

Result of the evaluation of crew-ground integration 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. By integrating room of maneuver to face ATC uncertainty, accordingly to actors constraints, CoO concept gives robust solution to manage flights and resources. This paper provides an overview of the foreseen validation of CoO and discusses the results of the second Human-in-the-Loop (HIL) evaluation of the concept of operations using CoO between Air Traffic Controllers (ATCOs) and aircrew. This experiment was carried out in October 2009 in SkyGuide premises in Geneva, Switzerland. Measurements on system performance (i.e., safety, efficiency, and capacity) as well as human performance (i.e., workload, situation awareness, and acceptability) for Air Traffic Controllers and pilots were collected and analyzed. Results show that ATCOs 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 currently “first come, first served”. 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. Results of the evaluations also show that CoO can be applied to 2008 and 2020 traffic levels in Europe without any impact on system safety.

Keywords

4D trajectory management; ATM; punctuality; Contract of Objectives; efficiency; crew-ground collaboration

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.

Air transport business stimulates national economies, global trade and tourism [2]. 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 Air Transport System (ATS) supply-chain is a complex one involving many partners (such as airports, airlines and ANSPs), these business imperatives will have to be supported and shared by everyone, even if their interests or costs-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 [3].

As stated by SESAR [4], 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. The providers of the air transport supply-chain are not always 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. 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 the delivery of real benefits.

The Contract-based Air Transportation System (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 [5]. 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 during the EUROCONTROL Experimental Centre’s Paradigm SHIFT Project [5], 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.

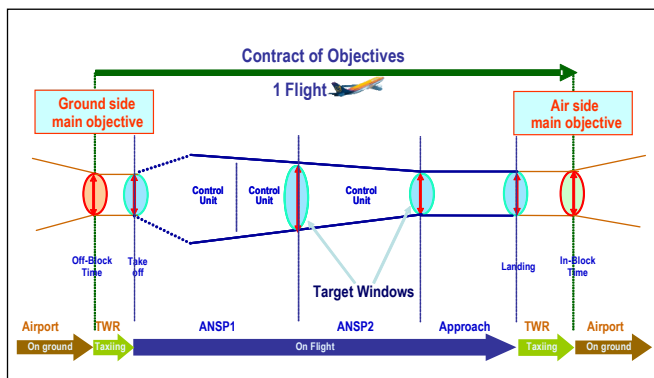


Figure 1. Contract of Objectives

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 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 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.

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.

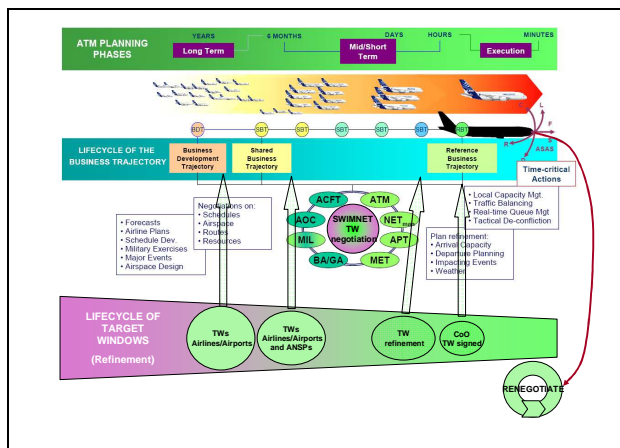


Figure 2. TW lifecycle

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.

SESAR concept of operations [5] 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.

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 ATC. The consortium includes Frequentis, EUROCONTROL Experimental Centre, Air France Consulting, Ente Nazionale Assistenza al Volo (ENAV SpA), Unique, University of Leiden, Swiss Federal Institute of Technology, Laboratorio di Ricerca Operativa Trieste University, and 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 CATS concept assessment, following European Operational Concept Validation Methodology (E-OCVM) [6], 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 (KPA) defined by SESAR [3] ;

- Systemic validation, which highlights the impacts for the overall ATS on safety and risk management, cost benefits, and legal consequences.

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.
- 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.
- 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.

This paper presents the results of the operational validation HIL-2 experiment.

HUMAN-IN-THE-LOOP 2 EXPERIMENT

Objectives

HIL-2 was carried out from 10 days in October 2008 in Geneva, and designed from the HIL-1 results [8]. The simulation devices encompassed coupled controller working position and cockpit simulators. One of the ideas of this experiment was to prove that “shared information can connect the air and ground elements to benefit to the overall system” [9]

The HIL-2 aim was to ascertain that:

- CoO implementation allows safe operations;
- TWs integrate flexibility to cope with uncertainty;
- The ATCOs' and aircrews' working methods deriving from CoO execution are acceptable;
- CoO execution does not impact the ATCOs' and aircrews' performance;
- CoO execution does 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.

Experiment 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 expected level of traffic in 2020 was determined by the

EUROCONTROL Statfor services. Traffic is expected to increase by 40% by 2020 in the measured area. The traffic growth is expressed in terms of the hourly throughput for each of the measured sectors. The difficulty managing the traffic depends on several factors like traffic load, but also the numbers of conflicts, the nature of conflicts, the way the traffic comes into the sector, the constraints imposed to meet the performance purpose, etc. Several traffic scenarios will be designed and their difficulty will be controlled. The number of conflicts will be calibrated for each scenario. Conflicts will be merging or catch-up conflicts.

Measurements

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

The aim of the system performance evaluation is to assess whether the CATS benefits are delivered as proposed. From the stakeholders concerns and SESAR performance framework [9], 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 Table 1.

System performance	
Safety	- Potential losses of separation - Aircraft separations
Efficiency	- Number of fulfilled TWs - Planned flight time divided by flight time into the sector - Aircraft fuel consumption
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 - Post experiment questionnaire – ATCO & Pilot
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 - Post-run debriefing - ATCO & Pilot - Post experiment questionnaire – ATCO & Pilot
Collaboration	- Communication duration – ATCO & Pilot - Communication content – ATCO & Pilot - Post-run debriefing – ATCO & Pilot - Post experiment questionnaire – ATCO & Pilot

Table 1. HIL-2 experiment measurements

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 3).

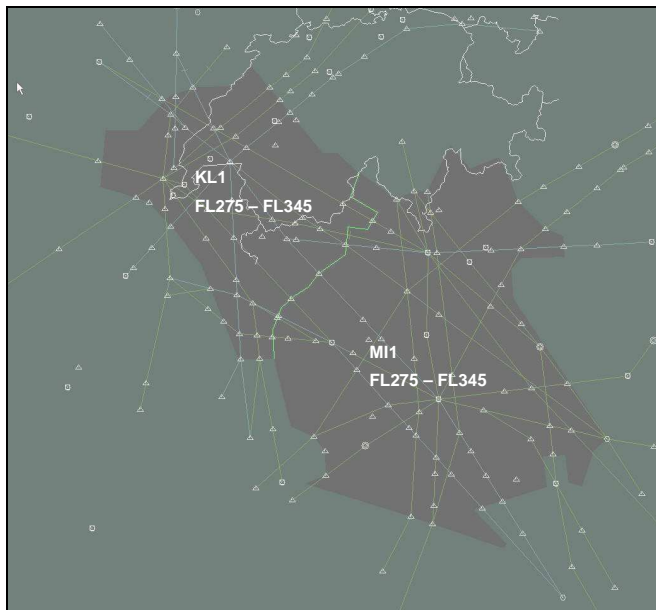


Figure 3. Measured sectors

A total of 4 controllers and 2 pilots participated in the CATS HIL-2. 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.

The simulation environment used was made up of two coupled simulators:

- SkyGuide simulator, with the standard Geneva services and tools. Specific HMI for TWs display and associated tools have been developed by SkySoft ATM (Figure 4).

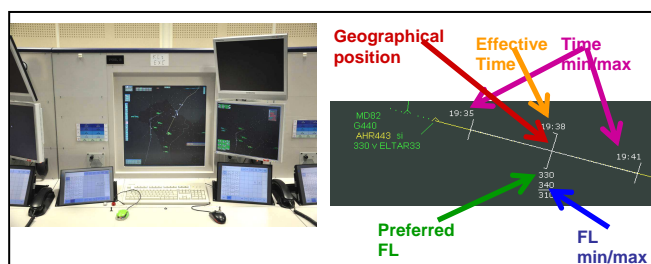


Figure 4. SkyGuide Simulator and HMI

- A320 cockpit "flight simulator 2004". Specific HMI for TWs display were developed by SkySoft ATM on the Navigational Display (Figure 5).



Figure 5. Cockpit Simulator

In each run, only 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 will be implemented at the ATCO working position. The data link will integrate latency delays between the instructions and their execution by aircraft.

Experimental plan

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

For the pilots, the CATS experiment followed a 2 (TW conditions) repeated measurements design, resulting in 2 experimental conditions with 64 repeated measurement (2 aircraft by run and for each pilot in 16 runs).

The experiment lasted 10 days, and the period timetable encompassed:

- Half a day for simulation device 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 the experimental environment;
- Six days for performing the 16 experimental runs;
- One spare day to cope with unexpected events, not used during this experiment;
- Final debriefing with all attendees closed the HIL-2 experiment period.

Simulation runs were conducted on the basis of three runs per day. Each run ran for about 70 minutes, 30 minutes added for filling in questionnaires. Each run encompassed:

- Short presentation of run and briefing;
- Performance of run (70 minutes);
- Break;
- Completion of questionnaires and self-evaluation scales (15 minutes);
- Debriefing (30 minutes).

RESULTS

HIL-2 results are reported firstly for human performances and secondly for system performance.

Workload

Controllers

ATCO workload was measured through two subjective methods: Instantaneous Self-Assessment of Workload (ISA) and NASA-Task Load index (NASA-TLX) [10]. The purpose was to measure the impact of TW management on the controller workload by comparing two similar traffic management situations: one without TWs and one with TWs. The results were subjected to a Wilcoxon test (Figures 6 & 7).

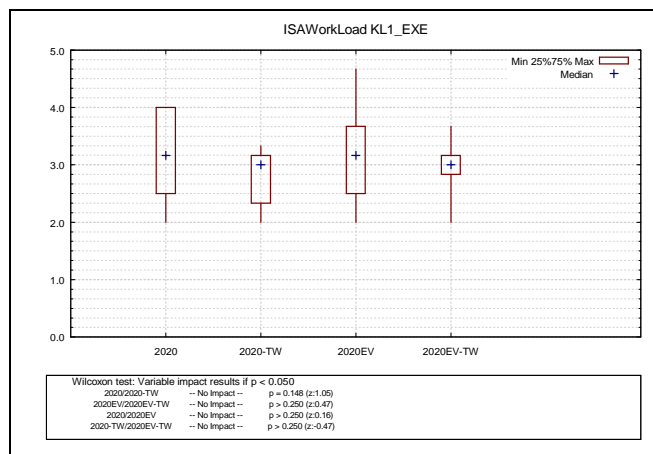


Figure 6. ISA sector KL1 executive controllers' results

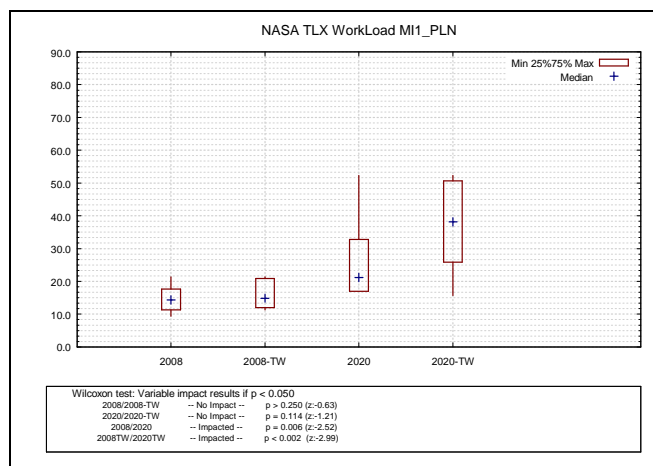


Figure 7. NASA sector MI1 executive controller' results

ISA and NASA-TLX results are mutually consistent and provide similar results. There is no significant difference ($p < 0.05$) between the "without TW" and "with TW" conditions whatever the traffic load, although the controllers perceived during the post-run debriefings and post-experiment questionnaire the TWs as an additional task, slightly impacting traffic management. This result is observed whatever the control position (executive or planner) and whatever the controlled sector (KL or MI).

There is a significant difference ($p < 0.05$) between the two traffic load conditions whatever the control position and the controlled sector. The analysis of median values shows the workload of 2008 traffic conditions was always lower than the 2020 traffic load conditions.

Pilots

Pilots' workload was measured through NASA-TLX. The purpose was to measure the impact of TW management on the controllers' workload by comparing the cruise phases into the measured sectors with and without TWs. The results were subjected to a Wilcoxon test (Figure 8).

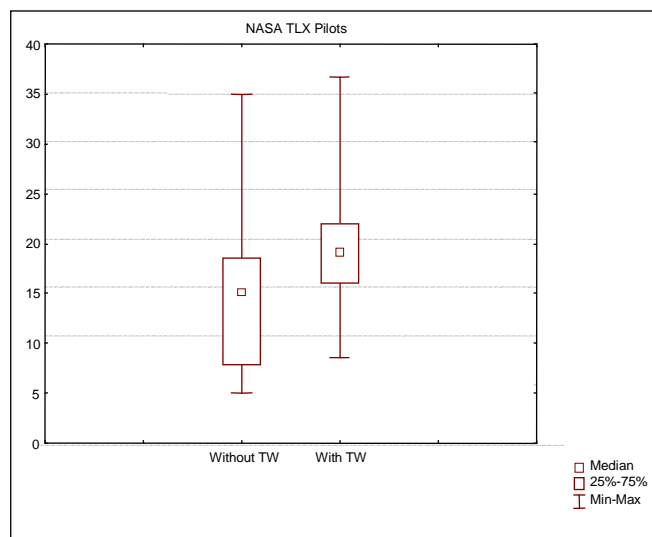


Figure 8. NASA pilots' results

Pilot workload is significantly impacted by the TWs. The impact is low, and during debriefings, pilots do not find this workload increase is critical during the cruise phase, excepted in the case of an emergency situation or abnormal procedures. They stressed the TW impact needs to be validated in other flight phases where the aircrew workload is highest (e.g. descent or approach in complex environments).

Situation awareness

Controllers

Controllers' situation awareness was evaluated through SASHA questionnaires [11] and also tackled during post-run questionnaires. The results were subjected to a Wilcoxon test (Figure 9).

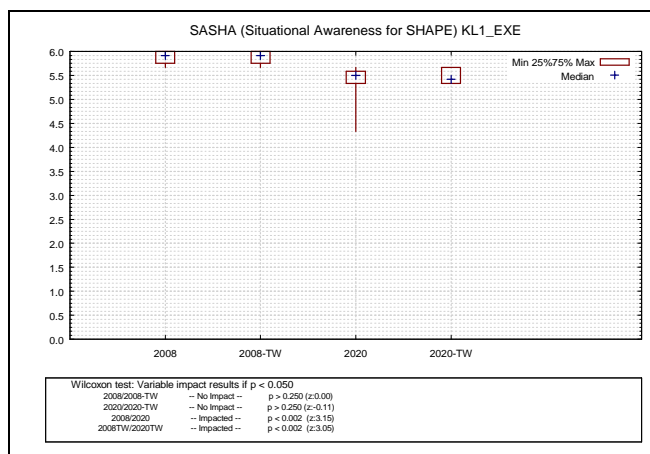


Figure 9. SASHA-Q sector KL1 executive controller results

Situation awareness is not significantly impaired by the implementation of TWs for KL1 (Geneva) sector planner and executive controllers and the MI (Milan) executive controller, whatever the traffic loads. For the MI (Milan) planner controller, there is a significant difference between the "without TW" and "with TW" conditions whatever the

traffic load. However, the levels of situation awareness are always high whatever the experimental conditions. The controllers' feeling on situation awareness is that TW information increases the traffic picture, although there was no statistically significant difference compared with the SASHA questionnaire results.

This feeling was justified by the specific information displayed for the TWs. This information allowed the controller to manage the flight plan more effectively than with the information currently displayed. TW information gave the controller more details, particularly regarding the exit conditions, to deal efficiently with the traffic, taking into account the overall constraints of the flight (not only the local sector constraints).

Pilots

Pilot situation awareness was evaluated through pilot-suitable SASHA-Q version, and also tackled during post-run questionnaires. The results were subjected to a Wilcoxon test (Figure 10).

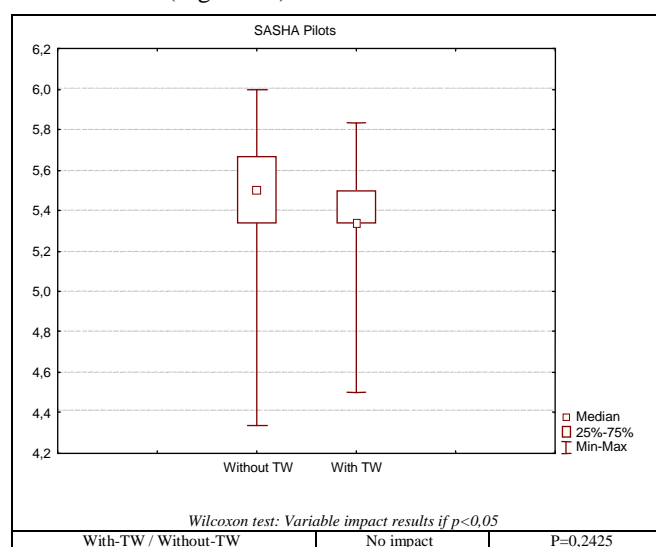


Figure 10. SA pilots results

There is no significant difference ($p < 0.05$) between the 'without TW' and 'with TW' conditions. This result is strengthened by the pilots' feeling gathered from the debriefings and the post-experiment questionnaire. Pilots stress that TW data is easy to perceive and understand.

Usability and acceptability

Controllers

The number of control instructions given increased when traffic load increased, but independently of TW use. Of the instructions given, more "flight level" and fewer "go to" instructions are given by the controllers. 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. The number of "go to" instructions is similar with and without TW use, but with TWs, the 'go to' instructions diverge less from the initial flight plan than without TWs. When safety may be impaired, the executive systematically applies a separation solution without considering the TW constraints. This reinforces the fact that safety concerns remain the first priority in the controller's mind.

Unanimously, controllers 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 quickly became familiarized with the concept, and were autonomous at their control working positions. This feeling was reinforced by the fact that the controllers found TW management easy to learn.

The high level of usability assessed during the simulation is a positive point of the concept for its future development. Nevertheless, efforts have to be made on the TW data display and the TW size and location on the sector.

Pilots

Although the flight simulator was a one-seater cockpit, pilots feel that TW management requires more communications between the captain and the first officer. One interesting issue is to determine which pilot in the aircrew has the best function for managing the TWs. Clearly, pilots say the Pilot Flying (PF) would be in the best position in the cockpit to manage TWs because he handles the aircraft and manages the trajectory. However, the Pilot Non Flying (PNF) cannot be excluded from this management process because he is in charge of communicating with ATC. Also, he helps the PF and he is able to cover him at any time.

Pilots strongly agreed that TWs are easy to use. This feeling was widely expressed during the post-run debriefings. Pilots quickly became familiarized with the concept, and were autonomous in managing the TWs in the cockpit. This impression was reinforced by the fact that pilots found TW management easy to learn.

The high level of usability assessed during the simulation is a strong point of the concept for its future development. Nevertheless, they did express one criticism on the TW display: the navigational display does not allow for an easy display of TWs in the long-term time horizon. The Multiple Control and Display Unit (MCDU) will meet this need and provide aircrew with a good degree of anticipation. Then, the issue is whether to display only on the MCDU or on the two displays (ND and MCDU), and to give to the pilots a choice of display, following the PF or the PNF function.

Collaboration between controllers and pilots

The collaboration process between controllers and pilots was analyzed through:

- Communications between the ground and the aircraft;
- TW use and the understanding between controllers and pilots.

Figure 11 shows the results of controller communication time with piloted aircraft in the four experimental conditions. The controller communication time with aircraft is calculated as a percentage of piloted aircraft flight time in the sectors. This means that 1.2 corresponds to 1.2 % of time flight of piloted aircraft in the two sectors (Geneva and Milan).

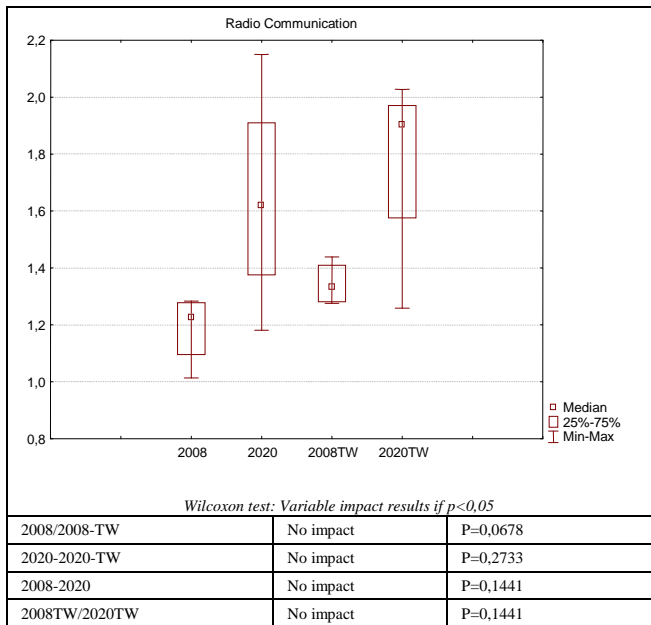


Figure 11. Controller communication time with piloted aircraft

There is no significant difference ($p < 0,05$) for the ATCO communication time in the two sectors whatever the traffic load conditions and the "with" or "without" TW conditions. TW management does not impact the way the controllers communicate with the aircrews.

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 saying it. 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 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.

By adding information on the flight plan data, the TWs improve the aircraft intent representation that ATCOs and pilots share. This heightens the feeling that collaboration is improved.

TWs are deemed positive for the collaboration process between ATCOs and pilots. The cost of this cooperation in terms of workload is rated as being without additional workload by controllers, and as increasing a little bit the workload by pilots.

Finally, pilots and ATCOs agree that in normal operative conditions, communications about TWs may be supported by data-link. Voice communication has to be kept for emergencies or situations where there is a lack of understanding.

Safety

The current level of ATM safety is high. Incidents and occurrences are rare, and most of the time, losses of

separation do not occur during an exercise. The HIL-1 experiment showed the lack of validity and sensitivity of the short-term conflict alert count, and recommended a more sensitive approach. For the HIL-2 experiment, safety was evaluated through aircraft separation performance.

Separation performance was assessed using the Separation Performance Tool (SPT) designed by EUROCONTROL [12] and dedicated questions in post-run questionnaires for controllers and pilots.

The SPT provides the actual and predicted flight times (in minutes) for different separation bands for all the flights. The separation is measured before and after controllers' tactical interventions. The actual separation represents the total flight time that the aircraft have flown during the exercises, grouped by the closest separation distance between aircraft. Predicted flight time is based on aircraft trajectories without controllers' interventions, and the closest separation distances according to the intended trajectories. Separation above 10 Nm and 1000 ft are grouped together with the traffic that did not risk loss of separation. Loss of separation are decomposed through different separation criteria: longitudinal < 5 NM and vertical < 1000 ft.

Separation performance was assessed for the four experimental conditions (with and without TWs, for 2008 and 2020 traffic loads). Figure 12 shows the results for the TW-2020 condition.

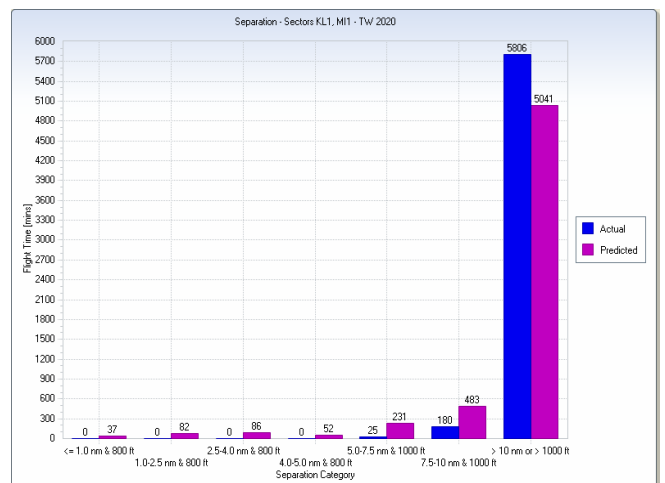


Figure 12. Aircraft separation for the TW-2020 condition for the 2 controlled sectors

The distribution of the flight time results in the four experimental conditions shows that there is no loss of separation. A high safety level is maintained whatever the traffic load conditions and/or TW conditions

The majority of the traffic is maintained at more than 10Nm and 1000ft. The controllers successfully separated the aircraft whatever the experimental conditions (traffic load and TWs) because the flight time of actual traffic is greater in the band > 10 NM than the flight time of the predicted traffic.

For the two bands between 5 NM and 10 NM, the flight time of the predicted traffic is greater than the flight time of the actual traffic. An interpretation of this result is that the majority of potential conflicts are avoided before these separation limits. Such results are consistent with the hypothesis that controllers have good anticipation in

conflict detection and solving. This result is found in the four experimental conditions.

The ATCOs' and pilots' feeling from debriefings and post-run questionnaires were consistent with the quantitative data, establishing that safety was not impacted (either positively or negatively) by TW use, even when capacity matched the forecast 2020 traffic load.

Efficiency

Traffic efficiency was assessed through three indicators: flight duration, number of fulfilled TWs, and fuel burned by the aircraft.

Flight duration is calculated by comparing the time flown by each aircraft into 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 ATCO actions (simulator flying the aircraft, following the flight plan). Flight duration was calculated for the 4 experimental conditions (Figure 13).

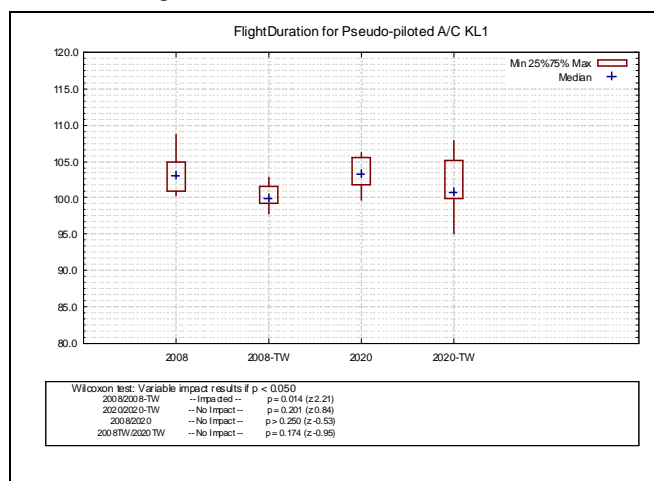


Figure 13. Flight Duration in KL (Geneva) Sector

Results show that the traffic load condition does not have an impact on flight duration. Whatever the measured sectors, flight duration is shorter with TWs. The difference is significant for 2008 traffic load and not for 2020 traffic load. 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. This suggests a better adherence to the trajectory. This outcome means that TW use increased traffic efficiency.

The number of aircraft fulfilling their TWs is a strong indicator of the concept validity and traffic efficiency. If controllers are not able to fulfill TWs and if too many aircraft are out of their TWs, the concept will lose its relevance and traffic efficiency will decrease. The percentage of 'out TW' aircraft was calculated for the results of each sector in the 2008 and 2020 TW conditions.

The results showed there is no significant difference ($p < 0.05$) between the two traffic load conditions whatever the controlled sector. The median value is always equal to 0 whatever the sectors and the traffic load. The percentages of TW Out are very low and fully compatible with operational use. The renegotiation process has to be initiated very rarely. The number of 'out TWs' aircraft was found to be acceptable by all ATCOs.

The flight simulator calculates the fuel consumption during the flight. The idea to analyze the fuel burned by the aircraft is an attempt to evaluate one factor of the flight cost. The calculation of the fuel burned is done by comparing the flight simulator fuel values at the sector entrance and exit for each piloted aircraft in the four experimental conditions (Figure 14).

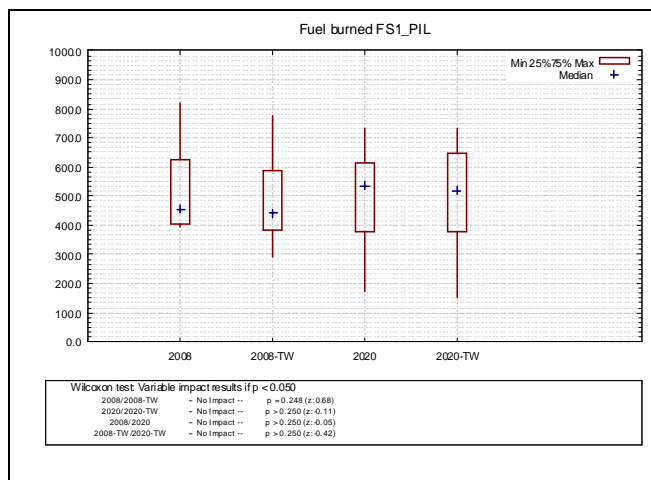


Figure 14. Fuel burned for piloted aircraft

The results show that there is no significant difference ($p < 0.05$) for the fuel burned by the aircraft whatever the traffic load conditions and whether or not under TW management. TWs, as well as the traffic load, do not impact the fuel burned by the aircraft.

The data collected during the HIL-2 experiment lead to the conclusion that TWs do not impact traffic efficiency. On the contrary, in an appropriate sector where the sector shape, size and airspace may positively impact the flight duration, an increase in traffic efficiency could be observed.

Capacity

The choice made in the HIL2 experiment for evaluating KPA capacity was to assess two levels of capacity, and not to progressively assess capacity growth and identify the breakpoint. The two levels of capacity were 2008 capacity and 2020 forecast capacity.

The results obtained during the experiment, mainly regarding system performance, indicated that the 2020 forecast capacity was properly and safely managed.

Predictability

Predictability indicators are defined by SESAR as the measurement of the trajectory flown against the reference business trajectory. The same applies for the HIL-2 experiment as indicators are used for assessing the efficiency. This means TW did not impair traffic predictability, and may even improve it with an appropriate control sector shape, size and airspace structure.

DISCUSSION

Controllers

The Contract of Objectives concept is manageable with the current 2008 and expected 2020 traffic loads in the two measured sectors, without any impact on traffic safety. Controllers deemed TW management to be feasible and acceptable, although TWs add some constraints when considering conflict resolution. The usability and ease of management of TWs is similar for executive and planner

controllers, although TWs are more suitable for planner controllers than executive controllers.

Controllers are more constrained by the heavy traffic load than by TW use. However, TW management involves more information, which increases the perception of workload. But this increase in information is also considered a positive aspect for improving the situation awareness. Objectively, quantitative data reveal that TW use has no impact on the workload and situation awareness. This outcome is a strong indicator for future development and concept acceptability.

Fundamentally, the Contract of Objectives does not modify the way the controllers work. The communication and cooperation processes are not impacted, and the common situation awareness between executive and planner controller is assessed satisfactory. Some slight changes are described for the executive when he (she) has to solve conflicts. He (she) also has to analyse the TW data to find the best solution for conflict resolution. The planner controller is not impacted. Controllers also say that it is easy to keep in mind safety as first priority. Thus, mainly in 2020 conditions, they concentrate on conflict solving, then return to ensuring TW fulfillment. There is no difficulty ensuring that safety is maintained.

Pilots

Contract of Objectives concept is manageable in the cockpit by the aircrew without any impact on safety. Pilots judged TW management to be feasible and acceptable, although TWs add some constraints as far as their management is concerned. From the pilots' point of view, the management of TWs in the flying task has to be the responsibility of the Pilot Flying (PF). However, the Pilot Not flying (PNF) needs to be kept in the loop of TW management.

Pilots are slightly constrained by TW use, since they modify the workload and increase collaboration between crew members. The impression of workload is increased and the quantitative data confirm this impression. However, the level of workload remains low. It is not a concern for the flying phases tested during the experiment, but the issue has to be considered for heavy workload phases or emergency situations. However, pilots are aware that safety is always the first goal, and then they are able to give up the TW constraint. Like for ATCOs, TW is also considered as positive in improving situation awareness.

Contract of Objectives does not modify the way the pilots work. The communication and cooperation processes with controllers are not impacted and the common situation awareness with controllers is perceived as being better. This is an important result in terms of the objective of increasing collaboration between crew and ground. Cooperation between the two crew members is deemed to be easy to manage with TWs, although pilots feel this will require a little more work.

System Performances Results

The results obtained in terms of system performances indicated the capacity expected in 2020 was properly and safely managed. CoO and TW concepts contribute to reaching the expected level of efficiency and predictability.

Safety data (obtained through the use of SPT), as well as qualitative data obtained through post-run questionnaires and debriefings, are consistent in confirming that safety was not impacted by TW use for the controllers and for the

pilots, even when capacity matched the 2020 forecast traffic load.

CONCLUSION

The HIL-2 experiment objectives were to assess the CoO concept and associated TWs for controllers and pilots, to investigate the impact of this concept on their activity and relationships, and to evaluate the operational acceptability from a controller's and pilot's point of view.

ATCOs and pilots were very positive about the concept. However, they 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. The HIL2 experiment results are consistent with HIL1 experiment [7] as far as the ATCO topics are concerned. Results are valuable in achieving a better understanding of the challenges raised by the implementation of the Contract of Objectives in Air Traffic Control for the ANSPs' controllers and airline pilots.

This experiment was the second step in the operational assessment planned to validate the CoO concept in the CATS project. This will be followed by the third and last step, dealing with the renegotiation process and its impact on air crews and controllers.

The HIL-2 results [13] 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.

REFERENCES

1. SESAR Definition Phase – Deliverable D5, SESAR Master Plan, www.sesar-consortium.aero.
2. SESAR Definition Phase – Deliverable 1, Air transport framework – the current situation. www.sesar-consortium.aero.
3. SESAR Definition Phase – Deliverable 2, Air transport framework – the performance target. www.sesar-consortium.aero.
4. SESAR Definition Phase – Deliverable D3. The ATM target concept. www.sesar-consortium.aero
5. L. Guichard, S. Guibert, H. Hering, D. Dohy, J.Y. Grau, J. Nobel, K. Belahcene. « Paradigm SHIFT » Concept Opérationnel. EEC Note No. 01/05, EUROCONTROL Experimental Centre.
6. EUROCONTROL. European Operational Concept Validation Methodology (E-OCVM) – Version 2. www.eurocontrol.int/valfor/public/standard_page/OCVMSupport.html
7. CATS, 2009, HIL1 Primary results analysis D2.1.1. www.cats-fp6.aero
8. A.Sipe and J.Moore. “Air Traffic Functions in the NextGen and SESAR airspace” in 28th Digital Avionics Systems Conference, Orlando, Florida, 2009.
9. Episode3, April 2008. Performance Framework. www.episode3.aero.
10. Hart, SandraG., Lovell E Staveland, 1988, Development of NASA TLX, in Human Mental

Workload , by Hancock, P.A. and Meshkati, N., Plenum, NY, Elsevier

11. EUROCONTROL, 2003, Solutions for Human-Automation Partnerships in European ATM, the development of Situational Awareness Measures in ATM systems, Document HRS/HSP 005 REP 01, Brussels, Belgium, EUROCONTROL
12. Pinska, E.; Hickling, B. (2009) Measuring En Route Separation Assurance Performance. In proceedings of EUROCONTROL Safety R&D Seminar 2009, Munich, Germany
13. CATS, 2010, HIL2 Primary results analysis D2.1.2. www.cats-fp6.aero