view of the actors (airport and airline operators, network manager) and operators (controllers and pilots).

CATS selected a representative operational context for performing the three operational validation activities, involving direct representatives of key ATM players. The fact that a tried and tested set of validation techniques and methods was selected ensures confidence in the results described above.

All participants were very positive about the concept. It was considered feasible and acceptable by the controllers and pilots, and the TWs were manageable, even with the 2020 traffic load, without any impact on safety. However, participants think that the potential benefits are of more concern for airlines and the Air Transport System as a whole than for themselves. They all recognize that implementation of the Contract-Of-Objectives concept will increase the collaboration between crew and ground, as they share not only the same data but also they visualize the same robust objective all along the flight. Actors and operators found the renegotiation concept fully manageable without major impacts on their activity. Actors identified with evidence the advantage of CoOs and the renegotiation process for improving the efficiency of the transportation system. All participants do agree on the principle of flying what was planned, agreed and negotiated (or re-negotiated), as opposed to the "first come first, served" approach. Finally, some improvements in terms of HMI are also required to strengthen the proposed concept, mainly regarding the renegotiation issues.

The HILs results [19][20][21] show that the CATS concept could be seen as a possible driver for implementing the SESAR Business Trajectory, and its assessment could also contribute a significant understanding of the validation required for such complex concepts. The introduction of TWs constitutes a fundamental tool to achieve CDM capabilities.

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